GLOBALIZATION AND THE BUSINESS CYCLE

By

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Dissertation

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Economics

August, 2009

Nashville, Tennessee

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To my parents

ACKNOWLEDGMENTS

First and foremost I would like to thank my advisor and chair of my dissertation committee, Mario Crucini.

I would also like to thank the members of my dissertation committee, Kevin Huang, Greg Huffman, Andrew Hughes Hallett, David Parsley, and Mototsugu Shintani for many helpful comments and suggestions, and for reading and reviewing countless drafts of each chapter in this dissertation.

I would also like to recognize Kevin Huang as my co-author for chapter IV.

I would like to thank Chris Young, Chris Peacock, Misa Tanaka, and the International Economic Analysis Division at the Bank of England, who in some way directly aided each chapter of this dissertation.

In addition I would like to thank my various office mates through the years, including Naoto Yamazaki, Sujan Rajbhandary, Lola Soumonni, Suman Seth, Tamara Trafton, Caleb Stroup, Zhao Yuling, Shabana Singh, and Alper Nakkas, whose assistance in everything from problem sets to thesis editing is greatly appreciated, and whose infinite patience is also acknowledged and appreciated.

Finally, I would like to thank my fellow "Macro Fridians", including P.J. Glandon and Greg Niemesh, in whose company over tacos and beer I codified a lot of what I know about macroeconomics.

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CHAPTER I

INTRODUCTION

This dissertation studies the effect of globalization, specifically increased international trade and financial integration, on various aspects of the international business cycle. This dissertation is composed of three essays entitled: "Globalization and International Business Cycle Co-movement", "Globalization and the Phillips Curve", and "Variable Markups and International Business Cycle Co-movement".

In chapter II, "Globalization and International Business Cycle Co-movement", I study the causal relationships between bilateral trade integration, bilateral financial integration, industrial specialization, and business cycle co-movement. I begin by measuring the sign and magnitude of these causal channels using a reduced form empirical approach. In accordance with existing empirical studies, I find increased trade has a positive effect on financial integration and finance has a positive effect on trade, trade has a negative effect on specialization and specialization has a negative effect on trade, financial integration has a positive effect on specialization and specialization has a positive effect on finance, while trade has a positive effect on co-movement but finance and specialization each have a negative effect on co-movement.

I then construct a multi-sector, multi-country real business cycle model that can potentially replicate each of the causal channels that we observe in the data. The goal here is to find which of the causal channels that we observe in the data can be explained by the real business cycle model and its classical assumptions. I find the model can replicate the positive causal channel from bilateral financial integration to industrial specialization, the positive effect of industrial specialization on financial integration, the positive effect of trade on cyclical co-movement, and the negative effects of finance and specialization on co-movement.

However this model cannot replicate the negative causal channels between trade integration and industrial specialization, or the positive channels between trade and financial integration.

The model based on classical assumptions predicts that trade has a positive effect on specialization and specialization has a positive effect on trade. The fact that these causal channels are positive in the classical model but negative in the data, has been noted in previous empirical studies and reflects the importance of *intra-industry* trade.

Also, in contrast with the empirical results, the model predicts that trade has a negative effect on financial integration and finance has no effect on trade. The negative effect of trade on finance has been found before in models based on classical assumptions. Movements in the terms of trade provide consumption risk sharing in the face of country specific production fluctuations and thus make risk sharing through international financial markets unnecessary. Some recent theoretical work argues that the positive effect of trade on finance in the data may be due to cross-country heterogeneity in financial development. The classical model has no role for cross-country heterogeneity in financial development, so a model based on classical assumptions shouldn't replicate the positive effect of trade on financial integration.

The model also predicts that bilateral financial integration should have no effect on bilateral trade integration. In the classical model, cross-country differences in the marginal cost of production are the main determinates of international trade flows. Some recent work argues that the positive effect of finance on trade in the data is due to cross-country financial frictions. According to the WTO, over 90% of world trade flows depend on some sort of external financing (usually trade credits). Greater bilateral financial integration may aid this external financing and thus lead to greater bilateral trade integration.

Chapter III, "Globalization and the Phillips Curve", deals with an issue that is very relevant to central bankers concerned with the effects of globalization on the conduct of monetary policy. I specifically study two closely related questions. First, will increased international trade integration make domestic inflation less responsive to movements in the domestic output gap (the flattening of the Phillips curve)? Secondly, will this increased trade integration make domestic inflation more responsive to movements in the foreign output gap?

If the answer to both of these questions is 'yes', then globalization will lead to the central bank losing control over the domestic inflation rate. This issue has created a bit of a stir in the profession with two working papers, one from the Fed Board of Governors and one from the Bank for International Settlements. These papers use different econometric techniques and reach opposite conclusions.

Both of these empirical studies suffer from two problems. First, no empircal study can truly separate out the effect of increased trade integration from other coincidental factors like improved central bank credibility that may affect the trade-off between inflation and the output gap. The second problem plaguing both of these empirical studies is a lack of data availability. Both studies are limited to $20-30$ years of quarterly production and inflation data. After controlling for factors like import price inflation and including the necessary lags to control for serial correlation, they are left with very few degrees of freedom.

To correct for both of these potential problems, I answer the two questions listed above using a sticky price DSGE model. A model allows me to change only the degree of trade integration while holding everything else, like the central bank decision rule, constant. The model is used as a data generating process to generate time series observations of production and inflation that can be used in the same regressions that appear in previous empirical studies. Since a model is used as a data generating process, data availability is not an issue.

With this model, I find that with increased trade integration there is a slight reduction in the sensitivity of inflation to movements in the domestic output gap and a slight increase in the sensitivity of inflation to movements in the foreign output gap. However I find that the effect of the trade integration of the last 30 years on the slope of the Phillips curve is negligible. Furthermore, using Monte Carlo methods, it is demonstrated that limited data availability can potentially lead to a wide range of possible answers to the question of how should globalization affect the slope of the Phillips curve. Specifically, the model shows that even after controlling for import price inflation, domestic inflation is somewhat sensitive to movements in the foreign output gap, but Monte Carlo methods show that this effect is labeled insignificant in a study involving only $20 - 30$ years of data.

In chapter IV, "Variable Markups and International Business Cycle Co-movement", I introduce endogenous markup variability into a real business cycle model to study the effects of cyclical changes in a firm's desired markup on the co-movement of aggregate production across countries.

In this model, a firm's desired markup is an increasing function of its market share. In this multi-country model, country specific productivity shocks lead to cyclical changes in the import share, and thus cyclical changes in both domestic and export firms' market shares. So country specific productivity shocks lead to cyclical changes in the desired markups of both domestic and export firms.

This markup variability leads to greater international business cycle correlation. The intuition is as follows. Suppose there is a positive shock to foreign productivity. Then foreign marginal costs fall. The relative price of foreign products decreases. Foreign producers will increase production and domestic producers will cut production. Thus the foreign shock leads to business cycle divergence.

Foreign producers gain market share at the expense of domestic producers, and thus foreign markups increase while domestic markups fall. These changes in markups cause the relative price of foreign goods to increase. Thus markup variability causes a change in relative prices that is exactly opposite to the change due to the initial productivity shock. Home and foreign business cycles will diverge less than they would have without variable markups.

Thus markup variability has a qualitative effect on business cycle correlation. In this chapter, I quantify that effect and show that markup variability has a significant effect on cyclical correlation. Furthermore I show that a real business cycle model with endogenous markup variability can reproduce the positive effect of trade on co-movement that is difficult to reproduce in an international real business cycle model with complete international asset markets.

