A Geographic Model with Capital Flows

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Abstract

We develop a dynamic trade model with spatially distinct capital markets in terms of bilateral movement cost. The model incorporates both intertemporal and intratemporal capital mobility, along with goods and labor mobility, to capture the role of friction in determining the equilibrium allocation. We show that the changes of local capital mobility friction would be smoothed by global asset porfolio decision, thus may impose relatively violent impacts on capital flows but rather insignificant ones on trade. We calibrate the model with OECD and BRICS countries to explain the capital and trade pattern change due to 2008 financial crisis. Also simulation results suggest that migration friction has the largest welfare effect and a country would experience a U-shaped welfare during its opening up in capital market from highly autarky to completely free.

JEL Classification Codes: E5

Keywords: Geographic Model, Bilateral Capital Flow, Dynamics

1 Introduction

The research of international trade has advanced in the last decade in dealing with the interaction between trade barriers and factor misallocation. As a result, we have general equilibrium workhorse models based on Eaton and Kortum (2002) to quantitatively assess the impacts of friction reduction in terms of both goods and labor mobility on welfare and the how these changes progagate spatially through input-output linkage. Capital market, viewed as one of the most crucial tools of economy, has also gained attention to try joining the framework, which should amplify the intertemporal smoothing channel.

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However, existing literature mostly consider the capital as nontradable aggregates of tradable intermediate goods, making it hard to identify capital related friction from trade friction. So far we are lack of a benchmark in discussing capital movement friction, especially when thinking of 2008 financial crisis actually leading to a direct capital market change. We argue that the primary difference between capital and goods movement is that investors all seek the opportunity of highest return accruing surplus to supply side while final good producers source for lowest price intermediate attaining surplus all on demand side.

Data Pattern: FDI

We first plot as Figure 1 the FDI outflow shares versus FDI inflow shares for OECD countries plus BRICS countries, namely Brazil, Russian Federation, India, China and South Africa, from 2004 to 2014. Here FDI shares are calculated over GDP. Color labels the level of GDP per capita, warm spectrum like orange and yellow corresponding to high GDP per capita while cold spectrum like blue corresponding to low GDP per capita.

FIGURE 1 INSERTED HERE

Observation 1: After 2008, overall FDI inflow and outflow shares both shrink.

Observation 2: Before 2008, countries with higher GDP per capita show higher FDI outflows over inflow relative to those with lower GDP per capita. But after 2008, those two groups approach.

Two main factors come into mind when explaining capital flow share change, friction and interest rate. Increase in capital movement friction usually tunes down both inflows and outflows. By saying capital movement friction, we mean not only the loss incurred when capital physically moves, but all the disadvantages preventing from totally free capital move including the institutional constraints, incomplete investing environment, etc.. And higher interest rate tends to attract more capital inflow while prevents local capital from outflowing. A natural thought for these two observations is that after 2008 financial crisis, there is a raise in capital movement friction and a decline in the relative interest rate of low GDP per capita countries over those with high GDP per capita. To further sketch the latter reason, we then plot the FDI inflow share and FDI outflow share versus long term interest rate separately in Figure 2 and Figure 3. Long term interest rate is the daily average of ten-year treasury bills interest rate on trading market, taken from IMF.

FIGURE 2 INSERTED HERE

FIGURE 3 INSERTED HERE

Observation 3: Low GDP per capita countries have higher interest rate, which however rarely plays a role on FDI inflow side.

Observation 4: On FDI outflow side, there is a negative correlation before 2008, which seems to disappear after 2008

In fact, we show that indeed there are interest premia in low GDP per capita countries, which is consistent with common sense that low income countries are relatively lack of capital. However, on the inflow side we cannot clearly see positive correlation between FDI inflow share and long term interest rate. Actually, similar sizes of FDI inflow share show up for all countries regardless of interest rate. But on the outflow side, a negative correlation, as predicted with interest rate driven capital movement, is displayed before 2008. Especially the elasticities of FDI outflow share with respect to interest rate express in a much greater magnitude for countries with higher GDP per capita. While after 2008 the negative correlation collapses dramatically as well on outflow side, mainly attributed to the reduction for high income countries. That may be explained by the intuition that friction reduces the sensitivity. Thus we may consider the FDI flow pattern as the following possible hypotheses:

Hypothesis 1: After 2008, capital movement friction increases.

Hypothesis 2: Capital movement friction works more as destination effect rather than origin effect.

Hypothesis 3: The relative competitiveness of high income countries reduces sharply

Motivation: Trade

We plot the export share change versus import share change in Figure 4 to see the change of trade patterns, where export share change is defined as the difference between adjacent two years.

FIGURE 4 INSERTED HERE

Observation 5: Overall trade shares are expanding, except for the deep falling down of 2009. But from 2013 on, trade shares tend to decrease.

Observation 6: There is a very clear positive correlation between import share change and export share change

The comovement of import share and export share indicates that trade friction is a very strong factor in explaining the trade pattern from 2004 to 2015. The 2008 financial crisis greatly reduced trade in 2009, followed by an intermediate bouncing back at 2010 and 2011. But after 2013, goods market showed up a declining trend.

Hypothesis 4: Trade friction plays a dominant role from 2004 to 2015

Hypothesis 5: Generally speaking, goods market keeps opening up until 2013.

Related Literature

The topic of geographic economics has developed rapidly into a huge literature. Geographic models are taken widely used in discussing global linkage and spatial misallocation. We can roughly category previous works into four groups by the objects they focus on.

The first branch still focus on goods market as extension of Eaton and Kortum (2002) benchmark model. Alvarez and Lucas (2007) added in a downstream non-tradable sector to approach a general equilibrium model. Caliendo and Parro (2014), Caliendo, Parro, Rossi-Hansberg and Sarte (2016) introduced multi-sector to further fit the model to input-output linkage data. Morrow and Trefler (2017) combined multiple-factor input to revisit the validity of HOV theorem. Besides, Ramondo and Rodriguez-Clare (2013) and Wang (2017) viewed multi-national firm production as another possible source of comparative advantage which amplifies the trade gain.

The second concerned about labor mobility. After Redding (2016) imposed a Frechet distribution on residential welfare shock to realize bilateral migration, Tombe and Zhu (2015), Ahlfeldt, Redding, Sturm and Wolf (2016) as well as Allen, Arkolakis and Li (2015) adopted a static model with labor migration or commuting friction to study the impacts of friction on labor misallocation. Allen and Arkolakis (2014) extended spatial distribution of economic activity to a continuous surface, providing conditions for the existence, uniqueness, and stability of a spatial economic equilibrium and deriving a simple set of equations which govern the relationship between economic activity and the geography of the surface. Also Artuc, Chaudhuri and McLaren (2010) applied Gumbel distribution labor mobility shock to generate dynamic migration and estimated the elasticities and friction of labor movement. This setup was followed by Caliendo, Dvorkin and Parro (2015) and Desmet, Nay and Rossi-Hansberg (2016) to research on the interaction of labor market and goods market. The general result is that labor mobility friction cause very large welfare loss.

The third considered technology itself a factor that may influence economic pattern via spatial spillover. Desmet and Rossi-Hansberg (2009, 2014) gave out the technology spillover function as available exponentially depreciated. They were then able to compare the evolution of US manufacturing and service sector along with the comovement of land rent across the country. Desmet, Nagy and Rossi-Hansberg (2016, 2017) then incorporated technology diffusion into labor and goods mobility, to characterize the balanced growth path and estimate the welfare improve after reducing migration cost.

The last branch also took capital into accounts when talking about geographic features. Reyes-Heroles (2015) extended the setup of Caliendo and Parro (2014) with free international bond borrowing, contributing the rise in trade imbalance scale to reduction of trade barriers for now countries are easier to conduct intertemporal smoothing. But Reyes-Heroles treated capital as exogenously given, canceling out the intertemporal saving decision. Eaton, Kortum, Neiman and Romalis (2016) solved a social central planner problem of optimal capital accumulation within countries to reexamine the driven force during recover from financial crisis. Alveraz (2017) brought decentralized intertemporal saving decision for symmetric countries but also without capital mobility. Ravikumar, Santacreu and Sposi (2018) further carried out Alveraz (2017) for asymmetric scenario.

What We Do

Previous literatures mostly took capital similar to final goods, a buyer-side market, in the sense that it is CES aggregated by sourcing the cheapest tradable intermediate goods. In this paper, we try to treat intratemporal capital decision as a seller-side market, as capital holders persue the opportunity of acquiring highest return. Thus the connection between interest rate and capital mobility can be visited and model is taken closer to reality.

So we are now trying to establish a decentralized dynamic geographic model with both capital intratemporal and intertemporal decision along with goods and labor mobility to quantitatively measure the friction change on three markets after 2008 financial crisis and counterfactually analysis how friction reduction would impact welfare. The main innovations are that we generate bilateral capital flows and the existence of capital movement friction makes the real interest rate across all countries not necessarily in parity even at steady state, which offers extra fitness of model to real data. The model now unifies all goods and factors mobility, which allows us to seriously discuss issues regarding capital movement friction and the interactions between markets quantitatively. The major difficulties lie in two ways. The first is heterogeneous captial holding makes value function infinite dimensions in terms of state variable, thus impossible to calculate. And the second is that, when labor mobility and saving decision occur simultaneously, the final goods across all the countries are heterogeneous. Then disparity across countries over time makes it hard to define investment.

We solve the model both for steady states and dynamic path, and calibrate the frictions with three bilateral flow data on goods, capital and labor mobility. The results suggest that during 2004 to 2013, geographic costs in trade gradually decrease, except for a jump in 2009. But the decreasing trend is disappearing. Relative export competitiveness for main developing countries keeps rising while developed countries actually impose more importing barriers. Also we conduct simulation and counterfactual analysis. It seems that a country's welfare exhibits a decreasing first then increasing U-shape on his way of removing capital inflow restrictions. But it will benefit the origin countries where capital flows from and hurt the rest of the world. Thus the best equilibrium strategy for a country would be either retreating to strictly capital control or progressing to free capital movement. In addition, capital movement friction change of country j targeting at origin country i would greately influence country i's local deposit rate and country j's loan rate, therefore cause violent fluctuation on country i's capital outflow share and country j's capital inflowshare, without resulting to significant influence on trade pattern. The intuition is that global portfolio decision smoothes the real price all over the world by adjusting local capital flows. The same logic determines a similarly smaller welfare effect of change in capital movement friction and trade barriers compared to labor mobility friction.

