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How Trade Restrictions Disperse: Policy Dynamics with Firm Selection

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Abstract

In this paper, I explore the aggregate effects of trade restrictions in a two-country, dynamic, stochastic, general equilibrium (DSGE) model with firm selection and variable adjustment of markup. As a response to trade collapse in the global crisis of 2008 and 2009, trade restrictions have emerged in several countries. By analyzing the dynamics of an economic slump in the home economy first, and the subsequent introduction of trade restrictions in the foreign economy, I show that both economies are in a worse position than they were during the economic downturn. The follow-ups to the recession and trade restrictions are analyzed through the three mechanisms: a) variable markup as a new avenue of increasing in competitive pressure for producers (e.g. more competitive firms lower their markups.); b) firms' individual specific productivity cut-off, which induces their optimum export choice (e.g. an increase in the export productivity cut-off means exporting becomes more difficult than before.); and c) the movement of international relative prices (e.g. real exchange rate and terms of trade).

Keywords: Trade Restrictions, Entry, Heterogeneity, Variable markup, Cut-off productivity, IRBC, Trade Policy

JEL Classification: F12, F41, F42, F44

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1 Introduction

During the economic crisis of 2008 and 2009, world output experienced the sharpest fall since the Great Depression in the 1930s. At the same time, world exports and imports in goods and services also collapsed tremendously. As illustrated in Figures 1 and 2, world exports and imports in goods and services declined steeply during 2009, and the trade level is similar to 2006 levels. This phenomenon happened not only in OECD countries but in most economies around the world. According to Gawande, Hoekman & Cui (2011) and Kee, Neagu & Nicita (2010)[1], the cause of this sudden and severe trade collapse was the global economic downturn[2] itself, and international trade-limiting measures during the crisis has a minor impact. Even so, trade restrictions have emerged in several countries in response to the global crisis. Evenett (2009) reported more than 1,400 new measures have employed between November 2008 and the end of 2010 that discriminate against foreign products and they are unfavourable to foreign investment. For example, in February 2009, the 'Buy American' provision of the fiscal stimulus package was created, stating that only US-produced iron, steel and manufactured goods could be used for projects funded by this provision. In December 2008, European Commission imposed duties on preserved fruits from China, and iron and steel products from Belarus, China and Russia. According to a WTO report, there were 155 anti-dumping measures investigations in 2008 that were implemented as trade remedies to shield domestic industries. A report in The Economist published on September 8th, 2012[3] noted that protectionism has been intensifying and suggested this is one of the causes of the recent drag on global trade. All of these examples clearly show the negative impact of protectionist measures. In this paper, I carefully analyze the follow-ups of a recession and trade restrictions as a short period reaction along international business

[1]They quantify trade policy changes and their trade impact for hundred countries during the trade collapse.

[2]The possible causes of the trade collapse are large demand shock (Chen (2010)), composition effect (Engel & Wang (2011)), vertical production linkages (Gawande et al. (2011), Yi (2009)), and drying up of the trade credit (Amiti & Weinstein (2009)).

[3]See http://www.economist.com/node/21562221

cycles, and I find that the result for both analyzed economies (home and foreign) are worse after the implementation of trade restrictions than would have otherwise been the case of the economic depression.

Figure 1: Yearly World Exports, 2000-2010 (OECD database)

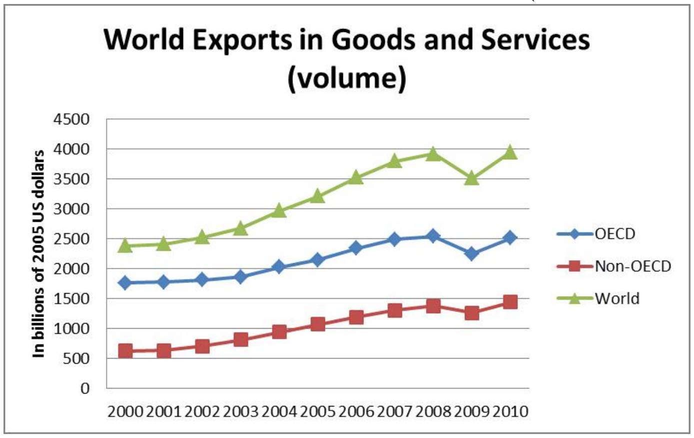
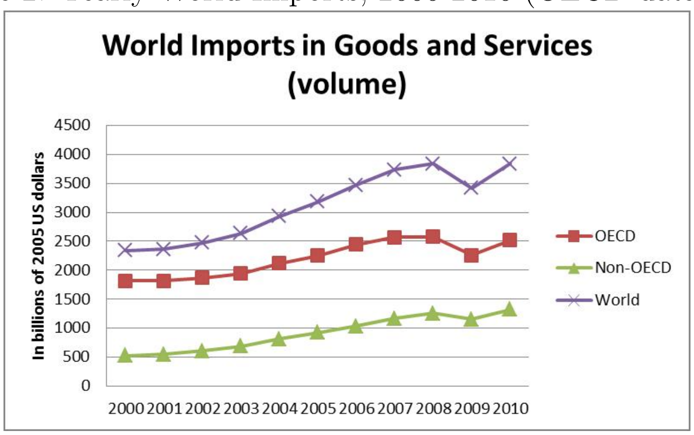


Figure 2: Yearly World Imports, 2000-2010 (OECD database)



Conventional international real business cycle (IRBC) models[4] assume international trade paradigms as exogenously given. An emerging class of IRBC models (New International Macroeconomic framework) adopts endogenous trade patterns from heterogenous firms in order to study macroeconomic dynamics. This class of IRBC models are capable of reproducing a variety of empirical regularities with an environment in which only the most productive firms become exporters and firms with relatively lower productivity are driven

[4]See Heathcote & Perri (2002), Kehoe & Perri (2002), Stockman & Tesar (1995), and Backus, Kehoe & Kydland (1994, 1992)

out of the market or sell only in domestic market. To achieve the objective of this paper, the benchmark model is built based on this emerging class of trade micro-founded IRBC models that are suitable for analyzing the aggregate effects of change in trade policy such as tariffs and quotas. Ghironi & Melitz (2005) analyze precise endogenous Harrod-Balassa-Samuelson effect[5] using endogenous tradability with heterogenous firm-specific productivity, extending the Melitz (2003) model to embed it in dynamic and stochastic framework. However, they only analyze the long-run consequences. Alessandria & Choi (2007) study whether sunk costs of exporting matter along the business cycles. They conclude that entry costs only matter for the firm-level dynamics, but have little effect on aggregate fluctuations. They use endogenous labor and capital as inputs, but they do not consider the entry process and treat the fraction of exporters as constant. Bergin & Corsetti (2008) and Bilbiie, Ghironi & Melitz (2008) study monetary policy, incorporating firm entry and nominal price rigidities. They find that monetary shock has significant effects on firm entry. Bilbiie et al. (2008) document that profits are positively correlated and markups are negatively correlated with income in their model. These are features of the data that previous IRBC models had a hard time explaining.

I present a two-country, dynamic, stochastic, general equilibrium (DSGE) model with firm selection and variable adjustment of markup. As in Bergin & Glick (2007) and Ghironi & Melitz (2005), the model incorporates firms' entry and exit process along with firm heterogeneity. Firms know their productivity only after entry and the tradability of its good is endogenously determined. This endogenous tradability determine the firm's export condition where the least productive firms sell only in the domestic market, and the most productive firms sell in foreign markets. The model also incorporates a sunk entry cost and iceberg trade costs that affect the decisions of monopolistically competitive intermediate goods producers. Before entering the market, producers have to pay a fixed

[5]Harrod-Balassa-Samuelson (HBS) or Balassa-Samuelson (BS) effect is that wealthier economies have higher average prices relative to their trading partners. As a result, the terms of trade or exchange rate appreciate when there is a positive aggregate productivity shock in the home economy.

entry cost. Afterwards, they learn productivitiy, which is drawn from a Pareto distribution. Also, variable markups are introduced as a new avenue of 'toughness' of firms' competition in a market such that competition will be tougher, firms charge lower markups, and aggregate productivity is higher. The variable adjustment of markups is generated from the non-homothetic preference of the final goods technology taken from Melitz & Ottaviano (2008) and Ottaviano, Tabuchi & Thisse (2002). Melitz & Ottaviano (2008) derive the intra-industry reallocation effects[6] and monopolistically competitive producers as in Melitz (2003), but add a new pro-competitive effect of trade through lowering markup[7]. They use a non-homothetic quasilinear-quadratic function as a consumer's utility function that makes it hard to manage the general equilibrium model[8]. Therefore, I use household' utility function as in Ghironi & Melitz (2005), but instead use non-homothetic and non-constant elasticity of substitution aggregates in the final goods production function. I assume that the financial asset markets are incomplete to exist some degree of international risk sharing mechanisms[9], but not perfect.

There is a growing line of literature that uses non-constant elasticity of substitution to explain behavior of international relative prices and how the composition of aggregate income affects trade patterns. Recently, several micro trade theory papers have incorporated non-homothetic preferences into their models. Foellmi, Hepenstrick & Zweimller (2011) explore the non-homothetic preferences into the new trade theory framework and compare its equilibrium outcomes with the case of standard homothetic preferences. Markusen (2010)

[6]Micro trade literature strongly approve these reallocation effects of trade with heterogeneous firms. These effects arise from firm selection of export status or trade liberalization. See Chaney (2008), Bernard, Jensen & Schott (2006), Bernard, Eaton, Jensen & Kortum (2003), Pavcnik (2002), Aw, Chung & Roberts (2000), and Bernard & Bradford Jensen (1999).

[7]These predictions match well the empirical findings of Campbell & Hopenhayn (2005), Syverson (2004) and Caballero & Hammour (1994). Campbell & Hopenhayn (2005) and Syverson (2004) found that U.S. retail trade industries in larger cities are more productive and competition is tougher. Caballero & Hammour (1994) show in their model that more efficient production units are created and less efficient ones are destroyed in which their model is essential for understanding growth and business cycles.

[8]Melitz & Ottaviano (2008) derive a partial equilibrium model to study the implications of different market sizes and trade policies.

[9]People cannot purchase an unemployment insurance policy that reimburse when they become unemployed. Countries cannot explicitly and efficiently insure against shocks.

and Simonovska (2010) aggregate differentiated consumer goods using variable elasticity of substitution preferences and explain several existing trade puzzles. Goksel (2009) present a multi-country general equilibrium model of trade with non-homothetic preferences and find that differences in income with trading partner act as trading barriers. This approach is seen not only in micro-trade papers, but also in business cycle literatures. Ottaviano (2011) presents a business cycle model with a non-homothetic utility function that is defined over a continuum of horizontally differentiated products, exogenous labor, and endogenous capital. He argues that existing models overstate the role of heterogeneous firms and endogenous entry as a transmission of aggregate productivity shock because of asymmetric size effect of firms on aggregate fluctuations. Sakane (2011) studies the terms of trade dynamics, incorporating non-homothetic preference into the consumption index with endogenous labor supply. Using vector autoregression (VAR) and maximum forecast error variance identification, she analyzes the consequences of the US labor productivity shock on the terms of trade in different asset market assumptions. Rodriguez-Lopez (2011) studies exchange rate pass-through,[10] building a model with sticky wage, heterogeneous firms and endogenous markups. Davis & Huang (2010) incorporate endogenous markup into a model with nominal rigidities and investigate IRBC properties, but their model does not have entry and exit dynamics.

There is also much literature on gains from trade openings analyzing long-run equilibrium of models. Melitz (2007) proposes a dynamic model of firm-level adjustment to trade liberalization that captures the entry, exit, export, and innovation decisions of heterogeneous firms. They find that the timing and the speed of trade liberalization matters for firm-level productivity improvement and the entry decisons to the export market. Alessandria & Choi (2011) estimate the effect of reducing tariffs on welfare, trade, and export participation and find that the tariff equivalent of the sunk exporting costs is around 30 percentage points. Antras & Caballero (2010) study long-run effects of trade liberalization with a dy-

[10]The elasticity of the price with respect to the terms of trade is the rate of exchange rate pass-through. Incomplete exchange rate pass-through arise when the movement of international relative prices tend to have a smaller impact on the price of imports.

namic general equilibrium model that incorporates financial constraints and the saving rate. Bernard et al. (2003) build a dynamic model with Bertrand competition in which heterogeneous firms are competing in prices and markups respond endogenously to these prices. In simulation results, they find that a 5 percent reduction of trade barriers lead to 4 percent increase in aggregate productivity and 4.7 percent increase in gross job creation. In opposition to the approaches taken in the papers above, this current study focuses on the aggregate effects of trade restrictions as a short-run feedback to economic slump of trading partner.

