Product Variety, Firm Entry, and Terms of Trade Dynamics

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November 26, 2010

Abstract

In this paper, I revisit the problem of the anomaly of terms of trade dynamics. First, I empirically analyze the effect of a US aggregate labor productivity shock on the US terms of trade using a VAR and Maximum Forecast Error Variance identification. I find that the shock appreciates the terms of trade of the US. Next, using a non-homothetic preference a lá Melitz and Ottaviano (2008), I explain the dynamics of the terms of trade in response to a positive aggregate productivity shock theoretically. Using a model with endogenous markup and heterogeneous firm-specific productivities, the appreciation of the terms of trade can be generated even under a complete asset market assumption. Unlike previous studies, I explain the dynamics of the terms of trade through a new channel, which is the channel of relative cutoff firm-specific productivity that determines the optimal export decisions of the firms. Depending on the asset market structure, two competing effects, i.e., the income effect and the markup effect, have different implication to terms of trade dynamics. Under the assumption of financial autarky, the income effect is bigger than the markup effect and the terms of trade depreciates in response to a positive aggregate productivity shock. However, if we allow for the trade of state-contingent or non-state contingent bonds, the income effect is mitigated and the markup effect appreciates the terms of trade, which is in line with the empirical findings.

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[†] I would like to thank my dissertation supervisor, Craig Burnside for his support and many discussions. I would also like to thank my dissertation committee members, Pietro Peretto, Barbara Rossi and Juan Rubio-Ramirez for useful comments and suggestions. I am also grateful to Kent Kimbrough and George Tauchen as well as seminar participants at Duke University for their helpful comments.

1 Introduction

International business cycle models have been used to analyze the determination of the terms of trade in response to aggregate productivity shocks. The standard two-country real business cycle (RBC) models such as Backus, Kehoe and Kydland (1994), hereafter BKK, imply that the terms of trade depreciates, i.e., the relative price of domestic goods decreases, in response to a positive productivity shock. In standard models, relative price of goods produced in domestic economy falls when domestic output goes up and this leads to a depreciation of the terms of trade. Obstfeld and Rogoff (2004) calculated how much depreciation of the terms of trade is needed to stabilize the current account of the US. According to the standard model, the magnitude of the depreciation of the terms of trade varies from 9% to 15%, depending on the parameters of the model.

However, the empirical literature has shown that the terms of trade tends to appreciate in response to a positive domestic productivity shock. Using VAR analyses and long-run identification[1], Corsetti, Dedola and Leduc (2006) show that the terms of trade appreciates in response to domestic labor productivity in large economies such as the US or Japan. Enders and Müller (2009) show similar results using data from the US and the aggregate of the industrialized countries.

In this paper, I argue that firms' endogenous markups and heterogeneity in firm-specific productivities are the key mechanism that induces the dynamics of the terms of trade observed in empirical studies. I use a non-homothetic preference as in Melitz and Ottaviano (2008) in a dynamic stochastic general equilibrium model[2]. In this model, firms decide whether to enter the export market depending on their firm-specific productivity. Importantly, this type of preference exhibits preference over different varieties of goods and it generates endogenous markup distribution across firms. The terms of trade derived in this model depends on two factors. One is the relative cost of units of effective labor and the other is the relative cutoff firm-specific productivity. I find that the latter factor is the channel that explains the dynamics of the terms of trade observed in empirical analyses. There are two competing effects that determine the dynamics of the terms of trade through the channel of the relative cutoff firm-specific productivity: the income effect, which depreciates the terms of trade, and the markup effect, which appreciates

[1] The long-run identification method is commonly used for identifying a productivity shock and was first used in Galí (1999).

[2] This type of preference was first introduced in Ottaviano, Tabuchi and Thisse (2002). The preference I use in my model differs from Melitz and Ottaviano (2008) since I incorporate both the income effect and the markup effect to understand the implications of this type of preference in a general equilibrium setting. I explain the details in Section 3.

the terms of trade. The relative degrees of these two effects differ according with the asset market structure assumed in the model. I simulated the model under three different assumptions of the asset market: financial autarky, an incomplete asset market and a complete asset market. Under the assumption of financial autarky, the income effect is bigger than the markup effect. A positive aggregate home productivity shock increases the income in the home economy and thus it increases the demand for varieties. Therefore, even less productive foreign firms can export and the relative cutoff productivity of foreign exporting firms decreases. Through this channel, the terms of trade depreciates under the assumption of financial autarky.

However, if we allow for the trade of state-contingent or state non-contingent bonds by using either complete or incomplete asset market assumption, the income effect is mitigated since the representative household can access to the bonds and the international risk sharing between two countries smoothes out the relative change of demand for goods across countries. In this case, the markup effect comes into play. In response to a positive aggregate productivity shock in the home economy, home firms can produce more goods at lower cost and more home firms enter the home market. Therefore, the number of home firms serving the home market increases. This means that the home market becomes more competitive and the average markup in the home market decreases. Foreign firms exporting to the home market face this higher competition and thus they need to decrease their markups as well. This generates a decrease in their expected profit and thus foreign firms which have relatively higher firm-specific productivity can enter the home market. Thus, the cutoff productivity of foreign exporting firm increases relative to that of home exporting firms and the terms of trade appreciates through this channel. The terms of trade appreciates most in the case of complete asset market.

There is a growing literature seeking a resolution to this anomaly of the terms of trade by introducing extensive margin into a standard two-country model. Corsetti, Martin and Pesenti (2007) analyze the changes in the terms of trade in response to a productivity gain using a model augmented with product variety. Their model predicts the appreciation of the terms of trade when there is a reduction of market entry costs, however, it does not predict the appreciation when there is a reduction of manufacturing costs. Ghironi and Melitz (2005) analyze the effect of an aggregate productivity shock on the real exchange rate using a model with heterogeneous firms and product variety. However, their model does not fully account for the appreciation of the terms of trade in the short run, although in the long run it tends to appreciate. In their model, the appreciation of the terms of trade arises from the change in relative production cost between two countries. If there is a positive productivity shock, then firms' production cost is reduced and it becomes easier for the firms to enter the market. This surges the increase of labor demand, which increases the equilibrium wage and the relative production cost. However, this result crucially depends on their assumptions about the labor market. In their model, labor is inelastically supplied in each period and thus exaggerates the effect of a surge of labor demand. Farhat (2009) analyzes the effect of a positive productivity shock in a model based on Ghironi and Melitz (2005) but augmented with an endogenous labor supply. In his model, the terms of trade depreciates in response to a positive productivity shock since an elastic labor supply curve mitigates the effect of a surge of labor demand on the equilibrium wage[3].

There is another strand of literature that uses a standard two-country model without extensive margin. Corsetti, Dedola and Leduc (2008) and Enders and Müller (2009) both show that the combination of an incomplete asset market and low elasticity of substitution between home and foreign goods can account for the appreciation of the terms of trade. It has been a common consensus that this anomaly cannot be resolved without the incomplete asset market assumption in a model without extensive margin. The intuition behind this result is as follows. If there is a positive productivity shock in the home economy, then the wealth of the home economy increases relative to the foreign economy if international risk sharing is not complete. This surges an increase of demand for domestically-produced goods if the substitution elasticity between the home and foreign goods is low. This increases the equilibrium price of domestic goods and appreciates the terms of trade.

This paper differs from previous studies in two important ways. First, unlike previous studies, by using a model augmented with heterogeneity in firm-specific productivities and firms' endogenous markups, I explain the dynamics of the terms of trade through a new channel, which is the channel of relative cutoff firm-specific productivity that determines the optimal export decisions of the firms. This resolution does not resort to strong assumptions on the labor market, home bias, elasticity of substitution between goods and the persistence of productivity that previous studies have imposed in their models. Second, this paper contributes to our understanding of the implications of financial openness on the terms of trade dynamics. I evaluate the model by analyzing three different cases of asset market assumptions: financial autarky, an incomplete market and a complete market.

There is a theoretical literature that demonstrates the importance of firms' variable

[3]Fattal-Jaef and Lopez (2010) also analyze a model based on Ghironi and Melitz (2005) but augmented with capital accumulation and endogenous markup. They also find that the terms of trade depreciates in response to a positive productivity shock.

markups to explain the behavior of tradable goods prices. Simonovska (2010) incorporates a non-homothetic preference into the monopolistic competition framework of Melitz (2003) and Chaney (2008). She analyzes the relative prices of goods between multiple countries in a static framework. Goksel (2008) incorporates a non-homothetic preference as in Melitz and Ottaviano (2008) into a static multiple-country framework. Rodriguez-Lopez (2006, 2010) analyzes the exchange rate pass-through using a model augmented with endogenous markup and sticky wage without firm entry. However, none of these studies have accounted for the implications of a productivity gain on the terms of trade dynamics while incorporating both the income effect and the markup effect in a dynamic stochastic general equilibrium (DSGE) setting.

The organization of this paper is as follows. In Section 2, I present empirical evidence for the effects of a positive productivity shock on the terms of trade. Section 3 outlines a two-country DSGE model augmented with heterogeneous productivity and endogenous markup. Section 4 explains the calibration parameters of the model. Section 5 explains the underlying mechanism that explains the dynamics of the terms of trade in my model. In Section 6, I show the results of impulse response analyses using the model. Section 7 compares the responses of the terms of trade observed in the data and obtained using the theoretical model in Section 3. Section 8 concludes.

2 Empirical Evidence

In this section, I empirically study the dynamics of the terms of trade of the US in response to a technology shock in the US. I estimate a Structural Vector Autoregression (SVAR) model and identify the shocks using the Maximum Forecast-Error Variance (MFEV) approach following Uhlig (2004a,b) and Francis, Owyang and Roush (2007)[4].

