Imperfect Competition and the Network Origin of Aggregate Fluctuations*

Yu Shi†, Kai Yan‡

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Abstract

This paper studies how imperfect competition can transmit and amplify sectoral shocks within an input-output network. We introduce a model with variable markups and input-output linkages to show that the degree of competitiveness in individual industries and the input-output network structure jointly determine how sectoral shocks are transmitted. A negative shock to any sector of the economy will cause firms to exit, which leads to both an increase in markup and a loss of variety. The negative shock travels through the input-output network due to decreasing demand and increasing real prices, generating a rich pattern of amplifications. We then use a detailed firm-level data set from China and the exogenous exchange rate regime switch in 2005 to empirically test our model’s predictions. We find evidence that a downstream industry is affected by a demand shock to another downstream industry that shares common upstream suppliers with them. Industries that suffered from a larger negative demand shock experienced more exit and also had higher increases in markup.

1 Introduction

This paper proposes imperfect competition as a factor determining how sectoral shocks transmit along an input-output network. The idea that idiosyncratic shocks on specific industries can contribute significantly to aggregate fluctuation dates back to Long and Plosser (1983). Following

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†Economics Department, Massachusetts Institute of Technology (yshi25@mit.edu)
‡International Monetary Fund (KYan@imf.org)
a recent formalization by Acemoglu et al. (2012), the literature has dived into characterizing the relationship between network structures and the aggregate fluctuation. We make both theoretical and empirical contributions to the current literature. Our theory proposes two additional channels through which sectoral shocks can be transmitted and amplified along the supply chain. Our paper is also the first to empirically document the role of industry-level imperfect competition in determining the transmission of shocks within an input-output network.

We theoretically propose the within-industry imperfect competition to be a factor that influences the amplification of idiosyncratic shocks within the input-output network. Our model combines previous models studying the input-output network with the monopolistic competition setup in Atkeson and Burstein (2008). In our model, industries are linked by input-output production networks. Each industry is populated with a finite number of firms. Companies compete in producing slightly different products. In addition, we keep the standard assumption of a constant return to scale in the input-output network literature, such that our results are purely driven by relaxing the perfect competition assumption. The monopolistically competitive structure with a finite number of producers introduces two extra channels to amplify shocks in addition to what is discussed in Acemoglu et al. (2012): gain from the variety and endogenous markup. The firms make entry and exit decisions in response to sectoral shocks. In a monopolistically competitive market, industry-level prices are negatively correlated with the number of firms. A general discussion on the “gain from variety” channel is provided by Baqee (2016).

Our model features an additional channel that can propagate and amplify sectoral shocks: the endogenous markup channel. In our model, the firm entry and exit decisions also have an impact on industry-level markup. Similar to Atkeson and Burstein (2008), in our model, each firm faces a demand elasticity which varies with the level of competitiveness of its industry. Since each industry only has a finite number of firms, the demand elasticity of each firm is a weighted average of the elasticity of substitution within the industry and the elasticity of substitution across industries. Each firm’s weights on the two elasticities of substitutions are determined by the market share the firm takes up in the industry. If a firm takes up a large market share in the industry, it will take more into account the across-industry elasticity of substitution, and vice versa. If we assume that the across-industry elasticity of substitution is smaller than the within-industry elasticity of substitution, the larger market share will lead to a less elastic demand and therefore, a higher markup. When one key downstream industry faces with a negative demand shock, it will reduce the need for upstream inputs, which decreases the number of firms in each upstream industry and pushes up the markup charged by all the remaining upstream firms. The endogenous markup adjustments then may increase the costs of all the downstream industries, translating this sectoral demand shock into an aggregate output loss.
The “gain from variety” channel and the “endogenous markup” channel combined allow demand shocks to propagate along the whole input-output network and thus become the source of aggregate fluctuations. This is in contrast to the prediction from the canonical network model with perfection competition and constant return to scale. In the canonical model, shocks to industries producing final goods will not be amplified. That is, a demand shock that reduces consumer demand for one downstream industry by 10% will not affect the real output of other final good producers. Consider a simple economy with two downstream industries A and B, both producing final goods using one unit of input from an upstream industry C. When industry A’s nominal demand is reduced by 10%. In the perfect competition benchmark, A’s revenue will be reduced by 10% as well. Industry B remain unaffected since the price index of industry C is unchanged given perfect competition. The total effect of this negative demand shock to the real GDP is restricted within industry A, given that GDP only counts for final goods. Therefore, any sectoral demand shock will not be amplified in a model with perfect competition and constant return to scale.

In our model, there exists an “up-and-down” channel indicating that demand shocks to final good producers are transmitted upstream and then downstream to other final good producers. Any negative demand shocks to the upstream industry will lead to exit in the industry, which will increase markup and reduce variety. These two channels will amplify the negative shock to the upstream industry and increase the production cost of the downstream industries for more than one-to-one. Therefore, the friction introduced by imperfect competition will act as an amplifier to the initial shocks on the downstream industry. A 10% reduction of nominal demand from downstream industry A will not only reduce the output of upstream industry C but also lead to more exits. Such exit behaviors for firms in C will push up the markup of remaining firms and lower gains from varieties for both industries A and B, thus decrease the real output of both downstream industries. In this way, a 10% demand shock on industry A thus will turn into a more than 10% reduction in the total real GDP.

We provide empirical evidence that supports our theoretical predictions using a difference-in-differences approach and considering an exchange rate regime switch in China as a demand-side policy shock. In July of 2005, the Chinese government announced that RMB became unpegged towards US dollars. In a little over a year, RMB appreciated by 30% towards major currencies. We consider the unanticipated appreciation of RMB as disproportionately affecting industries with different exposure to the international market. Industries with a larger export share prior to the regime switch were subject to a larger negative demand shock. Aggregating the shocks along the input-output network, we establish the following results from our empirical exercise:

1. Exporters in China and their upstream suppliers suffered more from the exchange rate regime switch in 2005 by generating lower revenue and output.
2. The number of firms at (3-digit) industry level declined more in more intensively exporting
industries and their upstream industries.

3. The demand elasticities faced by exporting firms and their upstream industries decreased more compared with non-exporting firms.

4. The “up-and-down” channel holds in data. Upon the exchange rate policy shock, downstream firms that had more common upstream suppliers with the exporters suffered a bigger loss in real output.

The above empirical findings point directly to the elements in our theory. The number of firms of each industry and the demand elasticity, hence markup, of each firm changed in response to demand shocks. In addition, the less competitive industries in the input-output network act as an “amplifier” of shocks passed from the downstream to the upstream.

Our paper is most closely related to the series of papers that theoretically emphasize the structure of the input-output network in the propagation and amplification of shocks, including Long and Plosser (1983), Acemoglu et al. (2012), Atalay (2015), and Bigio and La’O (2016). In all of these papers, the industries in the economy are characterized by a perfect competition market structure. The potential role of imperfect competition is therefore eliminated by assumption. In a more recent paper, Baqee (2016) considers a monopolistic competition market structure and provides a general discussion on the “gain from variety” channel. This paper contributes to the previous models by considering the endogenous price-to-cost markups of each firm.

Our paper also contribute to the growing empirical literature studying the propagation of shocks along supply chains, including Foerster, Sarte, and Watson (2011), di Giovanni, Levchenko, and Mejean (2014), Barrot and Sauvagnat (2016), Boehm, Flaaen, and Pandalai-Nayar (2015), and Carvalho et al. (2016). These papers either rely on strong assumptions for backing out sectoral shocks or focus on thoroughly documenting the how far the shocks can transmit along the supply chain. Our paper, on the other hand, ties more closely to the theoretical literature by directly providing evidence on the within-industry imperfect competition and its role in transmitting shocks to both the upstream and the downstream. To our knowledge, our paper is the first to empirical document the “up-and-down” transmission of demand shocks.

More broadly, our paper belongs to the literature on how idiosyncratic shocks can contribute to or even cause aggregate fluctuations. Gabaix (2011) and Gabaix and Carvalho (2013) demonstrates when the firm size has a fat-tail distribution, the idiosyncratic shocks to firms can explain a large proportion of the aggregate fluctuations. We share their insight by taking the concentration of each industry into account. But in our model, the concentration is an endogenous outcome of market structure and input-output linkages. We also take the structure of input-output networks into consideration.

Within the financial literature, input-output network has been proven to have an impact on stock market returns. For instance, Cohen and Frazzini (2008) find evidence of return predictability
across economically linked firms, while Kelly, Lustig, and Van Nieuwerburgh (2013) study how concentration in the network of input-output linkages impacts firm-level return volatility. Our paper provides new insights on taking into account the market structure of each industry when evaluating systemic shocks in the financial market.

Last but not least, our paper is related to the studies on the cyclicality of price-to-cost markups. The core of our theory is that firm-level markup increases in response to a negative demand shock. In our model, we use monopolistic competition with a finite number of market participants to generate a counter-cyclical markup. A similar response of markup to demand shocks can be rationalized using the New Keynesian set up (See Nekarda and Valerie (2013) for a review). Our paper emphasizes that the cyclicality of markups is not only important to evaluate the effect of monetary policy, but also crucial to understand how sectoral shocks can turn into aggregate fluctuations through input-output linkages.

The rest of this paper is organized as follows: The second section presents a simple example to illustrate the mechanisms of the model. The third section extends the second section’s simple model into a general equilibrium model with general network structure and shows that the results still hold. The fourth section presents our empirical findings. The fifth section concludes.

2 The Partial Equilibrium Framework

In this section, we propose a baseline economy that features a simple input-output network with two downstream industries and two upstream industries, exogenously fixed endowments of consumers, as well as exogenously fixed marginal costs for the upstream industries. All four industries are populated with a finite number of monopolistically competitive firms. We show that though the extensive adjustments (firm entry and exit) and intensive adjustments (changes in markup), a negative demand shock to the exporting sector leads to a decrease in the non-exporting sector’s real output. Thus, a sectoral demand shock is amplified by the input-output network and can turn into an aggregate downturn.

2.1 Notation and a Brief Description of the Baseline Model

Our baseline model features a simple network structure: the network consists of two upstream industries \((A, B)\) and two downstream industries \((a, b)\); each downstream industry use products of both upstream industries as inputs. The network structure is as below:
For each firm-specific variable in our model, we use the subscripts as firm index and the superscripts as industry index. When aggregating up quantities and prices, we use capital letters with industry index only to represent industry-level variables. The prices and flow of goods between upstream and downstream industries have double indices in our model. For example, \( y_{j}^{A \rightarrow a} \) denotes the amount of upstream industry \( A \)'s final products that are used by firm \( j \) in downstream industry \( a \) as \( j \)'s intermediate inputs. Correspondingly, the total amount of upstream industry \( A \)'s final goods purchased by downstream industry \( a \) is denoted as \( Y_{A \rightarrow a} \).

The degree of competitiveness, of each industry is determined by a per-period fixed operational cost, which is denoted by \( f^{k} \) for industry \( k \), where \( k \in \{a, b, A, B\} \). For both upstream industries, the production function follows a standard CES and the across-firm elasticity of substitution is \( \gamma^{U} > 1 \); similarly, the production function of both downstream industries follow a standard CES with across-firm elasticity of substitution of \( \gamma^{D} > 1 \). The elasticity of substitution between \( A \) and \( B \) is assumed to be 1.

There are a finite number of symmetric firms in each industry. These firms engage themselves in Bertrand competition, where they optimize on prices to maximize their profits. Since there are a finite number of firms within each industry, each firm takes into account the impact of its own price on the industry-level price index. We further assume that all firms adjust their prices simultaneously in each period, so that each firm will take the prices of other firms as given. In equilibrium, the actual number of firms in each period is pinned down by the zero-profit condition - the profit of the marginal firm has to be exactly equal to the fixed operational cost. The equilibrium concept in our baseline model is static Nash Equilibrium, given firms have no inter-temporal trade-offs.

The setup of within-industry competition follows closely with that of Atekson and Burstein (2008), with two important deviations. First of all, we assume away the heterogeneity in productivity between firms within the same industry (i.e, firms in the same industry are symmetric) for simplicity. Our results still hold qualitatively if we take such heterogeneity into account. Secondly, we endogenize the number of firms to match the observed entry and exit pattern in the data.
The rest of this section solves for a partial equilibrium result. In order to match the empirical study in section 3, we assume there is an international representative consumer that consumes only goods from sector $a$ (the tradable sector). We also assume that there is a domestic consumer that consumes from both sector $a$ and sector $b$, where $b$ is the non-tradable sector. When solving for the partial equilibrium, we consider the upstream input prices as unchanged, and domestic demand is not affected by demand changes from the foreign consumer.

2.2 The Consumer’s Problem

We assume that there are two representative consumers in the model: an international consumer and a domestic consumer. The utility functions for the international and the domestic consumers are as follows:

\[
U^*(C^{sa}) = C^{sa}
\]
\[
U(C^a, C^b) = (C^a)^\alpha (C^b)^{1-\alpha}
\]

The international consumer only consumes goods from sector $a$, and the domestic consumer consumes goods from both sector $a$ and sector $b$. $C^k, k \in \{a, b\}$ denotes the aggregate domestic consumption of the final good in sector $k$. $C^{sa}$ is the consumption of final good $a$ by international consumers.