As a quantitative study, I start by analyzing the impulse response of the aggregate variables to temporary, negative productivity shock in the home economy. When the home economy is in an economic downturn, consumption and GDP go down. Its demand for varieties reduces with negative productivity shock and fewer firms enter the home market than before. Reduced entry in the home market generate less competition among firms, markups for all producers increase, and the cut-off productivity of home exporting firms increases since exporting becomes more difficult than before. Foreign producers exporting to the home economy become relatively competitive, so lower their markups and increase in exporting profits. This allows even less productive foreign firms can enter the home market. Therefore, the cut-off productivity of foreign exporting firms decrease during a recession of its trading partner and the terms of trade for home economy depreciate. Next, I analyze the consequences of the trade restrictions imposed by the foreign economy to protect its domestic industries as a response to economic downturn of its trading partner. The results show that both analyzed economies end up in a position worse than the one they would have found themselves in otherwise. The terms of trade for the home economy further depreciates, while consumption and income for both economies also continues to decrease. In the foreign economy, firms respond to this trade policy change in a number of ways. The profits of firms selling domestically increase and their markups go down, but the profits of exporting firms decrease and their markups increase with trade restrictions. However, the loss of profits of the exporting firms and the consumers in the foreign economy far outweigh the gains of the domestic profits, and put itself into a less competitive position than it was during the economic slowdown of its trading partner.

Second, international business cycle statistics of the simulated model are analyzed with a 1 percent home aggregate productivity shock, and with calibration along the lines of trade micro literature. Aggregate volatilities are well observed as a simillar pattern as the data. For the correlation between a variable and GDP, domestic comovement matches well, except for counter-cyclical net export. The average profits is positively correlated and markup is negatively correlated with GDP. These are the feature of the data that is in line with empirical findings of Bilbiie et al. (2008). Regarding international correlations, the results shares the same failure of the conventional IRBC model. The model produces higher cross-country consumption correlations than output correlations. Also, the international correlations of labor and entry are strongly negatively correlated. However, due to the setting of the incomplete asset market, risk sharing between countries dampens demands of the goods, so international correlations of output is not strongly negatively correlated compared to conventional IRBC models and the relative consumption increase. It helps replicating the correlation between international relative prices and the consumption ratio across countries.

The paper is organized as follows. Section 2 provides stylized facts of international business cycle data. Section 3 describes the benchmark model that incorporates heterogeneous firms with selection to export and variable adjustment of markup in an incomplete asset market setting. Section 4 is the quantitative analysis, providing calibration, the transition dynamics of the economic slump and import restrictions, and international business cycle statistics of the model compared with data. Section 5 performs a sensitivity analysis, varying several key mechanisms of the model. Section 6 concludes.

2 Stylized Facts of International Business Cycle Data

This section provide stylized facts on the international business cycle data. I start by plotting the time series for GDP, consumption, investment, and labor for the U.S. over the sample post-Bretton Woods period, 1973Q1-2009Q4[11]. The time series plots are shown in Figure 3. The time series displays large fluctuations about its trend at shorter frequencies, and consumption, investment, and labor time series comove with the GDP series. To make a comparison of the model dynamics with the business cycle properties of the data, cyclical components of the data needs to be extracted. As in the analysis by King & Rebelo (1999) and Backus et al. (1992), the Hodrick & Prescott (1997) filter[12] with a smoothing parameter equal to 1600 is applied to the natural log of each series.

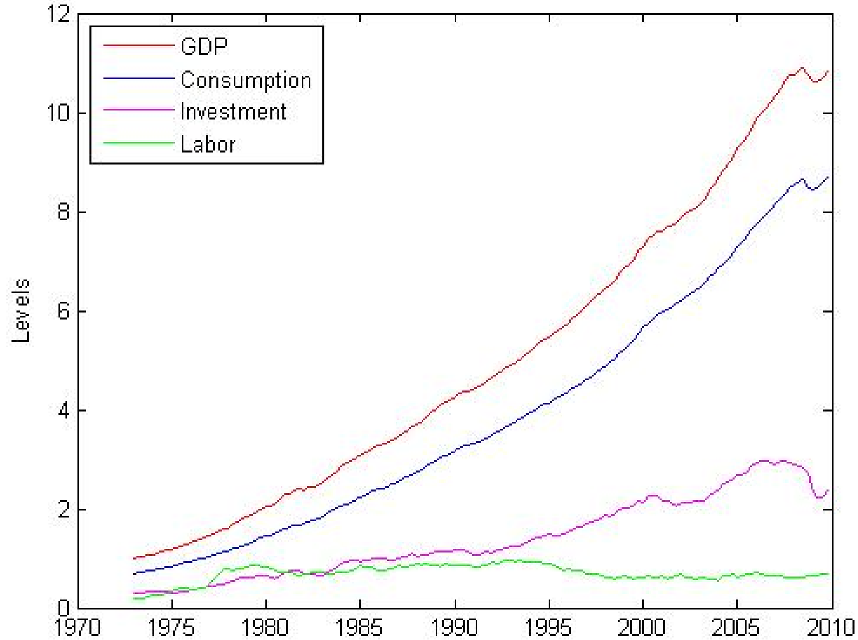
The data is organized into four categories: (1) the standard deviations of a variable relative to that of the log of output, (2) the correlation between a variable and the log of output as a domestic comovement, (3) the international correlations between home variables and foreign variables, and (4) the correlation between relative consumption and the terms of trade as an other correlation. Table 1 provides the U.S. business cycle statistics, 1973Q1-2009Q4 and its correlations with GDP. As is commonly known, investment is almost 4 times more volatile (3.87) than output, and consumption (0.72), and labor (0.58) is less volatile than output. For the domestic comovement, consumption, investment and labor are procyclical (0.86, 0.89, 0.79, respectively). The terms of trade is defined as the relative price of imports to exports. It is almost 1.5 times more volatile than output and its correlation with output is negative (-0.25). Table 2 provides international correlations between the U.S. and European aggregates[13], as well as the correlation between the terms of trade and relative

[11] U.S. quarterly data for GDP, consumption, investment is obtained from the International Financial Statistics provided by the International Monetary Fund (http://elibrary-data.imf.org/). The data for labor is obtained from the Bureau of Labor Statistics (http://www.bls.gov/) and OECD.StatExtracts (http://stats.oecd.org). More details about the U.S. time series are found in the appendix.

[12] Time series data consists of a cyclical component (y_t^c) and a trend component (y_t^d). To extract cyclical component, an HP filter is used. It is measurable by subtracting variations in the second difference of the trend minimizing $\left\{\sum_{t=0}^{T}(y_t - y_t^d)^2 + \lambda \sum_{t=2}^{T-1}((y_{t+1}^d - y_t^d) - (y_t^d - y_{t-1}^d))^2\right\}$.

[13] The quarterly data for the U.S. and Europe are taken from International Financial Statistics. European

Figure 3: Times Series using U.S. data



consumption as an other correlation. Cross-country output correlations (0.55) is larger than cross-country consumption correlations (0.42). Conventional IRBC models produce higher consumption correlations than output correlations. Investment and labor tend to be positively correlated across countries (0.39 and 0.28, respectively) in the data. The standard models fail to account for this feature and have counter-factually negative international correlations of investment and labor. Last, the terms of trade and the ratio of consumption

Table 1: U.S. Business Cycle Statistics (1973Q1-2009Q4)

	Volatility	Domestic Comovement
	% S.D. relative to GDP	Correlations with GDP
GDP	1	1
Consumption	0.72	0.86
Investment	3.87	0.89
Employment	0.58	0.79
TOT	1.44	-0.25

countries include: Austria, Finland, France, Germany, Italy, Sweden, Switzerland and the U.K.

are negatively linked in the data (-0.35)[14], but standard setups wrongly predict that they should be positively linked.

Table 2: International Correlations and Other Correlation (1973Q1-2008Q3)

GDP, GDP^*	0.55
C, C^*	0.42
X, X^*	0.39
L, L^*	0.28
TOT, Relative Consumption	-0.35 (CDL)

To evaluate the success and failure of the model, the data in this section and the simulated model is compared in the section 4.

3 A Model with Firm Selection and Variable Markup

In this section, I present a two-country, dynamic, stochastic, general equilibrium (DSGE) model that contains firm selection and variable adjustment of markup. The basic framework is built upon the models of Bergin & Glick (2007) and Ghironi & Melitz (2005) in which producers have heterogeneous firm-specific productivity and endogenous export participation with a sunk entry cost, and an ice-berg trade cost. The variable markups are introduced by non-homothetic preference of Melitz & Ottaviano (2008) that gives linear demand system for differentiated varieties. The world economy consists of two countries of equal size, home and foreign. The foreign variables are donoted by *. The model economy is composed of infinitely lived representative households, perfectly competitive final goods producers, and monopolistically competitive intermediate goods producers. I assume that international financial markets are incomplete, allowing only for trade in uncontingent home and foreign bonds. I restrict attention to the behaviors of domestic agents unless otherwise necessary.

[14] This data is taken from Corsetti, Dedola & Leduc (2008)

3.1 The Household's Behavior

In each period, the representative household of each country supplies L (L^*) units of labor inelastically at the wage rate W_t (W_t^*). The expected intertemporal utility function is characterized by: $E_0\left[\sum_{t=0}^{\infty}\beta^t\frac{C_t^{1-\eta}}{1-\eta}\right]$ where C_t denotes consumption. Here, the parameter $\beta \in (0,1)$ is the intertemporal discount factor and $\eta > 0$ is the inverse of the intertemporal elasticity of substitution. A unit mass of households in the home country face the sequence of budget constraints,

$$\begin{aligned}P_tC_t + P_tB_{H,t+1} + P_t^*B_{F,t+1} + \frac{n}{2}\left(P_tB_{H,t+1}^2 + P_t^*B_{F,t+1}^2\right) + \tilde{v}_t(N_{A,t} + N_{E,t})q_{t+1} \\ = (1+i_t)P_tB_{H,t} + (1+i_t^*)P_t^*B_{F,t} + N_{A,t}(\tilde{d}_t + \tilde{v}_t)q_t + W_tL + \pi_t \quad (1)\end{aligned}$$

where P_t denotes welfare-based price. $B_{H,t}$ and $B_{F,t}$ are home and foreign bond holdings in which pay an interest rate i_t and i_t^* each. Here, W_tL is the income from labor and W_t is the wage rate. As in Boileau & Normandin (2008), I assume a small quadratic portfolio cost (QPC) to avoid indeterminacy and non-stationarity of the steady states. The parameter that determines the cost of adjusting the holdings of bonds, n, is to be small, but positive. q_t is the shares in a mutual fund of home firms that pays an average total profits of firms $\tilde{d}_t$ as dividends. The price of traded shares in the stock market is $\tilde{v}_t$, therefore, $\tilde{v}_tN_{A,t}q_{t+1} + \tilde{v}_tN_{E,t}q_{t+1}$ is the total amount of resources allocated to accumulate shares in mutual funds. $N_{A,t}$ is the number of firms that are already operating at the time t, and $N_{E,t}$ is the number of new firms. Following Ghironi & Melitz (2005), I assume there is a one period time lag driven by depreciation in production. Therefore, at time t+1, only $(1-\delta_d)(N_{A,t}+N_{E,t})$ firms survive to produce. Here, δ_d is an exogenous death shock that hits firms at the end of period t. π_t is the rebate of resources using QPC to households, which is equal to $\frac{n}{2}(P_tB_{H,t+1}^2+P_t^*B_{F,t+1}^2)$ in equilibrium. Similarly, foreign households face the following sequence of budget constraints:

$$P_t^* C_t^* + P_t^* B_{F,t+1}^* + P_t B_{H,t+1}^* + \frac{n^*}{2}\left(P_t^* B_{F,t+1}^{*2} + P_t B_{H,t+1}^{*2}\right) + \tilde{v}_t{}^*(N_{A,t}^* + N_{E,t}^*) q_{t+1}^*$$
$$= (1+i_t^*) P_t^* B_{F,t}^* + (1+i_t) P_t B_{H,t}^* + N_{A,t}^* (\tilde{d}_t^* + \tilde{v}_t^*) q_t^* + W_t^* L^* + \pi_t^* \quad (2)$$

The first order conditions to the representative hosehold are achieved by maximizing the utility function subject to (1) by the Lagrangian method. The optimal condition for consumption is

$$\lambda_t P_t = C_t^{-\eta}, \quad (3)$$

where λ_t is the Lagrangian multiplier. The Euler equations for domestic and foreign bond holdings are

$$\lambda_t P_t (1 + n B_{H,t+1}) = \beta (1 + i_{t+1}) E_t \left\{ P_{t+1} \lambda_{t+1} \right\} \quad (4)$$

and

$$\lambda_t P_t^* (1 + n B_{F,t+1}) = \beta (1 + i_{t+1}^*) E_t \left\{ P_{t+1}^* \lambda_{t+1} \right\}. \quad (5)$$