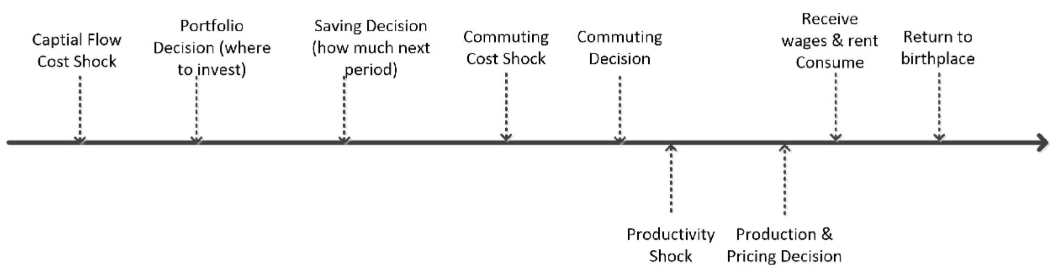
The rest of the paper is organized as follows. Section 2 describes the model part and the algorithm to solve. Section 3 states the data we use and calibration results.

Section 4 is the simulation report. Section 5 concludes. Section 6 gives out the future extension. Some proofs and derivations are put into Appendix.

2 The model

Consider an economy consisting of N countries and a number $\bar{l}_i$ of constant population is endowed to region i. At the beginning of each period t, individuals in region i hold capital amount $a_{i,t}$. To simplify the analysis, we only focus on the symmetric equilibrium, assuming that capital is equally distributed within the specific region. Later we will show that under rational expectation and homogeneous initial capital holding within region, individual intertemporal decisions indeed lead to symmetric equilibrium result.

During the period t, timeline is illustrated as below:



First comes the idiosyncratic capital return shock, upon which individuals in each region would make portfolio decisions as choosing the place with highest capital return to allocate asset for every dollar. The randomness of capital return enables us to generate the outcome characterizing both interest rate dispersion and bilateral capital flows. Saving decisions immediately follow behind the portfolio decisions, defined as the investment amount added to contemporary asset in order to form the next period asset. Then the commuting welfare shocks come to realization, and individuals work and consume where it brings the highest contemporary utility. Finally intermediate firms receive idiosyncratic productivity shocks to optimize production and import sourcing decisions are made. At the end period, individuals move back to birthplace waiting for the next period.

Two key assumptions here are worthy of further explanation. Commuting instead of migration simplifies the labor movement decision in the sense that individual only needs to focus on contemporary utility, which significantly reduces the complexity. Besides, commuting setup along with the timing of saving decision first saves us from discussing the capital holding distribution evolution over time horizon. Thus here in this paper individuals in a region make homogeneous portfolio and saving decisions but heterogenous commuting and consumption decisions in symmetric equilibrium, as we will discuss more detailedly later.

In this paper we haven't included any source of growth, no matter in exogenous or endogenous form. In a mult-region model, if we incorporate exogenous growth, then the existence of interior steady states requires identical exogenous growth rate across all regions, which will represent exactly the same pattern after detrending as the model without growth. Otherwise, the economy will collapse so that only regions with leading growth rates survive. Endogenous growth demands introduction of technology spillover or diffusion but it is not the focus of this paper, and we are planning to capture the features in our next paper.

2.1 Production

At each location i, there are a continuum of $\nu \in [0,1]$ firms using labor and capital to produce:

$$y_{i,t}^{\nu} = z_{i,t}^{\nu} \left(\frac{\left(\frac{k_{li,t}^{\nu}}{\alpha_i}\right)^{\alpha_i} \left(\frac{k_{fi,t}^{\nu}}{1-\alpha_i}\right)^{1-\alpha_i}}{\beta_i} \right)^{\beta_i} \left(\frac{l_{i,t}^{\nu}}{1-\beta_i} \right)^{1-\beta_i}$$

where $k_{li,t}^{\nu}$ is the capital input that firm ν uses coming from local investors in region i period t, $k_{fi,t}^{\nu}$ is that coming from foreign investors, $l_{i,t}^{\nu}$ is the labor input, and $z_{i,t}^{\nu}$ is a random variable drawn at the beginning of each period following a Frechet distribution independent across regions, firms and time:

$$G_{i,t}(z) = \exp\left\{ -\left(\frac{z}{T_i}\right)^{-\theta} \right\}$$

The distinction between local capital and foreign capital from firm side mainly works as a natural way to avoid multiple equilibria. If there is no categorization on capital type, it may occur that people born in countriess with low capital movement barrier find it optimal to hold zero or even negative asset in equilibrium. Restrictions on non-negative asset holding then will induce multiple possible equilibria conditional on our choice of countries imposing zero asset holding.

After observing the idiosyncratic shocks, firms make decision of all the inputs to maximize profit. An extra return of δ is required to compensate for depreciation where for simplicity we assume identical depreciation rate for both types of capital in all the countries.

$$\Pi_{i,t}^{\nu} = p_{i,t}^{\nu} y_{i,t}^{\nu} - \omega_{i,t} l_{i,t}^{\nu} - (r_{li,t}+\delta) k_{li,t}^{\nu} - (r_{fi,t}+\delta) k_{fi,t}^{\nu}$$

Due to perfectly competition, the price to local market is calculated by cost minimization.

$$p_{i,t}^{\nu}(z) = \frac{(r_{li,t}+\delta)^{\alpha_i\beta_i} (r_{fi,t}+\delta)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i}}{z_{i,t}^{\nu}} \tag{1}$$

2.2 Preferences and Commuting

Each agent f born in country i but working in country j at period t receives utility

$$U_i^f = E_0 \sum_{t=0}^{\infty} \rho^t u\left(c_{i,t}^{j,f}\right)$$

where $c_{i,t}^{j,f}$ is the composite good consumed in period t:

$$c_{i,t}^{j,f} = \left(\int_0^1 q_{j,t}^f(\nu)^{\frac{\sigma-1}{\sigma}} d\nu\right)^{\frac{\sigma}{\sigma-1}}$$

According to CES aggregation, we know that in optimal the real consumption equals nominal consumption divided by aggregated price. And the contemporary utility can be defined as the combination of log form real consumption and friction terms:

$$\begin{aligned} u\left(c_{i,t}^{j,f}\right) &= z_{i,t}^{j,f}\mu_i^j \ln\left(\frac{C_{i,t}^{j,f}}{P_{j,t}}\right) \\ &\equiv z_{i,t}^{j,f}\mu_i^j v_{i,t}^{j,f} \end{aligned} \tag{2}$$

where $v_{i,t}^{j,f} = \ln\left(\frac{C_{i,t}^{j,f}}{P_{j,t}}\right)$ is the direct consumption utility, $\mu_i^j \in [0,1]$ measures the commuting friction from region i to region j, and the commuting welfare idiosyncratic shock $z_{i,t}^{j,f}$ follows a unit mean Frechet distribution independent across individuals, countries and time as well:

$$\begin{aligned} F(z) &= e^{-(z\widetilde{\gamma}_l)^{-\kappa_l}} \\ \widetilde{\gamma}_l &\equiv \Gamma\left(1-\kappa_l^{-1}\right) \end{aligned}$$

Lemma 1 *Under the assumption of independent unit mean Frechet distribution $z_{i,t}^{j,f}$ and rational expectation, the commuting probability $ml_{i,t}^{j,f}$ of an individual born in country i but working in country j in period t and the ex ante expected contemporary utility $E\left(u\left(c_{i,t}^{j,f}\right)\right)$ can be expressed as:*

$$ml_{i,t}^{j,f} = \frac{\left(\mu_i^j v_{i,t}^{j,f}\right)^{\kappa_l}}{\sum_n \left(\mu_i^n v_{i,t}^{n,f}\right)^{\kappa_l}} \tag{3}$$

$$E\left(u\left(c_{i,t}^{j,f}\right)\right) = \left(\sum_n \left(\mu_i^n v_{i,t}^{n,f}\right)^{\kappa_l}\right)^{\frac{1}{\kappa_l}} \tag{4}$$

Similary with the help of law of large numbers, we interpret the commuting probability also as the fraction of individuals who is born in country i but commutes to country j, which increases with the real consumption in destination country $\nu_{i,t}^{n,f}$ and the reserved fraction of contemporary utility μ_i^j. Generally, no welfare loss is assumed for individuals choosing to work locally so $\mu_i^i = 1$.

2.3 Trade

With the standard iceberg cost assumption τ_i^j denoting the trade barrier from country i to country j, we can derive the probability that location j imports goods from location i is

$$\pi_{i,t}^j = \frac{\left(\tau_i^j \left(r_{li,t} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi,t} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i\right)^{-\theta}}{\Phi_t^j} \tag{5}$$

where

$$\Phi_t^j = \sum_i \left(\tau_i^j \left(r_{li,t} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi,t} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i\right)^{-\theta} \tag{6}$$

And the aggregate price index in country i writes:

$$P_{i,t} = \left[\Gamma\left(\frac{\theta + 1 - \sigma}{\theta}\right)\right]^{\frac{1}{1-\sigma}} \left(\Phi_t^i\right)^{-\frac{1}{\theta}} \tag{7}$$

Here we also introduce the definition of numerair goods in period t as the aggregate price under free trade:

$$1 = \left[\Gamma\left(\frac{\theta + 1 - \sigma}{\theta}\right)\right]^{\frac{1}{1-\sigma}} \left(\sum_i \left(\left(r_{li,t} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi,t} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i\right)^{-\theta}\right)^{-\frac{1}{\theta}} \tag{8}$$

In closed economy models, the only final good naturally acts as a numerair, such as benchmark Solow model. In static real models, any pick up of numerair goods would bring no difference due to the coindence of nominal and real terms under circumstances of no nominal rigidity, such as benchmark EK model. Even in dynamic models without durable goods to make intetemporal decision, the choice of numerair does not matter since economic activities can be considered as a pseudo dynamic process composed of intratemporal static models over time horizon. But in a dynamic multi-region model with saving decisions, we actually need a plausible numerair to deal with the disparity both among regions and between periods. The setup is borrowed from Alvarez (2017), and it means that under free trade all the countries have access to the same unit price final goods for consumption and investment next period, in terms of asset this period. With trade friction, the final goods price may vary across countries, all weakly greater than one. But individuals are still willing to allocate all of their assets into portfolio because excess capital return fully offset the appreciation.