CHAPTER II

GLOBALIZATION AND INTERNATIONAL BUSINESS CYCLE CO-MOVEMENT

Introduction

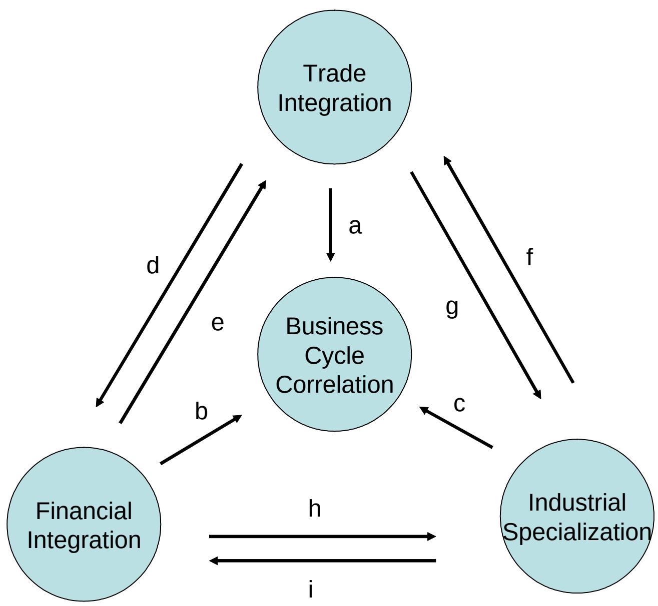
The era of globalization has seen a rapid increase in the degree of international trade and financial integration. As countries trade more goods and financial assets, it is natural to ask what effect will globalization have on the co-movement of business cycles between countries.

This question is more complicated than simply estimating the effects of bilateral trade and financial integration on business cycle correlation. Trade integration affects financial integration, and financial integration affects trade integration. Similarly, both trade and finance affect bilateral industrial specialization, which can also affect the co-movement of business cycles between countries.

The various channels between trade, finance, specialization, and co-movement are presented in figure 1. In this diagram, a causal channel is represented with an arrow. So for instance, if we are interested in the effect of greater bilateral trade integration on bilateral financial integration, we are interested in the arrow labeled "d". The effect of greater bilateral trade integration on bilateral business cycle co-movement is represented by the arrow labeled "a".

Imbs (2004, 2006) estimates most of these channels. He finds a clear positive causal channel from bilateral trade integration to bilateral financial integration and vice versa (channels d and e), a positive channel from financial integration to industrial specialization

Figure 1. The causal channels from trade integration, financial integration, and industrial specialization to business cycle co-movement, and the channels between trade, finance, and specialization



(channel h), and a negative causal channel from bilateral trade integration to industrial specialization and vice versa (g and f). He also shows that trade and financial integration lead to higher business cycle co-movement (a and b), while industrial specialization leads to less co-movement (c).[1]

The explanation for many, but not all, of these channels has been the subject of previous theoretical work.

The channel from trade integration to international business cycle co-movement is a common feature of the international business cycle literature. Specifically, the workhorse international real business cycle models (IRBC), in Backus, Kydland, and Kehoe (1992, 1994) and Baxter and Crucini (1993) predict that international trade integration actually lowers international cyclical co-movement. Ambler, Cardia, and Zimmermann (2002) are able to resolve the discrepancy between the negative effect of trade predicted by the IRBC model and the positive effect found in the data by changing the nature of trade to include trade in intermediate goods.

Baxter and Crucini (1995), Arvanitis and Mikkola (1996), and Kehoe and Perri (2002) find that bilateral financial integration should have a negative effect on cyclical co-movement. Integrated financial markets mean that capital can move from country to country chasing the highest marginal return. This leads to swings in investment that can exacerbate the effects of productivity driven business cycle fluctuations.

In addition to these papers that study the effects of exogenous increases in trade integration, financial integration, or industrial specialization on business cycle co-movement,

[1] These empirical findings are supported by Aviat and Coeurdacier (2007) and Lane and Milesi-Ferretti (2004), who find a complementarity between trade and financial integration. Kalemli-Ozcan, Sorensen and Yosha (2003) find a positive causal channel from financial integration to industrial specialization. Frankel and Rose (1998), Clark and van Wincoop (2001), and Baxter and Kouparitsas (2005) find evidence that higher bilateral trade integration leads to higher cyclical co-movement. This is also supported by Calderon, Chong and Stein (2007), who along with Kalemli-Ozcan, Sorensen and Yosha (2001) find evidence that bilateral industrial specialization has a negative effect on co-movement.

some papers have endogenized trade, finance, and specialization to model the channels between these three real variables.

In a model with endogenous industrial specialization, Dornbusch, Fisher, and Samuelson (1977, 1980) and Krugman (1991) show that trade integration should have a positive effect on industrial specialization.

Cole and Obstfeld (1991) show that under certain circumstances international trade integration can be a substitute for international financial integration, while Obstfeld and Rogoff (2000) and Lane and Milesi-Ferretti (2004) find, under different assumptions, an endogenous complementarity between trade and financial integration.

Similarly, in a model with endogenous financial integration Heathcote and Perri (2004) show how financial integration can arise endogenously between countries that are subject to idiosyncratic shocks. While not explicitly stated by Heathcote and Perri, this idiosyncratic country specific risk arises when economic fluctuations are at least partially driven by industry specific shocks and two countries are specialized in different industries.

This paper uses an IRBC model in the spirit of Backus, Kydland, and Kehoe (1994) and Kose and Yi (2006) to explain each of the channels in figure 1. In order to explain each one of these channels, it is necessary to endogenize trade integration, financial integration, and industrial specialization.

To provide an empirical benchmark from which to test the model's predictions, we also estimate the various causal channels as in Imbs (2004, 2006).

The second section describes the strategy we use to estimate the channels in figure 1 and the data used in this estimation. We then discuss the results from this estimation that will serve as an empirical benchmark. The model to explain these empirical results is described in the third section. The results are presented in the fourth section. Since the channels between financial integration and industrial specialization have not been previously discussed in the theoretical literature, we will first use the model to provide the intuition behind these two channels. Then we present the channels implied by the model and compare those to the empirical benchmark. Finally the fifth section concludes with a summary and some directions for further research.

Empirics

Variables

Endogenous Variables

In our empirical estimations, the first variable to consider is a measure of bilateral business cycle correlation. ρ_{jh} is the correlation of GDP fluctuations between countries j and h. We will use 58 countries in this study, so there are a total of 1653 country pairs jh. These 58 countries account for 95% of world GDP. The full list of countries can be found in the appendix. Since GDP is non-stationary, we need to detrend the data before finding correlations. Our primary detrending method is the Hodrick-Prescott filter, but for robustness we repeat the estimation using log differences and linear detrending.

The next endogenous variable to consider is the measure of bilateral financial integration. Since accurate and complete data on bilateral financial flows does not exist for a broad set of countries, we are forced to rely on a proxy for bilateral financial integration. To ensure that the results are not due to the particular proxy, we use four alternatives.

The primary measure of financial integration is introduced in Imbs (2004) and uses data on external assets and liabilities for a wide range of countries compiled by Lane and

Milesi-Ferretti (2007). This measure is the difference in relative net foreign asset positions between countries j and h:

$$F_{jh} = \left| \frac{nfa_j}{GDP_j} - \frac{nfa_h}{GDP_h} \right| \tag{II.1}$$

where nfa_j denotes the net foreign asset position of country j. If country j is a creditor country with a large and positive net foreign asset position and country h is a debtor country with a large and negative net foreign asset position, then it is likely that there are financial flows from country j to country h. In this case, F_{jh} will be large. If on the other hand both countries are creditor countries and have positive net foreign asset positions then it is less likely that there are financial flows between the two, and F_{jh} is small. Similarly, even if one country is a net creditor and one is a net debtor, but their net foreign asset positions are relatively small then the financial flows between the two may be small, and F_{jh} is small to reflect this.

The three alternative measures of financial integration are based on data from the IMF's Coordinated Portfolio Investment Survey (CPIS), the mean absolute deviation of cross-country differences in debt and equity returns, and a measure based on risk sharing. Details about each one of these alternative measures can be found in the appendix.

For data on bilateral trade flows we use the Trade, Production, and Protection database compiled by the World Bank and described in Nicita and Olarreaga (2006). This data set contains bilateral trade data, disaggregated into 28 manufacturing sectors corresponding to the 3 digit ISIC level of aggregation. It also contains country level production and tariff data with a similar level of disaggregation. The data set potentially covers 100 countries over the period $1976-2004$, but data availability is a problem for some countries, especially during the first half of the sample period. To maximize the number of countries in our sample, we use data for 58 countries from $1991-2004$.