Finally, the Euler equation for shares in a mutual fund is

$$\tilde{v}_t \lambda_t = \beta (1 - \delta_d) E_t \left\{ \lambda_{t+1} (\tilde{d}_{t+1} + \tilde{v}_{t+1}) \right\}. \quad (6)$$

3.2 Final Goods Producers

The final goods in the home country are produced by aggregating a set (Ω) of intermediate goods. The maximization problem of the final goods producer is

$$\max_{f_t(i)} P_t F_t - \int_{i \in \Omega} p_t(i) f_t(i) di \quad (7)$$

subject to the quasilinear non-constant elasticity of substitution technology that aggregates a continuum of horizontally differentiated intermediate goods as in Melitz & Ottaviano (2008) and Ottaviano et al. (2002):

$$F_t = \alpha \int_{i\in\Omega} f_t(i)di - \frac{\gamma}{2}\int_{i\in\Omega}[f_t(i)]^2\,di - \frac{\xi}{2}\left[\int_{i\in\Omega} f_t(i)di\right]^2. \tag{8}$$

Here, F_t is the production of final goods and $f_t(i)$ is the demand for varieties. $i \in \Omega$ denotes a continuum of differentiated varieties. I assume there is no homogeneous good in the preference[15]. Here, α measures the strength of the preference for differentiated products and ξ governs the substitutability of varieties. γ is a product differentiation index between intermediate goods in which consumers care more about the distribution of production across varieties as γ increases[16]. The solution to this problem gives the linear demand function for each variety:

$$f_t(i) = \frac{\alpha}{\gamma} - \frac{p_t(i)}{\gamma P_t} - \frac{\xi}{\gamma}\int_{i\in\Omega} f_t(i)di. \tag{9}$$

In the home economy, total number of producers are N_t. Therefore, all the varieties produced in home economy is achieved integrating (9) over N_t:

$$\begin{aligned}
\int_{i\in\Omega} f_t(i)di &= N_t\frac{\alpha}{\gamma} - \frac{1}{\gamma P_t}\int_{i\in\Omega} p_t(i)di - \frac{\xi}{\gamma}N_t\int_{i\in\Omega} f_t(i)di \\
&= \frac{\gamma}{\gamma+\xi N_t}\left[\frac{\alpha N_t}{\gamma} - \frac{1}{\gamma P_t}\int_{i\in\Omega} p_t(i)di\right] \\
&= \frac{\alpha N_t}{\gamma+\xi N_t} - \frac{N_t\tilde{p}_t}{P_t(\gamma+\xi N_t)}
\end{aligned}$$

where $\tilde{p}_t = \frac{1}{N_t}\int_{i\in\Omega} p_t(i)di$. Now, plugging this to (9) gives the expression for the variety demand without integral:

$$f_t(i) = \frac{\alpha}{\gamma} - \frac{p_t(i)}{\gamma P_t} - \frac{\xi}{\gamma}\left(\frac{\alpha N_t}{\gamma+\xi N_t}\right) + \frac{\xi}{\gamma}\frac{N_t\tilde{p}_t}{P_t(\gamma+\xi N_t)}. \tag{10}$$

The price bound, $p_{bound,t}$, is attained at which linear demand for each variety, $f_t(i)$ is driven to 0. If price is lower than $p_{bound,t}$, a firm would have zero demand. This price bound is the

[15]In Melitz & Ottaviano (2008), preference includes a homegenous good f_0 chosen as numeraire.

[16]When γ is zero, differentiated varieties are perfect substitutes.

driving force for the variable adjustment of markups and the cut-off productivity strategy of firms as it will be shown in the behavior of the intermediate goods producers.

$$p_{bound,t} = \frac{\alpha\gamma P_t + \xi N_t \tilde{p}_t}{\gamma + \xi N_t} \tag{11}$$

Notice that this price bound or threshold cost, $p_{bound,t}$ goes down when the total number of firms, N_t goes up or the average price, $\tilde{p}_t$ goes down. Both of which denote increase in competitive pressure at the micro firm-level dynamics.

3.3 Intermediate Goods Producers

Now, I consider the problem of monopolistically competitive intermediate goods producers in the home economy. These firms are endogenously segmented into domestic markets and foreign markets in their production and they maximize profits based on their linear variety demand system found as solutions to the problem of the final goods producers.

3.3.1 Firm Selection

There are $N_t(N_t^*)$ total mass of producers in the home (foreign) country and exporters pay sales with an ice-berg trade cost τ_t for each unit of goods. Given these definitions, the monopolistically competitive intermediate goods producers maximize their profits subject to the input demand functions for domestically produced varieties (13) and (14). Per-period profits for intermediate goods producers, $d_t(a)$ are divided into domestic sales profits, $d_{D,t}(a)$, and export sales profits, $d_{X,t}(a)$:

$$d_t(a) = d_{D,t}(a) + d_{X,t}(a). \tag{12}$$

Producers maximize their profits separately and decide how much to produce on each market. Producers selling domestically maximize $d_{D,t}(a) = p_{D,t}(a)f_{D,t}(a) - \frac{W_t}{aZ_t}f_{D,t}(a)$ subject to

$$f_{D,t}(a) = \frac{\alpha}{\gamma} - \frac{p_{D,t}(a)}{\gamma P_t} - \frac{\xi}{\gamma}\left(\frac{\alpha N_t}{\gamma + \xi N_t}\right) + \frac{\xi}{\gamma}\frac{N_t \tilde{p}_t}{P_t(\gamma + \xi N_t)} \tag{13}$$

while exporting producers maximize $d_{X,t}(a) = p_{X,t}(a)f_{X,t}(a) - \frac{W_t}{aZ_t}\tau_t f_{X,t}(a)$ subject to

$$f_{X,t}(a) = \frac{\alpha}{\gamma} - \frac{p_{X,t}(a)}{\gamma P_t^*} - \frac{\xi}{\gamma}\left(\frac{\alpha N_t^*}{\gamma + \xi N_t^*}\right) + \frac{\xi}{\gamma}\frac{N_t^* \tilde{p}_t^*}{P_t^*(\gamma + \xi N_t^*)}. \tag{14}$$

They take the total number of firms, N_t and the average price, $\tilde{p}_t$ as given. Here, $\frac{W_t}{aZ_t}$ is the marginal cost of production. Each producer faces a different marginal cost curve differentiated by individual specific productivity a. However, all firms are subject to a common aggregate productivity Z_t. Therefore, Z_t affects the production of all goods homogeneously while a is the firm-specific productivity.

Now, I write the price, $p_{D,t}(a)$ and $p_{X,t}(a)$, in the function of demands $f_{D,t}(a)$ and $f_{X,t}(a)$. They are total inverse demand functions: $p_{D,t}(a) = \frac{\alpha\gamma P_t + \xi N_t \tilde{p}_t}{\gamma + \xi N_t} - \gamma P_t f_{D,t}(a)$ and $p_{X,t}(a) = \frac{\alpha\gamma P_t^* + \xi N_t^* \tilde{p}_t^*}{\gamma + \xi N_t^*} - \gamma P_t^* f_{X,t}(a)$. I plug them back into profit function, and find the first order conditions with respect to $f_{D,t}(a)$ and $f_{X,t}(a)$:

$$f_{D,t}(a) = \frac{p_{D,t}(a) - \frac{W_t}{aZ_t}}{\gamma P_t}$$

$$f_{X,t}(a) = \frac{p_{X,t}(a) - \frac{W_t}{aZ_t}(a)\tau_t}{\gamma P_t^*}$$

Consequently, the optimal prices are found as follow.

$$p_{D,t}(a) = \frac{1}{2}\left[\frac{W_t}{aZ_t} + \frac{\alpha\gamma P_t + \xi N_t \tilde{p}_t}{\gamma + \xi N_t}\right] = \frac{\frac{W_t}{aZ_t} + p_{bound,t}}{2} \tag{15}$$

$$p_{X,t}(a) = \frac{1}{2}\left[\frac{W_t \tau_t}{aZ_t} + \frac{\alpha\gamma P_t^* + \xi N_t^* \tilde{p}_t^*}{\gamma + \xi N_t^*}\right] = \frac{\frac{W_t}{aZ_t}\tau_t + p_{bound,t}^*}{2}. \tag{16}$$

Here, $p_{bound,t}$ is defined as the price bound for the producers who are having domestic sales. If its price is lower than $p_{bound,t}$, a firm would have zero demand. Therefore, it is the threshold cost for the firms who are having domestic sales, and is equal to $p_{D,t}(a_{D,t})$ and $\frac{W_t}{a_{D,t}Z_t}$. Similarly, the price bound of producers who have export sales, $p^*_{bound,t}$ is defined when $f_{X,t}(a_{X,t})$ is zero. Therefore, it is the threshold cost for the firms who are having export sales, and is equal to $p_{X,t}(a_{X,t})$ and $\frac{W_t}{a_{X,t}Z_t}$.

Since demand functions are written in the function of the price function, I plug optimal prices and the threshold cost for the producers back into demand function and yield:

$$f_{D,t}(a) = \frac{1}{\gamma P_t}\left[\frac{\frac{W_t}{a_{D,t}Z_t} - \frac{W_t}{aZ_t}}{2}\right] \tag{17}$$

and

$$f_{X,t}(a) = \frac{1}{\gamma P^*_t}\left[\frac{\tau_t\frac{W_t}{a_{X,t}Z_t} - \frac{W_t}{aZ_t}\tau_t}{2}\right]. \tag{18}$$

As in the optimal prices, demand functions of the producers are bounded from above and determined by the cut-off productivity strategy.

3.3.2 Markups and Profits

The monopolistically competitive producers have excess capacity in which they operate on the downward sloping portion of their average total cost curve. Therefore, they produce less than the cost-minimizing output and have markup over marginal cost. The exogeneous markup is a common form in the IRBC models, because the good is aggregated using the constant elasticity of substitution (CES) technology. In this paper, the endogenous adjustment of markups of producers is generated from the variable elasticity of substitution (VES) technology of the final goods that aggregates a continuum of horizontally differentiated intermediate goods. Plugging the optimal pricing rules, $p_{D,t}(a)$ and $p_{X,t}(a)$ into markup formula, the expressions for markup are as follow.

$$mu_{D,t}(a) = p_{D,t}(a) - \frac{W_t}{aZ_t} = \frac{\frac{W_t}{a_{D,t}Z_t} - \frac{W_t}{aZ_t}}{2} \tag{19}$$

$$mu_{X,t}(a) = p_{X,t}(a) - \frac{W_t}{aZ_t} = \frac{\tau_t \frac{W_t}{a_{X,t}Z_t} - \frac{W_t}{aZ_t}}{2} \tag{20}$$

Similarly, the profits of domestic sales $d_{D,t}(a)$ and exporting sales $d_{X,t}(a)$ are found by plugging in the optimal pricing rules $p_{D,t}(a)$ and $p_{X,t}(a)$ and the demand functions $f_{D,t}(a)$ and $f_{X,t}(a)$ into profits formula, the expression for the profits are as follow.

$$d_{D,t}(a) = \left[p_{D,t}(a) - \frac{W_t}{aZ_t}\right] f_{D,t}(a) = \frac{1}{4\gamma P_t} \left[\frac{W_t}{a_{D,t}Z_t} - \frac{W_t}{aZ_t}\right]^2 \tag{21}$$

$$d_{X,t}(a) = \left[p_{X,t}(a) - \frac{W_t}{aZ_t}\tau_t\right] f_{X,t}(a) = \frac{1}{4\gamma P_t^*} \left[\tau_t \frac{W_t}{a_{X,t}Z_t} - \tau_t \frac{W_t}{aZ_t}\right]^2 \tag{22}$$

Note that the monopolistically competitive intermediate goods producers with higher productivity level, a or lower marginal costs, $\frac{W_t}{aZ_t}$ are able to generate higher markups and profits.