2.4 Portfolio decision

We assume in country i there are two types of competitive financial intermediaries collecting local and foreign capital respectively and renting to local firms. Firms in country i borrow local capital $k_{li,t}^{\nu}$ from intermediaries collecting local capital to produce and pay a risk free return $\left(1 + r_{li,t}\right) k_{li,t}^{\nu}$, among which the fraction of $1 - \delta$ is the undepreciated capital directly returning back and $r_{li,t} + \delta$ the actual capital rent. Similarly, foreign capital $k^{\nu}_{fi,t}$ is also borrowed from intermediaries collecting foreign capital and a risk free return $(1 + r_{fi,t})\, k^{\nu}_{fi,t}$ incurs.

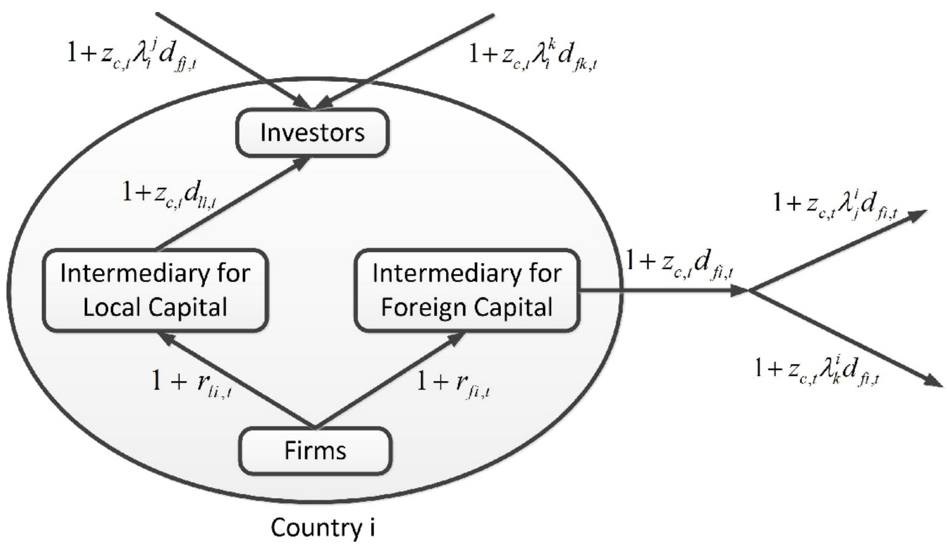
The activities between investors and intermediaries requires more description. Intermediaries collecting local capital only have access to capital from local investors while intermediaries collecting foreign capital receive investments only from foreign countries. The excess return for each dollar paying back to investors is Frechet distributed. Specifically, intermediaries collecting local capital in country i give back $1 + z_{c,t} d_{li,t}$ in total and those collecting foreign capital give back $1 + z_{c,t} d_{fi,t}$ in total, where $d_{li,t}$ and $d_{fi,t}$ are the corresponding excess mean for each type of intermediaries and the random capital return shock $z_{c,t}$ follows a Frechet distribution with unit mean independent across investments, countries and time:

$$
\begin{aligned}
F(z) &= e^{-(z\widetilde{\gamma}_c)^{-\kappa_c}} \\
\widetilde{\gamma}_c &\equiv \Gamma\left(1 - \kappa_c^{-1}\right)
\end{aligned}
$$

However, friction labeled as $\lambda_i^j \in [0, 1]$ occurs for investors in country i allocating assets in country j. Thus the effective gross capital returns for an individual in country i allocating each one dollar locally and globally write

$$
\begin{aligned}
&1 + z_{c,t} \lambda_i^j d_{fj,t} \\
&1 + z_{c,t} \lambda_i^i d_{li,t}
\end{aligned}
$$

To better illustrate the interactions among investors, intermediaries and firms, a explicative graph is shown as below:



Lemma 2 *Under the assumption of Frechet distributed capital return shock $z_{c,t}$, the optimal portfolio decision for individuals in country i is to allocate a fraction $mr_{i,t}^j$ of*

asset to region j. In this portfolio, mean gross capital returns from investing to all countries equalize, leading to an ex-post return of $\overline{R}_{i,t}$, where:

$$
\begin{aligned}
\overline{R}_{i,t} &= 1 + \left(\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c} \right)^{\frac{1}{\kappa_c}} && (9) \\
mr_{i,t}^j &= \frac{\left(\lambda_i^j d_{fj,t}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c}}, \ \textit{for } j \neq i && (10) \\
mr_{i,t}^i &= \frac{\left(\lambda_i^i d_{li,t}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c}} && (11)
\end{aligned}
$$

We can see that either less friction or higher ex-ante mean return in destination would inhance the portfolio share. Though the loan interest rates r_i and deposit interest rates d_i across countries are not necessarily the same, investors would himself equalize capital return by taking globally portfolio decisions. Here d_i and r_i differ in general case, because investors always find the highest possible return opportunity for each dollar. The existence of outside option distinguishes the ex-post realized returns from ex-ante mean ones. Perfect competition makes zero profit for the intermediaries in country i thus establishes the connection between the loan rates r and deposit rates d:

$$
\begin{aligned}
r_{fi,t} \sum_{n \neq i} mr_{n,t}^i a_{n,t} \bar{l}_n &= \sum_{n \neq i} mr_{n,t}^i a_{n,t} \bar{l}_n \frac{\overline{R}_{n,t} - 1}{\lambda_n^i} && (12) \\
r_{li,t} &= \frac{\overline{R}_{i,t} - 1}{\lambda_i^i} && (13)
\end{aligned}
$$

Generally speaking, intermediaries would charge a higher lending rate from firms to compensate the gap between ex-post realized return and ex-ante mean return generated by the investors' outside options. If we collapse the economy to only one country, then deposit rate d and loan rate r would show equalization. Also the loss in capital movement is

$$
L_{i,t} = \sum_{n} mr_{n,t}^i a_{n,t} \bar{l}_n \left(\overline{R}_{n,t} - 1\right) \frac{1 - \lambda_n^i}{\lambda_n^i}
$$

2.5 Individual optimization

As we just briefly mentioned at the beginning of this section, Immediately after the portfolio decision of where to allocate incumbent asset, an individual choose the amount of investment he'd like to bring into next period. Since intertemporal decisions are made ahead of realization of idiosyncratic commuting shocks and all the shocks are not time correlated, individuals within a country would invest the same amount given homogeneous capital holding at the beginning of period. So we are able to write the intertemporal optimization problem with omission of individual superscript f.

Also, we assume both consumption and investment are in terms of real goods. Therefore, for an individual working in country j, the real consumption and real investment should be normalized with the aggregate price where he works. And the asset available for global portfolio decision next period combines the undepreciated capital this period and the new investment. It is thus worthy of notice that in this setup, even in steady state the bilateral capital flows are not necessarily zero, for each period new investments are required to make up for depreciation in order to maintain constant level of capital.

$$\max_{\{a_{i,t+1}\}} \sum_{t=0}^{\infty} \rho^t \left(\sum_n \left[\mu_i^n \ln \left(\frac{C_{i,t}^n}{P_{n,t}} \right) \right]^{\kappa_l} \right)^{\frac{1}{\kappa_l}}$$

$$s.t.\ P_{n,t} \left(I_{i,t} + c_{i,t}^n \right) = \left(\overline{R}_{i,t} - 1 + \delta \right) a_{i,t} + \omega_{n,t} \tag{14}$$

$$a_{i,t+1} = (1 - \delta) a_{i,t} + I_{i,t} \tag{15}$$

And the first order condition writes:

$$\left(\sum_n \left(\mu_i^n v_{i,t}^n \right)^{\kappa_l} \right)^{\frac{1}{\kappa_l} - 1} \sum_n \frac{\left(\mu_i^n v_{i,t}^n \right)^{\kappa_l - 1} \mu_i^n}{c_{i,t}^n} \tag{16}$$

$$= \rho \left(\sum_n \left(\mu_i^n v_{i,t+1}^n \right)^{\kappa_l} \right)^{\frac{1}{\kappa_l} - 1} \sum_n \frac{\left(\mu_i^n v_{i,t+1}^n \right)^{\kappa_l - 1} \mu_i^n \left[\overline{R}_{i,t+1} + (P_{n,t+1} - 1)(1 - \delta) \right]}{c_{i,t}^n P_{n,t+1}}$$

2.6 Market clearing

Now the production of country i should coincide with the total expenditure on country i goods from all over the world, after deduction of capital movement loss. And expenditure of a country includes both final consumption and investment. A fixed share of firms revenue will be accrued as factor income according to Cobb-Douglas production function thus market clearing for factors implies the clearing of factor revenue as well:

$$\frac{\omega_{i,t} \sum_n m l_{n,t}^i \bar{l}_n}{1 - \beta_i} = \sum_j \pi_{i,t}^j \sum_n m l_{n,t}^j \bar{l}_n P_{j,t} \left(c_{n,t}^j + I_{n,t} \right) + L_i \tag{17}$$

$$(r_{fi,t} + \delta) \sum_{n \neq i} m r_{n,t}^i a_{n,t} \bar{l}_n = \frac{(1 - \alpha_i) \beta_i \omega_{i,t}}{1 - \beta_i} \sum_n m l_{n,t}^i \bar{l}_n \tag{18}$$

$$(r_{li,t} + \delta) m r_{i,t}^i a_{i,t} \bar{l}_{i,t} = \frac{\alpha_i \beta_i \omega_{i,t}}{1 - \beta_i} \sum_n m l_{n,t}^i \bar{l}_n \tag{19}$$