The budget constraints for international consumers and domestic consumers are, respectively, as follows:

\[
P^a C^{sa} \leq E^* E
\]
\[
P^a C^a + P^b C^b \leq E
\]

In the above equations, $P^k, k \in \{a, b\}$ denotes the aggregate price index of the downstream industries $a$ and $b$. $E$ and $E^*$ denotes the endowments of domestic and international consumers, respectively. The fixed endowment assumption will be generalize later, when we incorporate labor into the production function of firms. $E$ denotes the exchange rate. An increase in $E$ corresponds to a depreciation of domestic currency. The production function of final goods in sector $a$ and $b$ are as follows:
\[ Y^a = \sum_{j=1}^{N^a} (y^a_j)^{\frac{\gamma_D}{\gamma_D - 1}} \]

\[ Y^b = \sum_{l=1}^{N^b} (y^b_l)^{\frac{\gamma_D}{\gamma_D - 1}} \]

The quantity of each firm \( j \) in industry \( a \) is denoted by \( y^a_j \) and that of firm \( l \) in industry \( b \) is denoted by \( y^b_l \). The price of firm \( j \) in industry \( a \) is denoted as \( p^a_j \); the price of firm \( l \) in industry \( b \) is denoted as \( p^b_l \).

Following our notation in section 2.1, \( P^a \) and \( P^b \) are the aggregate price index for industries \( a \) and \( b \). Since the representative consumer has a Cobb-Douglas utility function, consumption of final good in \( a \) and \( b \) are pinned down by the share parameters \( \alpha \). The demand functions faced by \( a \) and \( b \) are thus:

\[ Y^a = C^a = \frac{\alpha E + E^*E}{p^a} \]
\[ Y^b = C^b = \frac{(1 - \alpha)E}{p^b} \]

### 2.3 The Downstream Industry’s Problem

Each firm in the downstream industry \( a \) produces according to the following production function:

\[ y^a_j = (y^A_j)^{\alpha^A} (y^B_j)^{\alpha^B} \]

\( y^A_j \) (\( y^B_j \)) represents the the amount of upstream industry \( A \)’s(B’s) final products that are used by firm \( j \) in downstream industry \( a \) as \( j \)’s intermediate inputs; \( \alpha^A \) and \( \alpha^B \) denote, respectively, the input share of upstream \( A \) and \( B \) in industry \( a \)’s total production. By constant return to scale, \( \alpha^A + \alpha^B = 1 \). Assuming no price discrimination, and downstream firms taking upstream prices \( P^A, P^B \) as given, the marginal cost of producing one unit of final good in sector \( a \) is thus:

\[ \phi^a = (P^A)^{\alpha^A} (P^B)^{\alpha^B} \]

The assumption of no price discrimination between producers may seem like a strong assump-
tion at the first glance. But if \( P^{A \to a} > P^{A \to b} \), firms in industry \( b \) can engage in arbitrage activities by purchasing cheap inputs from industry \( A \) and re-selling them to firms in industry \( a \). The arbitrage activities is likely to drive the price gaps to be near zero. In addition, the Bertrand competition avoids any collective price discrimination behaviors, if any firm changes \( a \) at a higher price, other firms would charge a lower price to take over the supply to industry \( a \).

Then when solving for the profit optimization problem of firm \( j \) in downstream industry \( a \), \( \phi^a \) is taken as given. The problem thus becomes:

\[
\max_{p^a_j} p^a_j y^a_j - \phi^a y^a_j \\
\text{s.t. } y^a_j = \left( \frac{p^a_j}{P^a} \right)^{-\gamma^D} Y^a
\]

The constraint comes from utility maximization of a representative consumer. Since all firms engage in a Bertrand competition, firm \( j \)'s choice parameter is thus the price at which the firm charges a representative consumer. The first-order condition implies:

\[
p^a_j = \frac{[1 - (p^a_j / P^a)^{1-\gamma^D}] \gamma^D + (p^a_j / P^a)^{1-\gamma^D} \phi^a}{[1 - (p^a_j / P^a)^{1-\gamma^D}] \gamma^D + (p^a_j / P^a)^{1-\gamma^D} - 1} y^a_j
\]

Define \( s^a_j = \left( \frac{p^a_j}{P^a} \right)^{1-\gamma^D} = \frac{p^a_j y^a_j}{P^a Y^a} \) as the market share (in terms of revenue) of firm \( j \) in industry \( a \), taking prices in other firms as given. The demand elasticity faced by firm \( j \) in industry \( a \) is thus:

\[
\epsilon(s^a_j) = (1 - s^a_j) \gamma^D + s^a_j
\]

Which is a weighted average of within-industry elasticity of substitution \((\gamma^D)\) and cross-industry elasticity of substitution \((1)\). The optimal price \( p^a_j \) can then be represented as:

\[
p^a_j = \frac{\epsilon(s^a_j)}{1 - \epsilon(s^a_j)} \phi^a
\]

Since we have assumed that all firms in the same industry are symmetric, they should all have the same market share. Therefore, we define the demand elasticity faced by each firm in industry \( a \) as:

\[
\epsilon^a = \epsilon\left(\frac{1}{N^a}\right) = (1 - \frac{1}{N^a}) \gamma^D + \frac{1}{N^a}
\]
To get some intuition of the elasticity, we consider two extreme cases of the degree of competitiveness. If \( N^a = 1 \), i.e. industry \( a \) has one monopoly, which faces a demand elasticity of \( \epsilon^a = 1 \). This is exactly equal to the elasticity of substitution between industry \( a \) and industry \( b \). If there is only one firm in the industry, the demand elasticity of the firm will be purely determined by the across-industry elasticity of substitution. When the market is perfectly competitive, i.e. \( N^a = \infty \), we get \( \epsilon^a = \gamma^D \), which is equal to the within-industry elasticity of substitution. When the number of firms in one industry is relatively low, firms mainly take into account the competition across industries, because their pricing behavior will have a large impact on the whole industry’s price index. When the number of firms in one industry is large, the pricing decisions of individual firms are more affected by the competition within a industry, thus the demand elasticity is closer to the within-industry elasticity of substitution. Similar results will apply for industry \( b \).

### 2.4 The Upstream Industry’s Problem

The upstream industry’s problem is very similar to the downstream industry’s problem. Upstream firm \( i \) in sector \( A \) solves the following profit maximization problem:

\[
\max_{p'^A_i} p'^A_i (y'^A_i \rightarrow^a + y'^A_i \rightarrow^b) - \phi^A_i (y'^A_i \rightarrow^a + y'^A_i \rightarrow^b)
\]

Here \( \phi^A \) is the marginal cost of firm \( i \) in sector \( A \), which we assume to be exogenous in this baseline model. \( y'^A_i \rightarrow^a + y'^A_i \rightarrow^b \) can be represented as:

\[
y'^A_i \rightarrow^a + y'^A_i \rightarrow^b = \left( \frac{p'^A_i}{pA} \right)^{-\gamma^A} \cdot s'^A_i \cdot (p'^A_i)^{-1} (p^{A \rightarrow^a} Y^A \rightarrow^a + p^{A \rightarrow^b} Y^A \rightarrow^b)
\]

Given that the final goods of industry \( a \) and \( b \) are produced in the following form:

\[
y'^a_i = (y'^A_i \rightarrow^a)^{a \rightarrow^a} (y'^B_i \rightarrow^b)^{a \rightarrow^a}
y'^b_i = (y'^A_i \rightarrow^b)^{a \rightarrow^b} (y'^B_i \rightarrow^b)^{a \rightarrow^b}
\]

In addition, we have solved for the demand elasticity \( \epsilon^a, \epsilon^b \) in section 2.3, then the following must hold:

\[
p^{A \rightarrow^a} Y^A \rightarrow^a + p^{A \rightarrow^b} Y^A \rightarrow^b = \frac{\epsilon^a - 1}{\epsilon^a} A^a p^{a \rightarrow^a} p^a Y^a + \frac{\epsilon^b - 1}{\epsilon^b} A^b p^b Y^b
\]
The right-hand side of this equation features the downstream industries’ demand on the products of upstream industries. Then the profit maximization problem of firm $i$ in upstream industry $A$ becomes:

$$\max_{p_i^A} (y_{A\rightarrow a}^i + y_{A\rightarrow b}^i) - \phi^A (y_{A\rightarrow a}^i + y_{A\rightarrow b}^i)$$

subject to:

$$y_{A\rightarrow a}^i + y_{A\rightarrow b}^i = (\frac{p_i^A}{p_i^A})^{1-\gamma_{ii}} \cdot (p_i^A)^{-1} \frac{\epsilon_{a} - 1}{\epsilon_{a}} \alpha^A_{A\rightarrow a} (\alpha E + E^* E) + \frac{\epsilon_{b} - 1}{\epsilon_{b}} \alpha^A_{A\rightarrow b} (1 - \alpha) E)$$

The solution to this problem is similar to the solution to downstream firms’ optimization problem:

$$p_i^A = \frac{\epsilon_i^A}{\epsilon_i^A - 1} \phi_i^A$$

where $\epsilon_i^A = (1 - s_i^A) \gamma^U + s_i^A$. Since we have assumed that $\gamma^U > 1, \epsilon_i^A > 1$.

We can get the results symmetrically for upstream industry $B$. Same as the formulas in the downstream industry, the demand elasticity a representative firm in industry $A$ faces is increasing in the number of firms. Firms in a less concentrated industry will face more elastic demand, and therefore, charge lower markups.

### 2.5 Equilibrium

The input-output links will expose the upstream industries to demand shocks in the downstream industry. Intuitively, if the demand of the downstream industries’ final goods decline, the downstream industries will produce less, and therefore, demand less from the upstream industries.

The response of the upstream industries will contain the changes in both prices and quantities. The change in prices is induced by firms exiting the industry, and a less concentrated industry charging a higher markup. The change in prices, on the other hand, will change the real output by reducing the total quantity the industry produces.

Given the above rationale, we solve the equilibrium using the following steps. The detailed solution is in the appendix:

1. We first solve for the equilibrium in downstream industries given prices in the upstream industries, i.e. the production cost of downstream firms. By imposing the free-entry condition $\pi_i^k = f^k, \forall k \in \{a, b\}, \forall i \in k$, we solve for the number of firms in equilibrium and thus the total
output and prices.

2. Taking the number of firms in downstream industries as given, the demand for firms in upstream industries are determined. Again by imposing the free-entry condition in the upstream industry ($\pi_i^k = f_k, \forall k \in \{A, B\}, \forall i \in k$), one can solve for the number of firms, total output and prices in equilibrium.

3. Combining the two equilibrium and we solve for the Nash Equilibrium result.

The equilibrium number of firms in the upstream industry $A$ can be characterized as:

$$N_A = \frac{g_A(f_a, f_b, \alpha_1, \alpha_2)}{\gamma_u f_A} + (1 - \frac{1}{\gamma_u})$$

$$g_A(f_a, f_b, \alpha_1, \alpha_2) = \frac{e^a - 1}{e^a} a^{A\rightarrow a}(aE + E^*E) + \frac{e^b - 1}{e^b} a^{A\rightarrow b}(1 - a)E$$

The $g_A$ function denotes the demand for final goods in $A$ from downstream industries. The $a^{A\rightarrow a}(aE + E^*E)$ is the demand for upstream industry $A$ from the downstream industry $a$. Intuitively, it is increasing in the demand of downstream industry ($a$) and also the share of the intermediate good $A$ in downstream industry $a$’s production.

The term $\frac{e^a - 1}{e^a}$ is the inverse of markup, which denotes the proportion of the revenue downstream industry $a$ spends on cost. The higher the markup, the lower the downstream industry $a$ spends on input, given its revenue. Therefore, the demand of the upstream industry is decreasing in the downstream industry’s markup. Given that the markup of a downstream industry is negatively correlated its degree of competitiveness, the demand for the upstream’s output is positively correlated with the downstream industry’s concentration, when all else are equal. Therefore, when a downstream industry becomes less competitive, it charges a higher markup on average, and its demand for upstream industries is lower.

In our empirical studies, we are primarily interested in how demand shocks (a shock to the Chinese exchange rate) are transmitted when taking industry-level imperfect competition into consideration. We therefore derive several implications of the model based on an exogenous shock to the exchange rate, $E$. This exchange rate shock will only directly affect downstream tradable industry $a$, since other industries are not exposed to the foreign market. We focus on two variables: average revenue, which is proportional to demand elasticity in the model and can also be directly
measured in our empirical studies, as well as real output, as the variable we ultimately aim at dis-
cussing. The following comparative statics are then derived from our model (see Appendix A for
detailed derivation):

The demand elasticity and average firm revenue of downstream industry $a$ and the two up-
stream industries will decrease in response to a negative exchange rate shock.

$$\frac{\partial e^k}{\partial \ln E} > 0, \quad \frac{\partial \bar{R}^k}{\partial \ln E} > 0, \quad \forall k \in \{A, B, a\}$$

The real output in downstream industry $b$ will decrease in response to the exchange rate shock.

$$\frac{\partial \ln Y^b}{\partial \ln E} > 0$$

The first comparative static is closely tied to the determination of markup:

$$e^k = \epsilon \left(1 - \frac{1}{N^k}\right) \gamma^k + \frac{1}{N^k}, \quad \forall k \in \{A, B, a, b\}$$

In the above equation, $N^k$ denotes the number of firms in industry $k$ and $\gamma^k$ denotes the within industry elasticity of substitution, which is larger than 1. The negative demand shock will lead to exit and reduce the number of firms ($N^k$). Hence $e^k$ will decrease when industry $k$ is facing a negative demand shock. In our theory, we also have the firm-level revenue as:

$$\bar{R}^k = e^k f^k$$

Therefore, a decrease in $e^k$ implies a decrease in firm revenue $\bar{R}^k$ as well.

The second comparative static comes directly from the two channels stated in the introduction.