3.4 Entry and Exit, Number of Producers

As in Ghironi & Melitz (2005), each producer knows its productivity only after entry. The mass of domestically producing and selling firms, $N_{D,t}$ and exporting firms to foreign country, $N_{X,t}$ are written as the proportion of the mass of already operating firms, $N_{A,t}$. They are $N_{D,t} = (1 - \Phi(a_{D,t}))\, N_{A,t}$ and $N_{X,t} = (1 - \Phi(a_{X,t}))\, N_{A,t}$. The total mass of producers, N_t in the home economy are made of the sum of number of producers who domestically produce and sell, $N_{D,t}$, and number of foreign producers who export to home market, $N_{X,t}^*$:

$$N_t = [1 - \Phi(a_{D,t})]\, N_{A,t} + \left[1 - \Phi(a_{X,t}^*)\right] N_{A,t}^*. \tag{23}$$

Similarly, the total mass of producers in the foreign economy is

$$N_t^* = \left[1 - \Phi(a_{D,t}^*)\right] N_{A,t}^* + \left[1 - \Phi(a_{X,t})\right] N_{A,t}. \tag{24}$$

As in Bilbiie et al. (2008) and Ghironi & Melitz (2005), the expected and discounted value of the future average total profits is characterized by $\tilde{v}_t = E_t \sum_{s=t+1}^{\infty} [\beta(1-\delta_d)]^{s-t} \left[\left(\frac{C_s}{C_t}\right)^{-\eta} \tilde{d}_s\right]$. This induces a free entry condition in which firms enter until $\tilde{v}_t$ is equal to the cost of entry that is proportional to marginal costs:

$$\tilde{v}_t = \frac{W_t f_{E,t}}{Z_t}. \tag{25}$$

3.5 Aggregation with Firm Averages

As in Melitz (2003) and Ghironi & Melitz (2005), a firm's individual productivity level a is Pareto distributed. The probability distribution function follows $\frac{\kappa a_{min}^{\kappa}}{a^{\kappa+1}}$ and the cumulative distribution function follows $1 - \Phi(a) = \left(\frac{a_{min}}{a}\right)^{\kappa}$ where $\kappa \geq 1$ is a shaping parameter (lower κ, higher heterogeneity[17]) and $a_{min} \in [0, a]$. Therefore, it can be said that $\tilde{a} \equiv \int_{a_{min}}^{\infty} a d\Phi(a)$, $\tilde{a}_{D,t} \equiv \frac{1}{1-\Phi(a)} \int_{a_{D,t}}^{\infty} a d\Phi(a)$, and $\tilde{a}_{X,t} \equiv \frac{1}{1-\Phi(a)} \int_{a_{X,t}}^{\infty} a d\Phi(a)$. Following closely with Ottaviano (2011), the parametrization of the average productivity and the variance of firm specific productivity are defined as $\tilde{a} = \frac{\kappa+1}{\kappa} \tilde{a}_{s,t}$, and $var(\tilde{a}) = \int_{a_{s,t}}^{\infty} a^2 d\Phi(a) - \tilde{a}_{s,t}^2 = \frac{\kappa \tilde{a}^2}{(\kappa+1)^2(\kappa+2)}$ where $s = \{D, X\}$. Using the parametrization above, the model is written without variety notation. The average prices and average markups are $\tilde{p}_{D,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W_t}{Z_t \tilde{a}_{D,t}}\right)$, $\tilde{p}_{X,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W_t \tau_t}{Z_t \tilde{a}_{X,t}}\right)$, $\tilde{mu}_{D,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W_t}{Z_t \tilde{a}_{D,t}}\right)$, and $\tilde{mu}_{X,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W_t \tau_t}{Z_t \tilde{a}_{X,t}}\right)$. The average linear demands are found as $\tilde{f}_{D,t} = \left(\frac{1}{2\gamma P_t}\right)\left(\frac{1}{\kappa+1}\right)\left(\frac{W_t}{Z_t \tilde{a}_{D,t}}\right)$ and $\tilde{f}_{X,t} = \left(\frac{1}{2\gamma P_t^*}\right)\left(\frac{1}{\kappa+1}\right)\left(\frac{W_t \tau_t}{Z_t \tilde{a}_{X,t}}\right)$. The average total profits consist of the average profit from domestic sales and export sales: $\tilde{d}_t = \tilde{d}_{D,t} + \tilde{d}_{X,t}$. As in Ottaviano (2011) and Melitz & Ottaviano (2008), average profits are defined as: $\tilde{d}_t = \int_{a_{D,t}}^{\infty} d_{D,t}(a) d\Phi(a) + \int_{a_{X,t}}^{\infty} d_{X,t}(a) d\Phi(a)$. Now, the average profit

[17] If κ=1, it is identical to uniform distribution over [0,a].

from domestic sales and export sales is found using the definition of average productivities: $\tilde{d}_{D,t} = \left(\frac{1}{2\gamma P_t(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}_{D,t}}\right)^{\kappa}\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2$ and $\tilde{d}_{X,t} = \left(\frac{1}{2\gamma P_t^*(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}_{X,t}}\right)^{\kappa}\left(\frac{W_t\tau_t}{Z_t\tilde{a}_{X,t}}\right)^2$. Aggregating technology of the final goods, F_t yields:

$$\begin{aligned}F_t &= \alpha\int_{i\in\Omega} f_t(i)di - \frac{\gamma}{2}\int_{i\in\Omega}\left[f_t(i)\right]^2 di - \frac{\xi}{2}\left[\int_{i\in\Omega} f_t(i)di\right]^2 \\ &= \left(\frac{\alpha N_t}{2\gamma(\kappa+1)P_t}\right)\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right) - \left(\frac{N_t}{4\gamma(\kappa+1)(\kappa+2)P_t^2}\right)\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2 \\ &- \frac{\xi}{2}\left(\frac{N_t}{2\gamma(\kappa+1)P_t}\right)^2\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2. \end{aligned} \tag{26}$$

3.6 Market Clearing Conditions and Equilibrium

The quilibrium for the benchmark model requires several market-clearing conditions. Firstly, the final goods produced, F_t in the economy are all consumed by households. Therefore, $F_t = C_t$. The model is closed by the bond market clearing conditions $B_{H,t+1}+B^*_{H,t+1} = 0$ and $B^*_{F,t+1} + B_{F,t+1} = 0$ as well as by the value of shares in a mutual fund market clearing condition $q_{t+1} = q^*_{t+1} = 1$. Subtracting foreign household's budget constraints (2) from the budget constraints of household in the home economy (1) and then applying the bond and mutual fund market clearing conditions gives the net foreign assets condition as follows.

$$\begin{aligned}P_tB_{H,t+1} + P_t^*B_{F,t+1} &= P_t(1+i_t)B_{H,t} + P_t^*(1+i_t^*)B_{F,t} + \frac{1}{2}\left(W_tL - W_t^*L^*\right) \\ &- \frac{1}{2}\left(P_tC_t - P_t^*C_t^*\right) + \frac{1}{2}\left(N_{A,t}\tilde{d}_t - N^*_{A,t}\tilde{d}^*_t\right) - \frac{1}{2}\left(N_{E,t}\tilde{v}_t - N^*_{E,t}\tilde{v}^*_t\right)\end{aligned} \tag{27}$$

Finally, the labor market clearing condition requires that labor employed in domestic production and exporting production, and labor employed to cover the entry costs equal the fixed labor supply L:

$$
\begin{aligned}
L =& \frac{\kappa}{W_t}\tilde{d}_{D,t}N_{D,t}\frac{1}{1-\Phi(a_{D,t})} + \frac{\kappa}{W_t}\tilde{d}_{X,t}N_{X,t}\frac{1}{1-\Phi(a_{X,t})} + \frac{N_{E,t}f_{E,t}}{Z_t} \\
=& \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)P_tW_t}\left(\frac{W_t}{\tilde{a}_{D,t}Z_t}\right)^2 N_{D,t} \\
&+ \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)P_t^*W_t}\left(\frac{W_t\tau_t}{\tilde{a}_{X,t}Z_t}\right)^2 N_{X,t} + \frac{N_{E,t}f_{E,t}}{Z_t}
\end{aligned}
\tag{28}
$$

The benchmark model economy and its associated steady state system has 45 independent equations, so 45 variables must be solved for: 23 home variables ($\lambda_t, C_t, W_t, i_t, P_t, \tilde{d}_t, \tilde{v}_t, N_{A,t}, N_{D,t}, N_{X,t}, N_{E,t}, \tilde{p}_t, \tilde{p}_{D,t}, \tilde{p}_{X,t}, \tilde{mu}_{D,t}, \tilde{mu}_{X,t}, \tilde{a}_{D,t}, \tilde{a}_{X,t}, N_t, \tilde{d}_{D,t}, \tilde{d}_{X,t}, B_{H,t}, B_{F,t}$) and 22 foreign variables ($\lambda_t^*, C_t^*, i_t^*, \tilde{d}_t^*, \tilde{v}_t^*, N_{A,t}^*, N_{D,t}^*, N_{X,t}^*, N_{E,t}^*, \tilde{p}_{D,t}^*, \tilde{p}_{X,t}^*, \tilde{mu}_{D,t}^*, \tilde{mu}_{X,t}^*, \tilde{a}_{D,t}^*, \tilde{a}_{X,t}^*, N_t^*, \tilde{d}_{D,t}^*, \tilde{d}_{X,t}^*, W_t^*, \tilde{p}_t^*, B_{F,t}^*, B_{H,t}^*$). I have chosen foreign welfare-based price, P_t^* as the numeraire. It has 6 exogenous policy variables: $Z_t, Z_t^*, f_{E,t}, f_{E,t}^*, \tau_t, \tau_t^*$. The full summary of all 45 systems of equations are provided in the Appendix.

4 Quantitative Analysis

In this section, the properties of the model are examined by numerical experiments. I have two purposes for the quantitative analysis: a) analyzing the consequences of an economic depression and trade restrictions dynamics, and b) studying properties of the international business cycle in the model. I start by presenting how the benchmark model is calibrated in order to fit the real world data. In order to capture the short-run effects of a recession and trade restrictions, the impulse responses for each scenario are thoroughly analyzed. Last, I compute the business cycle statistics produced when there is a stochastic productivity shock in the home economy. I solve the baseline model log-linearizing systems of equations around the steady state and solve the resulting system of linear difference equations as described in King, Plosser & Rebelo (2002) and applying Uhlig (1995) techniques. Given the parameters that characterize behavior around the steady states and the law of motion of shocks, DYNARE with MATLAB program[18] are used to solve and simulate a system of linear difference equations.

4.1 Benchmark Calibration

The benchmark values are chosen for the set of relevant parameters to match the features of the US economy. A standard choice in the literatures, the intertemporal discount factor of households β is set equal to 0.99. The inverse of the intertemporal elasticity of substitution η is set equal to 2 as in Ghironi & Melitz (2005) and the quadratic adjustment cost of bond holdings is set equal to $n = \beta^2 * 0.01$ as in Boileau & Normandin (2008). Following closely with Sakane (2011) and Rodriguez-Lopez (2011), I set the technology of the final goods parameters as α=9.5, γ=0.5, and ξ=1.1. Relying on Chaney (2008), the scaling parameter of the Pareto distribution κ condition holds in order to assure the standard deviation of the idiosyncratic shock is finite and positive. As documented by Bernard et al. (2003), this paramter also matches the standard deviation of the log of domestic US plant sales at 1.67 in a steady state. I set the probability of a death shock equal to 0.025, which implies that average annual death rate for US firms is 10%. As in Alessandria & Choi (2007) and Obstfeld & Rogoff (2000), I set the steady-state value of ice-berg transport cost equal to 1.4, and the steady-state value of the entry cost is 1 as in Ghironi & Melitz (2005). Labor endowment is normalized to 1 for both economies. The minimum value of the productivity, a_{min} is also set equal to 1, without loss of generality. The steady state cut-off productivity for produers who sell in domestic market, $\tilde{a}_D$ is found solving the symmetric steady-state equilibrium. Table 3 lists all calibrated parameters.

[18] I simulate the model using Dynare version 4.2.4. See Juillard (2001).

Table 3: Benchmark Parameter Values

Description	value
Strength of product differentiation coefficient	α=9.5
Product differentiation index	γ=0.5
Variety substitutability	ξ=1.1
Inverse of the intertemporal elasticity of substitution	η=2
Intertemporal discount factor	β=0.99
Probability of death shock	δ_d=0.025
Ice-berg transport cost	τ=1.4
Sunk entry costs parameter	f_E=1
Quadratic adjustment cost of bond holdings	$n = \beta^2 * 0.01$
Cut-off productivity for domestic firms	a_D=1.793
Lower bound of productivity	a_{min}=1
Characterizing parameter of $\Phi(a)$	κ=3.4
Labor endowment	$L = L^* = 1$

4.2 Shocks Strategy

4.2.1 Productivity Shocks

I solve for the dynamics in response to deterministic and stochastic shocks by log-linearizing the model around the steady state. In order to analyze the consequences of the economic slump in the home economy, a deterministic and negative shock to aggregate prodcuctivity in the order of 1 percent deviations from the steady-state value is considered. This deterministic shock is only allowed to be temporary (duration of the shock is one year), and the model eventually comes back to the steady state. The shock process is to study the impact of a change in regime, as home economy falls into recession.

In order to analyze the business cycle statistics, stochastic shocks to aggregate productivities are introduced. The positive shocks hit unexpectedly. For this, I use a bivariate autoregressive process for percent deviations of home and foreign aggregate productivities from their steady state. The symmetric and exogenous process can be expressed as follows (in the log-linearized form):

$$\begin{bmatrix} \tilde{z}_t \\ \tilde{z}_t^* \end{bmatrix} = \begin{bmatrix} \rho & \rho_{HF} \\ \rho_{FH} & \rho^* \end{bmatrix} \begin{bmatrix} \tilde{z_{t-1}} \\ \tilde{z_{t-1}^*} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix} with \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix} \sim N \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon\varepsilon^*} \\ \sigma_{\varepsilon\varepsilon^*} & \sigma_{\varepsilon_*}^2 \end{bmatrix} \right)$$

As in Backus et al. (1994), the persistence of the aggregate productivity shock (ρ, ρ^*) is set to 0.906. The spill over parameter ρ_{HF}, ρ_{FH} is set to 0.088. The standard deviation of the productivity innovations is 0.00852 and the correlation between productivity innovations is 0.258.