2.7 Equilibrium

Now we can define the dynamic competitive equilibrium as follows:

Definition: Given a set of countries i, and their initial capital holding and population $\left(a_{i,0}, \bar{l}_i \right)$, as well as their bilateral trade, commuting and capital flow cost

$\left(\tau_i^j, \mu_i^j, \lambda_i^j\right)$, a competitive equilibrium is a set of functions $\left\{a_{i,t}, \nu_{i,t}^j, \pi_{i,t}^j, mr_{i,t}^j, ml_{i,t}^j\right\}_{t=1}^{\infty}$ and $\left\{\omega_{i,t}, P_{i,t}, d_{li,t}, d_{fi,t}, r_{li,t}, r_{fi,t}, \overline{R}_{i,t}\right\}_{t=1}^{\infty}$ such that:

i) Given $\{\omega_{i,t}, r_{li,t}, r_{fi,t}\}$, firms maximize their profits and zero profit due to perfect competition (1).

ii) Given trade cost τ_i^j and unit price for intermediate goods determined by (1), import share $\pi_{i,t}^j$ and aggregated price $P_{i,t}$ are decided by (6)(5)(7)

iii) Given deposit rate $\{d_{li,t}, d_{fi,t}\}$ and capital flow cost λ_i^j, capital flow $mr_{i,t}^j$ and aggregated capital return $\overline{R}_{i,t}$ are decided by (10)(11)(9). Zero profits for intermediaries (13)(12) clear the one-to-one relationship between $\{d_{li,t}, d_{fi,t}\}$ and $\{r_{li,t}, r_{fi,t}\}$.

iv) Given commuting cost μ_i^j, expected contemporary utility on $\nu_{i,t}^j$ and commuting flow $ml_{i,t}^j$ are decided by (4)(3)

v) Labor, capital and goods market clear given by (17)(19)(18) along with numeraire definition (8) to pin down prices $\{\omega_{i,t}, d_{li,t}, d_{fi,t}\}$.

vi) Providing aggregated variables, individuals maximize their lifetime utility (16) by optimizing on $\{a_{i,t}\}$ subjected to budget constraints (14) and asset evolution (15).

2.8 Solution Algorithm

2.8.1 Steady State

First we solve steady state allocation with all real terms unchanged. To obtain the solution, we need to take a two-step algorithm described as follows.

- Step 1: For an arbitrary guess of steady state asset holding $\{a_i\}$ to solve for all intratemporal variables.

  Given capital related factor prices $\{d_{fi}, d_{li}\}$, we can derive capital related variables $\left\{\overline{R}_i, mr_i^j, r_{fi}, r_{li}\right\}$ along with capital movement loss L_i:

$$\overline{R}_i = \left[1 + \left(\sum_{n \neq i} \left(\lambda_i^n d_{fn}\right)^{\kappa_c} + \left(\lambda_i^i d_{li}\right)^{\kappa_c}\right)^{\frac{1}{\kappa_c}}\right]$$

$$mr_i^j = \frac{\left(\lambda_i^j d_{fj}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn}\right)^{\kappa_c} + \left(\lambda_i^i d_{li}\right)^{\kappa_c}}$$

$$mr_i^i = \frac{\left(\lambda_i^i d_{li}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn}\right)^{\kappa_c} + \left(\lambda_i^i d_{li}\right)^{\kappa_c}}$$

$$r_{fi} \sum_{n \neq i} mr_n^i a_n \bar{l}_n = \sum_{n \neq i} mr_n^i a_n \bar{l}_n \frac{\overline{R}_n - 1}{\lambda_n^i}, r_{li} = \frac{\overline{R}_i - 1}{\lambda_i^i}$$

$$L_i = \sum_n mr_n^i a_n \bar{l}_n \left(\overline{R}_n - 1\right) \frac{1 - \lambda_n^i}{\lambda_n^i}$$

Wages $\{\omega_i\}$ add up to solve for aggregate prices and imports:

$$\Phi^j = \sum_i \left(\tau_i^j \left(r_{li} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_i^{1-\beta_i} / T_i\right)^{-\theta}$$

$$\pi_i^j = \frac{\left(\tau_i^j \left(r_{li} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_i^{1-\beta_i} / T_i\right)^{-\theta}}{\Phi^j}$$

$$P_i = \left[\Gamma\left(\frac{\theta + 1 - \sigma}{\theta}\right)\right]^{\frac{1}{1-\sigma}} \left(\Phi^i\right)^{-\frac{1}{\theta}}$$

Individual budget constraints pin down consumptions and commution:

$$P_n c_i^n = \left(\overline{R}_i - 1 + \delta - \delta P_n\right) a_i + \omega_n$$

$$v_i^n = \ln\left(c_i^n\right)$$

$$ml_i^j = \frac{\left(\mu_i^j v_i^j\right)^{\kappa_l}}{\sum_n \left(\mu_i^n v_i^n\right)^{\kappa_l}}$$

Now market clearing completes the system for $3N$ unknown factor prices $\{d_{fi}, d_{li}, \omega_i\}$. Here we should be aware that Walrasian equilibrium for goods market requires one more equation, which determines the numerair of final good defined as the aggregate price in circumstances of free trade:

$$\begin{aligned}
\frac{\omega_i \sum_n m l_n^i \bar{l}_n}{1-\beta_i} &= \sum_j \pi_i^j \sum_n \left[m l_n^j \bar{l}_n P_j \left(c_n^j + \delta a_n \right) \right] + L_i \\
(r_{fi}+\delta) \sum_{n \neq i} m r_n^i a_n \bar{l}_n &= \frac{(1-\alpha_i)\beta_i \omega_i}{1-\beta_i} \sum_n m l_n^i \bar{l}_n \\
(r_{li}+\delta) m r_i^i a_i \bar{l}_i &= \frac{\alpha_i \beta_i \omega_i}{1-\beta_i} \sum_n m l_n^i \bar{l}_n \\
1 &= \left[\Gamma \left(\frac{\theta+1-\sigma}{\theta} \right) \right]^{\frac{1}{1-\sigma}} \left(\sum_i \left((r_{li}+\delta)^{\alpha_i \beta_i} (r_{fi}+\delta)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i \right)^{-\theta} \right)^{-\frac{1}{\theta}}
\end{aligned}$$

- Step 2: Solve for the steady state $\{a_i\}$

  Finally, individual intertemporal optimizations in N regions solve for the equilibrium asset holding $\{a_i\}$:

$$\begin{aligned}
&\left(\frac{1}{\rho} - 1 + \delta \right) \sum_n \frac{(\mu_i^n v_i^n)^{\kappa_l - 1} \mu_i^n}{c_i^n} \\
&= \sum_n \frac{(\mu_i^n v_i^n)^{\kappa_l - 1} \mu_i^n \left[\overline{R}_i - 1 + \delta \right]}{P_n c_i^n}
\end{aligned}$$

Proposition 1 *Steady state capital return* $\overline{R}_i \geq \frac{1}{\rho}$ *and equality holds only if only under free trade*

Two main results are worth discussing more. First, when there's trade friction, individuals require a capital return in premium of the benchmark real interest rate $\frac{1}{\rho}$. That's because trade friction levels up the aggregate final goods price, making investing more costly. The possibility of commuting urges individuals to take final goods prices elsewhere into consideration as well, which amplifies the propagation of trade friction towards capital market.

The second result is rather more interesting in the sense that under free trade, capital returns across all the countries equalize regardless of capital movement cost. Actually the existence of capital movement cost would differentiate the loan rate and deposit rate, but global portfolio allocation allows individuals themselves to smooth and equalize the capital return. Now since final goods in every country are priced one, no extra return is required for investing.

Also the welfare of country i can be defined as the expected lifetime utility, also known as the average lifetime utility in equilibrium:

$$W_i = \frac{\left(\sum_n (\mu_i^n v_i^n)^{\kappa_l} \right)^{\frac{1}{\kappa_l}}}{1-\rho}$$

2.8.2 Dynamics

To solve for the determinant dynamics, rational expectations on aggregate variables are needed. We log-linearize the system around steady state to form a decentralized Euler Equation system:

$$\mathbf{a}_{t+2} = \mathbf{A}\mathbf{a}_{t+1} + \mathbf{B}\mathbf{a}_t$$

where $\mathbf{a}_t \equiv \left(\widehat{a}_{1,t}, \widehat{a}_{2,t}, \ldots, \widehat{a}_{n,t}\right)^T$ is the vector space including the log difference of each country's asset holding from steady state. Then given arbitrary initial condition $\mathbf{a}_0$, the sufficient and necessary condition for a unique convergent path is that the number of countries (degrees of freedom) should equal the number of eigenvalues outside unit circle for the composite matrix

$$\mathbf{M} \equiv \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{I} & \mathbf{0} \end{bmatrix}$$

And the transition path can be calculated by setting the corresponding eigenvectors expanded by initial condition to be zero. Though without rigorous proof, so far we've found the condition holds. The details for log-linearization see the appendix.

3 Quantitative Analysis

In the model, parameters consist of fundamentals like sets of elasticity of substitution, discount factor, depreciation rate and production share, as well as three dimensions of frictions, i.e., commuting frictions, capital movement frictions and trade frictions. For some of the parameters, we borrow from the literature or simply apply calculate without structural estimation and list as follows.