2.1 Identification of a productivity shock using the MFEV approach

I begin by discussing the identification method using the MFEV approach following Francis, Owyang and Roush (2007). I first estimate the reduced-form VAR model as follows:

$$y_t = B(L)u_t, \tag{1}$$

where y_t denotes an $n \times 1$ vector of variables at time t with labor productivity, Z_t, placed at the top. $B(L) = \sum_{i=0}^{\infty} B_i L^i$ where L is the lag operator and u_t is a vector of the reduced

[4]This approach has been recently actively used also in the literature on news shock. For example, see Sims (2009), Barsky and Sims (2010) and Kurmann and Otrok (2010).

residuals at time t. I assume there is a mapping between the reduced residuals, u_t, and the structural residuals, ε_t, as follows:

$$u_t = A_0 \varepsilon_t. \tag{2}$$

The goal of the identification is to find the matrix, A_0. I can write y_t as a Moving Average (MA) representation using structural residuals, ε_t as follows:

$$y_t = C(L)\varepsilon_t, \tag{3}$$

where $C(L) = \sum_{i=0}^{\infty} C_i L^i$. I assume that the variance-covariance matrix of ε_t is an identity matrix, I. I can write $C(L)$ as

$$C(L) = B(L)A_0. \tag{4}$$

I assume that the variance-covariance matrix of u_t is Σ, i.e., $E_t\left[u_t u_t'\right] = \Sigma$. From (2), I can write Σ as $\Sigma = E_t[A_0 \varepsilon_t \varepsilon_t' A_0'] = A_0 A_0'$.

However, the decomposition into A_0 is not unique. Therefore, by using some arbitrary orthogonalization[5], $\tilde{A}_0$, and D where $DD' = I$, Σ can be decomposed as follows:

$$\Sigma = \tilde{A}_0 D D' \tilde{A}_0' \tag{5}$$

We can rewrite the impulse responses $C(L)$ associated with the structural shocks ε_t as:

$$C(L) = B(L)\tilde{A}_0 D. \tag{6}$$

Then the forecast error h-period ahead can be written as:

$$y_{t+h} - E_{t-1} y_{t+h} = \sum_{i=0}^{h} B_i \tilde{A}_0 D \varepsilon_{t+h-i}, \tag{7}$$

where E_{t-1} is the expectation operator at time $t-1$.

The share of the h-step-ahead forecast error variance for a variable j attributable to structural shock k is:

$$\omega_{jk}(h) = \frac{e_j'\left(\sum_{i=0}^{h} B_i \tilde{A}_0 D e_k e_k' D' \tilde{A}_0' B_i'\right) e_j}{e_j'\left(\sum_{i=0}^{h} B_i \Sigma B_i'\right) e_j} = \frac{\sum_{i=0}^{h} B_{j,i} \tilde{A}_0 \gamma \gamma' \tilde{A}_0' B_{j,i}'}{\sum_{i=0}^{h} B_{j,i} \Sigma B_{j,i}'}, \tag{8}$$

where e_j is an $n \times 1$ indicator vector which selects γ, the kth column of D.

[5] In practice, I use Cholesky decomposition following Francis, Owyang and Roush (2007) or Barsky and Sims (2010) for obtaining $\tilde{A}_0$. This decomposition ensures that the technology shock is orthogonal to other shocks in the system.

This identification method chooses an impulse vector, γ, which maximizes the forecast error variance as much as possible over h horizon. The impulse response generating matrix is $B_i \tilde{A}_0 \gamma$.

I identify a productivity shock by solving following maximization problem:

$$\max_{\gamma} \quad \omega_{1k}(h) \tag{9}$$

subject to

$$\gamma' \gamma = 1 \tag{10}$$

The maximization constraint, (10), is to ensure that the technology shocks have unit variance. In practice[6], this maximization problem is to solve the eigenvector associated with the maximum eigenvalue of a weighted sum of $\left(B_{1i}\tilde{A}_0\right)' \left(B_{1,i}\tilde{A}_0\right)$.

2.2 The Data

In order to identify the technology shock to the US and estimate the impulse responses of the terms of trade, I use following quarterly data. The sample covers the post-Bretton Woods period 1973Q1-2010Q2. For the US labor productivity, I use output per hour in the nonfarm business sector obtained from the website of the Bureau of Labor Statistics. To construct the US terms of trade, I divide the implicit deflator of imported goods by the implicit deflator of exported goods, obtained from the website of the Bureau of Economic Analysis. I also include US net exports, US consumption relative to that of an aggregate of other G7 countries, and US output relative to that of an aggregate of other G7 countries. To construct the US net exports, I obtain data on nominal exports, imports and GDP from the website of the Bureau of Economic Analysis. I first subtract the value of nominal imports from nominal exports and divide this by nominal GDP. For relative US consumption, I use data from SourceOECD. I construct an aggregate consumption of the rest of the world using private consumption data of the G7 countries except the US (Canada, France, Germany, Italy, Japan and UK) weighted by each country's GDP share in the total GDP of the G7 countries. I construct an aggregate output of the rest of the world in a similar way. All the variables are converted to log levels except net exports. In order to construct a stationary time series, I detrended the data by linear and quadratic detrending method.

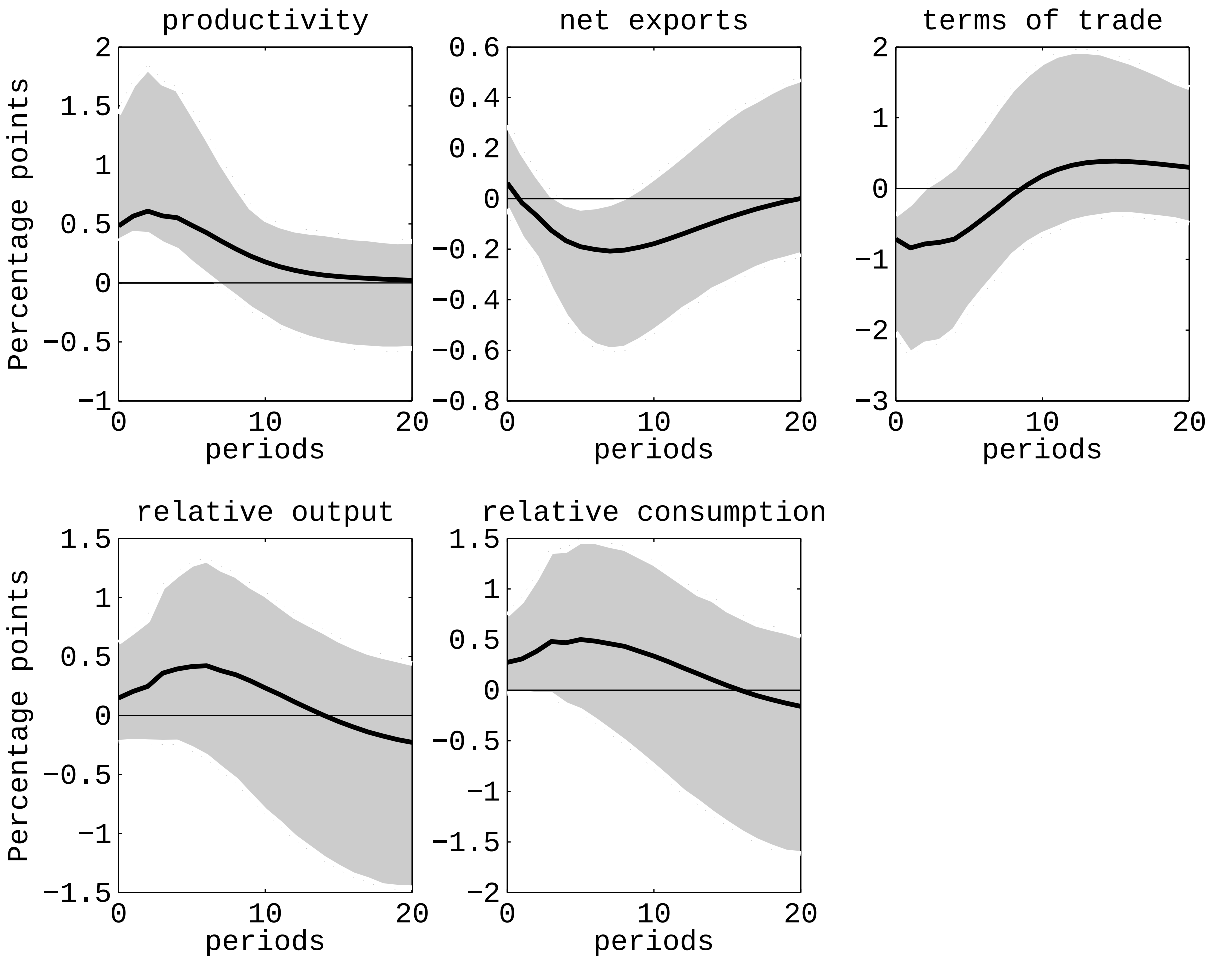

Figure 1: Effects of a positive US technology shock

2.3 Empirical Results

Figure 1 shows the impulse responses using MFEV identification. Following a positive technology shock to US labor productivity, the US terms of trade significantly appreciates on impact. US net exports decrease, although the initial response is not significant. Relative consumption and output tend to increase and exhibit hump-shaped responses.

3 The Model

In this section, I propose a two-country model in which firms have a heterogeneous firm-specific productivity and endogenously determine firm-specific markup. The basic framework is based on Ghironi and Melitz (2005) which features heterogeneous productivity.

[6] The appendix of Faust (1998) explains the proof. Kurmann and Otrok (2010) presents a detailed explanation.

However, I incorporate non-homothetic consumer preference a lá Melitz and Ottaviano (2008). Unlike Melitz and Ottaviano (2008), I do not incorporate an external homogeneous goods sector in order to incorporate the income effect fully in a general equilibrium model[7].

3.1 Household's utility and demand for variety

The economy consists of two countries, Home and Foreign. Foreign variables are denoted with stars. A representative household maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, 1 - H_t\right),$$

where β is a discount factor, C_t is total consumption of the household and H_t is the total hours worked.

For the instantaneous utility, I assume a Cobb-Douglas function as follows:

$$U\left(C_t, 1 - H_t\right) = \frac{\left\{C_t^{\kappa}(1 - H_t)^{1-\kappa}\right\}^{1-\sigma}}{1 - \sigma}.$$

Following Ottaviano, Tabuchi and Thisse (2002) and Melitz and Ottaviano (2008), C_t is given by:

$$C_t = \omega \int_{i \in \Omega} q_{it} di - \frac{1}{2}\gamma \int_{i \in \Omega} \left(q_{it}\right)^2 di - \frac{1}{2}\eta \left(\int_{i \in \Omega} q_{it} di\right)^2, \tag{11}$$

where q_{it} is the amount of consumption of each variety i, and Ω denotes the possibly-consumed set of goods. ω, γ and η are positive parameters; ω expresses the intensity of the preference for differentiated products, γ is the index of the degree of product differentiation between varieties and η is the index of the pattern of substitution. A large η means closer substitution between varieties.