Under permanent productivity shocks, the model reaches a new steady state and shocks are entirely expected. To study the effects of permanent productivity shocks hitting the economy today, the initial and ending values are set so as to calculate the transition path of each key variables. Since the results of the deterministic and permanent productivity shocks are similar to the one from stochastic productivity shocks, the resulting impulse response functions are only illustrated in the Appendix.

4.2.2 Trade Shocks

In an open macroeconomics model, one important variable is the interest rate rule by the monetary authority (e.g. central bank). The typical interest rate is generated by the Taylor rule which forcasts the consumer price index (CPI) inflation and output growth deviation from the steady-state values:

$$1 + i_t = i^{1-\rho_i}(1 + i_{t-1})^{\rho_i} E_t \left(\frac{\pi_{t+1}}{\pi}\right)^{(1-\rho_i)\eta_\pi} \left(\frac{Y_{t+1}}{Y}\right)^{(1-\rho_i)\eta_y}.$$

Motivated by this Taylor rule interest rate setting, goverments can determine their trade policy rule in response to economic recession of their trading partner. Following closely with

Larch & Lechthaler (2011), a simple trade restriction setting rule is generated as follow:

$$1 + \tau_t = (1 + \tau)\frac{Z}{Z_t} \tag{29}$$

and

$$1 + f_{E,t} = (1 + f_E)\frac{Z}{Z_t} \tag{30}$$

This trade shock process shows that as trade costs or entry costs decrease by 1 percent, aggregate productivity increases by 1 percent, and vice versa.

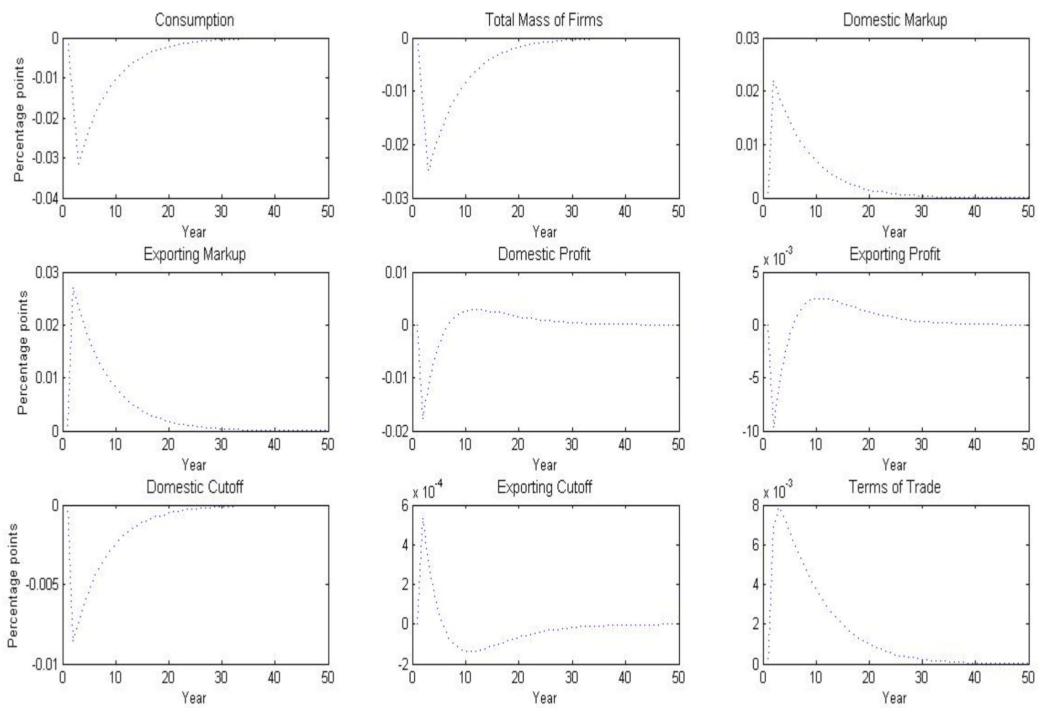
4.3 Macroeconomic Dynamics

In this subsection, the dynamics of a recession and trade restrictions are thoroughly analyzed. First, I begin by analyzing the follow-up to a recession in home country. After that, the subsequent introduction of trade restrictions in foreign economy is analyzed. The trade restrictions is imposed by foreign economy to protect its domestic industries that got hurt from the spillover of the home country's economic downturn through the interconnection of trade.

4.3.1 Economic Slump

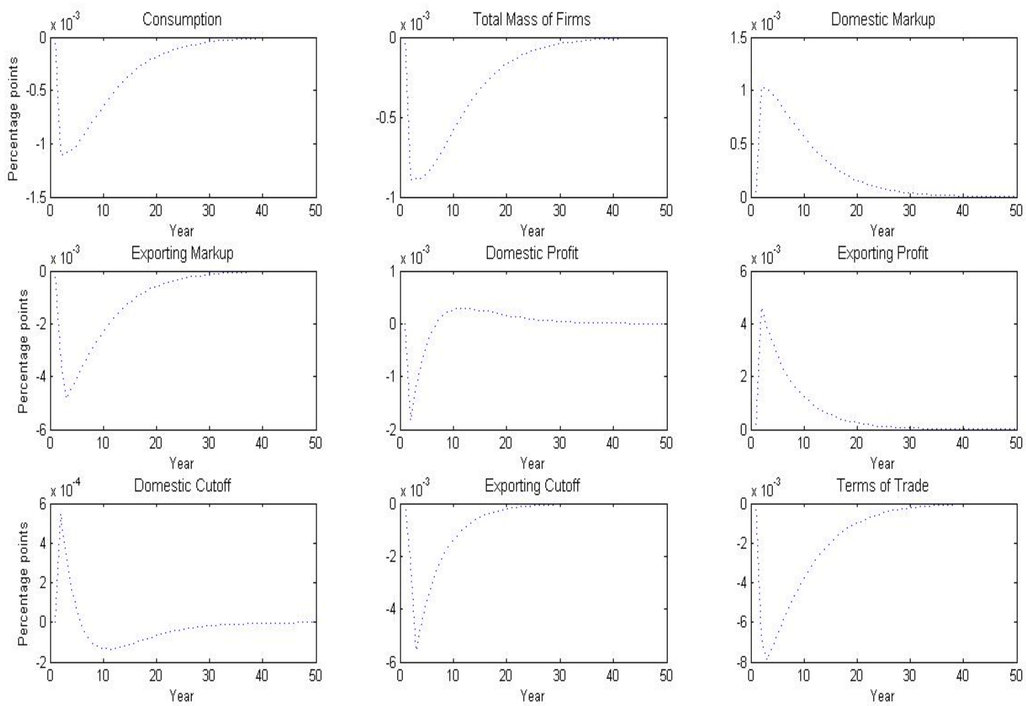
The first case is that of an economic downturn in the home economy. The economy starts from the stationary steady-state and a 1 percent exogenous, asymmetric, temporary, and negative productivity shock hits the home economy. The dynamic responses of main variables to this shock are illustrated in Figure 4 (home) and Figure 5 (foreign). The duration of the shock is one year and the horizontal axis on the impulse responses is the number of years after shock. The negative shock leads to a depression in the home economy. Not surprisingly, the economic slowdown in the home economy is followed by a decrease in consumption ($C \downarrow$) and income ($GDP \downarrow$) due to the drop in the aggregate productivity. For all producers in the home economy, the cost of units of labor is higher than before ($\frac{W}{Z} \uparrow$) as aggregate productivity falls ($Z \downarrow$). The economic slump also matters to the number of producers. Now, the home market is relatively less competitive than before and the number of newly created firms has decreased ($N_E \downarrow$). This leads the total number of producers to fall as well ($N \downarrow$) in the home economy. As previously described, firms' markups are the avenue of 'toughness' of competition and more competitive firms lower their markups in the micro firm-level dynamics. The result macroeconomic dynamics show that producers' variable markups have effect on aggregate fluctuations. Since the home market is less competitive than before, markups for home producers in domestic and exporting markets increase ($\tilde{mu}_D \uparrow$, $\tilde{mu}_X \uparrow$) during a recession. Note that the average profits of domestic and export production both go down as a consequence of the economic slump ($\tilde{d}_D \downarrow$, $\tilde{d}_X \downarrow$).

Figure 4: Economic Slump in Home: Home Economy



The recession in home country has an aftereffect on the foreign country through the interconnectedness of the trade between two countries. Consumption ($C^* \downarrow$) and income ($GDP^* \downarrow$) also go down in the foreign economy, although the magnitude of movement is much smaller than in the home economy. Because of the economic downturn in the home economy, fewer home producers export to foreign country ($N_X \downarrow$) and this leads the total number of producers to fall ($N^* \downarrow$) as well in the foreign economy ($N^* = N_D^* + N_X$). Interestingly, due to the fact that the home market is less competitive, foreign producers exporting to home economy become relatively competitive and decrease their markups ($\tilde{mu}_X^* \downarrow$). Consequently, the average profit of foreign exporting firms increases during the shock ($\tilde{d}_X^* \uparrow$). The increase in exporting profit in the foreign country makes them being relatively more productive than home exporting firms as their cut-off productivity decreases ($\tilde{a}_X^* \downarrow$). It means that relatively less productive foreign firms are able to export to home economy. In contrast, demands for varieties in the home economy decreases, exporting becomes harder for the home exporting firms and consequently, their cut-off productivity increases ($\tilde{a}_X \uparrow$).

Figure 5: Economic Slump in Home: Foreign Economy



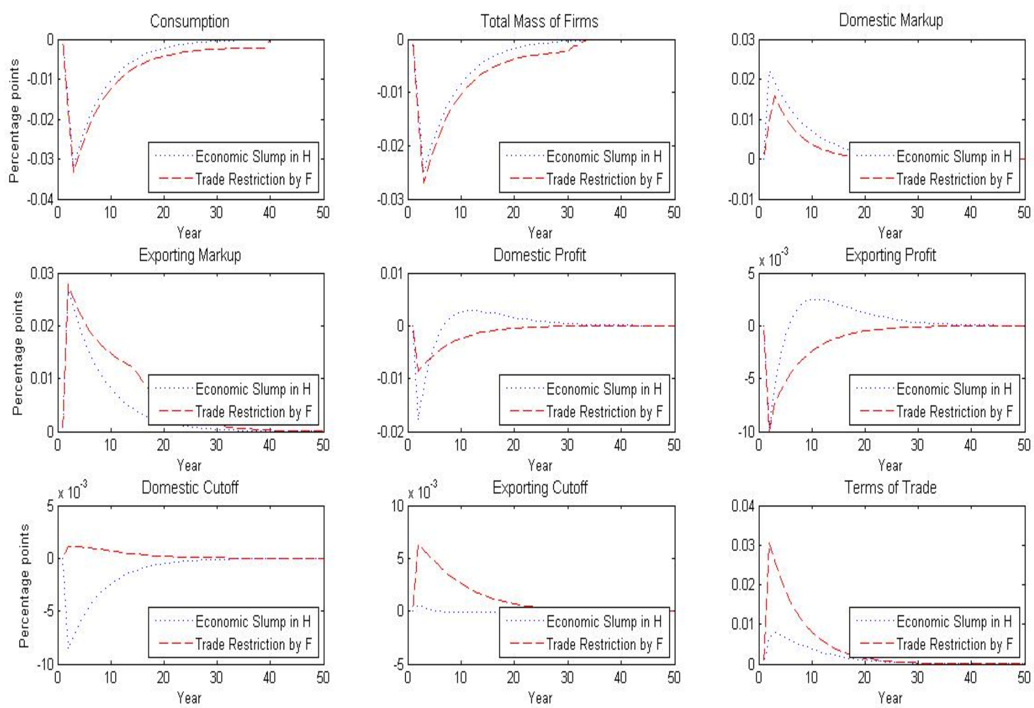
Finally, the international relative prices depreciate ($RER, TOT \uparrow$) in the home economy and appreciate in the foreign ($RER^*, TOT^* \downarrow$) economy. As an indicator of competitiveness in the trade balance of a country, the terms of trade is defined as the ratio of the price of imports to the price of exports ($TOT = \frac{P_{IMP}}{P_{EXP}}$). The real exchange rate is defined as the ratio of the price index of the final goods ($RER = \varsigma\frac{P^*}{P}$). During a recession of the home economy, the price of home exports become cheaper and the terms of trade and real exchange rate depreciate. The dynamic responses clearly show the depreciation of the terms of trade (Figure 4). I find that the terms of trade depreciation in the home economy occurs through the strong influence of the relative cut-off exporting productivity of both countries. In the benchmark model, the terms of trade can be written as $TOT = \frac{\tilde{a}_X}{\tilde{a}_X^*}\frac{\frac{W^*}{Z^*}}{\frac{W}{Z}}$. The first fraction is the relative cut-off productivity across countries ($\frac{\tilde{a}_X}{\tilde{a}_X^*}$) and the second fraction is the relative cost of units of labor ($\frac{\frac{W^*}{Z^*}}{\frac{W}{Z}}$). As previously found in the dynamics of the recession, home exporting firms' average individual specific productivity cut-off increase ($\tilde{a}_X \uparrow$) while foreign exporting firms' average productivity cut-off decrease ($\tilde{a}_X^* \downarrow$). Therefore, relative cut-off productivity obviously increase. The relative cost of units of labor decrease as $\frac{W}{Z}$ increase. However, the effect of the relative cut-off productivity is stronger than the effect of the relative cost of labor, and the international relative prices leads to depreciation with an economic slump in the home economy. In analyzing the outcome of the recession, the important point to note is that through international trade between two countries, the foreign country also suffers as a result of the economic slowdown in the home country, even though the effect is smaller than that felt in the home economy.