The exit of the upstream industry $A$ pushes up markup charged by its firms and also reduces the
class of inputs of industry $b$. A negative demand shock to industry $a$ eventually turns into a negative
supply shock of industry $b$. Thus, the exchange rate shock harms the production of the non-tradable
industry, by increasing its marginal cost on its production.
3 General Equilibrium Extensions

In this section, we extend the model into a general equilibrium version with a generic network structure. The general equilibrium extension consists of two parts. In the first part, we illustrate how the model responds to demand shocks when each industry has a constant return to scale production function and a perfectly competitive market (as assumed in Acemoglu et al. 2012). Especially, we demonstrate that no “up-and-down” channel exists under this set up. In the second part, we generalize our baseline partial equilibrium model into a general equilibrium model, and illustrate that, similar to the baseline model, there is still an “up-and-down” channel, which can turn sectoral demand shock into an aggregate shock.

The general equilibrium setup introduces extra complications to our comparative statics analysis. Without restricting the parameter space, the reduction in domestic consumption may outweigh the reduction in foreign consumption. Therefore, a firm that relies more on exporting may in turn be less affected by the reduction of foreign demand. When the exporting industries get negative demand shocks due to the exchange rate appreciation, two general equilibrium effects will hit the domestic economy. The first general equilibrium effect is a reduction of total labor income, which will reduce the final good consumption in the domestic economy. The second general equilibrium effect is a subsequent reduction of input usages by the firms which primarily serve the domestic consumers, which will further reduce the labor income.

Therefore, if we compare two firms, with one primarily serving the international consumers and the other one selling to domestic consumers or domestic firms, it is unclear the first one will suffer more from the reduction of foreign demand. The elasticity of substitution between labor and other inputs is the key element determining the relative magnitude of general equilibrium effect and the direct effect from exchange rate shock. Therefore, the size of the exporting industries, the elasticity of substitution between labor and other inputs are all important parameters. We are able to show that when the elasticity of substitution between labor and other inputs is bigger than 1, and large industries are not very concentrated ($f \ll R$), the direct effect dominates the general equilibrium effect, and the exporting industries will suffer more from the exchange rate shock, which maps into what we observe in data.

Once the above parametric assumptions hold, we will be able to show, as above, that the first-order effect also holds: suppliers to the exporters will suffer more from the Reform than the suppliers to the non-exporters. Finally, we will be able to demonstrate that the “up and down” channel still exist under this setup.
3.1 The Perfect Competition Benchmark

In this section, we intend to show that our empirical results can reject the predictions from a model with perfect competition set up, i.e. a Cobb-Douglas production function. The Cobb-Douglas production function corresponds to the perfect competition benchmark provided by Acemoglu et al. (2012). By this setup, we are replicating the results by Acemoglu et al. (2012) with only one difference: labor is used in the production function\(^1\).

Production

Suppose there are \(n\) industries in the economy. \(\forall 1 \leq k \leq n\), define \(R^k = P^k Y^k\) as industry \(k\)'s total revenue. The production function of industry \(k\) is as follows:

\[
Y^k = \prod_{i \in k} (y^k_i)^{\nu^i}
\]

\(y^k_i\) is the output of firm \(i\) in industry \(k\), which is produced as follows:

\[
y^k_i = \left( \prod_{l=1}^{n} (y_{l \rightarrow k}^i)^{a_{l \rightarrow k}} \right)^{1-\beta^k} \cdot (l^k)^{\beta^k}, \forall k
\]

Where \(y_{l \rightarrow k}^i\) is the amount of final goods of industry \(m\) that is used as industry \(k\)'s input; \(a_{l \rightarrow k}\) is the input share of final good \(l\) used in the production of \(k\), which is available from the input-output matrix. For industries that's not relevant to the production in industry \(k\), their input shares are just equal to 1. By constant return to scale, these input shares should also satisfy:

\[
\sum_{l=1}^{n} a_{l \rightarrow k} = 1 - \beta^k
\]

Where \(\beta^k\) is the labor share of industry \(k\).

Demand

We assume that there are two representative consumers in this economy: a domestic consumer who receives all income from labor, and a foreign consumer whose consumption is based on a

\(^1\)The results in this section is the same if we simply take the general equilibrium version of imperfect competition model, make the elasticity of substitution goes to infinity and at the same time make the fixed operational cost goes to zero. But it is still worth laying out the model in this way for comparisons with Acemoglu et al. (2012) and also for explaining clearly the intuition behind it.
fixed endowment, $E^*$, which is independent of the domestic economy. Both consumers follow a Cobb-Douglas preference, thus the utility maximization problem of the domestic consumer is:

$$\max_{C^1, C^2, \ldots, C^n} \prod_{k=1}^n (C^k)^{\alpha^k}$$

s.t. $\sum_{k=1}^n p^k C^k = wL$

Here $L$ is the total labor supply in the economy, $w$ is the wage rate; $\alpha^k$ is the share of industry $k$ in the domestic consumer’s consumption bundle. The exchange rate between the foreign currency and local currency is assumed to be $E$, the utility maximization problem of the foreign consumer is then:

$$\max_{C^1^*, C^2^*, \ldots, C^n^*} \prod_{k=1}^n (C^{k*})^{\alpha^{k*}}$$

s.t. $\sum_{k=1}^n p^k C^{k*} = E^*E$

$\alpha^{k*}$ is the share of industry $k$ in the foreign consumer’s consumption bundle.

In equilibrium, goods market clearing for each industry implies $\forall k$,

$$p^k Y^k = p^k C^k + p^k C^{k*} + \sum_{r \in kD} \sum_{j \in r} p^k x^{k \rightarrow r}_{j}$$

Based on the perfect competition assumption, no firms or industries charges a markup in this economy. Then industry $k$’s total revenue can then be written as:

$$R^k = p^k Y^k = \sum_{l=1}^n \alpha^{k \rightarrow l} R^l + \alpha^k E^*E + \alpha^k wL, \forall 1 \leq k \leq n$$

(1)

The first element, $\sum_{l=1}^n \alpha^{k \rightarrow l} R^l$, is the demand for final goods in industry $k$ from $k$’s downstream industries, $\alpha^{k \rightarrow l}$ is input share of industry $k$ in the production in industry $l$; the second element, $\alpha^k E^*E$, is the demand from international consumers; and the last element, $\alpha^k wL$, is the demand from the domestic consumer.
Prices

The price index of an industry $k$ is simply determined by its upstream price indices and wage:

$$p^k_j = \left[\prod_{l=1}^{n} (p^l)^{w^l\rightarrow k} \right]^{1-\eta^k} + w^{1-\eta^k}$$

The industry $k$'s price index follows:

$$p^k = \prod_{j \in k} (p^k)^{j^k}$$

Labor Supply

For simplicity, we assume there is an upward-sloping labor supply function, $L = f(w)$. The particular functional form of the labor supply function is not needed in deriving the comparative statics, as we will show in this section and section 3.2, all industries are equally affected by the wage change. However, an upward-sloping labor supply function will make sure the exchange rate shock will have some real effects at the macro level.

Results

In this economy, we can show that the following two results hold:

**Proposition 1:**

After an exchange rate shock, the proportional change in each industry’s revenue, as well as the proportional change in total labor income, are the same as the proportional change in exchange rate. I.e.,

$$\forall k, \partial \ln R^k = \partial \ln \mathcal{E}, \partial \ln (wL) = \partial \ln \mathcal{E}$$

In addition, this implies that the proportional change in each industry’s revenue does not depend on its export share.
Proof:

See Appendix B.

Proposition 2:

After an exchange rate shock, the proportional change in each industry’s price index is the same as the proportional change in exchange rate. This implies that the export exposure of one downstream industry should not affect the real output of another export industry that shares the same upstream industry with it. I.e., the “up-and-down” channel does not exist.

\[ \forall k, \partial \ln P_k = \partial \ln E - \partial \ln w \]

Proof:

See Appendix B.

The economic mechanism for this industry is straight forward. In this economy, the only factor that is used in production is labor. Since all the markets are perfectly competitive, there are no markups charged by any industry. Thus, each industry’s marginal cost, and therefore its price, is essentially a constant times wage. The fluctuations of each industry’s price is therefore the fluctuations of wage, which is independent of each industry’s exposure to the international market.

To illustrate this point better, let’s re-consider the simple economy with only three industries, upstream industry C and downstream industry A, B. C only uses labor to produce. Therefore \( y_C = AL \). Industry A and B both use the output of C and labor as their inputs. Their production functions can be written as:

\[ y_i^k = [(y_{i}^{C \rightarrow k})^{1-\frac{1}{\eta_k}} + (l_i^{k})^{1-\frac{1}{\eta_k}}]^{\frac{\eta_k}{\eta_k-1}}, \, k \in \{A, B\} \]

Immediately following the production functions, we are able to derive \( P_C = w/A \) from the perfect competition assumption. Therefore, for both downstream industries, their input comes from two sources: industry C’s input, which cost \( w/A \), and labor, which cost \( w \). The marginal cost of industry \( k \) can be written as:

\[ MC_i^k = [A^{1-\frac{1}{\eta_k}} + 1]^{\frac{\eta_k}{\eta_k-1}} w, \, k \in \{A, B\} \]
By the assumption of perfect competition, $P^k \propto MC_i^k \propto w, \forall k = A, B$. I.e., the price index is proportional to the marginal cost, thus it is also proportional to the wage rate. Therefore, the percentage change in the price index of each industry will be the same as the percentage change in wage. The percentage change in the price index, as well as the percentage change in the real output in each industry is therefore independent of their export or the export status of their downstream industries.

3.2 The Model with Variable Markups

Now we turn into the generalization of our baseline model in section 2. We primarily focus on the following distinctions between the variable markup model and the perfect competition benchmark:

1. The impact of demand shock on average revenue of each industry will depend on its export exposure. With substitutable labor and other inputs, as well as reasonably competitive industries, industries that are more exposed to exports reduce their average revenues more than industries that are less exposed to exports.

2. Industries that are hit by a negative demand shock experience both more firms exiting (the extensive adjustment) and a larger increase in markup (the intensive markup adjustment).

3. The “up and down” effect exists under very general conditions. If an industry shares the same upstream industries with the exporters, the industry will suffer from an additional decrease in its real outputs.

Switching from the perfect competition benchmark to the variable markup setup changes the fundamental mechanism of the model. In the perfect competition framework, the general equilibrium effect is as large as the direct demand shock, thus all industries experience the same demand shock and there is not across-industry variation. In the model with variable markups, demand shock makes a difference. A reduction of aggregate demand will induce exits in the industry, which will in turn push up the markups charged by the surviving firms. The price changes in various industries are not only affected by the change in wage rate, but also affected by the markup changes according to specific demand shocks to those industries. The change of aggregate labor income will crucially depend on the change of markups in various industries, and the elasticity of substitution
between labor and the outputs from those industries as inputs.

Whether or not a firm with higher export exposure will have more reduction in revenue after
the Reform depends on the relative proportional change of labor income against the exchange rate
appreciation. If wage changes by a smaller percentage, firms with higher export exposures will
suffer more revenue loss after the Reform.

The up-and-down channel is still at play in general equilibrium. The two channels we previ-
ously specified, “gain from variety” and intensive markup adjustment, are still the main channels
through which a shock on one downstream industry can spillover to other downstream industries.

We now describe the model as follows.

Production

Suppose there are \( n \) industries in the economy. \( \forall 1 \leq k \leq n \), define \( R^k = P^k Y^k \) as industry \( k \)'s
total revenue. The production function of industry \( k \) is as follows:

\[
Y^k = \left( \sum_{i \in k} (y^k_i)^{1 - \frac{1}{\eta^k}} \right)^{\frac{\eta^k}{\eta^k - 1}}
\]

\( \gamma^k \) is the within-industry elasticity of substitution between firms in industry \( k \), \( y^k_i \) is the output
of firm \( i \) in industry \( k \), which is produced as follows:

\[
y^k_i = \left( \prod_{l=1}^n (y^l_{i \rightarrow k})^{\alpha^l_{i \rightarrow k}} \right)^{1 - \frac{1}{\eta^k}} + (l^k_i)^{1 - \frac{1}{\eta^k}} \frac{\gamma^k}{\eta^k - 1}, \forall k, \eta^k > 0
\]

Where \( y^l_{i \rightarrow k}, \alpha^l_{i \rightarrow k} \) have the same definition as in section 3.1. Assuming \( \beta^k \) is the labor share of
industry \( k \), \( \sum_{i=1}^n \alpha^l_{i \rightarrow k} = 1 - \beta^k \). \( \prod_{l=1}^n (y^l_{i \rightarrow k})^{\alpha^l_{i \rightarrow k}} \) is the amount of intermediate input used by firm
\( i \) in industry \( k \), and \( \eta^k \) is the elasticity of substitution between this interim input and labor.

The production function in this model is different from the perfect competition benchmark in
two important ways. First, we switch back to the CES aggregation between different firms within
the same industry to allow for the existence of markups. Second, we are now assuming only a finite
number of firms in each industry to allow for the variation of markups induced by entry and exit.

Demand

The demand side is also assumed to be the same as in section 3.1. Then following the same
discussion, industry $k$’s total revenue can be represented as:

$$R^k = p^k \gamma^k$$

$$= \sum_{l=1}^{n} \alpha^{k \rightarrow r} \frac{e^l - 1}{e^l} R^l + \alpha^k w L + \alpha^k s E^s E, \ \forall 1 \leq k \leq n$$  \hspace{1cm} (2)

The first element, $\sum_{r \in \Omega} \alpha^{k \rightarrow r} \frac{e^l - 1}{e^l} R^l$, denotes the demand from $k$’s downstream industries, $\alpha^{k \rightarrow r}$ is the share of final good of industry $k$ used in the production of final good in industry $r$, $\beta^r$ is the equilibrium labor share in the total production cost. Since each industry has its own markup, the demand from the downstream industries is just the average of their production cost, $\frac{e^l - 1}{e^l} R^l$, weighted by the input share of industry $k$ to these industries. The second element, $\alpha^k w L$, is the demand from the domestic consumer; and the last element, $\alpha^k s E^s E$, is the demand from the international consumer.