Parameters	Description
$\theta = 6.5$	Elasticity of Trade
$\sigma = 4$	Elasticity of Substitution in Consumption
$\rho = 0.96$	Discount Factor
$\delta = 0.06$	Depreciation Rate
$\kappa_l = 3$	Dispersion of Commuting
$\kappa_c = 2.1$	Dispersion of investing

Regarding the elasticity of trade, there have been abundant researches estimating for international trade. Eaton & Kortum (2002) first estimated $\theta = 8.28$ for OECD manufacturing goods, and Simonovska & Waugh (2011) use cross-country price data to estimate $\theta \approx 4$. With tariff data, Parro (2013) estimated $\theta \in [4.5, 5.2]$ for manufacturing while Caliendo & Parro (2015) estimated sectoral θ ranging from 1 in Auto to 50 in Petroleum. For κ_l, Tombe & Zhu (2015) estimated within-China immigration dispersion to be 2.54 using 2005 Population Survey data. Ahlfeldt et al. (2015) used Berlin bilateral commuting data and real wage dispersion to get an estimation of $\kappa_l = 6.83$. Besides, in setup of Gumbel distribution, Artuc, Chaudhuri & McLaren (2010) calculated inter-state migration dispersion in US at a level between 1.5 and 5.6 after different kinds of bias adjustment, and Caliendo, Dvorkin & Parro (2017) modified ACM's utility from linear to log to acquire another estimation of 5.34 quarterly and 2.02 annually. And we take $\sigma = 4$ as Bernard et al. (2003) estimated with firm-level US manufacturing data. As for discount factor, we set $\rho = 0.96$ to roughly match the yearly interest rate of 4%. $\kappa_c = 2.1$ is to match the facts that US stock market has a sharpe ratio at around 0.4. The depreciation rate $\delta = 0.06$ is taken around the mean of WIOT Socio-Economic Accounts calculation for industry depreciation rate.

The parameters left to be calibrated are bilateral commuting cost μ_i^j, capital movement cost λ_i^j, trade barriers τ_i^j, along with production shares α_i, β_i and technology T_i (if needed).

3.1 Data Description

Due to the availability of data, we choose only WIOT countries with a time horizon from 2003 to 2012. For each calibration part, we will detailedly describe the data we use.

3.2 Production shares

To capture the factor shares α_i and β_i, we first use compensation of employees over GDP ratio to estimate $1 - \beta_i$. And use inward measure FDI income to estimate $\alpha_i \beta_i$.

3.3 Trade barriers

We use UNcomtrade bilateral trade data at AG0 level to calibrate τ_i^j. The calibration method is quite standard following literature.

If denoting X_i^j as the import in data of country j from country i, we can take the ratio between X_i^j and X_j^j to cancel out aggregate terms in denominator. Here domestic share X_j^j is calculated by adding GDP and net import.

$$\frac{X_i^j}{X_j^j} = \left(\frac{\tau_i^j \left(r_{li} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_i^{\beta_i} / T_i}{\left(r_{lj} + \delta\right)^{\alpha_j \beta_j} \left(r_{fj} + \delta\right)^{(1-\alpha_j)\beta_j} \omega_j^{\beta_j} / T_j} \right)^{-\theta}$$

And taking logs results in

$$\ln \left(\frac{X_i^j}{X_j^j} \right) = S_i - S_j - \theta \ln \tau_i^j$$

where $S_i \equiv -\frac{1}{\theta} \ln \left(\left(r_{li} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_i^{\beta_i} / T_i \right)$ characterizes the production cost in country i. Also trade cost τ_i^j can be further decomposed:

$$\ln \tau_i^j = d_k + b_{ij} + imt_j + \varepsilon_{ij}$$

Here d_k is the distance dummy with intervals defined as $[0, 375)$; $[375, 750)$; $[750, 1500)$; $[1500, 3000)$; $[3000, 6000)$ in miles. b_{ij} is a dummy indicating whether the two countries i and j are adjacent to each other. The distance and geography data are drawn from CEPII. imt_j is the importer fixed effect and ε_{ij} is the disturbance assuming orthogonal to all the dependent variables. Now we can estimate equations

$$\ln\left(\frac{X_i^j}{X_j^j}\right) = S_i - S_j - \theta d_k - \theta b_{ij} - \theta imt_j - \theta\varepsilon_{ij}$$

under normalization contraints that $\sum_i S_i = \sum_j imt_j = 0$.

The calibration results for d_k are shown as Figure 5. It is straight forward that as the distance between two countries expands, marginal cost increases. And during the time horizon from 2004 to 2014, the overall geographic cost gradually decline with 2009 being an exception. However, the descending trend is disappearing and in 2014 even increase in overall trade friction begin to show up.

FIGURE 5 INSERTED HERE

Competitiveness measures the relative advantage in production as graphed in Figure 6 and Figure 7. We can observe that developed countries are get less competitive in trading, which is consistent with the commen concept that developing countries are experiencing a rapid technology improvement and enjoying the bonus of cheap labor force. The result also indicates that Japan is losing competitiveness in a fastest pace. US and China share similar magnitude of competitiveness significantly ahead of other countries.

FIGURE 6 INSERTED HERE

FIGURE 7 INSERTED HERE

As for the destination effect in trade in Figure 8 and Figure 9, we actually show that again US and China have the lowest import barriers. But most developed countries express an increase trend of tuning up import barriers while developing countries almost keep cycling around a constant level.

FIGURE 8 INSERTED HERE

FIGURE 9 INSERTED HERE

3.4 Capital movement costs

For capital movement, we combine UNCTAD bilateral FDI stock data and OECD bilateral FDI stock data. These two datasets each has some observations the other does not include. So we use OECD data as a benchmark and fill in the potential blanks with UNCTAD. It is noticable that even the same observation may vary across the two datasets, but the difference is acceptable. Also the statistics of FDI instock reporting by country i originated from country j generally do not match the outstock reporting by country j flowing to country i, so we all choose the instock value as rule of thumb in dealing with trade data. To evaluate the capital stock accumulated by local residents, we use capital stock data in WIOD Socio-Economic Accounts.

If denoting Z_i^j as the FDI instock of country j from country i, we can also cancel out aggregate terms by taking ratio. Z_i^i is constructed by less total FDI instock from capital stock.

$$\frac{Z_i^j}{Z_i^i} = \left(\frac{\lambda_i^j d_{fj}}{d_{li}}\right)^{\kappa_c}$$

And taking logs result in

$$\ln\left(\frac{Z_i^j}{Z_i^i}\right) = I_{fj} - I_{li} + \kappa_c \ln \lambda_i^j$$

where $I_{fj} \equiv \kappa_c \ln d_{fj}$ and $I_{li} \equiv \kappa_c \ln d_{li}$ are treated as fixed effects and $\ln \lambda_i^j$ can be also further decomposed into distance, contiguity, inflow fixed effect and common currency:

$$\ln \lambda_i^j = d_k + b_{ij} + imk_j + e_{ij} + \varpi_{ij}$$

And we can as well apply the normalization constraints that $\sum_i I_{fi} = \sum_i I_{li} = \sum_i imk_i = 0$. But to deal with the zero, or even negative FDI stock values in data, in advance we assign the element in capital movement matrix $\{\lambda_i^j\}$ to zero if observing that $Z_i^j \leq 0$.

3.5 Commuting costs

Calibrating commuting cost is more complicated, for it's hard to identify directly from aggregate migration data the reason to move motivated by utility difference ν_i^j or commuting cost μ_i^j. So we can only derive the utility first from budget constraints.

$$P_{n,t} I_{i,t} + C_{i,t}^n = \left(\overline{R}_{i,t} - 1 + \delta\right) a_{i,t} + \omega_{n,t}$$

We map $\omega_{n,t}$ to the compensation of employees divided by population (employers) in country n, thus $C_{i,t}^n$ should be the final consumption expenditure over population in country i minus $\omega_{i,t}$ plus $\omega_{n,t}$. Then we proxy $P_{n,t}$ as PPP conversion factor in private consumption (in local currency) over official exchange rate towards US dollars. So we estimate $\widehat{\nu}_i^j \equiv \ln \frac{\widehat{C}_i^j}{\widehat{P}_i^j}$. Again taking logs of commuting ratio and decomposing the commuting cost will lead to

$$\ln\left(\frac{M_i^j}{M_i^i}\right) = \kappa_l \ln\left(\widehat{\nu}_i^j + c\right) - \kappa_l \ln\left(\widehat{\nu}_i^i + c\right) + \kappa_l \ln \mu_i^j$$
$$\ln \mu_i^j = d_k + b_{ij} + iml_j + \chi_{ij}$$

Here c is a constant adjusting the final good price. We then estimate c and all other standard parameters together.

4 Simulation Result

To illustrate the effect of friction reduction and check the robustness of model, we apply a simulation with four countries. The benchmark parameters are set as suggested in previous section. Frictions are artificially given by random draw. And the qualitative results are quite robust for different draws.

The first experiment is on capital movement cost λ_1^2 as shown in Figure 10, namely the unilateral capital movement cost of country 2 targeting at inflows from country 1. We can observe the local deposit rate in country 1 and the loan rate in country 2 both respond sensitively, creating large fluctuation in country 1's capital outflow share and country 2's capital inflow share. However the other real terms and trade pattern do not change much. As for welfare effect, the magnitude sizes small but a U-shape displays for country 2 while country 1 is getting better at the cost of the rest of world.

FIGURE 10 INSERTED HERE

The second experiment is on trade friction τ_1^2 as shown in Figure 11. The import share and export share changes comove in both country 1 and country 2 but in different channel. Reduction on trade barrier impose a positive demand shock for country 1's export, thus factor prices increase in country 1, which makes country 1's residents find it more beneficial to import instead of producing at home. The friction change for country 2 should be viewed more of a positive supply shock for providing cheaper intermediate goods. Then more competition reduces the factor prices and the intermediate goods price, boosting export.

FIGURE 11 INSERTED HERE

The last experiment is on commuting cost μ_1^2 as shown in Figure 12. Since labor and capital are complementary in production, then reduction of the labor mobility friction from country 1 to country 2 would increase labor force in country 2 but decrease that in country 1, then increase the foreign capital rent in country 2 but reduce that in country 1. Also more capital outflow from country 1 increase the local capital loan rate. In terms of welfare, more free labor mobility bring a large extent of improvement and unilateral labor friction reduction benefits all the countries.