Solving the expenditure-minimization problem, the demand function for each variety i is derived as:

$$q_t(i) = \frac{1}{\gamma}\left(\omega - \frac{1}{\lambda_t} p_t(i) - \eta Q_t\right), \tag{12}$$

where $Q_t \equiv \int_{i \in \Omega} q_{it} di$ and λ_t is the Lagrangian multiplier of the expenditure minimization problem.

Integrating over all the varieties consumed, the average consumption of the variety, $\bar{q}_t$, can be written as:

$$\bar{q}_t = \frac{\omega - \frac{1}{\lambda_t}\bar{p}_t}{\gamma + \eta N_t} \tag{13}$$

[7] This approach is similar to Goksel (2008) or Neary (2003).

where $\bar{p}_t$ is the average price and N_t is the measure of consumed varieties.

When the demand for variety i is zero, the maximum price the firm can set, $\hat{p}_t$, can be derived using (12) and (13) as:

$$\hat{p}_t = \frac{\omega\gamma\lambda_t + \eta N_t \bar{p}_t}{\gamma + \eta N_t}. \tag{14}$$

3.2 Firms

There is a continuum of firms which produce different varieties i. I assume that production requires only labor. Firms face aggregate labor productivity, Z_t. Each firm is identical prior to entry. They face a sunk cost of f_E effective labor units, which is $\frac{w_t f_{Et}}{Z_t}$. They also have a firm-specific productivity, z, which is revealed after they enter the market. Following Ghironi and Melitz (2005), it is assumed that z follows a Pareto distribution, $G(z) \equiv 1 - \left(\frac{z_{min}}{z}\right)^{\theta}$, with a lower bound z_{min}.

I assume that N_p firms possibly produce. Every period each firm faces a death shock with probability δ, following Ghironi and Melitz (2005).

3.2.1 Firms serving domestic sales

Each firm with firm-specific productivity z serving in the domestic market maximizes:

$$\max \pi_{Dt}(z) = p_{Dt}(z) q_{Dt}(z) - MC_t(z) q_{Dt}(z), \tag{15}$$

where $\pi_{Dt}(z)$ is the profit earned from domestic sales, $p_{Dt}(z)$ is the price charged for domestic sales, and $q_{Dt}(z)$ is the quantity of domestic sales. $MC_t(z)$ is the marginal cost for the firm with productivity z, which is equal to $\frac{W_t}{Z_t z}$.

The demand function for a good produced by a firm with productivity z is written using (12) as:

$$q_{Dt}(z) = \frac{1}{\gamma}\left(\omega - \frac{1}{\lambda_t} p_{Dt}(z) - \eta N_t \bar{q}_t\right). \tag{16}$$

Each firm serving the domestic market maximizes (15) subject to (16).

By solving the above profit maximization problem, I obtain the following equation that determines the optimal price charged by the firm:

$$q_{Dt}(z) = \frac{1}{\gamma\lambda_t}\left[p_{Dt}(z) - MC_t(z)\right] \tag{17}$$

Let z_{Dt} be the cutoff productivity with which the firm has positive sales. Therefore, $p_{Dt}(z_{Dt}) = MC_t(z_{Dt}) = \hat{p}_t$ and the demand level is $q_{Dt}(z_{Dt}) = 0$. Equating (16) and (17) and using (13), the optimal price can be further written using z_{Dt} as:

$$p_{Dt}(z) = \frac{1}{2} MC_t(z) + \frac{1}{2} MC_t(z_{Dt}). \tag{18}$$

Using z_{Dt}, the optimal output level, $q_{Dt}(z)$, markup, $\mu_{Dt}(z)$, and the profit level, $\pi_{Dt}(z)$ can be written as:

$$q_{Dt}(z) = \frac{1}{\gamma\lambda_t}\left[\frac{1}{2}MC_t(z_{Dt}) - \frac{1}{2}MC_t(z)\right] \tag{19}$$

$$\mu_{Dt}(z) = \frac{1}{2}MC_t(z_{Dt}) - \frac{1}{2}MC_t(z) \tag{20}$$

$$\pi_{Dt}(z) = \frac{1}{4\gamma\lambda_t}\left[MC_t(z_{Dt}) - MC_t(z)\right]^2. \tag{21}$$

Importantly, firms with lower cost or higher firm-specific productivity set lower prices and enjoy higher markups and profits. The prices and markups also depend on the cutoff productivity in the market, z_{Dt}.

3.2.2 A firm serving export sales

The profit maximization problem for a firm with productivity z serving export sales can be written as:

$$\max \pi_{Xt}(z) = p_{Xt}(z)q_{Xt}(z) - \tau_t MC_t(z)q_{Xt}(z) \tag{22}$$

where $\pi_{Xt}(z)$ is the profit earned from export sales, $p_{Xt}(z)$ is the price charged for export sales, and $q_{Xt}(z)$ is the quantity of the export sales.

The demand function associated with export sales can be written using (12) as:

$$q_{Xt}(z) = \frac{1}{\gamma}\left(\omega - \frac{1}{\lambda_t^*}p_{Xt}(z) - \eta N_t^* \bar{q}_t^*\right). \tag{23}$$

By solving this profit maximization problem, the optimal price for export sales can be derived using the following equation:

$$q_{Xt}(z) = \frac{1}{\gamma\lambda_t^*}\left[p_{Xt}(z) - \tau_t MC_t(z)\right]. \tag{24}$$

Let z_{Xt} be the cutoff productivity with which the firm obtains positive sales out of exporting. Therefore, $p_{Xt}(z_{Xt}) = \tau_t MC_t(z_{Xt}) = \hat{p}_t^*$ and the demand is $q_{Xt}(z_{Xt}) = 0$. Equating (23) and (24) and using the foreign counterpart of (13), the optimal price can be derived as:

$$p_{Xt}(z) = \frac{1}{2}\tau_t MC_t(z) + \frac{1}{2}\tau_t MC_t(z_{Xt}). \tag{25}$$

The optimal output level, markup, and the profit level for export sales can be written as:

$$q_{Xt}(z) = \frac{1}{\gamma\lambda_t^*}\left[\frac{1}{2}\tau_t MC_t(z_{Xt}) - \frac{1}{2}\tau_t MC_t(z)\right] \tag{26}$$

$$\mu_{Xt}(z) = \frac{1}{2}\tau_t MC_t(z_{Xt}) - \frac{1}{2}\tau_t MC_t(z) \tag{27}$$

$$\pi_{Xt}(z) = \frac{1}{4\gamma\lambda_t^*}\left[\tau_t MC_t(z_{Xt}) - \tau_t MC_t(z)\right]^2. \tag{28}$$

As in the case of firms serving domestic sales, I can infer from these equations that firms with lower cost have lower prices and enjoy higher markups and profits. Prices and markups depend on the cutoff productivity which determines the exportability, z_{Xt}.

3.3 Firm averages

Given a distribution of firm-specific productivity, $G(z)$, we can solve for the average values of price, output levels, and markups. For any function of z, $a_{jt}(z)$, where $j = D, X$, the average value $\overline{a}_{jt}$ is given by $\overline{a}_{jt} = \frac{1}{1-G(z)}\int_{z_{jt}}^{\infty} a_{jt}(z)dG(z)$.

Then the average prices satisfy:

$$\overline{p}_{Dt} = \frac{2\theta+1}{2(\theta+1)}\frac{W_t}{Z_t z_{Dt}},\ \overline{p}_{Xt} = \frac{2\theta+1}{2(\theta+1)}\frac{\tau_t W_t}{Z_t z_{Xt}}$$

$$\overline{q}_{Dt} = \frac{1}{2\gamma(\theta+1)\lambda_t}\frac{W_t}{Z_t z_{Dt}},\ \overline{q}_{Xt} = \frac{1}{2\gamma(\theta+1)\lambda_t^*}\frac{\tau_t W_t}{Z_t z_{Xt}}$$

$$\overline{\mu}_{Dt} = \frac{1}{2(\theta+1)}\frac{W_t}{Z_t z_{Dt}},\ \overline{\mu}_{Xt} = \frac{1}{2(\theta+1)}\frac{\tau_t W_t}{Z_t z_{Xt}}$$

The foreign average variables can be written analogously.

3.4 Free entry condition

I assume that entrants are forward-looking and able to correctly anticipate their future stream of expected profits. The present discounted value of the stream of expected profits after period $t+1$ can be written as:

$$v_t = E_t \sum_{s=t+1}^{\infty} [\beta(1-\delta)]^{s-t}\frac{U_c(C_{t+s}, 1-H_{t+s})}{U_c(C_t, 1-H_t)}\pi_s \tag{29}$$

where δ is the exogenous death rate of the firm and π_t is the one-period expected profit of the firm, π_t is the sum of the expected profit from domestic sales, π_{Dt}, and and export sales, π_{Xt}:

$$\pi_t = \pi_{Dt} + \pi_{Xt}. \tag{30}$$

π_{Dt} and π_{Xt} can be written as a function of the cutoff productivity as:

$$\pi_{Dt} = \int_{z_{Dt}}^{\infty} \pi_{Dt}(z) dG(z) = \frac{z_{min}^{\theta} \left(\frac{W_t}{Z_t}\right)^2 z_{Dt}^{-\theta-2}}{2\gamma(\theta+1)(\theta+2)\lambda_t} \tag{31}$$

$$\pi_{Xt} = \int_{z_{Xt}}^{\infty} \pi_{Xt}(z) dG(z) = \frac{z_{min}^{\theta} \tau_t^2 \left(\frac{W_t}{Z_t}\right)^2 z_{Xt}^{-\theta-2}}{2\gamma(\theta+1)(\theta+2)\lambda_t^*}. \tag{32}$$

The foreign average variables can be derived analogously.

The free entry condition can be written using the expected profit at time t, π_t and the discounted value of future expected profit after $t+1$, v_t, as[8]:

$$\pi_t + v_t = \frac{W_t f_{Et}}{Z_t}. \tag{33}$$

3.5 The cutoff productivity

In this section, I characterize the cutoff productivity, z_{Dt} and z_{Xt}. By construction, the firm with cutoff productivity exhibits zero sales. In order to have a positive profit in the domestic market, the firm with cutoff productivity, z_{Dt}, must satisfy following condition:

$$\frac{\omega\gamma\lambda_t + \eta N_t \bar{p}_t}{\gamma + \eta N_t} = \frac{W_t}{Z_t z_{Dt}} \tag{34}$$

where N_t is the total number of firms selling in the home economy.[9] This condition is derived from the fact that at the cutoff productivity, z_{Dt}, $p_{Dt}(z_{Dt}) = \hat{p}_t = MC_t(z_{Dt})$ holds.