We can see immediately that different from the perfect competition benchmark, the revenue all industries can no longer be represented with a system of equations. This is because with each firm charging a positive markup, the production cost of each industry is no longer equal to its revenue. In addition, the demand elasticity of each industry $\epsilon^l$ depends on its degree of competitiveness. Therefore, the production cost is also not a constant fraction of the revenue.

**Prices**

From our derivations in the simple baseline model, we know that in equilibrium

$$p^k = (N^k)^{1-\gamma^k} \cdot \left\{ \frac{e^k}{e^k - 1} \left[ (\phi^k)^{1-\eta^k} + w^{1-\eta^k} \right]^{\frac{1}{1-\eta^k}} \right\}$$  \hspace{1cm} (3)

$$\epsilon^k = (1 - \frac{1}{N^k}) \gamma^k + \frac{1}{N^k}$$  \hspace{1cm} (4)

$$N^k = \frac{1}{\gamma^k} [\frac{R^k}{f^k} - 1 + \gamma^k]$$  \hspace{1cm} (5)

$$\phi^k = \prod_{l=1}^{n} (p^l)^{\frac{e^{l-k}}{e^{l-k}-1}}$$  \hspace{1cm} (6)

Where $R^k$, $P^k$, $f^k$ are the total revenue, price index and per-period fixed cost of industry $k$, respectively. $\epsilon^k$ is the demand elasticity faced by industry $k$, and $N^k$ is the number of firms in industry $k$.  

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Most of the above equations come directly from the generalization of our baseline model. The price index of industry $k$ is now determined by the price of intermediate inputs, $\phi_k$, wage, firm level markup $\frac{\epsilon_k}{\epsilon_k - 1}$, and the total number of firms in the industry, $N_k$. Within each industry, the demand elasticity and the number of firms are still determined, separately, by the number of firms in each industry and by equating average profit to the fixed entry cost.

**Labor Supply**

As in the previous perfect competition benchmark, we assume there is an upward-sloping labor supply function, $L = f(w)$.

Following these setup, we are able to show the following results, the proofs of which are contained in the appendix:

**Proposition 3:**

When the local currency appreciates, the total revenue in each industry goes down, so as the number of firms and average demand elasticity. In addition, total labor income also decreases. I.e.

$$\frac{\partial \ln R_k}{\partial \ln E} > 0, \quad \frac{\partial \ln N_k}{\partial \ln E} > 0, \quad \frac{\partial \ln \epsilon_k}{\partial \ln E} > 0, \quad \frac{\partial \ln (wL)}{\partial \ln E} > 0$$

Under the circumstance when labor and the intermediate inputs are gross substitutes and $f \ll R$, controlling for indirect shocks, an industry with higher export share suffers more revenue losses from the exchange rate shock ($s_{k \rightarrow e}$ indicates the export share of industry $k$):

$$\frac{\partial \ln R_k}{\partial \ln E \partial s_{k \rightarrow e}} > 0$$

In addition, controlling for indirect shocks, the average revenue of an industry with also decrease more if it were to have a larger export share before the shock:

$$\frac{\partial \ln R_k - \partial \ln N_k}{\partial \ln E \partial s_{k \rightarrow e}} > 0$$

**Proof:**

See Appendix C.
Proposition 4:

Controlling for direct shock from the foreign consumers, an industry whose downstream industries are more exposed to export is more affected by the exchange rate appreciation.

Proof:

See Appendix C.

Proposition 5:

The “up-and-down” effect exists. The more a downstream industry connects with exporters via sharing the same upstream industry, its real output reduced more after the Reform.

Proof:

See Appendix C.

Proposition 4 is a direct generalization of the baseline partial equilibrium model. The intuitive result that when exchange rate appreciation occurs, the revenues and elasticities of all the industries will decrease accordingly is true for both the general equilibrium case and partial equilibrium case. The difference here is the change in domestic demand. In our baseline model, since domestic consumer has a fixed endowment, the domestic demand is not affected by the exchange rate shock. However in the general equilibrium model, the domestic consumer consumes out of his labor income. Therefore, the total labor income in the economy will decrease as labor cost decreases. Without limiting parameter settings, it is unclear whether an industry more exposed to exports (and therefore less exposed to domestic demand) will suffer a more severe drop in its revenue. In order to match the pattern in data, we use the parametrization with makes the general equilibrium effect (changes in labor income) smaller than the direct demand shock (changes in foreign demand). Our parameter space will be less restrictive if we assume other income sources of the domestic consumer, which are not effected by the labor market.

Proposition 5 and 6 are natural extensions of their partial equilibrium counterparts. If the parameters that satisfies proposition 4 holds, then industries with higher export exposures will experience a larger reduction in their revenue. They will correspondingly cut back on their usage of
intermediate inputs. This will therefore result in a greater reduction of their upstream industries’ revenues, compared to other upstream industries with non-exporters as their downstream. Thus, a greater reduction of demand for these upstream industries will induce exits in these industries, which will reduce variety and push up markups for all its downstream industries, introducing the “up and down” effect.

Compared to the perfect competition benchmark, we therefore have the following two major differences:

1. After the exchange rate appreciation, the decrease in industry-level total revenue and also average revenue now crucially depend on the industry’s exposure to exports. In the perfect competition benchmark, labor income, and therefore domestic demand, adjusts proportionally to foreign demand. Therefore, export exposures are irrelevant in determining the drop of revenue. In the imperfect competition framework, the change of markup and the entry and exit of firms will make the change of labor income different from the change of foreign demand.

2. The “up and down” effect is now present; demand shocks may have a large impact on the aggregate real output. In the perfect competition benchmark, the demand shocks will cause prices and wage to decrease proportionally across industries. Therefore, the change in real output is the same for all industries. In the imperfect competition framework, however, a loss of variety and an increase in markup will push up costs to all the sectors and reduce real outputs. A demand shock on one downstream industry can have spillover effect to other downstream industries that shares the same upstream industry with it.

4 Empirical Analysis

In this section, we use the difference-in-differences approach as our main identification strategy to empirically test the propositions of our model. The section is organized as follows:

First, we provide some evidence to justify for the validity of our empirical strategy. We document that the reform of exchange rate regime in 2005 (hereafter “the Reform”) is an exogenous negative demand shock to the exporters. Furthermore, we show exporting firms and non-exporting
firms shared similar trends in revenue, real output, profitability and employment growth before the Reform. These two facts combined provide justification for our difference-in-differences specification. Based on the similar trends of firm-level performances in exporting and non-exporting firms, we can interpret the coefficients generated by a difference-in-differences analysis as the causal impact of the Reform on firm-level performances.

We then proceed to test the hypotheses proposed by our model. The first set of specifications test the hypotheses about how the Reform affected firm-level revenue and real output. We control for both direct shocks and indirect shocks that are transmitted within the input-output network. These tests are to document the significant impact the Reform has on the exporting and connecting industries. If firms with different export shares differ significantly regarding revenue drops, this will also serve as evidence against the perfect competition benchmark. We show that, in perfect competition, the decline in revenue is independent of the export exposures. Therefore, if the drop in revenue is significantly increasing in export exposure, it can serve as evidence against the perfect competition framework.

The second set of hypotheses is specific to our model. We estimate the demand elasticity and markup at a 4-digit industry level and test how demand elasticity responds to the Reform. We also count the total number of firms at a 3-digit industry level and use it as another dependent variable to test our model’s implication on entry and exits. We show that immediately after the Reform, industries with higher export exposure (either by itself or through its downstream industries) had a larger increase in markup and a greater decrease in demand elasticity. These findings confirm one of the two key channels of our model - the adjustment of markup. We also find an increase in exits and a reduction of the number of firms in the industries with high export exposures, which corresponds to the loss of variety channel.

Lastly, we document the “up-and-down” channel, which is the most important prediction that is unique to our model. We show that an industry whose upstream industries are more exposed to indirect downstream exporting shocks also suffers more loss in its real output. In a perfect competition model, a negative demand shock on one of the downstream industries will decrease each upstream industries’ revenue proportionally, but will not affect other downstream industries connected to the same upstream industries.

The empirical results not only support our theoretical findings, but they also help us rule out several other possible models. We can rule out the model with perfect competition market structures by showing the significant “up and down” effect, as well as the changing markups and demand elasticities. In the following sections, we will lay out a detailed discussion on how we test our model against these benchmarks in detail.
4.1 The Exchange Rate Reform in 2005

The Chinese currency was effectively pegged to the U.S. dollar at the rate of 8.28 RMB/US dollar before 2005. In the July of 2005, the People’s Bank of China announced the Reform that transformed the exchange rate regime to a managed float with reference to a basket of currencies. At the same time, the Chinese currency is allowed to float within a wider band of its target value. In August 2005, Governor Zhou Xiaochuan disclosed in a speech a list of 11 currencies as components of the reference basket, which includes the U.S. Dollar (USD), the Euro (EUR), the Yen (JPY), the Pound (GBP), and several other currencies (see Frankel and Wei (2007) for more details). The corresponding weights for each currency, however, were not publicly announced.

The RMB started a significant appreciation against the USD and a basket of other major currencies (HKD, JPY, and EUR) after the announcement (Figure 1). The appreciation against USD was about 30% from 2005 to 2007. Ahmed (2009) used the 2005 exchange rate policy reform to study the elasticity of processed exports industry and non-processed exports industry. He found that the demand elasticity in both types of exports is substantially greater than one. This evidence supports the idea that the 30% appreciation of Chinese currency is a substantial shock to the Chinese exporting firms. Chen and Dao (2011) studies the impact of real exchange rate fluctuations on sectorial and regional employment in China from 1980 to 2008. Their reduced-form regressions of employment on real exchange rate show that the employment in both the tradable and non-tradable sectors contracts following a real appreciation. We will provide more evidence on the negative impact on exporting industries later in this section.
The reform of exchange rate regime is viewed as a shock unexpected to most firms. Although there has been international pressure on the appreciation of CNY, the central bank of China was firm on their exchange rate policy before 2005. In fact, the Chinese Qualified Domestic Institutional Investment experienced a net increase of 29.4 billion USD from 2004 to the first half of 2005 which implicitly certified that the domestic firms did not expect the exchange rate policy reform. Eichengreen and Tong (2011) uses event studies method to show that there are significant jumps in equity prices of importing and exporting firms before and after the announcement, which can also serve as another evidence to show that the announcement comes as a surprise.

The lack of instruments and knowledge on the global financial markets indicates that even if some firms expected the shock in 2005, they are unlikely to hedge exchange rate fluctuations. The Chinese central bank conducted a survey in 2006 on the hedging of exchange rate risks, and only 2% of the respondents reported that they used any tools to hedge the exchange rate risk.

Figure 2 shows how the Reform affected exporting and non-exporting firms differently. Prior to the Reform, after controlling for ownership and size, firms with vastly different export exposures exhibit similar trends in revenue, real output, profitability and employment on average. After 2005, however, there is a significant trend of convergence of the two types of firms - the growth of both exporting and non-exporting firms slowed down, with the exporting firms experienced a more severe slowdown. This is a preview of our first set of empirical results, which show that exporting suffered from a significantly larger negative shock in the Reform, in comparison with non-exporting firms.
We have provided some rationale on why the reform of exchange rate regime in China can be counted as an unexpected exogenous demand shock on exporters. Combining it with the identical trend evidence between exporters and non-exporters prior to the Reform, we would be able to interpret our empirical findings as the demand-side causal impact of the exchange rate shock on relevant firms.

4.2 Data

We constructed our data set using three sources: the firm survey data from the National Bureau of Statistics, the Input-Output data, and the trade data from UN Comtrade. We describe them one-by-one in the following paragraphs.

Data on Chinese firm-level variables are from the Annual Surveys of Industrial Production from 2002 to 2007, conducted by the National Bureau of Statistics (NBS) of China. The Annual Survey of Industrial Production is a census of all non-state-owned plants with more than 5 million CNY in revenue (about $800,000 under current exchange rate, $600,000 under the exchange rate before 2005) plus all state-owned plants. The data covers more than 90% firms in the manufacturing industry in China. The raw data consists of 162,855 plants in 2000 and grows to over 336,768 plants in 2007.

Our data source for sectoral linkages is the Chinese Input-Output table published by the Na-
tional Bureau of Statistics of China in 2002. We use the 2002 Input-Output table for the reason that it is the only table before 2005 which disaggregates the manufacturing sector into 122 industries (The other tables only disaggregated the manufacturing sector into 42 industries). Assuming the input-output network does not change much over time (as assumed in Acemoglu et.al(2012), Atalay(2014)), we use this input-output table to capture the sectoral linkages.

Our data on international trade are from the UN Comtrade data base, which provides bilateral imports and exports for six-digit HS Codes (Harmonized System Codes) products. We calculate the industry-wide import and export exposures according to trade data from China’s top 15 trading partners, which accounts for over 80% of the trade values of China each year.

To concord the UN Comtrade data with the Input-Output table, we used the correspondence table of HS 2002 to the 122 industries\textsuperscript{2} in the Input-Output table. Since the UN Comtrade data is categorized by the HS 1996 from 2000 to 2001, and by the HS 2002 from 2002 to 2006. We use the correspondence tables available at the UN Comtrade website\textsuperscript{3} to convert HS 1996 and HS 2002 to HS 2007. There are several HS products mapped into multiple sectors, but the number is negligible comparing to the total number of products. To merge the Annual Surveys of Industrial Production with the Input-Output table, we match the 4-digit ISIC with the 122 industries by their descriptions. Each one of the 4-digit level ISIC is mapped into a unique industry code in the Input-Output table.