Our primary measure of bilateral trade intensity is developed by Deardorff (1998) and used by Clark and van Wincoop (2001), among others. This measure is independent of the sizes of countries j and h. If the set $\mathcal{N}$ contains the 28 industries in the Trade, Production, and Protection data base, then our primary measure of trade intensity is given by:

$$T_{jh} = \frac{1}{2}\sum_{i\in\mathcal{N}} \frac{\left(X_{jh}^{i} + M_{jh}^{i}\right) GDP_w}{GDP_j GDP_h} \tag{II.2}$$

where X_{jh}^{i} represents the exports in sector i from country j to country h, M_{jh}^{i} represents imports in sector i to country j from country h, and GDP_w is world GDP.

For robustness we also use an alternate measure of trade integration, details on this alternate measure are found in the appendix.

With the sectoral value added data in the Trade, Production, and Protection database, we can construct a measure of bilateral industrial specialization. This measure,used by Clark and van Wincoop (2001) and Imbs (2004, 2006), is defined as follows:

$$S_{jh} = \sum_{i\in\mathcal{N}} \left| \frac{VA_j^i}{GDP_j} - \frac{VA_h^i}{GDP_h} \right| \tag{II.3}$$

where VA_j^i represents value-added in sector i in country j.

The basic summary statistics and unconditional correlations for our four endogenous variables across all 1653 country pairs are reported in table 1.

Exogenous Variables

The vector $\mathbf{X}_{jh}^{F}$ contains the exogenous variables that describe bilateral financial integration. This vector contains six elements. The first three are suggested by Portes and

Table 1. Summary statistics and unconditional correlations for the measures of cyclical correlation, financial integration, trade integration, and industrial specialization

Summary Statistics:

	Mean	Min	Max	St. Dev.
ρ	0.134	−0.945	0.978	0.011
F	0.434	0.00028	2.038	0.009
T	0.558	0.00003	81.396	0.069
S	0.157	0.036	0.421	0.002

Unconditional Correlations:

	ρ	F	T	S
ρ	1			
F	−0.084	1		
T	0.121	0.044	1	
S	−0.078	0.340	0.073	1

Rey (2005). They find that the gravity variables that are commonly used to describe bilateral trade integration are also useful in explaining bilateral financial integration. Therefore the first three elements of $\mathbf{X}_{jh}^F$ are the physical distance between the capital of j and the capital of h, a dummy variable equal to one if countries j and h share the same language, and a dummy variable equal to one if the two countries share a border. The next three elements of $\mathbf{X}_{jh}^F$ are from the law and finance literature, and are indices that describe the rule of law in a country, the strength of creditor rights, and the strength of shareholder rights. These indices were developed by La Porta et al. (1998), and this original paper supplies the data for most of the countries in this study. However we also refer to Pistor, Raiser, and Gelfer (2000) for similar indices for the Eastern European Transition Economies and Allen, Qian, and Qian (2005) for China. The actual index element in $\mathbf{X}_{jh}^F$ is simply the sum of the index value in countries j and h.

The vector $\mathbf{X}_{jh}^T$ contains exogenous variables that describe bilateral trade integration. This vector contains six variables, all from the gravity literature. The first five elements in $\mathbf{X}_{jh}^T$ are the physical distance between the capital of j and the capital of h, a dummy variable equal to one if countries j and h share the same language, a dummy variable equal to one if countries j and h share a border, the number of countries in the pair that are islands, and the number of countries in the pair that are landlocked. The sixth element in $\mathbf{X}_{jh}^{T}$ is a sum of tariff rates in countries j and h. The Trade, Production, and Protection data set contains information on country and sector specific tariff rates. t_j^i is the average tariff applied to imports from sector i into country j. The sixth element of $\mathbf{X}_{jh}^{T}$ is simply the sum of these tariff rates across countries j and h and across sectors in $\mathcal{N}$, $t_{jh} = \sum_{i \in \mathcal{N}} \left(t_j^i + t_h^i \right)$.

The vector $\mathbf{X}_{jh}^{S}$ contains three exogenous variables that describe bilateral industrial specialization. The first two of these describe per capita income in countries j and h. Imbs and Wacziarg (2003) show that sectoral diversification is closely related to per capita income. At low levels of income, countries are specialized, then as income increases they diversify. They also find that the relationship between income and diversification is non-monotonic. At high levels of income, as income increases, countries again specialize. For this reason, in his list of exogenous variables that influence specialization, Imbs (2004) includes the sum of per capita GDP across j and h to account for the fact that as income increases countries diversify, and he also includes the difference in per capita GDP across j and h to account for the non-monotonic relationship between income and diversification.

To these two variables we add a measure of comparative advantage. The revealed comparative advantage of country j for production in sector i is defined by Balasa (1965) as:

$$b_j^i = \frac{X_j^i}{\sum_i X_j^i} / \sum_j \left(\frac{X_j^i}{\sum_i X_j^i} \right) \tag{II.4}$$

where X_j^i are aggregate exports by country j in sector i. Our third term in $\mathbf{X}_{jh}^{S}$ is then defined as follows:

$$b_{jh} = \sum_{i \in \mathcal{N}} \left| b_j^i - b_h^i \right| \tag{II.5}$$

Regression Model

To estimate the effects of trade and financial integration on international business cycle correlation we use a simultaneous equations model similar to the one introduced in Imbs (2004). In this model, trade integration, financial integration, industrial specialization, and business cycle correlation are all determined endogenously. Thus our simultaneous equations model will consist of four equations:

$$\begin{aligned} \rho_{jh} &= \alpha + bF_{jh} + aT_{jh} + cS_{jh} + \varepsilon_{jh} \\ F_{jh} &= \delta + dT_{jh} + iS_{jh} + \boldsymbol{\delta}\mathbf{X}_{jh}^F + \upsilon_{jh} \\ T_{jh} &= \beta + eF_{jh} + fS_{jh} + \boldsymbol{\beta}\mathbf{X}_{jh}^T + \eta_{jh} \\ S_{jh} &= \gamma + hF_{jh} + gT_{jh} + \boldsymbol{\gamma}\mathbf{X}_{jh}^S + \mu_{jh} \end{aligned} \tag{II.6}$$

The nine channels labeled $a - i$ in figure 1 each correspond to specific coefficients in this system of equations.

Regression Results

The estimation results from the system of equations in (II.6) are reported in table 2. The table reports the results from both an estimation using OLS and an estimation using multiple equation GMM.

Table 2. OLS and GMM estimation for the channels between trade, finance, specialization, and output co-movement, using the notation from figure 1.

	Channel	OLS Coefficient	OLS SE	GMM Coefficient	GMM SE
a	T to ρ	0.075^{**}	(0.008)	0.116^{**}	(0.015)
b	F to ρ	-0.028^{**}	(0.010)	-0.175^{**}	(0.054)
c	S to ρ	-0.131^{**}	(0.026)	-0.258^{*}	(0.152)
d	T to F	0.153^{**}	(0.036)	0.595^{**}	(0.107)
e	F to T	0.100^{**}	(0.023)	0.858^{**}	(0.147)
f	S to T	0.828^{**}	(0.065)	-2.735^{**}	(0.359)
g	T to S	0.066^{**}	(0.009)	-0.063^{**}	(0.012)
h	F to S	0.074^{**}	(0.010)	0.218^{**}	(0.038)
i	S to F	0.467^{**}	(0.079)	2.809^{**}	(0.384)

Notes: F, T, and S are the logarithm of the variables that appear in the text. Intercepts and other control variables are not reported. The control variables for endogenous variable x are reported as $\mathbf{X}^x$ in the text, where $x = F, T$, or S. In the GMM estimation the control variables for x when x is a dependent variable served as the instruments for x when x is an independent variable.