FIGURE 12 INSERTED HERE

5 Conclusion

In this paper, we build a unified framework incorporating the mobility of goods, capital and labor market, generating the results for bilateral capital flows and differentiated interest rates at steady state. Intratemporal capital flows are realized by global portfolio decisions of individuals to seek the highest return opportunity. The assumption of commuting and saving first timing frees us from discussing capital distribution evolution. Then we take the model to data calibrating the frictions in each market and counterfactually analyse the effect of friction reduction.

Calibration results suggest that overall trade frictions regarding to distance gradually shrink except for a 2009 sudden jump, and the declining trend is disappearing. The relative trade competitiveness of low income countries like China, India, Russia and Mexico constantly rises up while that of high income countries including US, Japan, Germany levels down. Importing barriers of low income countries show no clear trend but those of high income countries have been built up.

For simulation results, we find it a U-shape welfare curve for a country's capital market to step from highly closed to completely free. The unilateral relax of capital control of country i on inflow from country j would benefit j but hurt the rest of world. Also local capital friction change would cause much greater local capital flow fluctuation than trade share variation, for global portfolio decision absorbs the local capital environment change and smoothes real term prices. And our simulation seconds the conclusion in previous literature that labor mobility friction would impose the most significant effect on welfare.

6 Future Work

- Add in persistent shocks to solve stochastically and revisit the macro puzzle.
- Extend into multiple sector model to review the structure change of a country during opening up

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Figures and Tables:

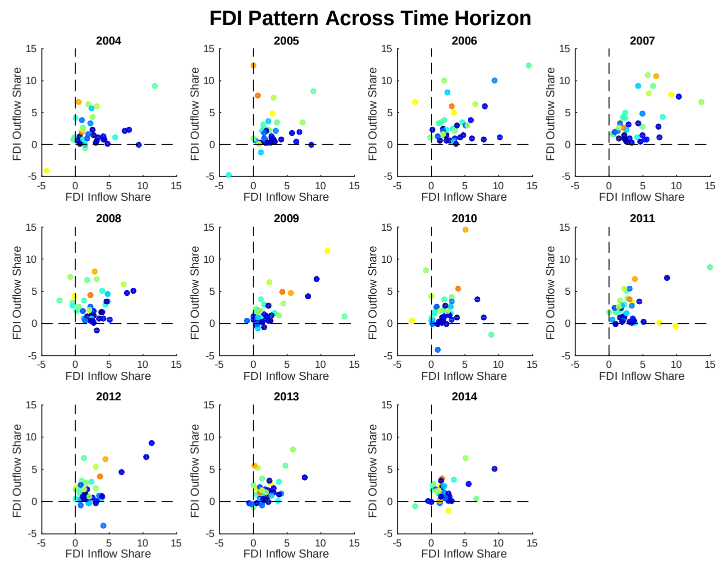


Figure 1

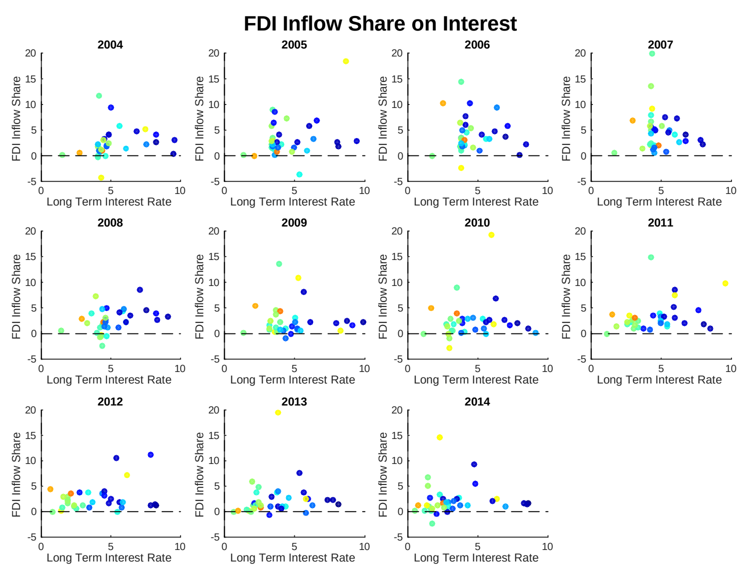
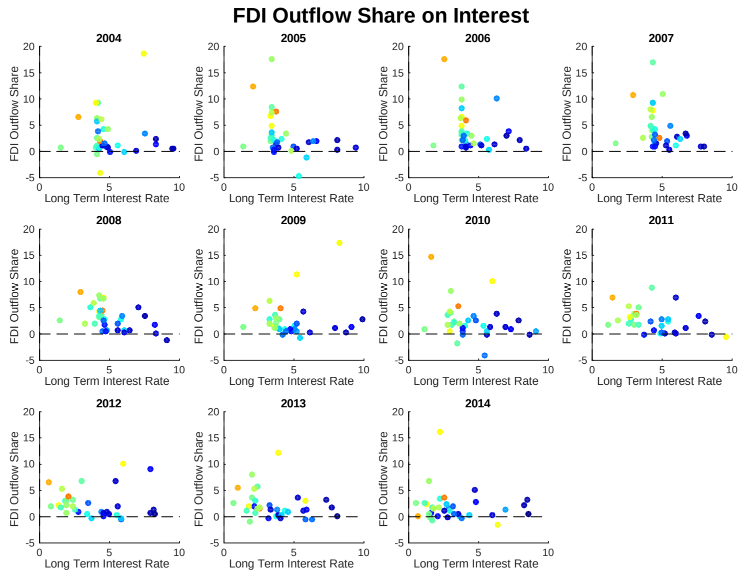


Figure 2



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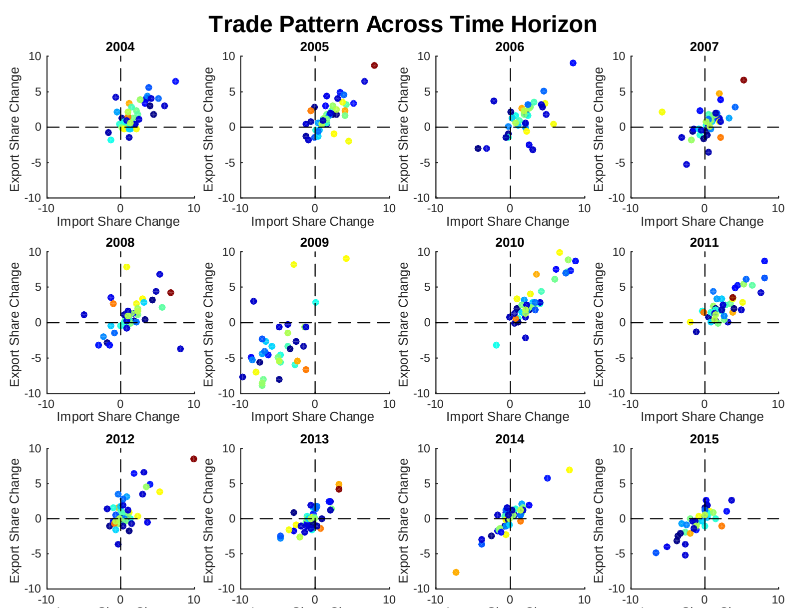

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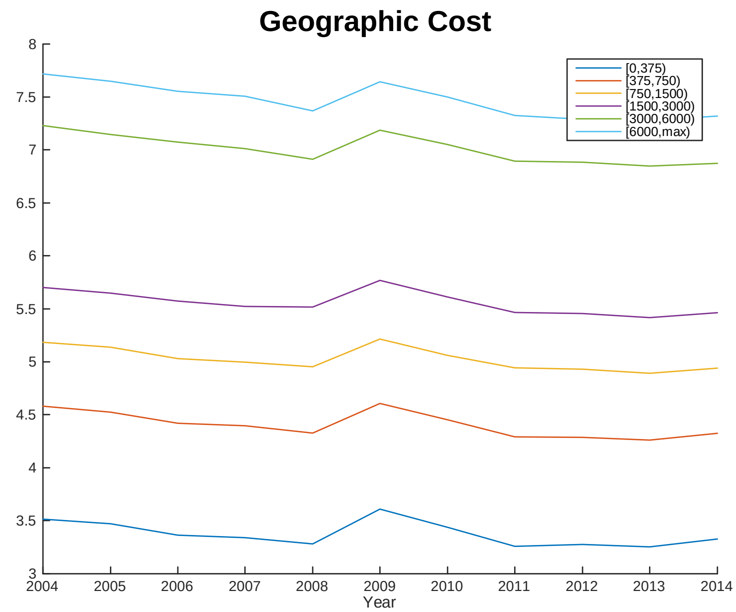

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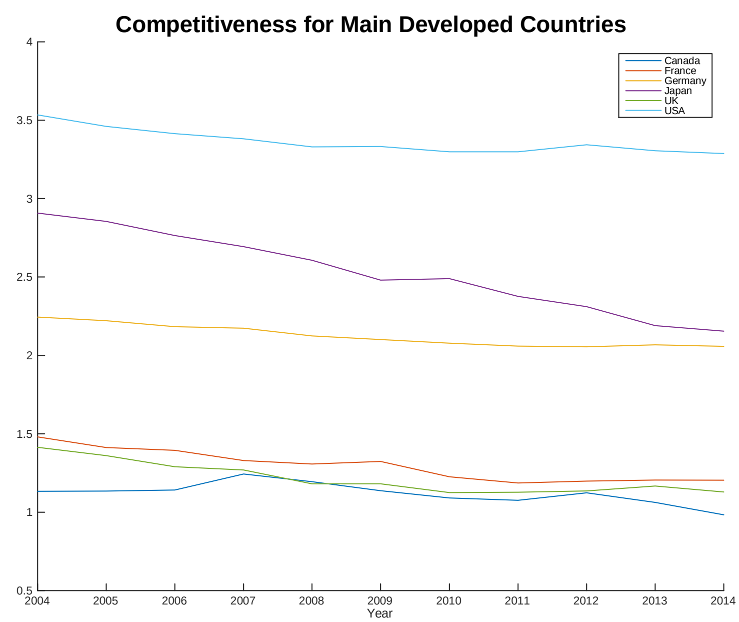