Similarly, the cutoff productivity, z_{Xt}, will satisfy

$$\frac{\omega\gamma\lambda_t^* + \eta N_t^* \bar{p}_t^*}{\gamma + \eta N_t^*} = \tau_t \frac{W_t}{Z_t z_{Xt}} \tag{35}$$

where N_t^* is the total number of firms selling in the foreign economy. This condition is derived from $p_{Xt}(z_{Xt}) = \hat{p}_t^* = \tau_t MC_t(z_{Xt})$.

[8] Ghironi and Melitz (2005) introduce a one-period time-to-build lag in the model and assume that entrants start producing at time $t+1$, and thus the free entry condition in their model becomes $v_t = \frac{W_t f_{Et}}{Z_t}$. This assumption will induce additional hump-shaped dynamics in the impulse responses, however, I do not assume this time-to-build lag structure.

[9] Therefore $N_t = N_{Dt} + N_{Xt}^*$, where N_{Dt} is the number of home firms selling in the home economy and N_{Xt}^* is the number of foreign firms selling in the home economy. Similarly, $N_t^* = N_{Dt}^* + N_{Xt}$, where N_{Dt}^* is the number of foreign firms selling in the foreign economy and N_{Xt} is the number of home firms selling in the foreign economy.

3.6 Number of the firms

Under the assumption of firm-specific productivity, $G(z) \equiv 1 - \left(\frac{z_{min}}{z}\right)^{\theta}$ and defining the number of firms possibly producing, N_p, I can write the number of domestic firms producing as:

$$N_{Dt} = N_{pt} \left(\frac{z_{min}}{z_{Dt}}\right)^{\theta}, \tag{36}$$

$$N_{Xt} = N_{pt} \left(\frac{z_{min}}{z_{Xt}}\right)^{\theta}. \tag{37}$$

Foreign variables can be written analogously.

Since there is a death shock each period with a probability δ, the evolution of N_{pt} becomes

$$N_p = (1-\delta)N_{pt-1} + N_{Et}, \tag{38}$$

where N_{Et} is the number of entrants.

3.7 Asset Market Structures

In this section, I discuss three cases of asset market structures. Later I compare the responses of the terms of trade for these three cases. In my model, the implications of an aggregate productivity shock crucially vary across different asset market structures.

3.7.1 Case 1: Financial Autarky and Balanced Trade Assumption

First I assume a financial autarky and a balanced trade assumption to see the adjustment in the terms of trade. Under this assumption, the value of exports equals the value of imports as:

$$N_{Xt}\frac{1}{1-G(z_{Xt})}\int_{z_{Xt}}^{\infty} p_{Xt}(z)q_{Xt}(z)dG(z) = N^*_{Xt}\frac{1}{1-G(z^*_{Xt})}\int_{z^*_{Xt}}^{\infty} p^*_{Xt}(z)q^*_{Xt}(z)dG(z).$$

This equation is simplified to:

$$\frac{N_{Xt}\tau_t^2\overline{MC}_t^2 z_{Xt}^{-2}}{\lambda_t^*} = \frac{N^*_{Xt}\tau_t^{*2}\overline{MC}_t^{*2} z_{Xt}^{*-2}}{\lambda_t}. \tag{39}$$

Under this assumption, there is no bond trading across countries and thus there is no international risk sharing. The consumption becomes equal to the value of the output.

3.7.2 Case 2: Incomplete asset market assumption

Next, I assume an incomplete asset market. Under this assumption, the representative household trades home bonds and foreign bonds. There are costs of adjusting holdings of home and foreing bonds. I follow the setting used in Ghironi and Melitz (2005).

In this case, the budget constraint of the household can be rewritten as:

$$\begin{aligned} & P_t^c B_{t+1} + P_t^{c*} B_{*t+1} + P_t^c \frac{\upsilon}{2} (B_{t+1})^2 + P_t^{c*} \frac{\upsilon}{2} (B_{*t+1})^2 + P_t^c C_t + N_{pt} \upsilon_t \\ = \; & (1+r_t) P_t^c B_t + (1+r_t^*) P_t^{c*} B_{*t} + T_t + W_t H_t + N_{p,t-1}(1-\delta)(\pi_t + \upsilon_t), \end{aligned}$$

where B_{t+1} is holdings of home bonds, B_{*t+1} is holdings of foreign bonds, $\frac{\upsilon}{2} (B_{t+1})^2$ is the cost of adjusting the holdings of home bonds, and $\frac{\upsilon}{2} (B_{*t+1})^2$ is the cost of adjusting the holdings of foreign bonds. T_t is the rebate to the household, which is equal to $P_t^c \frac{\upsilon}{2} (B_{t+1})^2 + P_t^{c*} \frac{\upsilon}{2} (B_{*t+1})^2$ at equilibrium. We assume υ, the parameter that determines the cost of adjusting the holdings of bonds, to be positive.

The representative foreign household has a similar budget constraint, as:

$$\begin{aligned} & P_t^c B_{t+1}^* + P_t^{c*} B_{*t+1}^* + P_t^c \frac{\upsilon}{2} \left(B_{t+1}^*\right)^2 + P_t^{c*} \frac{\upsilon}{2} \left(B_{*t+1}^*\right)^2 + P_t^{c*} C_t^* + N_{pt}^* \upsilon_t^* \\ = \; & (1+r_t) P_t^c B_t^* + (1+r_t^*) P_t^{c*} B_{*t}^* + T_t^* + W_t^* H_t^* + N_{p,t-1}^*(1-\delta)(\pi_t^* + \upsilon_t^*), \end{aligned}$$

where B_{t+1}^* is the holdings of home bonds, B_{*t+1}^* is the holdings of foreign bonds, $\frac{\upsilon}{2} \left(B_{t+1}^*\right)^2$ is the cost of adjusting the holdings of home bonds, and $\frac{\upsilon}{2} \left(B_{*t+1}^*\right)^2$ is the cost of adjusting the holdings of foreign bonds. T_t^* is the rebate to the household, which is equal to $P_t^c \frac{\upsilon}{2} \left(B_{t+1}^*\right)^2 + P_t^{c*} \frac{\upsilon}{2} \left(B_{*t+1}^*\right)^2$ at equilibrium.

The first order conditions for the choice of bond holdings, i.e., Euler equations for bond holdings for the representative home household are:

$$\mu_t(1 + \upsilon B_{t+1}) = \beta(1 + r_{t+1}) E_t \left\{\mu_{t+1}\right\}$$

$$\mu_t(1 + \upsilon B_{*t+1}) = \beta(1 + r_{t+1}^*) E_t \left\{\frac{RER_{t+1}}{RER_t} \mu_{t+1}\right\}$$

where RER_t is the real exchange rate defined using the consumer price index, i.e., $RER_t \equiv \frac{P_t^{c*}}{P_t^c}$.

For the foreign household,

$$\mu_t^*(1 + \upsilon B_{t+1}^*) = \beta(1 + r_{t+1}) E_t \left\{\frac{RER_t}{RER_{t+1}} \mu_{t+1}^*\right\}$$

$$\mu_t^*(1 + \upsilon B_{*t+1}^*) = \beta(1 + r_{t+1}^*) E_t \left\{\mu_{t+1}^*\right\}.$$

At equilibrium, home and foreign bonds should be in zero net supply:

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

$$B_{*t+1} + B^*_{*t+1} = 0. \tag{41}$$

At equilibrium, the rebates to households satisfy $T_t = P^c_t \frac{\upsilon}{2}\left(B_{t+1}\right)^2 + P^{c*}_t \frac{\upsilon}{2}\left(B_{*t+1}\right)^2$ and $T^*_t = P^c_t \frac{\upsilon}{2}\left(B^*_{t+1}\right)^2 + P^{c*}_t \frac{\upsilon}{2}\left(B^*_{*t+1}\right)^2$. Therefore, the aggregate accounting for the Home and Foreign economy can be written as:

$$\begin{aligned} & P^c_t B_{t+1} + P^{c*}_t B_{*t+1} + P^c_t C_t + N_{pt} v_t \\ = \ & (1+r_t) P^c_t B_t + (1+r^*_t) P^{c*}_t B_{*t} + W_t H_t + N_{p,t-1}(1-\delta)(\pi_t + v_t) \end{aligned} \tag{42}$$

and

$$\begin{aligned} & P^c_t B^*_{t+1} + P^{c*}_t B^*_{*t+1} + P^{c*}_t C^*_t + N^*_{pt} v^*_t \\ = \ & (1+r_t) P^c_t B^*_t + (1+r^*_t) P^{c*}_t B^*_{*t} + W^*_t H^*_t + N^*_{p,t-1}(1-\delta)(\pi^*_t + v^*_t). \end{aligned} \tag{43}$$

Deducting (43) from (42) and using the bond market equilibrium, (40) and (41), I obtain:

$$\begin{aligned} & P^c_t B_{t+1} + P^{c*}_t B_{*t+1} + \frac{1}{2}\left(P^c_t C_t - P^{c*}_t C^*_t\right) + \frac{1}{2}\left(N_{pt} v_t - N^*_{pt} v^*_t\right) \\ = \ & (1+r_t) P^c_t B_t + (1+r^*_t) P^{c*}_t B_{*t} + \frac{1}{2}\left(W_t H_t - W^*_t H^*_t\right) \\ & + \frac{1}{2}\left[N_{pt-1}(1-\delta)(\pi_t + v_t) - N^*_{pt-1}(1-\delta)(\pi^*_t + v^*_t)\right]. \end{aligned} \tag{44}$$

Labor market clearing conditions of the home and the foreign economy are[10]:

$$\begin{aligned} H_t = \ & \frac{\theta}{2\gamma(\theta+1)(\theta+2)\lambda_t W_t} N_{Dt} \overline{MC}^2_t z^{-2}_{Dt} + \frac{\theta}{2\gamma(\theta+1)(\theta+2)\lambda^*_t W_t} N_{Xt} \tau^2_t \overline{MC}^2_t z^{-2}_{Xt} \\ & + \frac{N_{Et} f_{Et}}{Z_t} \end{aligned} \tag{45}$$

and

$$\begin{aligned} H^*_t = \ & \frac{\theta}{2\gamma(\theta+1)(\theta+2)\lambda^*_t W^*_t} N^*_{Dt} \overline{MC}^{*2}_t z^{*-2}_{Dt} + \frac{\theta}{2\gamma(\theta+1)(\theta+2)\lambda_t W^*_t} N^*_{Xt} \tau^{*2}_t \overline{MC}^{*2}_t z^{*-2}_{Xt} \\ & + \frac{N^*_{Et} f^*_{Et}}{Z^*_t}. \end{aligned} \tag{46}$$

[10] Here, $H_t = N_{Dt}\overline{H}_{Dt} + N_{Xt}\overline{H}_{Xt} + \frac{N_{Et} f_{Et}}{Z_t}$. $\overline{H}_{Dt}$ can be derived as:

$$\overline{H}_{Dt} = \left[\frac{1}{1-G(z_{Dt})}\int_{z_{Dt}}^{\infty} p_{Dt}(z) q_{Dt}(z) dG(z) - \frac{1}{1-G(z_{Dt})}\int_{z_{Dt}}^{\infty} \pi_{Dt}(z) dG(z)\right] / W_t.$$

$\overline{H}_{Xt}$ can be derived in a similar way.