4.3.2 Trade Restrictions

In this subsection, I analyze the consequence of the trade restrictions in the case where foreign country raises its import restrictions in order to protect its domestic industries. As previously found, the exporting firms gain, but the average profit of the domestic production decreases in the foreign economy. Therefore, the foreign country implement this trade policy to shield its domestic producers who get hurt mostly from the economic slowdown in the home economy. The result dynamics are illustrated in Figure 6 (home) and Figure 7 (foreign).

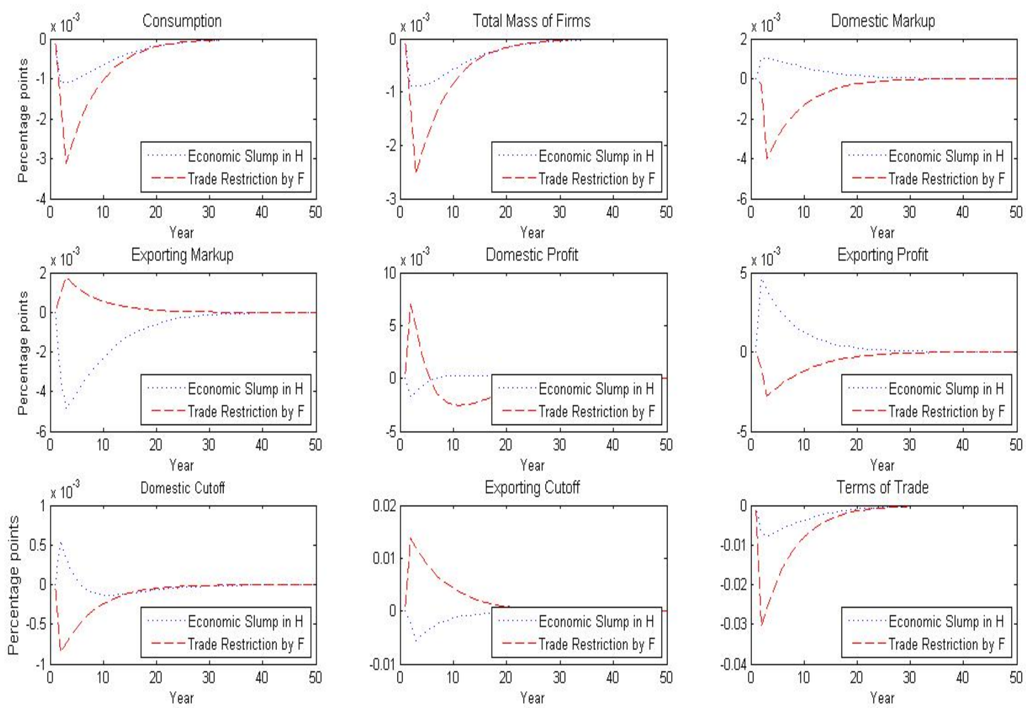
The blue dotted line represents the case of the economic slump in the home economy and the red dashed line represents the case of the trade restrictions imposed by the foreign economy. The trade cost or entry cost of home exporting firms to foreign economy only increased due to this change in trade policy. Since the home economy does not raise its trade restriction, the trade cost or entry cost for foreign exporting firms to the home economy does not change. Also, I assume that this imposed trade restrictions does not have any direct effect on foreign government revenue. Therefore, increase in trade cost can be understood as any types of non-tariff barriers such as a voluntary export restraint (VER), 'Buy national' policy, quota shares, or export subsidies.

Figure 6: Trade Restrictions by Foreign: Home Economy



Surprisingly, the increase in trade restrictions in the foreign economy is followed by a further decrease in consumption ($C, C^* \downarrow$) and income ($GDP, GDP^* \downarrow$) in both countries. As shown in the dynamic responses, consumption in the foreign economy drop sharply while consumption in the home economy decline slightly. This change in policy harm home and foreign consumers because of the increase in prices in the foreign country. Due to the trade limitation on home exports, the number of home exporting firms and their average profits further go down ($N_X \downarrow$, $\tilde{d}_X \downarrow$). This clearly shows through the further increase in the cut-off productivity of home exporting firms ($\tilde{a}_X \uparrow$) since exporting become difficult for them due to the trade barrier. In the foreign country, the trade limiting-measures lead to diverse results for domestically selling firms and exporting firms. Since domestic industries are shielded from cheap imports, they become competitive and markups actually go down ($\tilde{mu}^*_D \downarrow$). Consequently, their profits increase ($\tilde{d}^*_D \uparrow$). However, markups for exporting industry go up ($\tilde{mu}^*_X \uparrow$) and this lead to a sharp decline in exports ($\tilde{d}^*_X \downarrow$) along with an increase in the cut-off productivity ($\tilde{a}^*_X \uparrow$). Even though domestically selling producers generate positive profits, the strong decrease in the profits of the export-industry and losses to consumers dominates the profits of domestic industries and leads to a further decline in GDP.

Figure 7: Trade Restrictions by Foreign: Foreign Economy



In the home country, demand for varieties further diminishes and exporting producers raise their markup ($\tilde{mu}_X \uparrow$) more than before. This lead to further decrease in exporting profits ($\tilde{d}_X \downarrow$). This pushes their price level lower than before ($P \downarrow$) and its export price further go down ($P_{EXP} \downarrow$). This makes the real exchange rate and the terms of trade in home economy depreciate more ($RER, TOT \uparrow$) with implementation of trade restrictions of the foreign economy. The markup for producers selling in domestic market increase ($\tilde{mu}_D \uparrow$) and their average profits still decrease ($\tilde{d}_X \downarrow$), but less magnitude than economic slump in the economy.

In the foreign country, lower GDP and consumption, further appreciation of the international relative prices, a sharp decrease in average export profits, and increasing markup for exporting industries counteracts the reduced markup and increased average profits of domestically selling firms. These effects clealy show that trade restrictions not only hurt the trading partner, but also the country imposing them damaging its market competitiveness even though its domestic industries are protected from lower prices of imports. In summary, foreign country impose trade restrictions to protect its domestic industries that got hurt mostly from the recession of its trading partner. The policy benefit domestically producing and selling producers, but harm consumers and exporting producers in the economy. The losses to the trade restrictions far outweigh the gains, and analyzed economy end up worse off than they would be otherwise during the economic downturn of the home economy.

4.4 International Real Business Cycle Moments

To further evaluate the properties of the simulated model, business cycle statistics of the simulated model are computed with a stochastic shock to the aggregate productivity in the home economy. I augment the benchmark model (as in section 3) with elastic labor. Here, unconditional second moments are presented using the benchmark model and comparing this to what is observed in the economic data for the US and European countries (See section 2). I use the model to confront the observations on business cycle statistics. The Hodrick and

Prescott (HP)[19] filter is applied to compute the models statistics by logging and filtering the models artificial time series. The data for the correlation between relative consumption and the terms of trade is taken from Corsetti et al. (2008) and the source of the data for the net exports is Backus et al. (1992). Table 4 summarizes the main statistics of the simulated model under the benchmark parameters at the business cycle frequency. The impulse response functions are illustrated in the Appendix. I study the model's implications for (a) the standard deviations of a variable relative to that of the log of output, (b) the correlation between a variable and the log of output as a domestic comovement, (c) the international correlations between home variables and foreign variables, and (d) the correlation between relative consumption and the terms of trade as an other correlation. I compare the benchmark model with data, the simulated model of the CES technology of the final goods (Moon (2012)), the financial autarky asset market, and the case of the inelastic labor in incomplete market. The detailed descriptions of the model with CES technology of final goods and financial autarky appear in section 5.

In the results of the benchmark model, although the volatility of the terms of trade in the model (0.38) is much less than the data (1.44), the patterns of aggregate volatilities observed in the model are similar to those in the actual data. Entry is the most volatile (4.40) among the six key variables. In the IRBC model without physical capital accumulation, entry provides a similar framework as investment because it is defined as new firm construction with a one period 'time to build' lag[20]. That is why the volatility of entry is the highest in the benchmark model where capital is omitted. In the model of CES technology with capital stock, investment is the most volatile (2.99), and the entry is the second most (1.69). As in the data, consumption (0.32), employment (0.18), and net exports (0.58) are less volatile than GDP. Regarding domestic comovement, the key aggregate variables correctly predict

[19]The HP filter removes the cyclical component of a time series and is commonly used for macroeconomic data.

[20]In the literature, physical capital accumulation evolves according to $K_{t+1} = X_t + (1 - \delta_k)K_t$ of one period time lag driven by depreciation, where K_t is the capital stock and X_t is the investment in capital accumulation.

Table 4: Business Cycle Statistics: Baseline Parameters

	Data	CES	Inelastic Labor	Benchmark	
		IM	IM	IM	FA
Volatility					
% S.D. relative to GDP					
GDP	1	1	1	1	1
Consumption (C)	0.72	0.52	0.41	0.32	1
Employment (L)	0.58	0.58	_	0.18	0.25
Investment (X)	3.87	2.99	_	_	_
Net Export (NX/Y)	0.45 (BKK)	_	0.43	0.58	_
Terms of Trade (TOT)	1.44	0.32	0.38	0.38	0.08
Entry (N_E)	_	1.69	4.39	4.40	3.72
Domestic Comovement					
Correlations with GDP					
Consumption (C)	0.86	0.70	0.42	0.22	1
Employment (L)	0.79	0.61	_	0.68	0.68
Net Export (NX/Y)	-0.47 (BKK)	_	0.73	0.64	_
Terms of Trade (TOT)	-0.25	-0.53	-0.46	-0.48	0.58
Entry (N_E)	_	0.51	0.52	0.52	0.49
Mark-up ($\tilde{MU}$)	_	_	-0.90	-0.91	-0.89
Average Profits ($\tilde{d}$)	_	_	0.53	0.53	0.47
International Correlations					
GDP, GDP^*	0.55	-0.87	-0.23	-0.21	0.10
C, C^*	0.42	0.21	0.06	0.06	0.10
X, X^*	0.39	-0.89	_	_	_
L, L^*	0.28	-0.23	_	-0.91	0.65
N_E, N_E^*	_	-0.84	-0.92	-0.92	-0.81
Other Correlation					
Consumption ratio, TOT	-0.35 (CDL)	-0.93	-0.37	-0.39	0.18

cyclicity with GDP, except net exports. Consumption (0.22), employment (0.68), entry (0.52), and average profits (0.53) are positively correlated and terms of trade (-0.48) and average markup (-0.91) are negatively correlated. Pro-cyclical average profits and counter-cyclical markups are in line with empirical findings of Bilbiie et al. (2008). However, the benchmark model is not able to generate counter-cyclical net exports in the data.

International correlations of GDP (-0.21), labor (-0.91), and entry (-0.92) are negative in the benchmark model, due to the fact that production and the entry of firms transfer to more productive locations (International Production Shifting). These results share the failure of the standard IRBC models and adding entry and exit dynamics along with firm selection to the benchmark model does not help. The model also fails to predict the higher cross-country GDP correlations than consumption correlations (what Backus et al. (1992) call 'quantity anomaly') in the data. In the model, consumption is more closely correlated (0.06) across countries than GDP (-0.21). Note that the gap between the two cross correlations is smaller than what is found using the model with CES technology (-0.87 for GDP cross correlation, 0.21 for consumption cross correlation).