We limit the sample from 2003 to 2006 to avoid the effects of other country-wide shocks, such as China joining WTO (in 2001) and the US financial crisis (in 2007). For firm-level studies, we create a balanced sample that includes 63,692 firms to avoid unobserved firm heterogeneity. Usually a new entry will be accompanied with very volatile financial statement data. The exiting firms tend to have several years of very negative profits before they exit. These heterogeneity is not explicitly modeled in our theory. We are hoping to achieve a more homogeneous set of firms using balanced panel data. Our results still hold when we include new entrants after 2003. The firms that exit between 2005 and 2006 is automatically dropped from the sample because they do not have any observations after the Reform.

4.3 Difference-in-differences Specification

In this section, we discuss our difference-in-differences specification in details. There are two main reasons to use this approach as our primary specification:

\textsuperscript{2}Published by the National Bureau of Statistics of China in 2007.
\textsuperscript{3}http://unstats.un.org/unsd/cr/registry/regot.asp
1. Significant differences exist between exporting and non-exporting firms before the Reform in 2005. This is consistent with the model in Melitz (2003), where larger, more productive firms export and less productive firms serve the domestic markets. A difference-in-differences specification enables us to compare firms with the same export exposures before and after the shock, therefore eliminate the heterogeneity correlated with export exposures.

2. Before the Reform in 2005, firms with different export exposures have similar trends in the variable of our interests. The growth rate of profitability, real output, revenue and employment all showed identical trends regardless of how exposed the firms are to exports (Figure 2). This supports our identifying hypothesis, which by subtracting the non-exporting firms’ changes before and after the Reform from the changes of the exporting firms’, we may be able to identify the effect of the Reform on firm-level performances.

In general, we use the following specification:

$$\log Y_{jt}^k = \alpha_0 + \delta_j + \tau_t + \alpha_1^t D_{j,2004}^k + \alpha_2 I_t + \alpha_3^t D_{j,2004}^k I_t + \rho \log Y_{jt-1}^k + \beta^t X_{jt}^k + \epsilon_{jt}$$

(7)

In this regression, $k$ is an indicator of a 3-digit industry and $j$ is an indicator of a firm or a 4-digit industry, depending on the specification. $I_t$ is a dummy variable indicating whether $t$ is pre or post the Reform. $D_{j,2004}^k$ separates the treatment group from the control group. The variables we use for $D_{j,2004}^k$ depends on the question at hand. For how demand shocks directly affect the exporters, $D_{j,2004}^k$ would denote the export exposure of any firm in 2004. For how firms connected to the exporters are affected by the Reform, we use various weights implied by our model in section 3 to construct the direct and indirect export exposure variables. We also control for the lagged term of the dependent variable, which is $\log Y_{jt-1}^k$ on the right-hand side. This is in order to control for the firm-specific growth trend. It is well documented in the trade literature (Amiti, Itskhoki, Cunnings(2014), Gopinath, Newman (2014)) that exporters are different from non-exporters in their sizes, productivity, growth, etc. Adding the lagged dependent term on the right-hand side takes such differences into consideration. Moreover, it also estimates a more general mean reverting dynamics of the outcome variables. $X_{jt}^k$ denotes the control variables. We control for firm-, industry- and national-level variables. The firm-level variables contains the dummy for big firms, ownership, and government investment. State-owned enterprises are different from private firms in consumer base, production cost and so on. Controlling for ownership and other forms of government ownership allows us to eliminate the potential bias caused by the correlation between ownership and export patterns. At industry-level, we control for the import exposure of each industry by dividing import value by total cost of production. This is to shut down the potential supply shock caused
by the Reform. We also include the difference-in-differences term for the import exposure. Since import data is not available at firm level, there is high co-linearity between an industry’s direct import exposure and indirect import exposure. In order to avoid overfitting, we only include the direct import exposure variable here. Year fixed effects and firm fixed effects are also included in our controls, in order to control for more firm-level heterogeneity, country-wide economic growth, aggregate wage fluctuations and other national policy changes.

4.3.1 Shocks to the Exporting Firms and Their Suppliers

In our first set of empirical results, we examine how firms respond to the Reform. If the Reform were to generate a significant shock to firms, we would expect the following:

1. Firm-Level revenue and real output for exporters declined more after the Reform.
2. Firm-level revenue and real output in the industries that act as suppliers to the exporting industries are more negatively affected by the Reform.
3. The changes are larger for a firm with a higher export share, either directly or indirectly.

We use revenue and real output as a variable of interests for firm-level performances. The firm-level revenue is the total sales variable, which is directly measured in the survey. Due to data limitations, we compute the firm-level real output by dividing firm-level revenue by industry-level price indices.

Since we are interested in both the direct impact on exporters (the direct effect) and the first-order or higher-order network effect on the exporters’ suppliers, we will divide the treatment and control groups differently. We choose \( D_{j,t}^{k,2004} \) from three potential measurements: firm-level export exposure \( E_{j,t}^{k,2004} \), industry-level first-order export exposure \( FOD_{t}^{k,2004} \) and industry-level high-order export exposure \( HOD_{t}^{k,2004} \). The variables are constructed as follows:

\[
E_{j,t}^{k,2004} = \frac{ExpValue_{j,t}^{k,2004}}{Sales_{j,t}^{k,2004}}
\]

\[
FOD_{t}^{k,2004} = \sum_{l=1}^{n} s_{l \rightarrow j}E_{l,2004}^{k} = \sum_{l=1}^{n} s_{l \rightarrow j} \frac{ExpValue_{l,2004}^{k}}{Sales_{l,2004}^{k}}
\]

\[
HOD_{t}^{k,2004} = (I - \hat{\Omega})^{-1}E_{t,2004}^{k} - E_{2004}^{k}
\]

\( E_{j,t}^{k,2004} \) is the firm-level export share, which is computed by dividing the firm’s export value in 2004 by its total sales in 2004. This variable is a proxy to firms’ direct exposures to the exchange
rate shock. $FOD_k^{2004}$ is the industry-level first-order downstream export exposure, which captures industry $k$’s first-order indirect exposure to the exchange rate shock though the input-output relationship between industries. This variable is an average of $k$’s downstream direct export exposure, weighted by the output share from $k$ to its downstream industries ($s_{k\rightarrow l}$ is the output share of downstream industry $l$ in industry $k$’s total revenue). If an downstream industry $k$ is more important to downstream industry $k$ ($s_{k\rightarrow l}$ is larger), or the downstream industry has more export exposure in 2004 ($E_{l,2004}$ is larger), then the indicator is larger. Finally, $HOD_k^{2004}$ is computed by multiplying the inverse of Leontief matrix of the output share matrix $(I - \hat{\Omega})^{-1}$ by industry direct export exposure $\overrightarrow{E}_{2004}$, where $\hat{\Omega}(k, l) = s_{k\rightarrow l}$. This is an aggregation of indirect export exposure at all orders. In our data, we observe a sizable correlation between $FOD_k^{2004}$ and $HOD_k^{2004}$. In order to avoid the collinearity issue, we separate the two variables into different regressions.

Table 1 below shows the importance of the Reform to Chinese manufacturing firms in all industries. Column (1) indicates that firms with a higher export exposure in 2004 suffered from a larger negative shock after the Reform. On average, companies that only sell to international consumers experienced an approximately 10% more decline in sales compared to non-exporters. Considering the annual appreciation of CNY to USD was 2-3% in 2005 and 2006, this is a sizable difference. Also, the coefficient of the difference-in-differences term for first-order downstream export exposure is negative and significant. In magnitude, the coefficient estimate of the difference-in-differences term for the first-order downstream export exposure is even larger than the coefficient estimate of the direct export exposure diff-in-diff term in magnitude. An upstream industry that only supplies 100% exporters experienced a 28.5% greater decrease in the revenue than an upstream that only supplies non-exporters. All else equal, firms whose downstream industries are more exposed to the exchange rate shock are more negatively affected by the Reform. For Column (2), we replace the first-order export exposure with the high-order export exposure, in order to control for the high-order effects through the input-output network. The high-order specification generates similar results: firms whose downstream industries (connected both directly and indirectly through the input-output network) are more exposed to the exchange rate shock experienced a larger drop in their revenue growth after the Reform.
Table 2 below shows that the effect of the Reform on firm-level real output is rather similar. The Reform direct led to exporters’ output grew by 8% less compared to non-exporters’ output growth. The impact of indirect demand shock on firm-level output growth is about -14%, which is larger than the impact of a direct demand shock. Note that the coefficients in Table 2 are not directly comparable with Table 1. This is because we construct the real output as total output value divided by industry-level price indices, instead of using total sales. We test the two theoretical channels in our model in the following analyses.

<table>
<thead>
<tr>
<th>Table 1: The Effects of Demand Shocks on Firm-level Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable:</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Reform ( = 1 if after 2004)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Reform * Firm-level export share</td>
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<tr>
<td></td>
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<tr>
<td>Reform * Downstream export share (1st order)</td>
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<tr>
<td></td>
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<tr>
<td>Reform * Downstream export share (high order)</td>
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<td></td>
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<tr>
<td>One-year lagged log (total sales)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Controls</td>
</tr>
<tr>
<td>Year fixed effects</td>
</tr>
<tr>
<td>Firm fixed effects</td>
</tr>
<tr>
<td>R-squared</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>

Note: This table presents the outcome of the diff-in-diff analysis regarding how firm-level total sales respond to direct or indirect demand shocks. The first-order downstream export share is constructed as an average of downstream export shares weighted by output shares; the high-order downstream export share is computed using the Leontif inverse of the input-output table as weights. Firm size, ownership, government investment, and industry-level import exposure are added as controls. Standard errors reported in parentheses are clustered at the industry level.

*** Significant at the 1 percent level
** Significant at the 5 percent level
* Significant at the 10 percent level

Table 2 below shows that the effect of the Reform on firm-level real output is rather similar. The Reform direct led to exporters’ output grew by 8% less compared to non-exporters’ output growth. The impact of indirect demand shock on firm-level output growth is about -14%, which is larger than the impact of a direct demand shock. Note that the coefficients in Table 2 are not directly comparable with Table 1. This is because we construct the real output as total output value divided by industry-level price indices, instead of using total sales. We test the two theoretical channels in our model in the following analyses.
4.3.2 The Response of Demand Elasticity and Markups

This section presents how markups and demand elasticities of the exporting industries and their upstream industries change in the face of the Reform. We show evidence on both industry-level markup and the average demand elasticity of firms. This is a crucial step that tests our model against the perfect competition benchmark. If firm-level demand elasticity decreases, or markup increases after a negative demand shock, we then can reject the perfectly competitive benchmark.

Moreover, the test below is an important stepping stone to the tests on the “up-and-down” channel. Note that in our theoretical model the “up-and-down” channel attributes to two frictions associated with imperfect competition: the loss of variety and the increase of markup. We are able to provide support for the second friction in this section, by documenting the decreased demand elasticity and the increased markups.

The demand elasticity at firm level is constructed by dividing the revenue by profit per firm per year:
\[ \epsilon_{jk} = \frac{Sales_{jk}^k}{Profit_{jk}^k} \]

This relationship is directly implied by the CES production function. We further take the average of firm-level demand elasticities, which is weighted by their corresponding market shares, to compute the demand elasticity at the industry level. For industry-specific markups, we follow the approach discussed in Hall(1988, 1990) and Klette(1999). We first run the following regression at the industry level:

\[ \Delta \ln Y_{jk}^k = \alpha^k_t + \mu^k_t \Delta \ln X_{jk}^k + \epsilon_{jk}^k \]

The left-hand-side of the equation is the first-order differencing in the log real output at firm level, \( \Delta \ln X_{jk}^k \) is the first-order differencing in the log input at firm level, which is instrumented using its own lagged terms. Klette(1999) show that under the assumption of perfect competition, input share should be exactly equal to \( \mu^k_t \). We then compute the difference between average input share in 4-digit industry \( k \) and \( \hat{\mu}^k_t \) and use it as the industry-level markup estimate.

Table 3 and Table 4 summarizes the empirical findings regarding the response of industry-level demand elasticity and markup to the Reform. Column (1) in both tables show that the demand elasticity of firms with a higher export exposure in 2004 increased less (or dropped more) after the Reform; on the other hand, their markups grew faster. This evidence supports our theory’s prediction on markup adjustments. Although exporters suffered from a larger demand shock, their demand elasticities decrease more and thus they can charge a higher markup. Column (1) of Table 3 also indicates that the coefficient of the difference-in-differences term for first-order downstream export exposure is negative and significant; while the same coefficient in column (2) of Table 4 is positive and significant. All else equal, firms whose downstream industries are more exposed to the exchange rate shock are faced with a less elastic demand as a result, and charge a higher markup. For column (2) of Table 3, we replace the first-order export exposure with the high-order export exposure, to control for the high-order effects through the input-output network. The high-order specification implies similar results: firms whose downstream industries (connected both directly and indirectly through the input-output network) are more exposed to the exchange rate shock experienced a larger drop in their demand elasticity growth after the Reform. Column (3) of Table This insignificant result is most likely to come from the high co-linearity between the high-order difference-in-differences variable and the direct difference-in-difference variable. From Table
4, we can see that a larger high-order export exposure significantly increases the growth rate of industry-level markups after the Reform.