3.7.3 Case 3: Complete Market Assumption

Finally, I consider the case with a complete market, where the representative household trades a complete set of state-contingent securities in the international asset market.

The household's period budget constraint can be written as follows:

$$P_t^c C_t + E_t Q_{t,t+1} B_{t+1} + N_{pt} v_t = W_t H_t + B_t + N_{pt-1}(1-\delta)(\pi_t + v_t) \tag{47}$$

where $Q_{t,t+1}$ is the stochastic discount factor to price the state-contingent security, B_{t+1} and v_t is the post-entry average value of the firm.

Under this assumption, balanced trade is not necessary in an outcome. The trade balance can be written as:

$$\begin{aligned} TB_t &= \frac{N_{Xt}\frac{1}{1-G(z_{Xt})}\int_{z_{Xt}}^{\infty} p_{Xt}(z)q_{Xt}(z)dG(z) - N_{Xt}^{*}\frac{1}{1-G(z_{Xt}^{*})}\int_{z_{Xt}^{*}}^{\infty} p_{Xt}^{*}(z)q_{Xt}^{*}(z)dG(z)}{N_{Dt}\frac{1}{1-G(z_{Dt})}\int_{z_{Dt}}^{\infty} p_{Dt}(z)q_{Dt}(z)dG(z) + N_{Xt}\frac{1}{1-G(z_{Xt})}\int_{z_{Xt}}^{\infty} p_{Xt}(z)q_{Xt}(z)dG(z)} \\ &= \frac{\frac{N_{Xt}\tau_t^2\overline{MC}_t^2 z_{Xt}^{-2}}{2\gamma(\theta+2)\lambda_t^*} - \frac{N_{Xt}^*\tau_t^{*2}\overline{MC}_t^{*2} z_{Xt}^{*-2}}{2\gamma(\theta+2)\lambda_t}}{\frac{N_{Dt}\overline{MC}_t^2 z_{Dt}^{-2}}{2\gamma(\theta+2)\lambda_t} + \frac{N_{Xt}\tau_t^2\overline{MC}_t^2 z_{Xt}^{-2}}{2\gamma(\theta+2)\lambda_t^*}} \\ &= \frac{\frac{N_{Xt}\tau_t^2\overline{MC}_t^2 z_{Xt}^{-2}}{\lambda_t^*} - \frac{N_{Xt}^*\tau_t^{*2}\overline{MC}_t^{*2} z_{Xt}^{*-2}}{\lambda_t}}{\frac{N_{Dt}\overline{MC}_t^2 z_{Dt}^{-2}}{\lambda_t} + \frac{N_{Xt}\tau_t^2\overline{MC}_t^2 z_{Xt}^{-2}}{\lambda_t^*}}. \end{aligned} \tag{48}$$

3.8 Shocks

In order to close the model, I specify the shock process of productivity. Following Backus, Kehoe and Kydland (1992), I assume a standard bivariate AR(1) process for home and foreign productivity:

$$\begin{bmatrix} Z_t \\ Z_t^* \end{bmatrix} = \begin{bmatrix} \phi_Z & \phi_{ZZ^*} \\ \phi_{Z^*Z} & \phi_{Z^*} \end{bmatrix} \begin{bmatrix} Z_{t-1} \\ Z_{t-1}^* \end{bmatrix} + \begin{bmatrix} \xi_t \\ \xi_t^* \end{bmatrix}. \tag{49}$$

4 Calibration

I calibrate the parameters as follows. I set the discount factor as $\beta = 0.99$ and exogenous probability of firm death is set as $\delta = 0.025$, following Ghironi and Melitz (2005). For the basic set of calibration, I assume parameters that characterize non-homothetic preference as $\omega = 10$, $\gamma = 0.5$ and $\eta = 1$ following Rodriguez-Lopez (2006). I assume the value of the iceberg cost, τ, to be 1.734, following Alessandria and Choi (2010). I assume the fixed entry cost as $f_E = 0.1$. I normalize the lower bound of productivity as $z_{min} = 0.1$ without loss of generality.[11] The parameter characterizing the shape of Pareto distribution $G(z)$

[11] This choice of z_{min} makes sure the resulting steady state of z_{Dt} is higher than z_{min}.

is set as $\theta = 3.4$ following Ghironi and Melitz (2005). For the parameters that govern the Cobb-Douglas utility, I first set σ to 2. Then κ, which determines the weight of consumption and leisure in the Cobb-Douglas utility, is set so that the steady state value of hours worked becomes $H = 0.2$. For the case of an incomplete asset market, I assume the bond adjustment cost parameter to be $\nu = 0.0001$, which is a small number commonly assumed in previous literature.

Following Backus, Kehoe and Kydland (1992), I assume $\phi_Z = \phi_{Z^*} = 0.906$, $\phi_{ZZ^*} = \phi_{Z^*Z} = 0.088$.

5 The roles of the income effect and the markup effect

In this section, before I summarize the results of the impulse response analysis in the next section, I explain the potential roles of the income effect and the markup effect that drives the dynamics of the terms of trade. In this analysis, I assume there is a 1 percent increase in home aggregate productivity, Z. The increase in Z has implications for the terms of trade through two effects, the income effect and the markup effect.

The underlying mechanism is as follows. The terms of trade, TOT_t, can be decomposed into two parts as follows:

$$TOT_t \equiv \frac{\overline{p}^*_{Xt}}{\overline{p}_{Xt}} = \underbrace{\left(\frac{\frac{\tau^*_t W^*_t}{Z^*_t}}{\frac{\tau_t W_t}{Z_t}}\right)}_{\text{Relative cost of units of effective labor}} \overbrace{\left(\frac{z_{Xt}}{z^*_{Xt}}\right)}^{\text{Relative cutoff productivity}} \tag{50}$$

where $\overline{p}^*_{Xt}$ is the average price of an imported good and $\overline{p}_{Xt}$ is the average price of an exported good of the home economy. These are derived in Section 3.3. For simplicity, I do not assume any exogenous change in τ_t or τ^*_t here.

If there is a 1 percent increase in the home aggregate productivity, Z, the home income increases. This induces the increase in demand for varieties and thus even less productive foreign firms can enter the market, which decreases the cutoff productivity of foreign firms exporting to the home economy, z^*_{Xt}. This induces an increase in the relative cutoff productivity, which is the second factor in (50). This effect works to depreciate the terms of trade. I call this effect the "income effect".

However, another effect through relative cutoff productivity comes into play. If there is a 1 percent increase in Z, the cost of producing is reduced in the home economy and more firms enter in the home market. Then the markups charged by the firms serving the home market decrease and thus only more productive foreign firms can enter the market. Therefore, z^*_{Xt} increases. This induces an decrease in the relative cutoff productivity in (50) and this effect appreciates the terms of trade. I call this effect as the "markup effect".

As I discuss in the following sections in detail, the relative importance of these two effects, income effect and markup effect, differ across different asset market structures: financial autarky, incomplete asset market, and complete asset market.

6 Impulse response analysis: The important role of markup effect through variable markup

In this section, I explain the implications of financial openness to the relative importance of two effects, income effect and markup effect, which works through the channel of relative cutoff productivity in (50).

6.1 Under financial autarky assumption

Figure 2 displays the results under financial autarky. Under this assumption, there is no risk sharing across countries.

In this case, the income effect becomes much more important than the markup effect since there is no bond trading between two countries and the transfer of income is not possible. Therefore, the terms of trade depreciates. The intuition here is as follows. The positive labor productivity shock increases Home income and this increases the demand for varieties. This surges the increase in labor demand in the labor market and thus the first factor in (50), the relative cost of units of effective labor, decreases. However, this is not enough to appreciate the terms of trade. Even less productive foreign firms can enter the market because of this increase in the demand for varieties and thus the relative cutoff productivity, $\frac{z_{Xt}}{z^*_{Xt}}$, increases. This positive income effect through the channel of relative cutoff productivity depreciates the terms of trade.

6.2 Under incomplete asset market assumption

Next I analyze the case of the incomplete asset market. In this case the state non-contingent bonds are traded across countries. Therefore, the international risk sharing across countries occurs to some extent, however, it is not as perfect as the complete asset market case.