The model's prediction regarding co-movement between relative consumption and the terms of trade has novel. They are negatively correlated (-0.39) in the benchmark model just as in the data, solving the Backus-Smith puzzle (Backus & Smith (1993)). The Backus-Smith puzzle is an anomaly in which conventional IRBC models predict that the terms of trade is positively correlated with the relative consumption across countries, but they are negatively correlated in the data. Following a productivity shock in the home economy, GDP and consumption go up in the home country. Consumption also goes up in the foreign economy, but less so than in the home economy, so it results in increase in relative consumption ($\frac{C}{C^*}$). This is due to an incomplete financial market[21] that allows international risk sharing between home and foreign countries. Trading bonds internationally allows households dampen their demands for goods as home exports become more expensive and the terms of trade appreciate.

5 Robustness Analysis

To understand the robustness of the main results under different assumptions, two additional cases are compared. In the first case, the final goods are aggregated using CES technology. In the second case, the model with financial autarky and endogeneous labor is considered. Table 4 reports the business cycle statistics of simulated models for these two cases.

[21]See Letendre (2000), Baxter & Crucini (1995), and Arvanitis & Mikkola (1996)

5.1 Exogenous Markup (CES preference)

Based on the model of Bergin & Glick (2007) and Ghironi & Melitz (2005), Moon (2012) studies international relative prices and endogenous tradability, incorporating endogeneous labor and capital along the IRBC setting. The technology of the final goods is that combines home and foreign produced intermediate goods as in Armington (1969):

$$F_t = \left[\left\{ \int_{a \in \Lambda_{D,t}} f_{D,t}(a)^{\frac{\theta-1}{\theta}} da \right\}^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} + \left\{ \int_{a \in \Lambda^*_{X,t}} f^*_{X,t}(a)^{\frac{\theta-1}{\theta}} da \right\}^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}} \tag{31}$$

where γ is the elasticity of substitution between domestic and foreign varieties of intermediate goods, and θ is the elasticity of substitution among domestic varieties. Dixit & Stiglitz (1977) refer to θ as a 'love of variety' parameter in which, when more varieties are available, more goods are produced, and more consumers are satisfied.

5.2 Financial Autarky

Endogenizing labor, the utility function of the representative households is characterized by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\{C_t^{\eta}(1-L_t)^{1-\eta}\}^{1-\psi}}{1-\psi} \right]$$

where C_t denotes consumption, and L_t represents hours worked. Here, the parameter β is the intertemporal discount factor, η is the consumption weights in utility, and ψ is the coefficient of relative risk aversion. In the case of the financial autarky, the buget constraint is as follows:

$$P_t C_t + P_t B_{t+1} + \tilde{v}_t(N_{A,t} + N_{E,t})q_{t+1} = W_t L_t + (1+i_t)P_t B_t + N_{A,t}(\tilde{d}_t + \tilde{v}_t)q_t. \tag{32}$$

The Euler equation for bond holdings is

$$[C_t^{\eta}(1-L_t)^{1-\eta}]^{1-\psi}\frac{1}{C_t} = \beta(1+i_{t+1})E_t\left[[C_{t+1}^{\eta}(1-L_{t+1})^{1-\eta}]^{1-\psi}\frac{1}{C_{t+1}}\right]. \tag{33}$$

The Euler equation for the shares in a mutual fund is

$$\tilde{v}_t = \beta(1-\delta)E_t\left[\left(\frac{P_tC_t}{P_{t+1}C_{t+1}}\right)\frac{[C_{t+1}^{\eta}(1-L_{t+1})^{1-\eta}]^{1-\psi}}{[C_t^{\eta}(1-L_t)^{1-\eta}]^{1-\psi}}(\tilde{d}_{t+1}+\tilde{v}_{t+1})\right]. \tag{34}$$

The financial autarky model is closed by the bond market clearing condition $B_{t+1} = B^*_{t+1} = 0$ and the value of shares in a mutual fund market clearing condition $q_{t+1} = q^*_{t+1} = 1$. Applying these market clearing conditions to the budget constraint implies the following aggregate accounting identity: $P_tC_t + \tilde{v}_tN_{E,t} = W_tL_t + \tilde{d}_tN_{A,t}$. This equation is explained as financial autarky of income equal to spending. Spending on consumption and investment of new firms is equal to labor and investment income. Finally, the financial autarky assumption requires a balanced trading equation in which the value of home exports is equal to the value of imports from the foreign country. The balanced trading equation using firm averages is written as follows:

$$P_tN_{X,t}\left(\frac{W_t\tau_t}{Z_t\tilde{a}_{X,t}}\right)^2 = P^*_tN^*_{X,t}\left(\frac{W^*_t\tau^*_t}{Z^*_t\tilde{a}^*_{X,t}}\right)^2 \tag{35}$$

The system of equations and its associated steady state system have 41 independent equations, 41 of which must be solved for: 21 home variables $(C_t, W_t, L_t, P_t, \tilde{d}_t, \tilde{v}_t, N_{A,t}, N_{D,t}, N_{X,t}, N_{E,t}, \tilde{p}_t, \tilde{p}_{D,t}, \tilde{p}_{X,t}, \tilde{mu}_{D,t}, \tilde{mu}_{X,t}, \tilde{a}_{D,t}, \tilde{a}_{X,t}, N_t, \tilde{d}_{D,t}, \tilde{d}_{X,t}, i_t)$, 20 foreign variables $(C^*_t, W^*_t, L^*_t, \tilde{d}^*_t, \tilde{v}^*_t, N^*_{A,t}, N^*_{D,t}, N^*_{X,t}, N^*_{E,t}, \tilde{p}^*_{D,t}, \tilde{p}^*_{X,t}, \tilde{mu}^*_{D,t}, \tilde{mu}^*_{X,t}, \tilde{a}^*_{D,t}, \tilde{a}^*_{X,t}, N^*_t, \tilde{d}^*_{D,t}, \tilde{d}^*_{X,t}, i^*_t, \tilde{p}^*_t)$, and I chose foreign welfare-based price, P^*_t as the numeraire. It has 6 exogenous policy variables: $Z_t, Z^*_t, f_{E,t}, f^*_{E,t}, \tau_t, \tau^*_t$. The full summary of 41 system of equations and its log-linearized model are available upon request.

6 Concluding Remarks

This paper explored the aggregate effects of an economic slump and trade restrictions as a short-run response along international real business cycles. During the crisis of 2008 and 2009, world output, exports, and imports collapsed tremendously. As a response to global crisis, international trade-limiting measures have emerged in several countries. In order to capture the recession and the change in trade policy along the IRBC, I proposed a DSGE model with firm entry and exit dynamics, non-homothetic preferences of the final goods technology with product differentiation, and heterogeneity in firm productivity. The variable adjustment of markups was generated from the non-homothetic, non-constant elasticity of substitution production function of the final goods. By analyzing the dynamics of an economic slump in the home economy and then an increase in trade restrictions in the foreign economy as part of a policy to protect itself from the diffusion of recession, I showed that both economies are in a worse position than during the economic downturn. The follow-ups to the recession and trade restrictions were analyzed through the variable markups, firms' individual specific productivity cut-off, and the movement of international relative prices such as real exchange rate and terms of trade. The foreign country suffered from the economic downturn of its trading partner and imposed trade restrictions on import goods from the home economy. There were winners and losers from the implementation of the import restrictions, but the losses far outweighed the gains, and both analyzed economies ended up worse off than they would be.

The simulated model replicated several U.S. business cycle statistics and emphasized the fact that the endogenous entry of heterogeneous firms with various adjustment of markup may have important effects for the interpretation of the international transmission of business cycles. Possible future work will be to augment the model with banking sector, analyzing the effect of banking deregulation and to explore the ability of the model using quasilinear non-constant elasticity of substitution production function and heterogeneous producers.

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Appendix

A Data Sources

Data for most countries are from the International Financial Statistics (IFS) provided by the International Monetary Fund (http://elibrary-data.inf.org/). U.S. quarterly data (1973Q1-2009Q4) for GDP, consumption, and investment is extracted and all variables have been logged and detrened using the Hodrick-Prescott filter (smoothing parameter of 1600). U.S. labor data is obtained from the Bureau of Labor Statistics (http://www.bls.gov/) and the OECD.StatExtracts (http://stat.oecd.org). To calculate the international correlations, U.S. data and Europe aggregates are compared. The quarterly data (1973Q1-2008Q3) for GDP, consumption, investment, and civilian employment are from IFS. European countries include Austria, Finrand, France, Germany, Italy, Sweden, Switzerland, and the U.K. Investment includes gross fixed capital formation and changes in inventories. Labor input per capital is calculated as hours per worker multiplied by civilian employment and then devided by population age 16 and over. I follow the tradition of the international business cycle literature in defining the terms of trade as the relative price of imports to exports.

B The Set of Equations

B.1 Benchmark Model - Incomplete Asset Market

I list summary of 45 equilibrium system of equations of the model.

♦ Optimal conditions for Consumption

$$\lambda_t P_t = C_t^{-\eta} \tag{B.1}$$

$$\lambda_t^* = C_t^{*-\eta} \tag{B.2}$$

♦ Euler Equations (Bonds)

$$\lambda_t P_t (1 + nB_{H,t+1}) = \beta(1 + i_{t+1}) E_t \{P_{t+1}\lambda_{t+1}\} \tag{B.3}$$

$$\lambda_t (1 + nB_{F,t+1}) = \beta(1 + i_{t+1}^*) E_t \{\lambda_{t+1}\} \tag{B.4}$$

$$\lambda_t^* (1 + nB_{F,t+1}^*) = \beta(1 + i_{t+1}^*) E_t \left\{\lambda_{t+1}^*\right\} \tag{B.5}$$

$$\lambda_t^* P_t (1 + nB_{H,t+1}) = \beta(1 + i_{t+1}) E_t \left\{P_{t+1}\lambda_{t+1}^*\right\} \tag{B.6}$$

♦ Euler Equations (Shares)

$$\tilde{v}_t \lambda_t = \beta(1 - \delta_d) E_t \left\{\lambda_{t+1}(\tilde{d}_{t+1} + \tilde{v}_{t+1})\right\} \tag{B.7}$$

$$\tilde{v}_t^* \lambda_t^* = \beta(1 - \delta_d) E_t \left\{\lambda_{t+1}^*(\tilde{d}_{t+1}^* + \tilde{v}_{t+1}^*)\right\} \tag{B.8}$$

♦ Free Entry Conditions

$$\tilde{v}_t = f_{E,t} \frac{W_t}{Z_t} \tag{B.9}$$

$$\tilde{v}_t^* = f_{E,t}^* \frac{W_t^*}{Z_t^*} \tag{B.10}$$

♦ Number of Firms and New Firm Creation

$$N_t = N_{D,t} + N_{X,t}^* \tag{B.11}$$

$$N_t^* = N_{D,t}^* + N_{X,t} \tag{B.12}$$

$$N_{A,t+1} = (1 - \delta_d)\left(N_{A.t} + N_{E,t}\right) \tag{B.13}$$

$$N_{A,t+1}^* = (1 - \delta_d)\left(N_{A.t}^* + N_{E,t}^*\right) \tag{B.14}$$

$$N_{D,t} = (1 - \Phi(a_{D,t}))\, N_{A,t} \tag{B.15}$$

$$N_{X,t} = (1 - \Phi(a_{X,t}))\, N_{A,t} \tag{B.16}$$

$$N^*_{D,t} = \left(1 - \Phi(a^*_{D,t})\right) N^*_{A,t} \tag{B.17}$$

$$N^*_{X,t} = \left(1 - \Phi(a^*_{X,t})\right) N^*_{A,t} \tag{B.18}$$

♦ Total Average Profits

$$\tilde{d}_t = \tilde{d}_{D,t} + \tilde{d}_{X,t} \tag{B.19}$$

$$\tilde{d}^*_t = \tilde{d}^*_{D,t} + \tilde{d}^*_{X,t} \tag{B.20}$$

♦ Average Profits from Domestic Sales

$$\tilde{d}_{D,t} = \left(\frac{1}{2\gamma P_t(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}_{D,t}}\right)^{\kappa}\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2 \tag{B.21}$$

$$\tilde{d}^*_{D,t} = \left(\frac{1}{2\gamma(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}^*_{D,t}}\right)^{\kappa}\left(\frac{W^*_t}{Z^*_t\tilde{a}^*_{D,t}}\right)^2 \tag{B.22}$$

♦ Average Profits from Foreign Sales

$$\tilde{d}_{X,t} = \left(\frac{1}{2\gamma(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}_{X,t}}\right)^{\kappa}\left(\frac{W_t\tau_t}{Z_t\tilde{a}_{X,t}}\right)^2. \tag{B.23}$$

$$\tilde{d}^*_{X,t} = \left(\frac{1}{2\gamma P_t(\kappa+1)(\kappa+2)}\right)\left(\frac{a_{min}}{\tilde{a}^*_{X,t}}\right)^{\kappa}\left(\frac{W^*_t\tau^*_t}{Z^*_t\tilde{a}^*_{X,t}}\right)^2 \tag{B.24}$$