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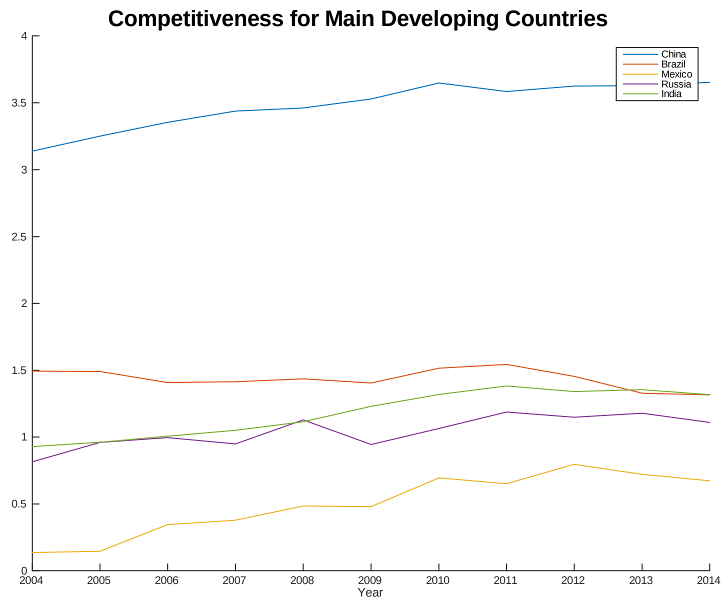

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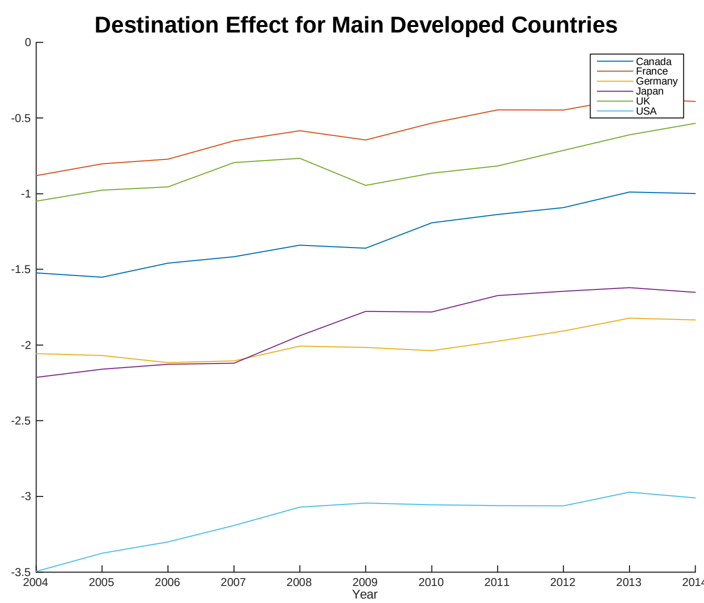
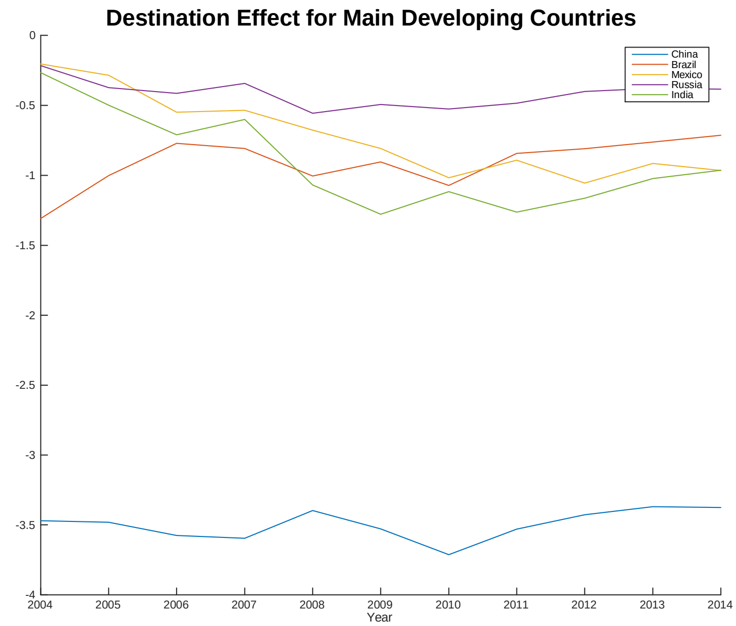


Figure 8



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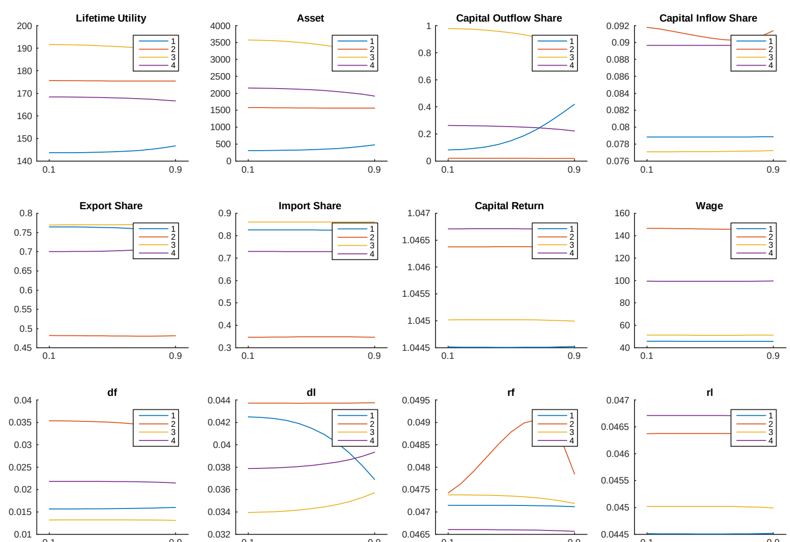

Figure 10. The Change of Capital Movement Cost λ_1^2

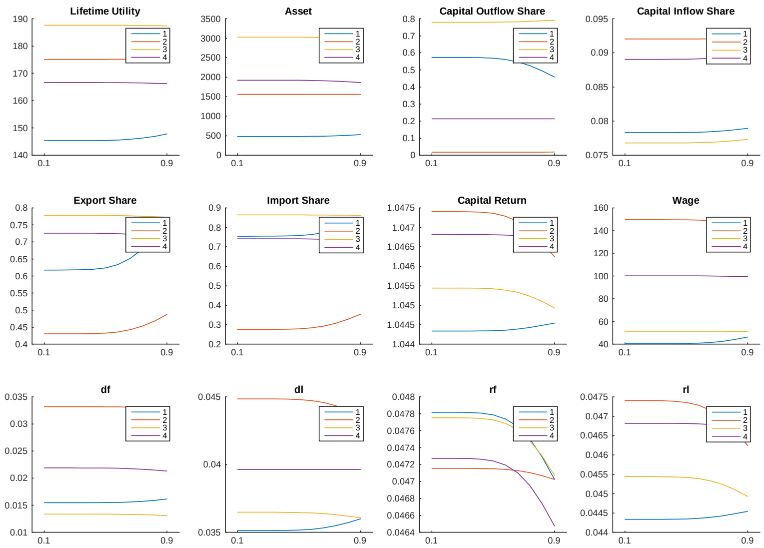

Figure 11. The Change of Trade Friction $1/\tau_1^2$

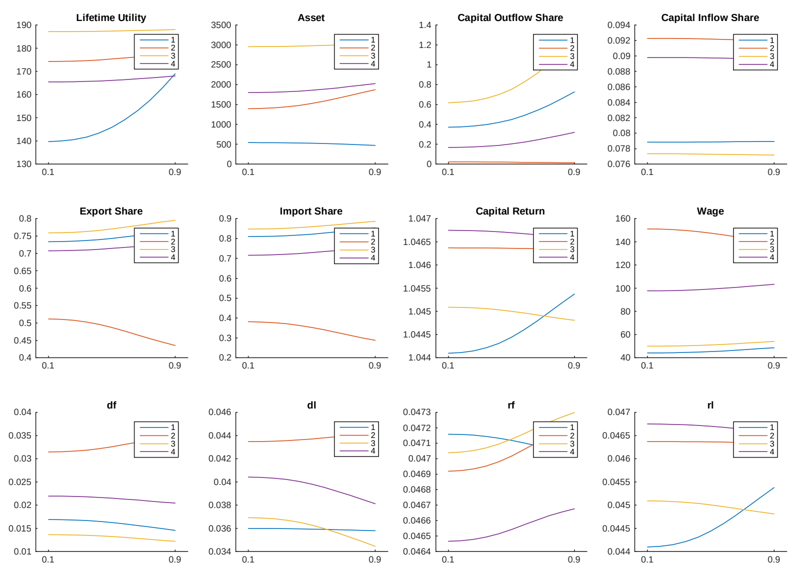

Figure 12. The Change of Commuting Cost μ_1^2

Appendix A: Derivation of Dynamic system

The capital related equations:

$$
\begin{aligned}
\overline{R}_{i,t} - 1 &= \left(\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c} \right)^{\frac{1}{\kappa_c}} \\
mr_{i,t}^j &= \frac{\left(\lambda_i^j d_{fj,t}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c}} \\
mr_{i,t}^i &= \frac{\left(\lambda_i^i d_{li,t}\right)^{\kappa_c}}{\sum_{n \neq i} \left(\lambda_i^n d_{fn,t}\right)^{\kappa_c} + \left(\lambda_i^i d_{li,t}\right)^{\kappa_c}} \\
r_{fi,t} \sum_{n \neq i} mr_{n,t}^i a_{n,t} \bar{l}_n &= \sum_{n \neq i} mr_{n,t}^i a_{n,t} \bar{l}_n \frac{\overline{R}_{n,t} - 1}{\lambda_n^i} \\
r_{li,t} &= \frac{\overline{R}_{i,t} - 1}{\lambda_i^i} \\
L_{i,t} &= \sum_n mr_{n,t}^i a_{n,t} \bar{l}_n \left(\overline{R}_{n,t} - 1\right) \frac{1 - \lambda_n^i}{\lambda_n^i}
\end{aligned}
$$