Figure 3 shows the impulse responses. In this case, the positive labor productivity shock induces an increase in the demand for variety, but less so compared to the case of

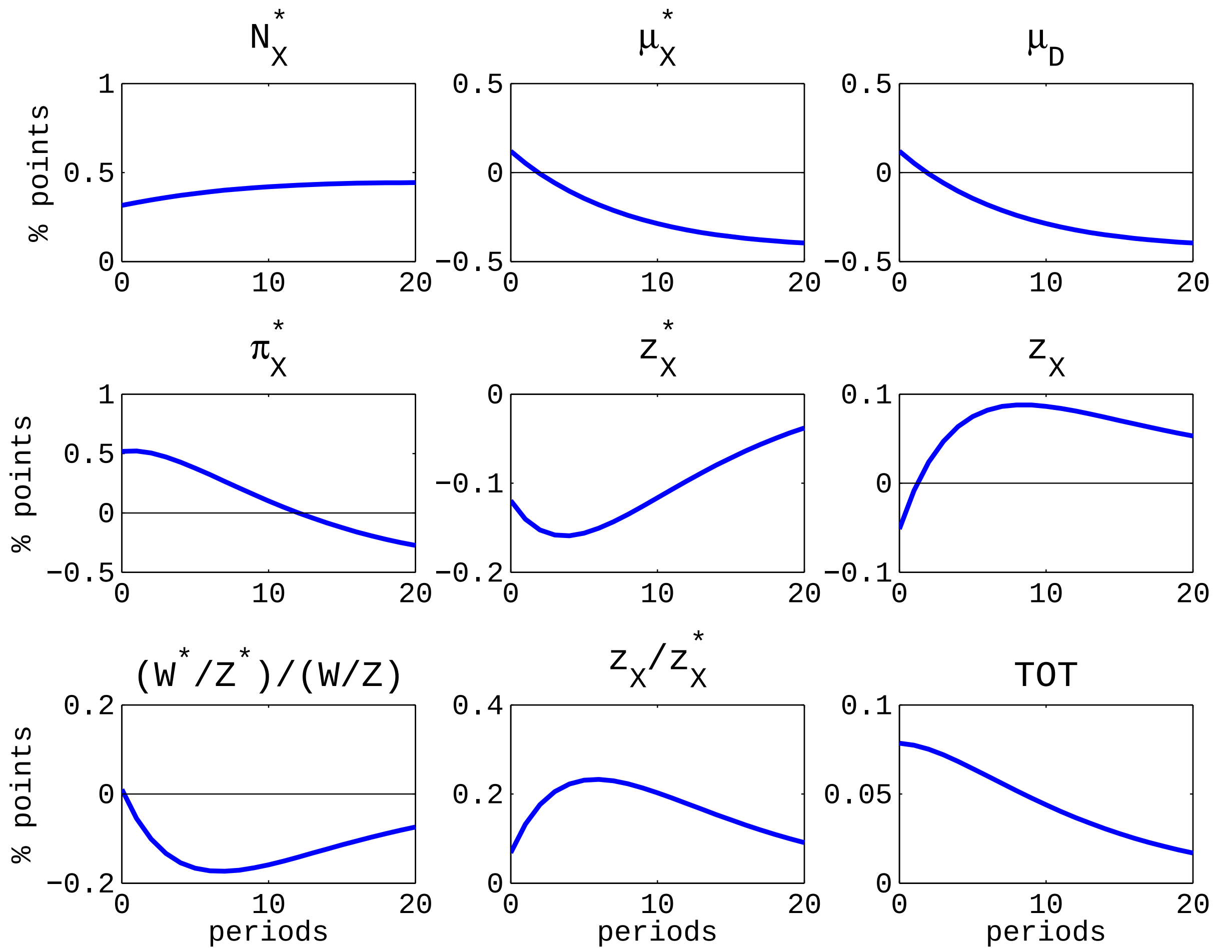

Figure 2: Effect of Home positive aggregate productivity shock (1 percent increase) in a model with financial autarky

financial autarky since the household has the demand for buying bonds under this asset market assumption. Therefore, the income effect is mitigated compared to the case of financial autarky.

In this case, the income effect is mitigated since the representative household can access to the bonds. The markup effect comes into play. In response to a positive labor productivity shock, Home firms can produce more goods at lower cost and more Home firms enter the home market. Therefore, the number of home firms serving the home market, N_{Dt}, increases. This means that the home market becomes more competitive and the average markup charged, $\bar{\mu}_{Dt}$, decreases. Foreign firms exporting to the home market face this higher competition and thus they need to decrease their markup as well. Therefore, $\bar{\mu}^*_{Xt}$, also decreases. However, this generates a decrease in the expected profit. The average profit of the foreign firms exporting to the home market, π^*_{Xt}, decreases. This means that Foreign firms which have relatively higher firm-specific productivity can enter the Home market, i.e., z^*_{Xt} increases. z_{Xt}, the cutoff productivity of Home firms exporting to Foreign economy, decreases more than the case of financial autarky since the Foreign demand for the varieties of goods more than the case of financial autarky because of the wealth tranfer to the Foreign economy. Thus, the relative cutoff productivity, $\frac{z_{Xt}}{z^*_{Xt}}$, decreases in this case and thus the terms of trade still appreciates. Thus, it is shown that the markup effect through variable markup is important in this case.

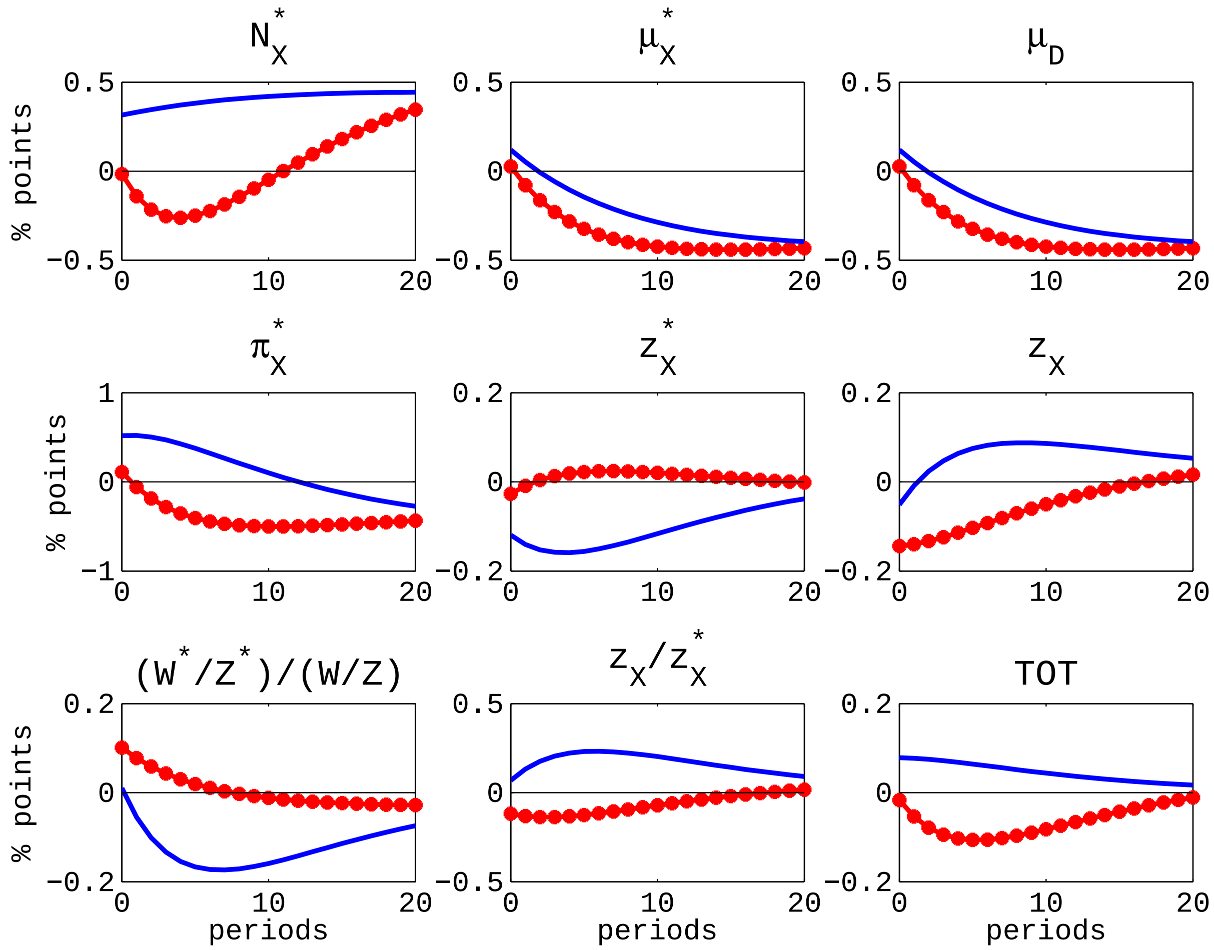

FIGURE 3: EFFECT OF HOME POSITIVE TFP SHOCK (1 PERCENT INCREASE) IN A MODEL WITH INCOMPLETE ASSET MARKET. (BLUE LINES: UNDER FINANCIAL AUTARKY, RED LINES: UNDER AN INCOMPLETE ASSET MARKET)

6.3 Under the complete asset market assumption

Finally, I analyze the case of the complete asset market assumption. Figure 4 displays the results. Under this assumption, the household trades state-contingent claims and the international risk sharing across countries is complete.