Turning first to the channels between bilateral trade and bilateral financial integration (channels d and e), we see that trade has a positive effect on financial integration and finance has a positive effect on trade. This confirms the complementarity between trade and financial integration found in previous empirical studies.

The channels between bilateral trade integration and bilateral industrial specialization (channels f and g) show that trade has a negative effect on specialization and vice versa. This finding, which seems to contradict the findings of many trade models, has been found in previous empirical studies and reflects the importance of intra-industry trade.

The channels between bilateral financial integration and bilateral industrial specialization (channels h and i) show that financial integration has a positive effect on specialization and vice versa. This confirms the findings of previous empirical works that have shown a positive causal channel from financial integration to industrial specialization and it confirms the predictions of previous theoretical papers that predict financial integration should arise endogenously between countries that are subject to idiosyncratic shocks.

The channels from trade, finance, and specialization to bilateral business cycle co-movement (channels a, b, and c) shows that trade leads to business cycle convergence while finance and specialization both lead to business cycle divergence. This confirms the findings of many previous empirical and theoretical studies.

The model

The model in this paper is a multi-sector international real business cycle model. As in Kose and Yi (2006) there are three countries, two small countries (country 1 and country 2) and the rest of the world (w). These three countries trade both final goods and intermediate inputs. Production in each country is in two sectors: non-durable manufacturing and durable manufacturing. Country 1 is given an absolute advantage in the non-durable manufacturing sector and country 2 has an absolute advantage in the durable sector.[2] Production is a function of labor, which is mobile across sectors but not countries, physical capital, which is not mobile across sectors or countries, and traded intermediate inputs. In this model, economic fluctuations are driven by exogenous productivity shocks. There is one representative household and two representative firms (one in the durable sector and one in the non-durable sector) in each country. The household consumes final goods and supplies labor to domestic firms. Household income is a function of wage income and dividend payments from both domestic and foreign firms. Firms own capital, and they use final goods to invest in new capital. The firm pays a dividend to shareholders that is equal to its operating income (revenue minus the wage bill and the cost of intermediate inputs)

[2] We label to sectors durable and non-durable merely for convenience. The two small countries are symmetric except for the fact that one county has an absolute advantage in one sector and one has an absolute advantage in the other sector. The two sectors are identical and the degrees of the absolute advantages are identical. Thus the real variables like aggregate consumption, aggregate labor, and aggregate capital stock are equal across the two countries in the steady state.

minus capital expenditures.

We begin with a description of the household's problem, preferences, and budget constraints. Then we will describe the objectives and production technologies of each firm. Then finally we will discuss the process driving the exogenous productivity shocks and some key parameters in the model.

Households

The one representative household per country derives utility from consumption and leisure. The household in country j, with $j = 1, 2, w$, maximizes expected lifetime utility:

$$E_0 \sum_{t=o}^{\infty} \beta_t \left\{ \frac{1}{1-\sigma} (C_{jt})^{1-\sigma} - \kappa \frac{\sigma^h}{\sigma^h + 1} (N_{jt})^{\frac{\sigma^h+1}{\sigma^h}} \right\} \tag{II.7}$$

where σ is the coefficient of relative risk aversion and σ^h is the labor supply elasticity. C_{jt} represents consumption of final goods, and N_{jt} represents the labor supplied by the household in country j at time t. Households can only supply labor to domestic firms, so the total labor supplied, N_{jt}, equals the sum of labor demanded by firms in the nondurable and durable sectors (n and d) for both the production of intermediate inputs and the production of final goods, $\sum_{i \in n,d} \left(N_{jt}^{xi} + N_{jt}^{yi} \right)$. The superscript x denotes that the labor is an input into the production of intermediate goods and the superscript y denotes that the labor is an input into the production of final goods.

In period 0, the representative firms in the durable and nondurable sectors are held entirely by the domestic household. In period 0 the representative domestic household can sell shares of these firms to households in the other two countries and buy shares of foreign firms. For the household in country j in period 0 the value of the domestic firm in sector $i = n, d$ is $\mathcal{P}_j^i$ and the value of the foreign firms in sector i is $\mathcal{P}_h^i$ (where $h \neq j$). The representative household will then sell shares of the domestic firms and buy shares of the foreign firms. The period 0 budget constraint for the representative household in country j is:

$$C_{j,0} + \sum_{i \in n,d} \lambda_{jj}^i \mathcal{P}_j^i + \sum_{i \in n,d} \lambda_{hj}^i \mathcal{P}_h^i + \sum_{i \in n,d} \lambda_{wj}^i \mathcal{P}_w^i = w_{j,0} N_{j,0} + \sum_{i \in n,d} \left(\mathcal{P}_j^i + d_{j,0}^i \right) \tag{II.8}$$

where d_{jt}^i are dividends paid by the firm in sector i in country j, and λ_{hj}^i is the share of the firm in sector i in country h that is held by households in country j. The shares of the firm held in the three countries must sum to unity, so $\lambda_{h1}^i + \lambda_{h2}^i + \lambda_{hw}^i = 1$, for all i and h.

After period 0 the representative household in each country earns labor income from domestic firms and dividend income from domestic and foreign firms. The budget constraints for the representative households in countries 1 and 2 are:

$$C_{jt} = w_{jt} N_{jt} + \sum_{i \in n,d} \lambda_{jj}^i d_{jt}^i + \sum_{i \in n,d} (1 - \tau) \lambda_{hj}^i r x_t^{jh} d_{ht}^i + \sum_{i \in n,d} (1 - \tau) \lambda_{wj}^i r x_t^{jw} d_{wt}^i \tag{II.9}$$

where cross-border dividend payments are taxed at a rate τ. Also notice that since dividends are in terms of the domestic consumption good, cross border dividends from country h to country j are adjusted by the real exchange rate rx_t^{jh}.

Firms and Technology

Production Technology

Production in each sector and in each country is in two stages. There is the intermediate goods production stage and the final goods production stage. The intermediate goods production stage is the simplest, since it is just a function of internationally immobile capital and labor. N_{jt}^{xi} and K_{jt}^{xi} are the labor and capital devoted to the production of intermediate goods in sector $i = n, d$ and country $j = 1, 2$ at time t.[3] Notice the superscript x which denotes the use of the inputs in the intermediate goods production stage. This labor and capital are combined in a Cobb-Douglas production function to produce the intermediate good from sector i in country j, X_{jt}^{i}.

$$X_{jt}^{i} = A_{jt}^{i} \left(N_{jt}^{xi}\right)^{\theta} \left(K_{jt}^{xi}\right)^{1-\theta} \tag{II.10}$$

Production is augmented by A_{jt}^{i}, which is a productivity parameter specific to sector i in country j at time t. In this real business cycle model, shocks to A drive business cycle fluctuations. There are more details about the shock process and calibration in a later section.

Output from the intermediate goods production stage, X_{jt}^{i}, is then distributed as an intermediate input to both sectors in all three countries, subject to the following constraint:

[3] In this description of the production technology, country j is one of the two small countries, not the rest of the world. Since the small countries and the rest of the world differ only in size, the model equations are nearly identical. The only difference is in the resource constraints in (II.11) and (II.16)

$$\pi X_{jt}^{i} = \sum_{k \in n,d} \left(\pi x_{j1t}^{ik} + \pi x_{j2t}^{ik} + (1 - 2\pi)\, x_{jwt}^{ik} \right) \tag{II.11}$$

where x_{jht}^{ik} is an intermediate input supplied by sector $i = n, d$ in country $j = 1, 2$ that is used by sector $k = n, d$ in country 1, 2, or w at time t. Since all variables are in per capita terms, the resource constraint must be altered to account for the relative size of each of the small countries. π is the size of each of the two small counties, and $1 - 2\pi$ is the size of the rest of the world. In this constraint, $j = 1$ or 2, if instead j were the rest of the world, then the coefficient of X_{jt}^{i} would be $1 - 2\pi$ instead of π . Notice that when the intermediate goods are written as an output from the first stage of production, they are written with capital letters, X. When the intermediate goods are then used as an input they are written with lower case letters, x. This capital/lower case - output/input convention will be used throughout this paper.