<table>
<thead>
<tr>
<th>Table 3: The Effects of Demand Shocks on 4-digit-level Demand Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable: Log(Demand Elasticity)</td>
</tr>
<tr>
<td>Independent Variables</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Policy * Firm-level export share</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Policy * Downstream export share (1st order)</td>
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<tr>
<td></td>
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<tr>
<td>Policy * Downstream export share (high order)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Lagged dependent var (1 period)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>R-squared</td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>Note: Standard errors in parentheses, *** p&lt;0.01, ** p&lt;0.05, * p&lt;0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: The Effects of Demand Shocks on 4-digit-level Markup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable: Log(4-digit industry markups)</td>
</tr>
<tr>
<td>Independent Variables</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Policy * Firm-level export share</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Policy * Downstream export share (1st order)</td>
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<tr>
<td>Policy * Downstream export share (high order)</td>
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<td></td>
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<tr>
<td>Lagged log markup (1 period)</td>
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<tr>
<td>R-squared</td>
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<tr>
<td>Observations</td>
</tr>
<tr>
<td>Note: Standard errors in parentheses, *** p&lt;0.01, ** p&lt;0.05, * p&lt;0.1</td>
</tr>
</tbody>
</table>

4.3.3 The Response of Entry and Exit

In this section, we show our empirical findings on how industry-level entry and exit pattern responds to a negative demand shock. Specifically, we intend to document whether industries that are either exporters or the suppliers of exporters experienced a larger reduction (or a smaller growth) of the number of firms after the Reform. The results in this section become a support of our first friction in the variable markup model, as we observe massive exits in the exporting industries and its suppliers after the Reform.
Note that the empirical results of this section are also not necessarily tests of our model against other benchmarks. In the models with perfect competition, the entry and exit decision of firms is undetermined. Therefore, industries could experience more companies exiting in the face of a negative demand shock. However, such exit patterns should not be systematically correlated with the export status, in particular, the downstream export exposure of an industry. In addition, the purpose of presenting these results is to complete our two channels of transmission: loss of variety and the drop of demand elasticity. Therefore, the result in this section and section 4.3.2 illustrate a thorough test of our theoretical model - when assuming within-industry imperfect competition with a finite number of firms, firms will exit and industry markup increase after a negative demand shock.

Table 5 below presents our main findings in terms of the entry and exit patterns. Overall, industries that are more connected with the international market through exporting experienced more net exits after the Reform. With estimates reported in Table 5, we expect that comparing to the log size of non-exporting industries, the size of an industry with 100% export share is around 20% smaller after the exchange rate reform. The upstream suppliers of the exporting industries also grew slower compared to the suppliers of the non-exporting industries. The results are robust in our specification of both first-order downstream demand shock and high-order downstream demand shock.
4.3.4 The “Up-and-down” Channel

Our third set of results focus on examining the “up-and-down” effect. In our theoretical derivations, we demonstrate that the real output of an industry who shares the same upstream as exporters will suffer from a drop in real output. To test this result, we replace the left-hand side variable in equation (7) with 4-digit industry-level real output. The 4-digit industry-level real output is computed by dividing the total sales by the price index of the corresponding industry. For the export exposure vector $D_{i,2004}^k$ in addition to the direct and indirect export exposure discussed above, we add an extra variable for the “up-and-down” channel:

$$UD_{k,2004} = \sum_{l=1}^{n} \alpha_{l\rightarrow k} FOD_{l,2004}$$

Here $FOD_{l,2004}$ is the first-order exposure of industry $l$, which measures industry $l$’s first-order indirect export exposure; $\alpha_{l\rightarrow k}$ is the input share of upstream industry $l$ to downstream industry $k$. Thus, the “up-and-down” variable of industry $k$ can be interpreted as the average upstream
industries’ first-order downstream indirect export exposure, weighted by the input shares of the upstream industries to industry $k$. To clarify this, note that the “up-and-down” effect refer to the fact that any negative shock on the downstream industry can be transmitted into a negative shock to other downstream industries which share the same upstream industry with the originally shocked industry. $UD_{k,2004}$ will increase if industry $l$’s suppliers have a larger demand from their downstream exporters in year 2004. A negative and significant sign will indicate the existence of the “up-and-down” effect.

Table 6 summarizes our results from the second specification. Column (1) and (2) indicate that in response to the exchange rate shock, firms with higher export share or more export-intensive downstream consumers suffered more in terms of real output. Column (3) and (4) are our key tests for the “up-and-down” effect: the coefficient of the difference-in-differences term that features the “up-and-down” variable is significant and negative. That is to say, if a firm’s upstream industries have higher first-order downstream export exposure on average, the real output of this firm decrease more after the Reform.

\begin{table}[h]
\centering
\begin{tabular}{lccccc}
\hline
 & \multicolumn{5}{c}{Log (real output)} \\
 & (1) & (2) & (3) & (4) \\
\hline
Reform * Firm-level export share & -0.081*** & -0.077*** & -0.081*** & -0.079*** \\
 & (0.016) & (0.027) & (0.017) & (0.024) \\
Reform * Downstream export share (1st order) & -0.144 & -0.036 \\
 & (0.101) & (0.039) \\
Reform * Downstream export share (high order) & -0.139** & -0.0601 \\
 & (0.061) & (0.042) \\
Reform * Export share of upstream’s other downstream & -0.184*** \\
 & (0.055) \\
Reform * High-order "up-and-down" variable & -0.229** \\
 & (0.096) \\

Controls & YES & YES & YES & YES \\
Firm fixed effects & YES & YES & YES & YES \\
Year fixed effects & YES & YES & YES & YES \\
R-squared & 0.842 & 0.845 & 0.842 & 0.846 \\
Observations & 949,037 & 949,037 & 949,037 & 949,037 \\
\hline
\end{tabular}
\caption{Testing the "Up-and-down" Channel}
\end{table}

Note: This table presents the test results for the "up-and-down" channel. The firm-level real output is computed by dividing total output value over industry-level price index. The first-order downstream export share is constructed as an average of downstream export shares weighted by output shares; the high-order downstream export share is computed using the Leontif inverse of the input-output table as weights. The "up-and-down" variables are computed by averaging the upstream supplier's indirect exposure to the exchange rate shock. Firm size, ownership, government investment, and industry-level import exposure are added as controls. Standard errors reported in parentheses are clustered at the industry level.

*** Significant at the 1 percent level
** Significant at the 5 percent level
* Significant at the 10 percent level
The results above have significant implications for the transmission of shocks within input-output networks. They present evidence on the amplification of demand shocks within the input-output network. In the perfect competition benchmark, a demand shock to any of the downstream industries will not be amplified to reduce the real GDP because the other downstream industries will not be affected. However, our evidence here clearly demonstrates that if a downstream industry shares the same upstream industry with other industries that experience negative demand shocks, its real output will also decline.

This result combined with the previous two sections, also draw a roadmap on the mechanism of shock transmissions that correspond to the prediction of our model. We have documented above that the upstream industries which are more exposed to exporters experience more exit in the industry level and also a decrease in industry-level demand elasticity. Combining the above findings with the finding in this section, we have completed the mechanisms for the “up-and-down” channel. The upstream industries that are more exposed to exporters experienced both exit and a reduction of demand elasticity. At the same time, the other downstream industries that are connected to these upstream industries experienced a reduction in real output.

4.3.5 Discussion

The difference-in-differences specification takes advantage the unexpectedness of the exchange rate policy reform in China. In addition, it shuts down the effect of the Reform on export exposure at the firm and industry level, by only using the export exposure in 2004 to separate the treatment group and control group. However, this specification also has several drawbacks. In this section, we discuss why these drawbacks are not likely to significantly undermine the tests of our theoretical model.

The first drawback is the potential bias caused by industries’ structural changes after the Reform. The government might have adopted a policy in favor of exporting industries to dampen the negative shock. To survive, exporting firms that are more exposed to the exchange rate shock might also have improved their productivity after the Reform. Although not controlled in the regressions, these potential structural changes are more likely to mitigate the negative shock, i.e. to result in more positive effects on exporting industries than non-exporting industries. Thus although the structural changes are likely to be positively correlated with industry export exposure, our negative and significant coefficients are at least a lower bound estimate of the actual difference between exporting and non-exporting industries. For our most important result - the “up-and-down” effect, the bias should be negligible since it is unlikely that structural changes of industries
are the endogenous response to their upstream industries’ demand shocks. As a robustness check, we repeat our primary empirical analyses on firm-level sales and real output using only data in 2004 and 2005 to avoid possible structural changes. The results are qualitatively similar to our main specification and are reported in Appendix D.

The second drawback is the general equilibrium response, which takes effect through the decrease in labor income. Upon the negative exchange rate shock, real wage decreases, which creates another negative demand shock from the domestic consumers. Since the consumption share of domestic consumers is not observable, the correlation between domestic exposure (the share of domestic consumption in an industry’s total sales) and export exposures could potentially cause bias in our estimates. However by construction, the downstream output shares, the export share, and the domestic exposure will add up to 1 for any given industries. Therefore, after controlling for the downstream shocks, industries with higher export exposure are more likely to have lower domestic exposure. Similarly, after controlling for the direct export exposure, industries facing a higher downstream export exposure are more likely to be less exposed to the domestic market. Thus, taking the general equilibrium response into considering, our difference-in-differences estimates still qualitatively capture the actual difference between industries suffered more from the exchange rate shock and the ones suffered less. The tests for our model predictions is still valid under this circumstance. Vavra and Stroebel (2016) argue that lower wealth may result in households become more price sensitive, so producers face a higher demand elasticity in the domestic market. As long as the change in demand elasticity does not systematically correlate with industry export shares, our estimates are still valid. One needs to take into account the variation in household demand elasticity though when estimating the aggregate effect of our channels.

Another general equilibrium response that can potentially change our results is from the supply side. The reduction of wage rate is a cost reduction for most industries. Intuitively, such reduction in labor cost will be more pronounced in industries that are labor intensive. However, from our discussion on Proposition 5 in Section 3.2, we show that the wage reduction has a uniform effect on all industries in terms of their real output. Therefore, adding in a year fixed-effect in our empirical specification will get rid of the effects of wage changes.

Finally, only controlling for the export exposures on the right-hand-side might be problematic if different industries export with different currencies with different valuation changes against RMB. However, we argue here that the problem is not important for our sample. From UN Comtrade data, we observe that the three largest exporting destinations of China are Hong Kong, United States and Japan, which consist of over 90% of the total export of China. Figure 2 implies that the appreciation of RMB towards HKD, USD and JPY followed similar trends from 2003 to 2006. Therefore, the neglect of export destinations is not likely to cause significant bias in our empirical
5 Conclusion

This paper introduces imperfect competition as a key determinant of the transmission of shocks within the input-output network. By introducing imperfect competition in each industry within the input output network, we first show theoretically that the model exhibits different patterns under demand shocks than the perfect competition benchmark. The difference comes from two channels which is absent in the model with perfect competition. The first channel comes from the loss of variety caused by industry-level exits. The second channel comes from the change of markup with the surviving firms. These two channels combined can amplify idiosyncratic demand shocks on a given sector into a economy-wide shock.

Our empirical results lend support to our theoretical findings. Using the exchange rate regime reform in China as a natural experiment, we are able to document that industries connected to exporting industries experience an increase of exits and a decrease of demand elasticity. As a result, the downstream industries which share the same upstream industries with the exporting industries are also affected by the exchange rate shock.

Future research can further explore the quantitative implications of the above two mechanisms. By introducing imperfect competition into a quantitative macroeconomic model with input-output linkages, one can better access how much idiosyncratic shocks can account for aggregate fluctuations.
References


Appendix

Appendix A: Equilibrium Solution for the Baseline Model

We solve the equilibrium by first solving the downstream industry’s problem then solving the upstream industry’s problem.

Downstream industry

Given $P^A, P^B$, the free-entry condition for industry $a$ must be satisfied and thus:

$$\pi_j^a = f^a = \frac{r_j^a}{\epsilon(\frac{1}{Na})} = \frac{1}{Na} P^a Y^a$$

Defining $e^a = \epsilon(\frac{1}{Na})$, the free-entry condition implies:
The price index of industry $a$ is:

$$p^a = (N^a)^{1-\gamma^D} \frac{e^a}{e^a - 1} (p^A)^{a \rightarrow a} (p^B)^{a \rightarrow b}$$

In this equation, $(N^a)^{1-\gamma^D}$ refers to the “loss of variety” (or “gain from variety”) channel; $\frac{e^a}{e^a - 1}$ is the firm-level markup in industry $a$, which is an increasing function in $N^a$ - when a market become less competitive, each firm charges a higher markup. This is what we discussed as the intensive markup adjustment channel.

Given the price index and revenue of industry $a$, the total real output of this industry is then:

$$Y^a = \frac{aE + E^a E}{p^a}$$

Similarly, the number of firms in industry $b$ can be represented as:

$$N^b = \frac{1}{\gamma^D} \left[ (1-a)E \right] \frac{1 + \gamma^D}{f^b}$$

$$p^b = (N^b)^{1-\gamma^D} \frac{e^b}{e^b - 1} (p^A)^{a \rightarrow b} (p^B)^{b \rightarrow b}$$

$$Y^b = \frac{(1-a)E}{p^b}$$

**Upstream industry**

The total revenue of sector $A$ is:

$$R^A = N^A e^A f^A$$

This should also be equivalent to the total sales to downstream sector $a$ and sector $b$:
\[
p^A(Y^{A\rightarrow a} + Y^{A\rightarrow b}) = a^{A\rightarrow a} \cdot \frac{e^a - 1}{e^a} p^a Y^a + a^{A\rightarrow b} \cdot \frac{e^b - 1}{e^b} p^b Y^b \\
= a^{A\rightarrow a} \cdot \frac{e^a - 1}{e^a} (\alpha + E^* E) + a^{A\rightarrow b} \cdot \frac{e^b - 1}{e^b} (1 - \alpha) E
\]

The equilibrium then features:

\[
N^A e^A f^A = a^{A\rightarrow a} \cdot \frac{e^a - 1}{e^a} (\alpha + E^* E) + a^{A\rightarrow b} \cdot \frac{e^b - 1}{e^b} (1 - \alpha) E
\]

\[
\Rightarrow N^A = \frac{1}{\gamma^U} \left[ \frac{a^{A\rightarrow a} \cdot \frac{e^a - 1}{e^a} (\alpha + E^* E) + a^{A\rightarrow b} \cdot \frac{e^b - 1}{e^b} (1 - \alpha) E}{f^A} \right] - 1 + \gamma^D \quad (11)
\]

This assumption can lend us a lot of tractability because it avoids a complicated sector-specific pricing equilibrium. The literature does point to some evidence of price by bargaining in the producer product marker (Goldberg and Tille, 2014), but we assume that away by making the trade happen in a large centralized market. The assumption is likely to contradict with the conditions of some real-life markets.