The trade related equations:

$$
\begin{aligned}
\Phi_t^j &= \sum_i \left(\tau_i^j \left(r_{li,t} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi,t} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i \right)^{-\theta} \\
\pi_{i,t}^j &= \frac{\left(\tau_i^j \left(r_{li,t} + \delta\right)^{\alpha_i \beta_i} \left(r_{fi,t} + \delta\right)^{(1-\alpha_i)\beta_i} \omega_{i,t}^{1-\beta_i} / T_i \right)^{-\theta}}{\Phi_t^j} \\
P_{i,t} &= \left[\Gamma \left(\frac{\theta + 1 - \sigma}{\theta} \right) \right]^{\frac{1}{1-\sigma}} \left(\Phi_t^i\right)^{-\frac{1}{\theta}}
\end{aligned}
$$

The utility and commuting related equations:

$$
\begin{aligned}
P_{n,t} \left(a_{i,t+1} + c_{i,t}^n\right) &= \left(\overline{R}_{i,t} - 1 + \delta + (1 - \delta) P_{n,t}\right) a_{i,t} + \omega_{n,t} \\
v_{i,t}^n &= \ln \left(c_{i,t}^n\right) \\
ml_{i,t}^j &= \frac{\left(\mu_i^j v_{i,t}^j\right)^{\kappa_l}}{\sum_n \left(\mu_i^n v_{i,t}^n\right)^{\kappa_l}}
\end{aligned}
$$

The market clearing equations:

$$\begin{aligned}
\frac{\omega_{i,t}\sum_n ml^i_{n,t}\bar{l}_n}{1-\beta_i} &= \sum_j \pi^j_{i,t}\sum_n \left[ml^j_{n,t}\bar{l}_n P_{j,t}\left(c^j_{n,t}+\left(a_{n,t+1}-\left(1-\delta\right)a_{n,t}\right)\right)\right]+L_{i,t}\\
\left(r_{fi,t}+\delta\right)\sum_{n\neq i} mr^i_{n,t}a_{n,t}\bar{l}_n &= \frac{\left(1-\alpha_i\right)\beta_i\omega_{i,t}}{1-\beta_i}\sum_n ml^i_{n,t}\bar{l}_n\\
\left(r_{li,t}+\delta\right)mr^i_{i,t}a_{i,t}\bar{l}_i &= \frac{\alpha_i\beta_i\omega_{i,t}}{1-\beta_i}\sum_n ml^i_{n,t}\bar{l}_n\\
1 &= \left[\Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)\right]^{\frac{1}{1-\sigma}}\left(\sum_i\left(\left(r_{li,t}+\delta\right)^{\alpha_i\beta_i}\left(r_{fi,t}+\delta\right)^{(1-\alpha_i)\beta_i}\omega^{1-\beta_i}_{i,t}/T_i\right)^{-\theta}\right)^{-\frac{1}{\theta}}
\end{aligned}$$

And intertemporal optimization conditions:

$$\begin{aligned}
&\left(\sum_n\left(\mu^n_i v^n_{i,t}\right)^{\kappa_l}\right)^{\frac{1}{\kappa_l}-1}\sum_n ml^n_{i,t}\frac{1}{c^n_{i,t}v^n_{i,t}}\\
=\;&\rho\left(\sum_n\left(\mu^n_i v^n_{i,t+1}\right)^{\kappa_l}\right)^{\frac{1}{\kappa_l}-1}\sum_n\frac{ml^n_{i,t+1}\left[\overline{R}_{i,t+1}+\left(P_{n,t+1}-1\right)\left(1-\delta\right)\right]}{v^n_{i,t}P_{n,t+1}c^n_{i,t+1}}
\end{aligned}$$

Then the trade related dynamics:

$$\begin{aligned}
\widehat{\pi}^j_{i,t} &= -\theta\left(\alpha_i\beta_i\frac{r_{li}\widehat{r}_{li,t}}{r_{li}+\delta}+\left(1-\alpha_i\right)\beta_i\frac{r_{fi}\widehat{r}_{fi,t}}{r_{fi}+\delta}+\left(1-\beta_i\right)\widehat{\omega}_{i,t}\right)-\widehat{\Phi}^j_t\\
\widehat{\Phi}^j_t &= -\theta\sum_i\pi^j_i\left(\alpha_i\beta_i\frac{r_{li}\widehat{r}_{li,t}}{r_{li}+\delta}+\left(1-\alpha_i\right)\beta_i\frac{r_{fi}\widehat{r}_{fi,t}}{r_{fi}+\delta}+\left(1-\beta_i\right)\widehat{\omega}_{i,t}\right)\\
\widehat{P}_{i,t} &= -\frac{1}{\theta}\widehat{\Phi}^i_t
\end{aligned}$$

Now the commuting related dynamics:

$$\begin{aligned}
\delta P_n a_i\widehat{P}_{n,t}+P_n a_i\widehat{a}_{i,t+1}+C^n_i\widehat{C}^n_{i,t} &= \left(\overline{R}_i-1+\delta+P_n\left(1-\delta\right)\right)a_i\widehat{a}_{i,t}\\
&\quad+a_i\left(\overline{R}_i-1\right)\left(\widehat{\overline{R}_i-1}\right)+\omega_n\widehat{\omega}_{n,t}+G_i\widehat{G}_{i,t}\\
v^n_i\widehat{v}^n_{i,t} &= \widehat{C}^n_{i,t}-\widehat{P}_{n,t}\\
\widehat{ml}^j_{i,t} &= \kappa_l\left(\widehat{v}^j_{i,t}-\sum_n ml^n_i\widehat{v}^n_{i,t}\right)
\end{aligned}$$

And the market clearing dynamics:

$$\widehat{\omega}_{i,t} = \frac{\sum_j \pi_i^j \sum_n \left[ml_{n,t}^j \bar{l}_n E_n^j\right] \left(\widehat{\pi}_{i,t}^j + \widehat{ml}_{n,t}^j + \widehat{E}_{n,t}^j\right) + L_i \widehat{L}_{i,t}}{R_i + L_i} - \frac{\sum_n ml_n^i \bar{l}_n \left(\widehat{ml}_{n,t}^i\right)}{\sum_n ml_n^i \bar{l}_n}$$

$$E_{n,t}^j \widehat{E}_{n,t}^j = C_n^j \widehat{C}_{n,t}^j + \delta P_j a_n \left(\widehat{P}_{j,t} + \frac{\widehat{a}_{n,t+1} - (1-\delta)\widehat{a}_{n,t}}{\delta}\right)$$

$$\widehat{\omega}_{i,t} = \frac{r_{fi}\widehat{r}_{fi,t}}{r_{fi}+\delta} + \frac{\sum_{n\neq i} mr_n^i a_n \bar{l}_n \left(\widehat{mr}_{n,t}^i + \widehat{a}_{n,t}\right)}{\sum_{n\neq i} mr_n^i a_n \bar{l}_n} - \frac{\sum_n ml_n^i \bar{l}_n \left(\widehat{ml}_{n,t}^i\right)}{\sum_n ml_n^i \bar{l}_n}$$

$$\widehat{\omega}_{i,t} = \frac{r_{li}\widehat{r}_{li,t}}{r_{li}+\delta} + \widehat{mr}_{i,t}^i + \widehat{a}_{i,t} - \frac{\sum_n ml_{n,t}^i \bar{l}_n \widehat{ml}_{n,t}^i}{\sum_n ml_{n,t}^i \bar{l}_n}$$

$$0 = \sum_i \left((r_{li}+\delta)^{\alpha_i\beta_i} (r_{fi}+\delta)^{(1-\alpha_i)\beta_i} \omega_i^{1-\beta_i}/T_i\right)^{-\theta} \left(\alpha_i\beta_i \frac{r_{li}\widehat{r}_{li,t}}{r_{li}+\delta} + (1-\alpha_i)\beta_i \frac{r_{fi}\widehat{r}_{fi,t}}{r_{fi}+\delta} + (1-\beta_i)\widehat{\omega}_{i,t}\right)$$

Finally the intertemporal optimization dynamics:

$$(1-\kappa_l)\sum_n ml_i^n \widehat{v}_{i,t}^n + \frac{\sum_n ml_i^n \frac{P_n}{C_i^n v_i^n}\left(\widehat{ml}_{i,t}^n + \widehat{P}_{n,t} - \widehat{C}_{i,t}^n - \widehat{v}_{i,t}^n\right)}{\sum_n ml_i^n \frac{P_n}{C_i^n v_i^n}} - (1-\kappa_l)\sum_n ml_i^n \widehat{v}_{i,t+1}^n$$

$$= \frac{\sum_n \frac{ml_i^n\left[\overline{R}_i - 1 + \delta + P_n(1-\delta)\right]}{C_i^n v_i^n}\left(\widehat{ml}_{i,t+1}^n - \widehat{C}_{i,t+1}^n - \widehat{v}_{i,t+1}^n\right) + \sum_n \frac{ml_i^n\left(\left(\overline{R}_i - 1\right)\widehat{\overline{R}_{i,t+1}-1} + (1-\delta)P_n\widehat{P}_{n,t+1}\right)}{C_i^n v_i^n}}{\sum_n \frac{ml_i^n\left[\overline{R}_i - 1 + \delta + P_n(1-\delta)\right]}{C_i^n v_i^n}}$$