The intermediate inputs $x_{1jt}^{ik}, x_{2jt}^{ik}, x_{wjt}^{ik}$ are stage 1 outputs from sector i in country $1, 2$, or w used as inputs in sector k in country j. Domestic and foreign inputs are imperfect substitutes, and they are combined in the following CES aggregator:

$$x_{jt}^{ik} = \left[\omega_{1j}^{x} \left(x_{1jt}^{ik} \right)^{\frac{\sigma^x - 1}{\sigma^x}} + \omega_{2j}^{x} \left(x_{2jt}^{ik} \right)^{\frac{\sigma^x - 1}{\sigma^x}} + \omega_{wj}^{x} \left(x_{wjt}^{ik} \right)^{\frac{\sigma^x - 1}{\sigma^x}} \right]^{\frac{\sigma^x}{\sigma^x - 1}} \tag{II.12}$$

where σ^x is the elasticity of substitution between domestic and imported intermediate inputs, and ω_{hj}^{x} is the weight placed on intermediate goods produced by country h and used in country j. These ω parameters are set such that the volume of bilateral trade predicted by the model is the same as in the data.

The intermediate inputs x_{jt}^{nk} and x_{jt}^{dk} are both inputs into sector k but are imperfect substitutes. They are combined into one intermediate input term by the following CES function:

$$x_{jt}^{k} = \left[\eta \left(x_{jt}^{kk} \right)^{\frac{\sigma^{II}-1}{\sigma^{II}}} + (1-\eta) \left(x_{jt}^{ik} \right)^{\frac{\sigma^{II}-1}{\sigma^{II}}} \right]^{\frac{\sigma^{II}}{\sigma^{II}-1}} \text{ where } i \neq k \tag{II.13}$$

where σ^{II} is the elasticity of substitution between intermediate inputs into sector k, and η is the weight placed on inputs from sector k into sector k.

There is also a value added component to the production of final goods. The inputs into the value added component are labor and capital, N_{jt}^{yk} and K_{jt}^{yk} (notice that the labor and capital terms are written the same as in equation (II.10), only now they are written with a superscript y to denote their use in producing final goods). The technology that combines the two is the same as in the intermediate production stage.

$$VA_{jt}^{k} = A_{jt}^{k} \left(N_{jt}^{yk} \right)^{\theta} \left(K_{jt}^{yk} \right)^{1-\theta} \tag{II.14}$$

In production of final goods the value added component, VA_{jt}^{k}, is combined with the intermediate inputs component, x_{jt}^{k}, to produce the final good. This combination is described by the following CES function:

$$Y_{jt}^{k} = \left[\gamma \left(VA_{jt}^{k} \right)^{\frac{\sigma^{VI}-1}{\sigma^{VI}}} + (1-\gamma) \left(x_{jt}^{k} \right)^{\frac{\sigma^{VI}-1}{\sigma^{VI}}} \right]^{\frac{\sigma^{VI}}{\sigma^{VI}-1}} \tag{II.15}$$

where σ^{VI} is the elasticity of substitution between value added and intermediate inputs.

This final good Y_{jt}^{k} is then used domestically or exported. The distribution is subject to the following constraint:

$$\pi Y_{jt}^{k} = \pi y_{j1t}^{k} + \pi y_{j2t}^{k} + (1-2\pi)\, y_{jwt}^{k} \tag{II.16}$$

Notice again that the size parameter π is included in the resource constraint to account for the size of the two small countries relative to the rest of the world. If instead of representing the distribution of final goods from one of the two small counties the equation was meant to represent the distribution of final goods from the rest of the world then the coefficient of Y_{jt}^{k} is $1-2\pi$.

Just as before when combining domestic and foreign intermediate inputs, domestic and foreign final goods are imperfect substitutes and are combined in the following CES function:

$$y_{jt}^{k} = \left[\omega_{1j}^{y}\left(y_{1jt}^{k}\right)^{\frac{\sigma^{y}-1}{\sigma^{y}}} + \omega_{2j}^{y}\left(y_{2jt}^{k}\right)^{\frac{\sigma^{y}-1}{\sigma^{y}}} + \omega_{wj}^{y}\left(y_{wjt}^{k}\right)^{\frac{\sigma^{y}-1}{\sigma^{y}}}\right]^{\frac{\sigma^{y}}{\sigma^{y}-1}} \tag{II.17}$$

for $k = n, d$, where σ^{y} is the elasticity of substitution between home and foreign varieties of the final good, and ω_{hj}^{y} is a parameter used to calibrate the volume of trade in final goods from country h to country j.

The final goods from each sector are combined in another CES aggregator function to form aggregate output in country j:

$$y_{jt} = \left[\frac{1}{2}\left(y_{jt}^{n}\right)^{\frac{\sigma^{f}-1}{\sigma^{f}}} + \frac{1}{2}\left(y_{jt}^{d}\right)^{\frac{\sigma^{f}-1}{\sigma^{f}}}\right]^{\frac{\sigma^{f}}{\sigma^{f}-1}} \tag{II.18}$$

where σ^{f} is the elasticity of substitution across the final output from each sector.

This final output is then used by households for consumption and firms for investment:

$$y_{jt} = C_{jt} + \sum_{i \in n,d} I^i_{jt} \tag{II.19}$$

where I^i_{jt} is investment in physical capital undertaken by the firm in sector i in country j at time t.

The country and sector specific capital stock evolves according to:

$$K^i_{jt+1} = (1-\delta) K^i_{jt} + \phi\left(\frac{I^i_{jt}}{K^i_{jt}}\right) K^i_{jt} \tag{II.20}$$

where δ is the one-period depreciation rate of capital, and $\phi(x)$ that describes the cost of capital adjustment.[4] The capital stock available to sector i in country j at time t, K^i_{jt}, equals the capital demanded for both the production of intermediate inputs and the production of final goods, $K^{xi}_{jt} + K^{yi}_{jt}$.

Dividends and the firm's problem

The firm's objective is to maximize its stock price. The solution to the household's maximization problem in the appendix reveals that the firm's stock price, $\mathcal{P}^i_{jt}$, is simply the expected discounted value of future dividends:

$$\mathcal{P}^i_{jt} = E_t \sum_{\tau=1}^{\infty} Q^i_{jt+\tau} d^i_{jt+\tau} \tag{II.21}$$

where $Q^i_{jt+\tau}$ is the price that the firm in sector i and country j uses to value dividend payments in time $t+\tau$ relative to consumption at time t.[5] The firm's dividend (in units

[4] $\phi' > 0$ and $\phi'' < 0$. The model is solved using a first-oder approximation, so a specific functional form for $\phi(x)$ is not necessary, but the function can be expressed as $\phi(x) = \left[x - \frac{\kappa}{2}(x-\delta)^2\right]$ with $\kappa \geq 0$.

[5] We will assume that the domestic firm discounts future dividends in time $t+\tau$ by the time discounting factor β multiplied by a ratio of the domestic marginal utility of consumption in time $t+\tau$ to the domestic

of the final consumption/investment good), d^i_{jt}, is equal to its operating income at time t minus any capital expenditures:

$$d^i_{jt} = \left(P^{yi}_{jt}Y^i_{jt} + P^{xi}_{jt}X^i_{jt}\right) - w_{jt}\left(N^{yi}_{jt} + N^{xi}_{jt}\right) - \sum_{k=n,d} p^{xk}_{jt}x^{ki}_{jjt} - \sum_{k=n,d} rx^{hj}_t p^{xk}_{ht}x^{ki}_{hjt} - \sum_{k=n,d} rx^{wj}_t p^{xk}_{wt}x^{ki}_{wjt} - I^i_{jt} \tag{II.22}$$

where P^{yi}_{jt} and P^{xi}_{jt} are the prices of final output and intermediate goods, respectively. Thus $P^{yi}_{jt}Y^i_{jt} + P^{xi}_{jt}X^i_{jt}$ is total revenue of the firm in sector i in country j. w_{jt} is the wage rate paid to workers in country j, so $w_{jt}\left(N^{yi}_{jt} + N^{xi}_{jt}\right)$ is the firm's wage bill.[6] $\sum_{k=n,d} p^{xk}_{jt}x^{ki}_{jjt}$ is the expenditure on domestically supplied intermediate inputs from both sectors, and $\sum_{k=n,d} rx^{hj}_t p^{xk}_{ht}x^{ki}_{hjt} + \sum_{k=n,d} rx^{wj}_t p^{xk}_{wt}x^{ki}_{lwjt}$ is the expenditure on imported intermediate inputs. Since the price of foreign intermediate inputs, p^{xk}_{ht} and p^{xk}_{lt}, is in terms of the foreign consumption/investment good, foreign prices must also be multiplied by the real exchange rates rx^{hj}_t and rx^{wj}_t. Finally, capital expenditure is simply the real cost of physical capital investment, I^i_{jt}.