The price index of industry A is:

\[
p^A = (N^A)^{1-\gamma^U} f^A \cdot e^A \cdot e^A - 1
\]

And total output of industry A is:

\[
Y^A = a^{A\rightarrow a} \cdot \frac{e^a - 1}{e^a} (\alpha + E^* E) + a^{A\rightarrow b} \cdot \frac{e^b - 1}{e^b} (1 - \alpha) E
\]

Similar results will apply to industry B as well.

**Comparative Statics**

In this section, we derive the comparative statics following an exogenous decrease in the exchange rate \(E\), i.e. in the case of local currency appreciation.

Following equations (8), for given \(f^a\) there is

\[
\frac{\partial N^a}{\partial \ln E} > 0
\]

From equation (9), we know that \(e^a\) is increasing in \(N^a\). In addition, \(e^b\) is not changed after the
exchange rate shock, since industry b’s total revenue is not affected. Then we can further derive that

$$\frac{\partial \epsilon^a}{\partial \ln E} > 0, \frac{\partial \epsilon^a - 1}{\partial \ln E} > 0$$

Combining the results above with (11), we can further show that

$$\frac{\partial N^A}{\partial \ln E}, \frac{\partial N^B}{\partial \ln E} > 0$$

From the expressions of industry-specific demand elasticity, we know that $\epsilon^a$ is increasing in $N^a$ and $\epsilon^A$ is increasing in $N^A$. Therefore,

$$\frac{\partial \epsilon^a}{\partial \ln E}, \frac{\partial \epsilon^A}{\partial \ln E}, \frac{\partial \epsilon^B}{\partial \ln E} > 0$$

The “Up-and-down” Channel

The shock negative shock on industry $a$ can be transmitted to industry $b$. The transmission channel can be easily derived from the above conclusions. First of all, we know that the real output of industry $b$ is as follows:

$$Y^b = \frac{(1 - \alpha)E}{p^b}$$

Given that neither $(1 - \alpha)$ nor $E$ are affected by the demand shock to industry $a$, we focus on how $p^b$ can change. We know from the above derivation that:

$$\frac{\partial N^A}{\partial \ln E} > 0$$

So an appreciation of exchange rate (a reduction in $E$) will lead to a reduction of $N^A$. We also know from the price index of industry $A$ that:

$$p^A = (N^A)^{1-\gamma^A} \phi^A \cdot \frac{\epsilon^A}{\epsilon^A - 1}$$

which is decreasing in $N^A$ both because $(N^A)^{1-\gamma^A}$ is decreasing in $N^A$ (the gain from variety) and the fact that $\epsilon^A$ is decreasing in $N^A$ (the gain from competitiveness). Therefore, a decrease in $E$ will increase $p^A$. Similarly, $p^B$ increases in response to the exchange rate appreciation of local currency.
In addition, the price index of industry $b$ can be written as:

$$P^b = (N^b)^{1 - \gamma \xi} \cdot \phi^b \cdot \frac{\epsilon^b}{\epsilon^b - 1}$$

Where $\phi^b$ is an increasing function of $P^A, P^B$. We now only need to determine how $N^b$ changes with $\mathcal{E}$. From equation (10),

$$N^b = \frac{1}{\gamma^b} \left[ \frac{(1 - \alpha)E}{f^b} - 1 + \gamma^D \right]$$

which is fixed given exogenous parameters. So when $\mathcal{E}$ decreases, the increases in $P^A, P^B$ lead to an increase in $P^b$. Since the total revenue $(1 - \alpha)E$ is unchanged and $P^b$ is decreasing in $\mathcal{E}$, we show that the real output of industry $b$ ($Y^b$) will decrease when $\mathcal{E}$ decreases. This is the “up-and-down” channel.

**Appendix B: Proof of Propositions for the Perfect Competition Model**

**Proposition 1:**

After an exchange rate shock, the proportional change in each industry’s revenue, as well as the proportional change in total labor income, are the same as the proportional change in exchange rate. I.e.,

$$\forall k, \partial \ln R^k = \partial \ln \mathcal{E}, \partial \ln (wL) = \partial \ln \mathcal{E}$$

In addition, this implies that the proportional change in each industry’s revenue does not depend on its export share.

**Proof:**

We prove the proposition by first solving for the equilibrium in this model. In this model, it is easy to see that the total labor income, $wL$, can be return as a linear combination of the industry revenue $R$’s:

$$wL = \sum_{k=1}^{n} \beta^k R^k$$

Where $\beta^k$ is the labor share of industry $k$. Plugging back into equation (1), we get the following system of equations:
\[ R^k = \sum_{i=1}^{n} \alpha^{k \rightarrow l} R^l + \alpha^k E^* E + \alpha^k \sum_{i=1}^{n} \beta^l R^l \]
\[ = \sum_{i=1}^{n} (\alpha^{k \rightarrow l} + \alpha^k \beta^l) R^l + \alpha^k E^* E \]

We can re-write the system of equations into a matrix form:

\[ \overrightarrow{R} = (\Omega + \overrightarrow{A} \overrightarrow{B}') \overrightarrow{R} + \overrightarrow{A}^* E^* E \]

Here \( \Omega \) is the input share matrix, \( \Omega(m,k) = \alpha^{m \rightarrow k} \); \( \overrightarrow{R} = (R^1, R^2, ..., R^n)' \) is the vector of industry-level revenue; \( \overrightarrow{B} = (\beta^1, \beta^2, ..., \beta^n)' \) is the vector of labor share; \( \overrightarrow{A} = (\alpha^1, \alpha^2, ..., \alpha^n)' \) is the consumption share of a representative domestic consumer; \( \overrightarrow{A}^* = (\alpha^1^*, \alpha^2^*, ..., \alpha^n^*)' \) is the consumption share of the foreign consumer. Thus, as long as \( (I - \Omega - \overrightarrow{A} \overrightarrow{B}') \) is non-singular, there is a unique solution for \( \overrightarrow{R} \):

\[ \overrightarrow{R} = (I - \Omega - \overrightarrow{A} \overrightarrow{B}')(I - \Omega - \overrightarrow{A} \overrightarrow{B}')^{-1} \overrightarrow{A}^* E^* E \]  
(12)

Note that for a given industry \( k \), its labor share can be solved as:

\[ \beta^k = \frac{\left(\prod_{l=1}^{n} (P^l)^{\alpha^{l \rightarrow k}}\right)^{\gamma^{k \rightarrow k}} - 1}{\left(\prod_{l=1}^{n} (P^l)^{\alpha^{l \rightarrow k}}\right)^{\gamma^{k \rightarrow k}} + w^{\gamma^{k \rightarrow k}} - 1} \]

So in a model with perfect competition, the relative prices between industries do not change upon any shocks. Therefore, the labor shares, \( \beta^k \), in all industries stay constant. The labor income can then be solved as:

\[ wL = \sum_{k=1}^{n} \beta^k R^k \]
\[ \overrightarrow{B}' \overrightarrow{R} = \overrightarrow{B}' \overrightarrow{R} = \overrightarrow{B}' (I - \Omega - \overrightarrow{A} \overrightarrow{B}')(I - \Omega - \overrightarrow{A} \overrightarrow{B}')^{-1} \overrightarrow{A}^* E^* E \]

(13)

The proof of this fact follows directly from the equilibrium solution derived above. From equation (12) and (13), we know that the following two equations hold with equality in any equilibrium:
\[ \vec{R} = (I - \Omega - \vec{A} \vec{B}')^{-1} \vec{A}^\dagger \vec{E}^\dagger \vec{E} \]

\[ wL = \vec{B}^\dagger (I - \Omega - \vec{A} \vec{B}')^{-1} \vec{A}^\dagger \vec{E}^\dagger \vec{E} \]

Since the share vectors and matrices do not change over time, the proportional change in revenue and labor income is exactly the same as the proportional change in exchange rate, \( \vec{E} \). I.e.,

\[ \forall k, \partial \ln R^k = \partial \ln \vec{E}, \partial \ln (wL) = \partial \ln \vec{E} \]

\[ \square \]

**Proposition 2:**

After an exchange rate shock, the proportional change in each industry’s price index is a constant proportion of the proportional change in exchange rate. This implies that the “up-and-down” exposure should not affect the proportional change in an industry’s real output.

**Proof:**

The price index of an industry \( k \) is simply determined by its upstream price indices and wage:

\[ p^k_j = \left[ \left( \prod_{l=1}^{l-\eta^k} \frac{p^l_j}{\sum_{l'=l}^{l-\eta^k}} \right)^{1-\eta^k} + w^{1-\eta^k} \right]^{1-\eta^k} \]

The industry \( k \)’s price index follows:

\[ p^k = \prod_{j \in k} (p^k_j)^{v^k_j} \]

Given the relative prices between industries do not change over time,

\[ \forall k, p^k \propto w \]

The proportional change in real output becomes:

\[ \partial \ln Y = \partial \ln R^k - \partial \ln p^k \]

\[ = \partial \ln \vec{E} - \partial \ln w, \forall k \]
It is easy to see that for a given industry \( k \), the export shares of \( k \)'s upstream industries' other downstream industries does not affect \( \partial \ln Y^k \).

\[ \square \]

**Appendix C: Proof of Propositions for the General Equilibrium Model with Variable Markup**

**Proposition 3:**

When the local currency appreciates, the total revenue in each industry goes down, so as the number of firms and average demand elasticity. In addition, total labor income also decreases. I.e.

\[
\frac{\partial \ln R^k}{\partial \ln E} > 0, \quad \frac{\partial \ln N^k}{\partial \ln E} > 0, \quad \frac{\partial \ln \epsilon^k}{\partial \ln E} > 0, \quad \frac{\partial \ln (wL)}{\partial \ln E} > 0
\]

Under proper parameter specifications, controlling for indirect shocks, an industry with higher export share suffers more revenue losses from the exchange rate shock (\( s_k \rightarrow e \) indicates the export share of industry \( k \)):

\[
\frac{\partial \ln R^k}{\partial \ln E \partial s_k \rightarrow e} > 0
\]

In addition, controlling for indirect shocks, the average revenue of an industry with also decrease more if it were to have a larger export share before the shock:

\[
\frac{\partial \ln R^k - \partial \ln N^k}{\partial \ln E \partial s_k \rightarrow e} > 0
\]

**Proof:**

**Part 1:**

We first prove that \( \frac{\partial \ln R^k}{\partial \ln E} > 0, \frac{\partial \ln N^k}{\partial \ln E} > 0, \frac{\partial \ln \epsilon^k}{\partial \ln E} > 0, \frac{\partial \ln (wL)}{\partial \ln E} > 0 \). From equation(4) and (5), we can show that \( \frac{\epsilon^r - 1}{\epsilon} R^r \) is a linear function of \( R^r \):

\[
\frac{\epsilon^r - 1}{\epsilon} R^r = \frac{(N^r - 1)(\gamma^r - 1)}{N^r \gamma^r - \gamma^r + 1} R^r
\]

\[
= \frac{R^r / f^r - R^r / (f^r \gamma^r) + 1 - 1/ \gamma^r R^r}{R^r / f^r}
\]

\[
= (1 - \frac{1}{\gamma^r})(R^r - f^r)
\]
Re-writing the systems of equations (2), we can then get that:

\[ R^k = \sum_{r \in k'} \alpha^{k \to r} (1 - \frac{1}{\gamma^r})(R^r - f^r) + \alpha^k E^* E + \alpha^k wL \]  

(14)

Equations (3) to (6) implies that:

\[ \partial \ln p^k = \frac{1}{1 - \gamma^k} \ln N^k + \ln \frac{\epsilon^k}{e^k - 1} + \sum_{l=1}^{n} \alpha^{l \to k} \partial \ln p^l + \beta^k \partial \ln w \]  

(15)

And the total labor income follows:

\[ w = wL = \sum_{k=1}^{n} \beta^k (1 - \frac{1}{\gamma^k})(R^k - f^k) \]  

(16)

Where \( \beta^k \) is the labor share in industry \( k \) prior to the exchange rate shock. Plugging equation (16) into equations (14) and, we can re-write the system of equations as:

\[ \hat{R} = \Omega \Gamma (\hat{R} - \hat{f}) - \hat{A} \hat{B}' \Gamma (\hat{R} - \hat{f}) + \hat{A}^* E^* E \]  

(17)

Since \( \partial \ln(\hat{R} - \hat{f}) \) has the same sign of \( \partial \ln \hat{R} \), it must be that \( \forall k, \partial \ln N^k > 0, \partial \ln \epsilon^k > 0, \partial \ln (wL) > 0. \)

Next, from equations (4), (5) and (16) we can write \( N^k, \epsilon^k, wL \) as an increasing function of the \( R \)'s:

\[ N^k = \frac{1}{\gamma^k} \frac{R^k}{\gamma^k} - 1 + \gamma^k \]

\[ \epsilon^k = \gamma^k - \gamma^k - 1 \frac{N^k}{N^k} \]

\[ wL = \sum_{k=1}^{n} \beta^k (1 - \frac{1}{\gamma^k})(R^k - f^k) \]