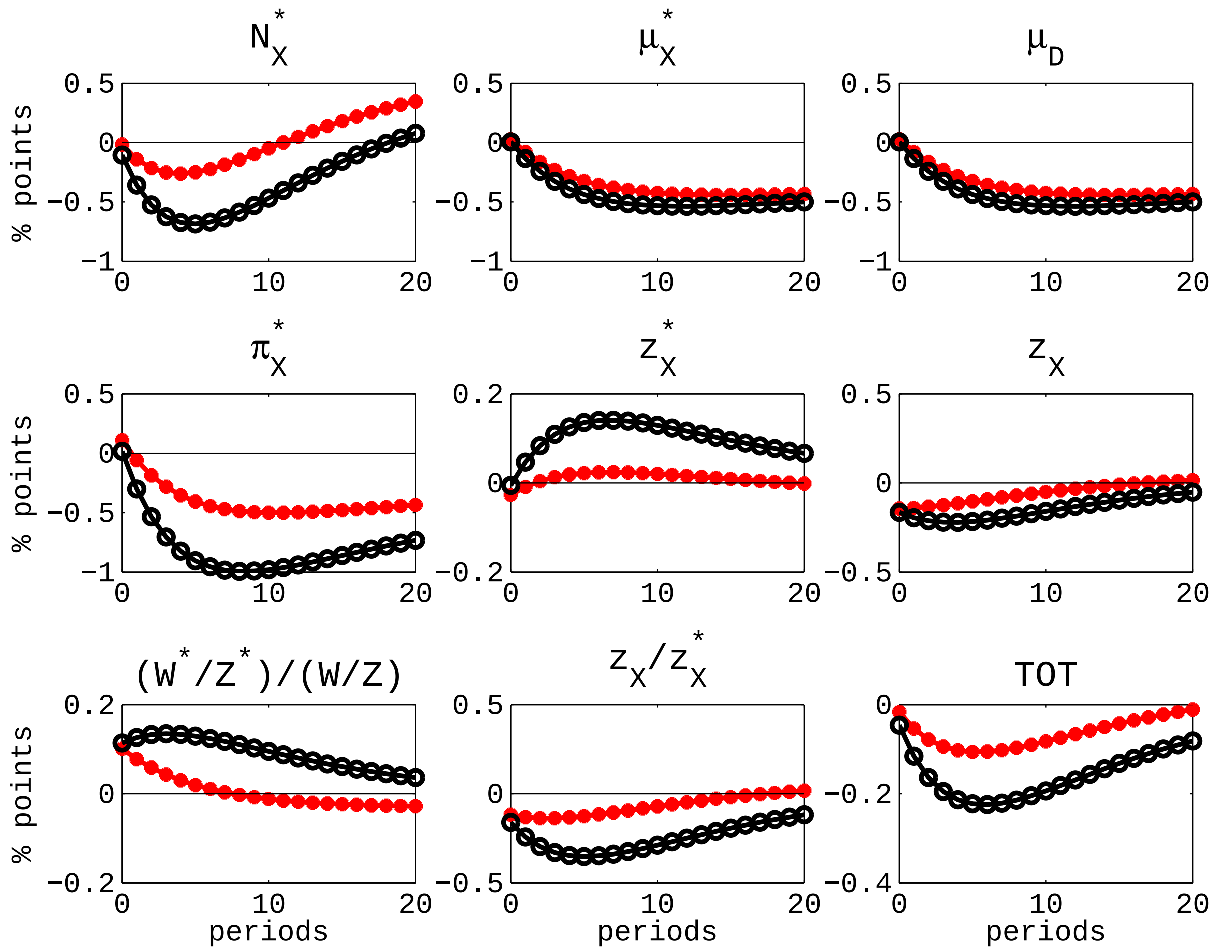

FIGURE 4: EFFECT OF HOME POSITIVE TFP SHOCK IN A MODEL WITH COMPLETE MARKET. (RED LINES: UNDER AN INCOMPLETE ASSET MARKET, BLACK LINES: UNDER A COMPLETE MARKET)

In this case, the income effect is mitigated much more compared to the case of an incomplete asset market and thus the terms of trade appreciates more than in the case of an incomplete asset market. The mechanism that induces the appreciation is the same as in the case of an incomplete asset market.

The striking feature in this result is that the terms of trade appreciates even under the assumption of a complete asset market. It is known that under a complete asset market it is difficult to generate appreciation of the terms of trade. For instance, Enders and Müller (2009) used a conventional two country real business cycle model without heterogeneity in firm productivity and showed that the appreciation of the terms of trade is hard to reconcile without the assumption of an incomplete asset market. However, in my model, using the markup effect explained above, it is possible to explain the appreciation of terms of trade even without an incomplete asset market. This resolution does not resort to strong assumptions regarding the labor market, home bias, elasticity of substitution between goods, and the persistence of productivity that previous studies have imposed.

7 Comparing the Data and the Model Response of the Terms of Trade

In this section, I compare the average impulse response of the terms of trade from the VAR estimation performed in Section 2 and that from theoretical model. By feeding the empirical response of US labor productivity obtained in the VAR analysis into the theoretical model under the assumption of complete market, I calculate the response from the model. Then I calculate the average impulse responses over 4, 8, 12, 16, 20 periods and compare with the responses from the data. In this exercise, I use the assumption of incomplete asset market.

Before comparing the theoretical and empirical impulse responses, I estimate θ, η, γ, ω by matching the model-based impulse responses with the empirical impulse responses. First, I collect the empirical impulse responses to the vector in IR^{data} and choose Φ to be a diagonal matrix with the variance of impulse responses along its diagonal. The parameters are estimated using the following minimization problem [12]:

$$\min_{\Theta} \left(IR(\Theta) - IR^{data}\right)' \Phi^{-1} \left(IR(\Theta) - IR^{data}\right)$$

where $\Theta = \{\theta, \eta, \gamma, \omega\}$. $IR(\Theta)$ denotes a vector that consists of model-based impulse responses. I match impulse responses of the terms of trade and relative consumption for 10 quarters. Estimated parameters are listed in Table 7.

The main challenge in the previous literature has been to explain the appreciation of the terms of trade in response to a positive productivity shock. Backus, Kehoe and Kydland (1994) fails to tackle this challenge, i.e., the terms of trade depreciates in their standard real business cycle model. This is because the relative price of goods produced domestically decreases since there is an increase in supply of goods. However, the model presented in Section 3 is able to account for the appreciation of the terms of trade as shown in Table 7.

[12] When I conduct the estimation, I set following minimum boundaries for the parameters to facilitate the estimation. Minimum boundaries for $\Theta = \{\theta, \eta, \gamma, \omega\}$ are $\{1, 0.00001, 0.00001, 1\}$.

Table 1: Estimated parameters

Parameter	Estimated value	Description
θ	21.08	Shape parameter of Pareto distribution
η	0.003	Index of the pattern of substitution between varieties
γ	0.11	Degree of product differentiation
ω	1.65	Intensity of the preference for differentiated products

Table 2: Average responses of the terms of trade (TOT) in data and model

Periods	TOT response from data VAR	TOT response from the model
4	-0.77	-0.40
8	-0.63	-0.33
12	-0.38	-0.29
16	-0.19	-0.26

8 Conclusion

In this paper, I revisited the problem of the anomaly of terms of trade dynamics. Using non-homothetic preference a lá Melitz and Ottaviano (2008), I explained the dynamics of terms of trade in response to a positive aggregate productivity shock. Using a model with endogenous markup and heterogeneous firm-specific productivities, the appreciation in the terms of trade can be generated even under the complete asset market assumption.

Unlike previous studies, I explained the dynamics of the terms of trade through a new channel, which is the channel of relative cutoff firm-specific productivity that determines the optimal export decisions of firms. This resolution does not resort to any strong assumptions regarding the labor market, home bias, elasticity of substitution between goods and the persistence of productivity that previous studies have imposed on their models. Depending on the asset market structure, two competing effects, i.e., the income effect and the markup effect, have different implications for the terms of trade dynamics.

Under the assumption of financial autarky, the income effect is bigger than the markup effect and the terms of trade depreciates in response to a positive aggregate productivity shock. However, if we allow for the trade of state-contingent or state non-contingent bonds, the income effect is mitigated and the markup effect appreciates the terms of trade, which is in line with the empirical findings in previous literature.

This paper opens up a new research avenue for understanding the relationship between the asset market integration and the terms of trade. The theoretical analyses conducted in this paper suggest that the terms of trade movement varies across different stages of asset market integration. Another possible future work will involve understanding international co-movements of macroeconomic variables. The model I use in this paper is rich enough to understand the moments of consumption and production. In addition, analyzing optimal monetary policy using this type of model will be a promising avenue for future research.

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A Equilibrium conditions in dynamic analysis

In this section, I list the equilibrium conditions in the DSGE model under the financial autarky assumption.

- Average prices

$$\overline{p}_{Dt} = \frac{2\theta + 1}{2(\theta + 1)} \overline{MC}_t z_{Dt}^{-1} \tag{A.1}$$

$$\overline{p}^*_{Dt} = \frac{2\theta + 1}{2(\theta + 1)} \overline{MC}^*_t z_{Dt}^{*-1} \tag{A.2}$$

$$\overline{p}_{Xt} = \frac{2\theta + 1}{2(\theta + 1)} \tau_t \overline{MC}_t z_{Xt}^{-1} \tag{A.3}$$

$$\overline{p}^*_{Xt} = \frac{2\theta + 1}{2(\theta + 1)} \tau^*_t \overline{MC}^*_t z_{Xt}^{*-1} \tag{A.4}$$

$$\overline{p}_t = \frac{1}{N_t} \left(N_{Dt} \overline{p}_{Dt} + N^*_{Xt} \overline{p}^*_{Xt} \right) \tag{A.5}$$

$$\overline{p}^*_t = \frac{1}{N^*_t} \left(N^*_{Dt} \overline{p}^*_{Dt} + N_{Xt} \overline{p}_{Xt} \right) \tag{A.6}$$

- Average markups

$$\overline{\mu}_{Dt} = \frac{1}{2(\theta + 1)} \overline{MC}_t z_{Dt}^{-1} \tag{A.7}$$

$$\overline{\mu}^*_{Dt} = \frac{1}{2(\theta + 1)} \overline{MC}^*_t z_{Dt}^{*-1} \tag{A.8}$$

$$\overline{\mu}_{Xt} = \frac{1}{2(\theta + 1)} \tau_t \overline{MC}_t z_{Xt}^{-1} \tag{A.9}$$

$$\overline{\mu}^*_{Xt} = \frac{1}{2(\theta + 1)} \tau^*_t \overline{MC}^*_t z_{Xt}^{*-1} \tag{A.10}$$

- Expected profit

$$\pi_{Dt} = \frac{z_{min}^{\theta} \overline{MC}_t^2 z_{Dt}^{-\theta-2}}{2\gamma(\theta + 1)(\theta + 2)\lambda_t} \tag{A.11}$$

$$\pi^*_{Dt} = \frac{z^{\theta}_{min}\overline{MC}^{*2}_t z^{*-\theta-2}_{Dt}}{2\gamma(\theta+1)(\theta+2)\lambda^*_t} \tag{A.12}$$

$$\pi_{Xt} = \frac{z^{\theta}_{min}\tau^2_t\overline{MC}^{2}_t z^{-\theta-2}_{Xt}}{2\gamma(\theta+1)(\theta+2)\lambda^*_t} \tag{A.13}$$

$$\pi^*_{Xt} = \frac{z^{\theta}_{min}\tau^{*2}_t\overline{MC}^{*2}_t z^{*-\theta-2}_{Xt}}{2\gamma(\theta+1)(\theta+2)\lambda_t} \tag{A.14}$$

$$\pi_t = \pi_{Dt} + \pi_{Xt} \tag{A.15}$$

$$\pi^*_t = \pi^*_{Dt} + \pi^*_{Xt} \tag{A.16}$$

- Cutoff productivity

$$\frac{\omega\gamma\lambda_t + \eta N_t\overline{p}_t}{\gamma + \eta N_t} = \overline{MC}_t z^{-1}_{Dt} \tag{A.17}$$

$$\frac{\omega\gamma\lambda^*_t + \eta N^*_t\overline{p}^*_t}{\gamma + \eta N^*_t} = \overline{MC}^*_t z^{*-1}_{Dt} \tag{A.18}$$

$$\frac{\omega\gamma\lambda_t + \eta N_t\overline{p}_t}{\gamma + \eta N_t} = \tau^*_t\overline{MC}^*_t z^{*-1}_{Xt} \tag{A.19}$$

$$\frac{\omega\gamma\lambda^*_t + \eta N^*_t\overline{p}^*_t}{\gamma + \eta N^*_t} = \tau_t\overline{MC}_t z^{-1}_{Xt} \tag{A.20}$$