Since markets are perfectly competitive, the representative firm's operating income can be represented as the capital stock available to the firm at time t multiplied by the sector and country specific shadow price of capital, r^i_{jt}:

$$d^i_{jt} = r^i_{jt}K^i_{jt} - I^i_{jt} \tag{II.23}$$

marginal utility of consumption in time t, $Q^i_{jt+\tau} = \frac{\beta^\tau MU_{jt+\tau}}{MU_{jt}}$. This discount rate can be altered to account for foreign marginal utilities as well, and this may be reasonable when the firm is owned by both domestic and foreign residents. But including both domestic and foreign marginal utilities in the discount factor can give rise to a specific type of externality highlighted in Heathcote and Perri (2004). Under certain circumstances this externality can give rise to multiple equilibria. To insure that the results from the model are not clouded by the existence of these multiple equilibria, we will assume the firm's discount factor is determined by domestic preferences alone.

[6] Labor is mobile across sectors (nondurable and durable) and across stages of production (intermediate and final goods stages), but is not mobile across countries. Thus the wage rate, w_j, is country specific.

Exogenous Productivity Shocks

In this model the exogenous productivity parameter A^i_{jt} serves two purposes. As in all real business cycle models, changes in A^i_{jt} represent technology shocks that shift the supply curve and drive business cycle fluctuations. Also, in this multi-sector, multi-country model we can also use the steady state value of A^i_j to give one country an absolute advantage in a certain sector, and thus induce industrial specialization.

To describe the stochastic movements in A^i_{jt}, we first calculate Solow residuals in the durable and nondurable sectors in 17 countries using sector level value added, employment, and capital stock data taken from the OECD's STAN database.[7] We use these 34 time series of Solow residuals (2 sectors per country, 17 countries) to estimate 2 sector specific shocks and 16 country specific shocks using the factor model in Stockman (1988).

Therefore each of our 34 time series of Solow residuals can be decomposed into a sector specific component, a country specific component, and an idiosyncratic component:

$$\hat{A}^i_{jt} = \hat{A}^i_t + \hat{A}_{jt} + \hat{a}^i_{jt} \tag{II.24}$$

If we assume that the industry specific shocks are orthogonal to the country specific shocks then we can separately estimate the process driving the industry specific shocks and the process driving the country specific shocks. We write the two sector specific shocks as a vector, $\mathbf{A}^s_t = \begin{bmatrix} \hat{A}^n_t & \hat{A}^d_t \end{bmatrix}'$, and assume that they follow a VAR(1) process described by:

$$\begin{aligned} \mathbf{A}^s_t &= \boldsymbol{\rho}^s \mathbf{A}^s_{t-1} + \boldsymbol{\varepsilon}_t \qquad \text{(II.25)} \\ \text{where } \boldsymbol{\Omega}^s &= \mathbf{E}\left(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}'_t\right) \end{aligned}$$

[7] Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Mexico, Norway, Portugal, Sweden, United Kingdom, and the United States

Furthermore since we are using nondurables and durables as names for generic, identical sectors, we need to make the $\boldsymbol{\rho}^s$ and $\boldsymbol{\Omega}^s$ matrices symmetric:

$$\boldsymbol{\rho}^s = \begin{bmatrix} 0.3449 & 0.0344 \\ 0.0344 & 0.3449 \end{bmatrix} \text{ and } \boldsymbol{\Omega}^s = 10^{-3} \begin{bmatrix} 0.3570 & 0.2414 \\ 0.2414 & 0.3570 \end{bmatrix} \tag{II.26}$$

Similarly we can write any pair of country specific shocks as a vector, $\mathbf{A}_t^c = \begin{bmatrix} \hat{A}_{jt} & \hat{A}_{kt} \end{bmatrix}'$, and assume they follow a VAR(1) process described by:

$$\begin{aligned} \mathbf{A}_t^c &= \boldsymbol{\rho}^c \mathbf{A}_{t-1}^c + \boldsymbol{\varepsilon}_t \\ \text{where } \boldsymbol{\Omega}^c &= \mathbf{E}\left(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t'\right) \end{aligned} \tag{II.27}$$

If we average the $\boldsymbol{\rho}^c$ and $\boldsymbol{\Omega}^c$ matrices across all country pairs, jk, then the stochastic process describing the country specific shocks is:

$$\boldsymbol{\rho}^c = \begin{bmatrix} 0.4280 & -0.0480 \\ -0.0480 & 0.4280 \end{bmatrix} \text{ and } \boldsymbol{\Omega}^c = \begin{bmatrix} 0.0025 & 0.0006 \\ 0.0006 & 0.0025 \end{bmatrix} \tag{II.28}$$

Finally, if we combine the sector and country specific idiosyncratic shocks for any pair of countries into a 4x1 vector, $\mathbf{a}_t^i = \begin{bmatrix} a_{jt}^n & a_{jt}^d & a_{kt}^n & a_{kt}^d \end{bmatrix}'$, then we can calculate the variance matrix of the idiosyncratic shocks for any pair of countries. The variance matrix when averaged across all country pairs is:

$$\mathbf{\Omega}^i = 10^{-3} \begin{bmatrix} 0.4130 & -0.4130 & -0.0262 & 0.0262 \\ -0.4130 & 0.4130 & 0.0262 & -0.0262 \\ -0.0262 & 0.0262 & 0.4130 & -0.4130 \\ 0.0262 & -0.0262 & -0.4130 & 0.4130 \end{bmatrix} \tag{II.29}$$

Other Parameters

All parameter values are listed in table 6. The first 9 parameters are taken from existing business cycle literature. In the various simulations in the next section, the period length is one quarter. The first two parameters, the discount factor and the depreciation rate, are commonly found in the literature for periods of one quarter. The elasticity of substitution across final goods from different sectors, σ^f, is taken from Ambler, Cardia, and Zimmermann (2002). The elasticity of substitution between home and foreign goods can be thought of as the import demand elasticity. Anderson and van Wincoop (2004) survey the literature that attempts to measure this elasticity and find that at the sectoral level of disaggregation, the import demand elasticity is somewhere between five and ten. We assume that this elasticity is equal to five.

The next three parameters like labor share, θ, the weight placed on intra-industry intermediate inputs, η, and the share of value added in the production of final goods, γ, are all derived from input-output tables. The parameter that describes the relative size of one of the two small countries, π, is set to equal the relative size of one of the countries in our empirical estimations.

The investment adjustment cost parameter, κ, is calibrated such that in the model,

Table 3. Parameter values for the model in chaper II

Symbol	Value	Description
β	0.99	discount factor
δ	0.025	capital depreciation rate
σ	2	coefficient of relative risk aversion
σ^f	0.9	eos* across final goods
σ^y	5	eos* between home and foreign final goods
σ^{VI}	0.5	eos* between value added and intermediate inputs
σ^{II}	0.5	eos* between intermediate inputs from various sectors
σ^x	5	eos* between home and foreign intermediate goods
θ	0.6136	labor share
η	0.8615	weight placed on inputs into sector i from sector i
γ	0.4397	weight placed on value added in production of final goods
π	0.015	relative size of one of the two small countries
κ	7	investment adjustment cost parameter
ω_w^x	0.5734	weight on imported intermediate inputs from ROW
ω_w^y	0.2373	weight on imported final goods from ROW
ω^x	0.0098	weight on imported intermediate inputs from the other small country
ω^y	0.0041	weight on imported final goods from the other small country
τ	0.0044	tax rate on foreign dividends
A_1^n, A_2^d	1.0719	absolute advantage of country 1 in sector n and country 2 in sector d

* eos=elasticity of substitution

investment is about 2.75 times more volatile than GDP.