Thus we can also show that \( \partial \ln N^k \partial \ln E > 0, \partial \ln \epsilon^k \partial \ln E > 0, \partial \ln (wL) \partial \ln E > 0. \)

Part 2:

Following equation (16), we can re-write the labor income as:

\[ wL = \sum_{k=1}^{n} \beta^k (1 - \frac{1}{\gamma^k})(R^k - f^k) \]

Also in the economy, labor income is both the production labor cost and the domestic consumer’s consumption. So the foreigner’s consumption is just used to generate the profits for each
industry:

\[ \sum_{k=1}^{n} N_k f^k = E^* \mathcal{E} \]

Next following equation (5),

\[ N_k = \frac{1}{\gamma_k} \left( \frac{R_k}{f^k} - 1 + \gamma_k \right) \]

\[ \Rightarrow N_k f^k = \frac{1}{\gamma_k} (R_k - f^k) + f^k \]

Thus the proportional change of exchange rate, \( \mathcal{E} \), and labor income, \( wL \), can be written as:

\[ \partial \ln (wL) = \sum_{k=1}^{n} \tau_k \left[ \partial \ln (R_k - f^k) + \partial \ln \beta^k \right] \]

\[ \partial \ln \mathcal{E} = \sum_{k=1}^{n} \omega_k \partial \ln (R_k - f^k) \]

Where \( \tau_k = \frac{\beta_k (1 - 1/\gamma_k^2) (R_k - f^k)}{wL} \), is the share of industry \( k \)'s labor income in the total income of the economy; \( \omega_k = \frac{N_k f^k}{E^* \mathcal{E}} \cdot \frac{R_k - f^k}{R_k - f^k + \gamma_k^2 f^k} \), is the share of \( R_k - f^k \gamma_k^2 \) in the total profit of the economy. Since \( \forall k, f_k > 0 \), we must have \( \sum_{k=1}^{n} \omega_k < 1 = \sum_{k=1}^{n} \tau_k \). If labor share \( \beta^k \) is constant, non-generically we will have \( \partial \ln (wL) > \partial \ln \mathcal{E} \). Next we show that only when the elasticity of substitution between the intermediate input and labor is bigger than 1, i.e. \( \eta^k > 1 \), we can potentially achieve the patterns in data.

Note that for any industry \( k \), the elasticity of substitution between labor and intermediate input is \( \eta^k > 1 \), so in equilibrium

\[ \frac{w^k}{\phi^k X^k} = \left( \frac{w}{\phi^k} \right)^{1-\eta^k} \]

From equation (3) and (6), it's easy to see that given \( N^k, \epsilon^k \), the price index in any industry is linear in \( w \). Thus after a negative demand shock, imperfect competition leads to \( N^k \downarrow \) and \( \frac{\epsilon^k}{\epsilon^*-1} \uparrow \). Therefore, \((P^k/w) \uparrow \) for any industry \( k \). Then it directly follows \( \frac{w}{\phi^k} = \frac{w}{\prod_{i \in k} (P^i)^{m_{i-k}}} \downarrow \Rightarrow \frac{w^k}{\phi^k X^k} \uparrow \Rightarrow \beta^k \uparrow \). Similarly we can show that the labor share in all industries go up after a negative shock in exchange rate, i.e. \( \partial \ln \mathcal{E} < 0 \); and they go down when \( \partial \ln \mathcal{E} > 0 \). Thus,
∀k, \partial \ln R^k \cdot \partial \ln \beta^k < 0

Intuitively, when f's are very small and \eta's are large, \sum_{k=1}^{n} \omega^k \approx 1 and \partial \ln \beta^k is significantly larger than 0 after the exchange rate appreciation. Therefore under such parameterization, the proportional change in labor income can be smaller than the exchange rate shock. I.e., the general equilibrium effect dampened the foreign demand shock:

\partial \ln (wL) < \partial \ln \mathcal{E}

Following equation (2), the first-order difference of the demand side equation of each industry becomes:

\begin{align*}
\partial \ln R^k &= \frac{1}{R^k} \left( \sum_{r \in \mathcal{D}_k} \alpha^k \rightarrow r \frac{\partial (R^r - f^r)}{\partial \mathcal{E}} + \alpha^k \rightarrow e \frac{\partial (wL)}{\partial \mathcal{E}} \right) \\
&= \sum_{r \in \mathcal{D}_k} s^k \rightarrow r \frac{\partial (R^r - f^r)}{R^r - f^r} + s^k \rightarrow e \frac{\partial \mathcal{E}}{\mathcal{E}} + s^k \rightarrow d \frac{\partial (wL)}{wL} \\
&= \sum_{r \in \mathcal{D}_k} s^k \rightarrow r \partial \ln (R^r - f^r) + s^k \rightarrow e \partial \ln \mathcal{E} + s^k \rightarrow d \partial \ln (wL) \quad (18)
\end{align*}

Where \( s^k \rightarrow r = \frac{(1-\beta^r)R^r}{R^k} \) is the share of sales to downstream industry r in industry k's total revenue; \( s^k \rightarrow d = \frac{wL}{R^k} \) is the share of sales to domestic consumers in industry k's total revenue; \( s^k \rightarrow e = \frac{\alpha \rightarrow e \mathcal{E}}{R^k} \) is the export share of industry k. Given \( \partial \ln \mathcal{E} > \partial \ln (wL) \), as predicted by our empirical results below, we can see that controlling for the indirect shocks, i.e. the first element in the equation, a larger \( s^k \rightarrow e \) implies a smaller \( s^k \rightarrow d \). I.e.,

\[ \frac{\partial \ln R^k}{\partial \ln \mathcal{E} \partial s^k \rightarrow e} > 0 \]

Part 3:

Following equation (5),
\[ N_k \ = \ \frac{1}{\gamma_k} \left( \frac{R^k}{f^k} - 1 + \gamma_k \right) \]

\[ \Rightarrow \partial \ln R^k - \partial \ln N_k \ = \ \partial \ln R^k - \partial \ln \left( R^k + f^k (\gamma_k - 1) \right) \]

Taking the first order derivative of the right-hand-side with respect to \( \partial \ln R^k \),

\[ \frac{\partial [\ln R^k - \ln(R^k + f^k (\gamma_k - 1))]}{\partial \ln R^k} = 1 - \frac{R^k}{R^k + f^k (\gamma_k - 1)} > 0 \]

Then

\[ \frac{\partial \ln R^k}{\partial \ln E_{s_k \rightarrow e}} > 0 \Rightarrow \frac{\partial \ln R^k - \partial \ln N_k}{\partial \ln E_{s_k \rightarrow e}} > 0 \]

This implies that as long as we control for the initial revenue \( R \), industry size \( N \) and indirect shocks, the average revenue of an industry with a higher export share also decrease more after the exchange rate shock.

\[ \Box \]

**Proposition 4:**

Controlling for direct shock from the foreign consumers, an industry whose downstream industries are more exposed to export is more affected by the Reform.

**Proof:**

From equation (18), we can write the proportional change in industry \( k \)'s revenue as:

\[ \partial \ln R^k = \sum_{r \in k_D} s_{k \rightarrow r} \partial \ln (R' - f') + s_{k \rightarrow e} \partial \ln E + s_{k \rightarrow d} \partial \ln (wL) \]

Since we have shown that in the equilibrium we observed in data,

\[ \forall k, \quad \frac{\partial \ln R^k}{\partial \ln E_{s_k \rightarrow e}} > 0 \]

Thus for any industry \( k \),

\[ \forall k, \quad \frac{\partial \ln (R^k - f^k)}{\partial \ln E_{s_k \rightarrow e}} > 0 \]

I.e., for a given industry \( k \), the export share can be a proxy of it’s proportional change in total costs. Then aggregating up the average downstream export exposure is a proxy of the indirect
shock from downstream firms.

□

**Proposition 5:**

The “up-and-down” effect exists.

**Proof:**

The total real output in industry follows:

\[ \ln Y^k = \ln R^k - \ln P^k \]

From equation (15), we know that \( \ln P^k \) can be written as:

\[
\partial \ln P^k = \frac{1}{1 - \gamma^k} \partial \ln N^k + \partial \ln \frac{\epsilon^k}{\epsilon^k - 1} + \sum_{i=1}^{n} \alpha^i \partial \ln P^i + \beta^k \partial \ln w
\]

Then given the systems of equations can be solved as:

\[
\partial \ln \vec{R} = (I - \Omega')^{-1} (\vec{B} \partial \ln \vec{w} + \ln \frac{1}{1 - \gamma} N + \ln \frac{\epsilon}{\epsilon - 1})
\]

\[
= (I - \Omega')^{-1} (\vec{B} \partial \ln \vec{w} - \frac{1}{\gamma - 1} \partial \ln \vec{N} - \partial \ln (\vec{R} - \vec{f}) + \partial \ln \vec{R})
\]

Thus the proportional change in real output can be represented as:

\[
\partial \ln \vec{Y} = [I - (I - \Omega')^{-1}] \partial \ln \vec{R} + (I - \Omega')^{-1} [\frac{1}{\gamma - 1} \partial \ln \vec{N} + \partial \ln (\vec{R} - \vec{f})] - B \partial \ln \vec{w}
\]

\[
= [I - (I - \Omega')^{-1}] \partial \ln \vec{R} + (I - \Omega')^{-1} [\frac{1}{\gamma - 1} \partial \ln \vec{N} + \partial \ln (\vec{R} - \vec{f})] - \vec{f} \partial \ln w
\]

\[
= \partial \ln \vec{R} + (I - \Omega')^{-1} [\frac{1}{\gamma - 1} \partial \ln \vec{N} + \partial \ln (\vec{R} - \vec{f}) - \partial \ln \vec{R}] - \vec{f} \partial \ln w
\]

(19)

If we consider the high-order shocks that can be approximated with export shares, a proxy for the first term is thus:

\[ (I - \hat{\Omega})^{-1} \vec{S}_E \]

Where \( \Omega \) is the input share matrix, and \( \hat{\Omega} \) is the output share matrix. Then following equation (19), a proxy for the second term becomes:
\[(I - \Omega')(I - \hat{\Omega})^{-1} \tilde{S}_E\]

Controlling for the direct shocks and indirect downstream shocks to revenue, the “up-and-down” effect is captured by \((I - \Omega')^{-1}(1 - \hat{\Omega})^{-1}\). In addition, since \(\bar{1} = (1, 1, ..., 1)'\), the wage change can be controlled by adding a year fixed effect.

\[\square\]

**Appendix D: Robustness Tests using Cross-sectional Specifications**

In this section, we repeat the primary empirical analyses for firm-level sales and real output using data only from 2004 and 2005. The results are shown in Table D.1 to Table D.3.

<table>
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<tr>
<th>Table D.1: The Effects of Demand Shocks on Firm-level Sales</th>
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<th>(3)</th>
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<tr>
<td>Independent Variables</td>
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<td>(0.413)</td>
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<tr>
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<td>Downstream export share (high order)</td>
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</tr>
</tbody>
</table>

Note: 1. Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
2. The sample consists of data from year 2004 and 2005, to avoid firm and industry structural changes
3. Demand shock is constructed as the sum of the export share (to different countries) times the percentage appreciation of RMB to corresponding currency
4. Supply shock is constructed as the sum of the import share (from different countries) times the percentage appreciation of RMB to corresponding currency
Table D.2: The Effects of Demand Shocks on Firm-level Demand Elasticity

<table>
<thead>
<tr>
<th>Dependent Variable: demand elasticity</th>
<th>Independent Variables</th>
<th>Empirical var-cov matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Firm-level demand shock from export</td>
<td>-13.05***</td>
<td>-12.10***</td>
</tr>
<tr>
<td></td>
<td>(1.182)</td>
<td>(1.188)</td>
</tr>
<tr>
<td>Downstream demand shock (1st order)</td>
<td>-17.49***</td>
<td>-11.72***</td>
</tr>
<tr>
<td></td>
<td>(2.262)</td>
<td>(2.692)</td>
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<tr>
<td>Industry-level supply shock from import</td>
<td>-1.307***</td>
<td>-1.746***</td>
</tr>
<tr>
<td></td>
<td>(0.503)</td>
<td>(0.504)</td>
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<tr>
<td>Upstream supply shock (1st order)</td>
<td></td>
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<tr>
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<tr>
<td>Downstream export share (high order)</td>
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</tr>
<tr>
<td>Constant</td>
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<td>0.0177***</td>
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<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
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<tr>
<td>Controls</td>
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</tr>
<tr>
<td>Year FE</td>
<td>Y</td>
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</tr>
<tr>
<td>Observations</td>
<td>114,089</td>
<td>114,089</td>
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</tbody>
</table>

Note: 1. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1  
2. The sample consists of data from year 2004 and 2005, to avoid firm and industry structural changes  
3. Demand shock is constructed as the sum of the export share (to different countries) times the percentage appreciation of RMB to corresponding currency  
4. Supply shock is constructed as the sum of the import share (from different countries) times the percentage appreciation of RMB to corresponding currency
<table>
<thead>
<tr>
<th>Dependent Variable: real output</th>
<th>Empirical var-cov matrix</th>
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<tbody>
<tr>
<td>Independent Variables</td>
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<tr>
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<td>Downstream demand shock (1st order)</td>
<td>-6.450***</td>
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<td>(0.805)</td>
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<td>Industry-level supply shock from import</td>
<td>-0.133</td>
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<td>(0.229)</td>
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<tr>
<td>Demand shock to upstream's other downstream</td>
<td>-19.78***</td>
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<td>(1.937)</td>
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<tr>
<td>Supply shock to downstream's other upstream</td>
<td>-9.294***</td>
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<td></td>
<td>(1.358)</td>
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<td>Downstream's demand shock (high order)</td>
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<td>-1.693***</td>
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<td>Constant</td>
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<tr>
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