- Number of firms

$$N_t = N_{Dt} + N^*_{Xt} \tag{A.21}$$

$$N^*_t = N^*_{Dt} + N_{Xt} \tag{A.22}$$

- Factor prices

$$\overline{MC}_t = \frac{W_t}{Z_t} \tag{A.23}$$

$$\overline{MC}^*_t = \frac{W^*_t}{Z^*_t} \tag{A.24}$$

- Free entry

$$\pi_t + v_t = \overline{MC}_t f_{Et} \tag{A.25}$$

$$\pi_t^* + v_t^* = \overline{MC}_t^* f_{Et}^* \tag{A.26}$$

- N_{Dt}, N_{Dt}^*, N_{Xt} and N_{Xt}^*

$$N_{Dt} = N_{pt} \left(\frac{z_{min}}{z_{Dt}} \right)^{\theta} \tag{A.27}$$

$$N_{Dt}^* = N_{pt}^* \left(\frac{z_{min}}{z_{Dt}^*} \right)^{\theta} \tag{A.28}$$

$$N_{Xt} = N_{pt} \left(\frac{z_{min}}{z_{Xt}} \right)^{\theta} \tag{A.29}$$

$$N_{Xt}^* = N_{pt}^* \left(\frac{z_{min}}{z_{Xt}^*} \right)^{\theta} \tag{A.30}$$

- Evolution of total pool of firms

$$N_{pt} = (1 - \delta) N_{pt-1} + N_{Et} \tag{A.31}$$

$$N_{pt}^* = (1 - \delta) N_{pt-1}^* + N_{Et}^* \tag{A.32}$$

- Optimality conditions for household's consumption and hours worked

$$U_C(C_t, 1 - H_t) = P_t^c \mu_t \tag{A.33}$$

$$U_{C^*}(C_t^*, 1 - H_t^*) = P_t^{*c} \mu_t^* \tag{A.34}$$

$$U_H(C_t, 1 - H_t) + \mu_t W_t = 0 \tag{A.35}$$

$$U_{H^*}(C_t^*, 1 - H_t^*) + \mu_t^* = 0 \tag{A.36}$$

- FOCs for shares

$$\beta \mu_{t+1} (1 - \delta)(\pi_{t+1} + v_{t+1}) = \mu_t v_t \tag{A.37}$$

$$\beta \mu_{t+1}^* (1 - \delta)(\pi_{t+1}^* + v_{t+1}^*) = \mu_t^* v_t^* \tag{A.38}$$

- Aggregate accounting

$$P_t^c C_t + N_{pt} v_t = W_t H_t + N_{pt-1}(1-\delta)(\pi_t + v_t) \tag{A.39}$$

$$P_t^{*c} C_t^* + N_{pt}^* v_t^* = H_t^* + N_{pt-1}^*(1-\delta)(\pi_t^* + v_t^*) \tag{A.40}$$

- Balanced trade assumption

$$\frac{N_{Xt}\tau_t^2 \overline{MC}_t^2 z_{Xt}^{-2}}{\lambda_t^*} = \frac{N_{Xt}^* \tau_t^{*2} \overline{MC}_t^{*2} z_{Xt}^{*-2}}{\lambda_t} \tag{A.41}$$

- Consumer price index

$$P_t^c C_t = \frac{\overline{MC}_t^2 N_t z_{Dt}^{-2}}{2\gamma(\theta+2)\lambda_t} \tag{A.42}$$

$$P_t^{*c} C_t^* = \frac{\overline{MC}_t^{*2} N_t^* z_{Dt}^{*-2}}{2\gamma(\theta+2)\lambda_t^*} \tag{A.43}$$

- Consumption index

$$C_t = \frac{\omega N_t \overline{MC}_t z_{Dt}^{-1}}{2\gamma(\theta+1)\lambda_t} - \frac{N_t \overline{MC}_t^2 z_{Dt}^{-2}}{4\gamma(\theta+1)(\theta+2)\lambda_t^2} - \frac{\eta}{2}\left(\frac{N_t \overline{MC}_t z_{Dt}^{-1}}{2\gamma(\theta+1)\lambda_t}\right)^2 \tag{A.44}$$

$$C_t^* = \frac{\omega N_t^* \overline{MC}_t^* z_{Dt}^{*-1}}{2\gamma(\theta+1)\lambda_t^*} - \frac{N_t^* \overline{MC}_t^{*2} z_{Dt}^{*-2}}{4\gamma(\theta+1)(\theta+2)\lambda_t^{*2}} - \frac{\eta}{2}\left(\frac{N_t^* \overline{*}_t z_{Dt}^{*-1}}{2\gamma(\theta+1)\lambda_t^*}\right)^2 \tag{A.45}$$

B Steady states

In this section, I calculate the steady state values of the variables. I denote steady state values using variables without time subscripts. I assume that the variables of Home and Foreign economy are symmetric in the steady state. I assume $Z = Z^* = 1$. Since I use the foreign wage as numeraire, I assume $W = W^* = 1$. I assume the steady state value of hours worked as $H = H^* = 0.2$.

From (A.25) and (A.23), I obtain:

$$\pi + v = \overline{MC} f_E = \frac{W}{Z} f_E = f_E \tag{B.1}$$

At the steady state, (A.37) becomes:

$$\beta(1-\delta)(\pi + v) = v \tag{B.2}$$

Using (B.1) into (B.2), I obtain:

$$\pi = \{1 - \beta(1-\delta)\} f_E. \tag{B.3}$$

Therefore, from (B.1) and (B.3),

$$v = \beta(1-\delta) f_E. \tag{B.4}$$

Using (A.11), (A.13) and (A.15),

$$\begin{aligned} \pi &= \pi_D + \pi_X \\ &= \frac{z_{min}^{\theta} \overline{MC}^2 z_D^{-\theta-2}}{2\gamma(\theta+1)(\theta+2)\lambda} + \frac{z_{min}^{\theta} \tau^2 \overline{MC}^2 z_X^{-\theta-2}}{2\gamma(\theta+1)(\theta+2)} \end{aligned} \tag{B.5}$$

(A.17) and (A.19) imply

$$\overline{MC} z_D^{-1} = \tau^* \overline{MC}^* z_X^{*-1} = \tau \overline{MC} z_X^{-1}.$$

Therefore,

$$z_D^{-1} = \tau z_X^{-1}. \tag{B.6}$$

Substituting (B.6) into (B.5) and using $\overline{MC} = \frac{W}{Z} = 1$, I obtain

$$\lambda = \frac{\Psi_1}{\pi} z_D^{-\theta-2} \tag{B.7}$$

where $\Psi_1 \equiv \frac{z_{min}^{\theta}(1+\tau^{-\theta})}{2\gamma(\theta+1)(\theta+2)}$ and π is given in (B.3).

(A.1), (A.3), (A.5), (A.21) and (B.6) imply that

$$\overline{p} = \frac{2\theta+1}{2(\theta+1)} z_D^{-1} \tag{B.8}$$

and (A.17) implies

$$\frac{\omega\gamma\lambda + \eta N \overline{p}}{\gamma + \eta N} = \overline{MC} z_D^{-1}. \tag{B.9}$$

Substituting (B.7) and (B.8) into (B.9), I obtain N as a function of z_D as follows:

$$N = \frac{2(\theta+1)\omega\gamma\Psi_1}{\eta\pi} z_D^{-\theta-1} - \frac{2(\theta+1)\gamma}{\eta}. \tag{B.10}$$

(A.21), (A.27) and (A.30) imply:

$$\begin{aligned} N &= N_D + N_X^* \\ &= N_p z_{min}^{\theta} z_D^{-\theta} + N_p z_{min}^{\theta} z_X^{-\theta} \\ &= N_p z_{min}^{\theta} (1+\tau^{-\theta}) z_D^{-\theta}. \end{aligned} \tag{B.11}$$

The third equality above is derived using (B.6). From (B.10) and (B.11), I obtain N_p as a function of z_D:

$$N_p = \frac{2(\theta+1)\omega\gamma\Psi_1}{\eta\pi z_{min}^{\theta}(1+\tau^{-\theta})} z_D^{-1} - \frac{2(\theta+1)\gamma}{\eta z_{min}^{\theta}(1+\tau^{-\theta})} z_D^{\theta}. \tag{B.12}$$

Using (B.7), (A.42) implies that:

$$\begin{aligned} P^c C &= \frac{\overline{MC}^2 N z_D^{-2}}{2\gamma(\theta+2)\lambda} \\ &= \frac{\pi}{2\gamma(\theta+2)\Psi_1} z_D^{\theta} N \\ &= \frac{\omega(\theta+1)}{\eta(\theta+2)} z_D^{-1} - \frac{(\theta+1)\pi}{\eta(\theta+2)\Psi_1} z_D^{\theta}. \end{aligned} \tag{B.13}$$

The third equality above is derived using (B.10).

From (A.39),

$$\begin{aligned} P^c C &= WH + N_p(1-\delta)(\pi+v) - N_p v \\ &= H + \{(1-\delta)(\pi+v) - v\} N_p. \end{aligned} \tag{B.14}$$

Substituting (B.12) and (B.13) into (B.14), I obtain the equation with z_D:

$$\Psi_2 z_D^{-1} - \Psi_3 z_D^{\theta} = H + \{(1-\delta)(\pi+v) - v\} \left(\Psi_4 z_D^{-1} - \Psi_5 z_D^{\theta}\right), \tag{B.15}$$

where

$$\Psi_2 \equiv \frac{\omega(\theta+1)}{\eta(\theta+2)}, \quad \Psi_3 \equiv \frac{(\theta+1)\pi}{\eta(\theta+2)\Psi_1}, \quad \Psi_4 \equiv \frac{2(\theta+1)\omega\gamma\Psi_1}{\eta\pi z_{min}^{\theta}(1+\tau^{-\theta})}, \quad \Psi_5 = \frac{2(\theta+1)\gamma}{\eta z_{min}^{\theta}(1+\tau^{-\theta})}.$$

Solving (B.15), I obtain the steady state value of z_D. The steady state values of all other variables can be derived using this value.