The model is calibrated to match observed steady state levels of trade integration, financial integration, and industrial specialization. These observed steady state levels are referred to as *targets*. In the calibration of the model we have six *targets* to hit.

These targets are the average levels of trade integration, financial integration, and industrial specialization from the countries in our empirical estimations.

The target variable measuring trade integration is defined in (II.2). This variable can loosely be defined as the import penetration ratio. Specifically, our target measure of intermediate goods trade integration is 0.321 and our target level of final goods trade integration is 0.237. Since the measure of trade integration in (II.2) is independent of country size, these target values are the same whether we are describing trade between the two small countries or one country and the rest of the world.[8] Our target measure of industrial specialization is also taken from the empirical model. In the data, the average level of industrial specialization, as defined by (II.3), is 0.157. The target for financial integration is the percent of a household's equity portfolio that is made up of foreign equities. The model is calibrated such that 10% of the household's equity portfolio is made up of foreign securities..

To hit these targets, we use six parameters, technology parameters describing preference for imported intermediate and final goods from the other small country and the rest of the world, $\omega^x_{jh}, \omega^x_{wj}, \omega^y_{jh}, \omega^y_{wj}$, the tax rates on foreign dividends, τ , and the exogenous absolute productivity advantage for country j in sector i, A^i_j. The benchmark values of these parameters are listed in table 6.

Results

Intuition for the channels between finance and specialization

First, consider the solution to the household's problem presented in the appendix. We can use the first order conditions with respect to domestic and foreign asset holdings to derive an expression for the value of a share of firm i in country j. The same stream of dividend payments may be valued differently by domestic and foreign investors because of tax rates, exchange rates, and differences in discount factors. Therefore the value of the firm to households in country j and country h is, respectively:

[8] This size independence is the virtue of using the measure of trade integration defined in (II.2) instead of the measure defined in (A.7).

$$\mathcal{P}^i_{jj} = \frac{\sum_{t=1}^{\infty} \beta^t E_0 \left(\upsilon_{jt} d^i_{jt} \right)}{\upsilon_{j,0}} \tag{II.30}$$

$$\mathcal{P}^i_{jh} = \frac{(1-\tau) \sum_{t=1}^{\infty} \beta^t E_0 \left(\upsilon_{ht} \frac{d^i_{jt}}{rx_t} \right)}{\upsilon_{h,0}}$$

where $\mathcal{P}^i_{jj}$ is the value of firm i in country j to investors in country j and $\mathcal{P}^i_{jh}$ is the value of the same firm to foreign investors in country h.

υ_{jt} is equal to the marginal utility of consumption in country j, $(C_{jt})^{-\sigma}$. Thus if we apply a second order approximation to the terms $E_0 \left(\upsilon_{jt} d^i_{jt} \right)$ and $E_0 \left(\upsilon_{ht} \frac{d^i_{jt}}{rx_t} \right)$ the asset prices can be written as:

$$\mathcal{P}^i_{jj} = \frac{\beta d^i_j \left(1 + \frac{1}{2}\sigma (\sigma+1) E\left(\hat{c}^2_{jt} \right) - \sigma E \left(\hat{d}^i_{jt} \hat{c}_{jt} \right) \right)}{(1-\beta)} \tag{II.31}$$

$$\mathcal{P}^i_{jh} = \frac{(1-\tau) \beta d^i_{jt} \left(1 + \frac{1}{2}\sigma (\sigma+1) E\left(\hat{c}^2_{ht} \right) - \sigma E \left(\hat{c}_{ht} \hat{d}^i_{jt} \right) \right)}{(1-\beta)}$$

where a "hat" over a variable represents a percent deviation from its steady state value.[9] Therefore $E\left(\hat{x}^2\right)$ is the variance of x and $E\left(\hat{x}\hat{y}\right)$ is the covariance between x and y.

We will stop here with the asset price equations and now turn to the firm's investment decision. Consider the first order condition of the firm's problem with respect to the capital stock in the next period. For the sake of simplicity, assume that there are no investment adjustment costs:

$$E_t \beta \left\{ Q^i_{jt+1} \left(1 - \delta + r^i_{jt+1} \right) \right\} = Q^i_{jt} \tag{II.32}$$

Use the fact that $Q^i_{jt+\tau} = \frac{\beta^\tau \upsilon_{jt+\tau}}{\upsilon_{jt}}$, and then take a second order approximation

[9] For clarity of explanation we omitted the covariances involving rx_t from the second order approximation of $\mathcal{P}^i_{jh}$. They are included in the actual numerical simulations. But they are usually one order of magnitude smaller than the other covariances, so they can be omitted without jeopardizing any intuitive explanation.

of the term $E_t\beta\left\{Q^i_{jt+1}\left(1-\delta+r^i_{jt+1}\right)\right\}$ to find the required rate of return on capital in sector i in country j:

$$r^i_j = r^{rf}_j \frac{1+\frac{1}{2}\sigma\left(\sigma+1\right)E\left(\hat{c}^2_{jt}\right)}{1+\frac{1}{2}\sigma\left(\sigma+1\right)E\left(\hat{c}^2_{jt}\right)-\sigma E\left(\hat{c}_{jt}\hat{r}^i_{jt}\right)} \tag{II.33}$$

where r^{rf}_j is the risk free rate of interest, $r^{rf}_j = \left(\frac{1}{\beta\left(1+\frac{1}{2}\sigma(\sigma+1)E\left(\hat{c}^2_{jt}\right)\right)}-1+\delta\right)$

If we consider the "market portfolio" in country j to have identical fluctuations with consumption in country j, then we can use this last expression to find a version of the consumption-CAPM, as in Lucas (1978) and Breeden (1979).

$$r^i_j = r^{rf}_j + \beta^i_j\left(r^c_j - r^{rf}_j\right) \tag{II.34}$$

where r^c_j is the return on the market portfolio, and β^i_j measures the riskiness of capital in sector i by measuring the covariance between r^i_j and returns to the market portfolio.

For the intuition of how financial integration leads to industrial specialization and how industrial specialization leads to financial integration, consider the household's budget constraint in period t:

$$C_{jt} = w_{jt}N_{jt} + \sum_{i\in n,d}\lambda^i_{jj}d^i_{jt} + \sum_{i\in n,d}\left(1-\tau\right)\lambda^i_{hj}rx^{jh}_t d^i_{ht} + \sum_{i\in n,d}\left(1-\tau\right)\lambda^i_{wj}rx^{jw}_t d^i_{wt}$$

Imagine that the degree of international financial integration is low; thus households hold equity portfolios that are strongly biased towards home assets ($\lambda_{jj}\approx 1$ and $\lambda_{hj},\lambda_{wj}\approx 0$). Now, imagine that production in each country is at least partially specialized, with country j partially specialized in sector n and country h partially specialized in sector d. Then a large percentage of household j's dividend income, and thus income, comes from sector n, and a large percentage of household h's income comes from sector d. If business cycles are at least partially driven by industry specific shocks, countries j and h have highly idiosyncratic income fluctuations.

The combination of home biased portfolios and industrial specialization means that the covariance of fluctuations in d^n_{jt} and C_{jt} is high, and the covariance of fluctuations in d^n_{jt} and C_{ht} is low. From the asset price equations in (II.31) we can see that households in country j will assign a low value to shares in the home firm in sector n, but household's in country h will assign a high value to the same shares, $\mathcal{P}^i_{jh} > \mathcal{P}^i_{jj}$.