♦ Price Bounds/Cost Threshold

$$\frac{W_t}{Z_t\tilde{a}_{D,t}} = \frac{\alpha\gamma P_t + \xi N_t\tilde{p}_t}{\gamma + \xi N_t} \tag{B.25}$$

$$\frac{W_t\tau_t}{Z_t\tilde{a}_{X,t}} = \frac{\alpha\gamma + \xi N^*_t\tilde{p}^*_t}{\gamma + \xi N^*_t} \tag{B.26}$$

$$\frac{W^*_t}{Z^*_t\tilde{a}^*_{D,t}} = \frac{\alpha\gamma + \xi N^*_t\tilde{p}^*_t}{\gamma + \xi N^*_t} \tag{B.27}$$

$$\frac{W^*_t\tau^*_t}{Z^*_t\tilde{a}^*_{X,t}} = \frac{\alpha\gamma P_t + \xi N_t\tilde{p}_t}{\gamma + \xi N_t} \tag{B.28}$$

♦ Average Relative Prices

$$\tilde{p}_{D,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right) \tag{B.29}$$

$$\tilde{p}_{X,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W_t\tau_t}{Z_t\tilde{a}_{X,t}}\right) \tag{B.30}$$

$$\tilde{p}^*_{D,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W^*_t}{Z^*_t \tilde{a}^*_{D,t}}\right) \tag{B.31}$$

$$\tilde{p}^*_{X,t} = \left(\frac{2\kappa+1}{2\kappa+2}\right)\left(\frac{W^*_t \tau^*_t}{Z^*_t \tilde{a}^*_{X,t}}\right) \tag{B.32}$$

$$N_t \tilde{p}_t = N_{D,t}\tilde{p}_{D,t} + N^*_{X,t}\tilde{p}^*_{X,t} \tag{B.33}$$

$$N^*_t \tilde{p}^*_t = N^*_{D,t}\tilde{p}^*_{D,t} + N_{X,t}\tilde{p}_{X,t} \tag{B.34}$$

♦ Variable Markups

$$\tilde{mu}_{D,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W_t}{Z_t \tilde{a}_{D,t}}\right) \tag{B.35}$$

$$\tilde{mu}_{X,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W_t \tau_t}{Z_t \tilde{a}_{X,t}}\right) \tag{B.36}$$

$$\tilde{mu}^*_{D,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W^*_t}{Z^*_t \tilde{a}^*_{D,t}}\right) \tag{B.37}$$

$$\tilde{mu}^*_{X,t} = \left(\frac{1}{2\kappa+2}\right)\left(\frac{W^*_t \tau^*_t}{Z^*_t \tilde{a}^*_{X,t}}\right) \tag{B.38}$$

♦ Bond Market Equilibrium

$$B_{H,t+1} + B^*_{H,t+1} = 0 \tag{B.39}$$

$$B^*_{F,t+1} + B_{F,t+1} = 0 \tag{B.40}$$

♦ Labor Market Equilibrium

$$\begin{aligned} L =& \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)P_t W_t}\left(\frac{W_t}{\tilde{a}_{D,t} Z_t}\right)^2 N_{D,t} + \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)W_t}\left(\frac{W_t \tau_t}{\tilde{a}_{X,t} Z_t}\right)^2 N_{X,t} \\ &+ \frac{N_{E,t} f_{E,t}}{Z_t} = 1 \end{aligned} \tag{B.41}$$

$$\begin{aligned} L^* =& \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)W^*_t}\left(\frac{W^*_t}{\tilde{a}^*_{D,t} Z^*_t}\right)^2 N^*_{D,t} + \frac{\kappa}{2\gamma(\kappa+1)(\kappa+2)P_t W^*_t}\left(\frac{W^*_t \tau_t}{\tilde{a}^*_{X,t} Z^*_t}\right)^2 N^*_{X,t} \\ &+ \frac{N^*_{E,t} f^*_{E,t}}{Z^*_t} = 1 \end{aligned} \tag{B.42}$$

♦ Final Goods Technology

$$F_t = \left(\frac{\alpha N_t}{2\gamma(\kappa+1)P_t}\right)\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right) - \left(\frac{N_t}{4\gamma(\kappa+1)(\kappa+2)P_t^2}\right)\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2$$
$$-\frac{\xi}{2}\left(\frac{N_t}{2\gamma(\kappa+1)P_t}\right)^2\left(\frac{W_t}{Z_t\tilde{a}_{D,t}}\right)^2 = C_t \quad \text{(B.43)}$$

$$F_t^* = \left(\frac{\alpha N_t^*}{2\gamma(\kappa+1)}\right)\left(\frac{W_t^*}{Z_t^*\tilde{a}_{D,t}^*}\right) - \left(\frac{N_t^*}{4\gamma(\kappa+1)(\kappa+2)}\right)\left(\frac{W_t^*}{Z_t^*\tilde{a}_{D,t}^*}\right)^2$$
$$-\frac{\xi}{2}\left(\frac{N_t^*}{2\gamma(\kappa+1)}\right)^2\left(\frac{W_t^*}{Z_t^*\tilde{a}_{D,t}^*}\right)^2 = C_t^* \quad \text{(B.44)}$$

♦ Net Foreign Assets

$$P_tB_{H,t+1} + B_{F,t+1} = (1+i_t)P_tB_{H,t} + (1+i_t^*)B_{F,t} + \frac{1}{2}\left(W_tL - W_t^*L^*\right) \quad \text{(B.45)}$$
$$-\frac{1}{2}\left(P_tC_t - C_t^*\right) + \frac{1}{2}\left(N_{A,t}\tilde{d}_t - N_{A,t}^*\tilde{d}_t^*\right) - \frac{1}{2}\left(N_{E,t}\tilde{v}_t - N_{E,t}^*\tilde{v}_t^*\right)$$

C Figures

Figure 8: U.S. data: HP filtered trend

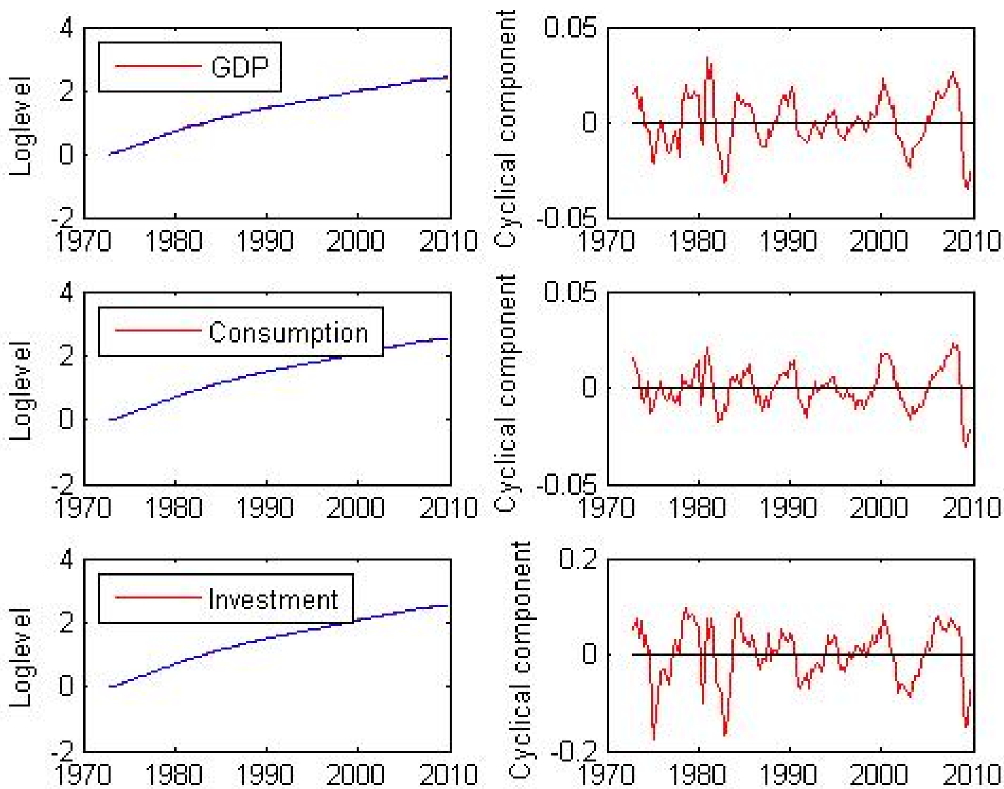

Figure 9: Dynamic Responses to Home Aggregate Productivity Shock

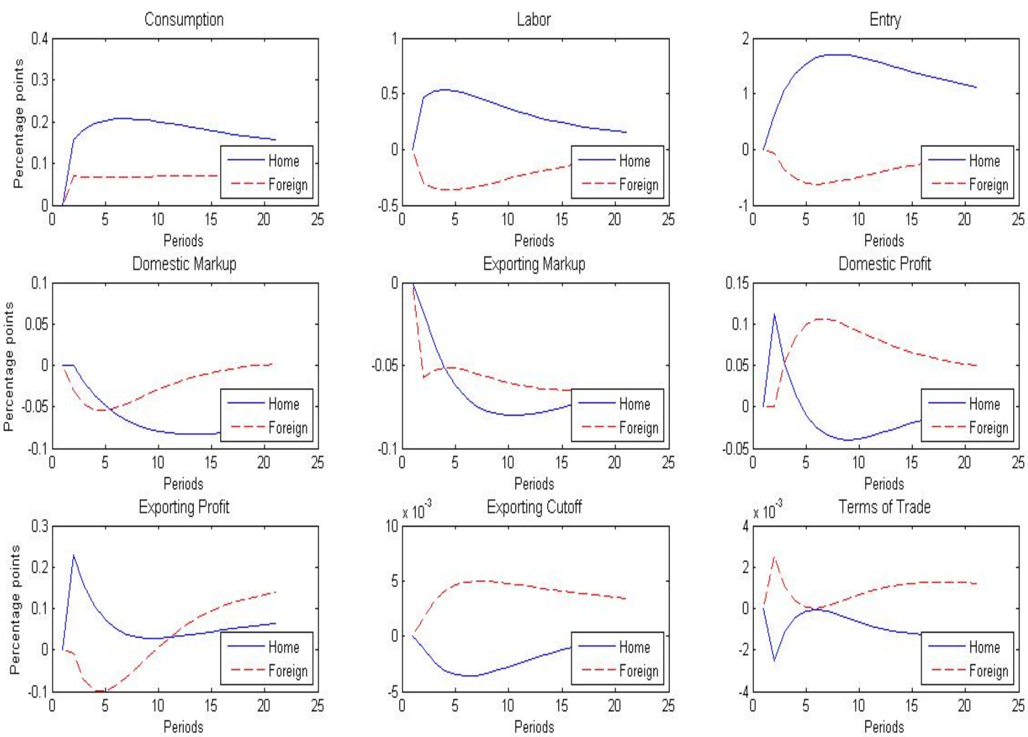

Figure 10: Dynamic Responses to Permanent Increase in Z_t

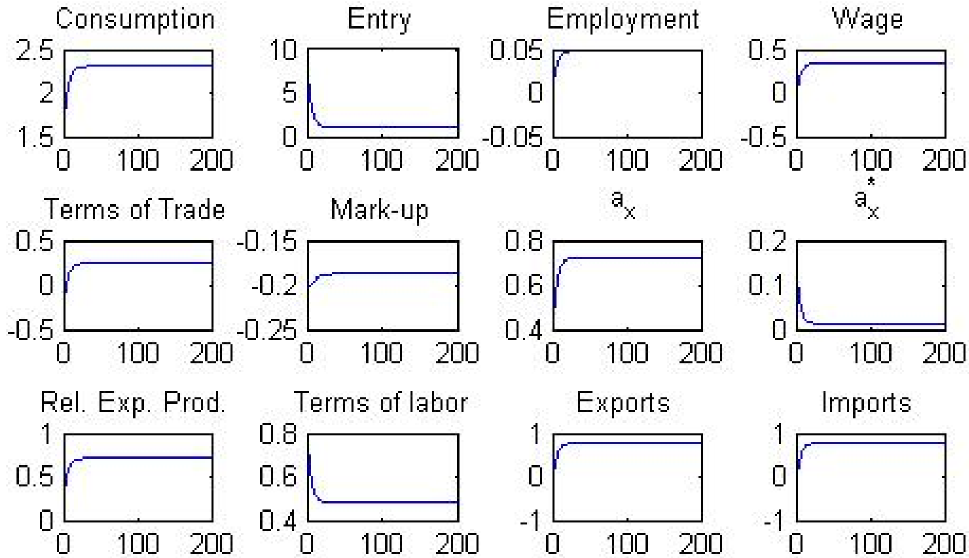

Figure 11: Dynamic Responses to Permanent Decrease in τ_t and f_E