In equilibrium, both domestic and foreign households assign the same value to the firm. Households in country j will sell shares of the domestic firm in sector n to households in country h, $\lambda^n_{jj} \downarrow$ and $\lambda^n_{jh} \uparrow$. This portfolio adjustment will cause the covariance of fluctuations in d^n_{jt} and C_{jt} to fall and the covariance of fluctuations in d^n_{jt} and C_{ht} to rise. This portfolio adjustment will continue until $\mathcal{P}^i_{jh} = \mathcal{P}^i_{jj}$ and there are no gains to international asset trade.

The tax rate τ will lessen and potentially negate these gains from asset trade, but as long as τ is low enough that households hold a portfolio comprised of both home and foreign assets, and industry specific shocks play some role in business cycle fluctuations, then greater bilateral industrial specialization will lead to greater bilateral financial integration.

For the intuition of why financial integration leads to industrial specialization, again turn to the household's budget constraint. Imagine that country j has an absolute advantage in sector n. This means that country j will be at least partially specialized in sector n. If households own highly home biased equity portfolios, then household income in country j is highly dependent on the fortunes of sector n. Thus the covariance between fluctuations in r^n_{jt} and C_{jt} is high. The required rate of return on investments in sector n in country j is high, as shown by (II.33). This high required rate of return will lead to less investment and production in sector n, even though country j has an absolute advantage. Financial integration will mean that the household does not hold a portfolio as heavily biased towards home assets, and this will separate idiosyncratic fluctuations in sector n from household income in country j. This will cause the covariance between r^n_{jt} and C_{jt} to fall, and thus the required rate of return will fall. This will lead to more investment and production in sector n, and country j will specialize in order to realize the potential benefits of their absolute advantage.

Numerical results from the model

The steady state solution to the model will depend on the variances and covariances of real variables (e.g., the covariance between consumption and dividend payments). We find these variances and covariances through a stochastic approximation, and a stochastic approximation is only good in the neighborhood of the steady state. Therefore we need to solve the model using a solution algorithm described in the appendix.

To measure the channels between trade, finance, and specialization, and between these three real variables and cyclical correlation, we make use of the fact that trade, finance, specialization, and cyclical correlation are all endogenous in this model.

The channels we wish to measure are labeled $a - i$ in figure 1. However we cannot simply increase bilateral trade integration and measure the resulting change business cycle correlation to find a. As the figure shows, since financial integration and industrial specialization are both endogenous, increasing trade has an effect on finance and specialization which in turn have their own effects on cyclical correlation. Therefore simply measuring the change in cyclical correlation resulting from an exogenous change in trade integration will capture the direct effect of trade on correlation as well as any indirect effects through finance and specialization.

These direct and indirect effects and how they relate to the nine channels in figure 1 are listed in table 4. If, for instance, we were to measure the change in financial integration resulting from an exogenous increase in trade integration, we would measure both the direct channel (d) and the indirect channel whereby trade affects specialization which in turn affects finance ($g \times h$). Our measured change in financial integration resulting from an exogenous increase in trade integration is equal to $d + g \times h$. If we engineer exogenous changes in trade, finance, or specialization and measure the resulting change in the other two endogenous variables as well as cyclical correlation then table 4 shows how the various direct channels (a through i) can be found by solving a non-linear system of nine equations and nine unknowns.

Table 4. The direct and indirect effects of trade, finance, and specialization on business cycle co-movement, using the notation in figure 1

Channel	Direct Effect	Indirect Effect
T to ρ	a	$d \times b + g \times c + d \times h \times c + g \times i \times b$
F to ρ	b	$e \times a + h \times c + e \times g \times c + h \times f \times a$
S to ρ	c	$f \times a + i \times b + f \times d \times b + i \times e \times a$
T to F	d	$g \times h$
F to T	e	$h \times f$
S to T	f	$i \times e$
T to S	g	$d \times h$
F to S	h	$e \times g$
S to F	i	$f \times d$

These nine channels are listed in the first column in table 5. The numerical results from the model are directly comparable to the estimation results in table 2. Specifically, the table shows the percent change in an endogenous variable arising from an exogenous 1% increase in another variable. Thus turning to the channel from trade integration to financial integration (channel d), the first column of table 5 shows that an exogenous 1% increase in bilateral trade leads to an endogenous fall in bilateral financial integration of about 0.5%.

Thus the model predicts that trade has a negative effect on financial integration. This is consistent with the findings from Cole and Obstfeld (1991), who show that trade and financial integration are substitutes in terms of providing consumption risk sharing. However Forbes (2008) argues that cross-country differences in financial development, not risk sharing, are the main driver of international financial flows. Similarly, Antràs and Caballero (2007) argue that the complementarity of trade and financial integration in the data is due to trade and financial flows involving less financially developed economies. Risk sharing through portfolio diversification is the primary reason for bilateral financial integration in this model, and there are no differences across countries in financial development, so consistent with the risk sharing channel from Cole and Obstfeld, we should expect a trade to have a negative effect on financial integration.

Table 5. Theoretical predictions of the elasticities of output co-movement, trade integration, financial integration, and industrial specialization with respect to changes in trade, finance, and specialization

		Elasticities implied by the model	
	Channel	without 3^{rd} country effect	with 3^{rd} country effect
a	T to ρ	0.004	0.029
b	F to ρ	-0.004	-0.004
c	S to ρ	-0.0001	-0.008
d	T to F	-0.580	-6.347
e	F to T	0.000	0.000
f	S to T	0.009	0.009
g	T to S	0.020	0.520
h	F to S	0.0002	0.0003
i	S to F	15.759	3.512

In the data we also see that finance has a positive effect on trade, channel e. The model predicts that finance has no effect on trade. This is consistent with Manova (2008) who argues that the empirical finding of a positive effect of finance on trade is due to borrowing constraints, since the vast majority of world trade is facilitated with financial instruments like trade credits. Since no borrowing constraints are introduced in this model, we shouldn't expect the model to predict a positive effect of finance on trade.

The channels from bilateral trade to bilateral industrial specialization and vice versa are indexed f and g. In the data we find that trade has a negative effect on specialization and specialization has a negative effect on trade. This is consistent with Imbs (2004, 2006) who argues that this is due to the importance of intra-industry trade. In the model, trade and finance have a positive effect on one another. This robust result of trade theory should be expected in this case where we are not specifically increasing the degree of *intra-industry* trade integration.

The channels from bilateral financial integration to bilateral industrial specialization and vice versa are indexed h and i. In the data we find that financial integration has a positive effect on specialization and specialization has a positive effect on finance. In the model these two channels are positive as well. This is not surprising since in an earlier section the model is used to show the intuition behind the channels from finance to specialization and vice versa.

The channels from bilateral trade integration, financial integration, and industrial specialization to output correlation are indexed $a-c$. In the data, trade has a positive effect on co-movement but specialization and finance each have a negative effect. The positive effect of trade and the negative effects of finance and specialization hold in the model as well.

A comparison of the model's results in the first column of table 5 with the empirical results in table 2 shows that the international real business cycle model preforms reasonably well in qualitatively matching the data. However the model does not come close to quantitatively matching the data, and usually the channels as measured by the model are a few orders of magnitude smaller than the channels as measured from the data. Kose and Yi (2006) encounter this problem in their three country model as well and conclude that it is due to empirical overestimation, not underestimation in the model. They conclude that the empirical results suffer from omitted variables bias.

The volume of trade between any two countries is usually pretty small, so doubling trade between any two countries does not lead to a large increase in the volume of trade between them. Thus a small increase in the volume of bilateral trade probably doesn't have a great effect on bilateral correlation. When the empirical model measures the effect of increases in bilateral trade integration on bilateral cyclical correlation, it is not controlling for trade with the rest of the world. The empirical results are picking up the fact that for a country pair, an increase in bilateral trade is highly correlated with an increase in total trade. Thus if the two countries have similar trading partners then a large fraction of the effect of trade integration on cyclical correlation is due to increased trade through a third country. This third country effect would be controlled for if a measure of total trade were included in the earlier empirical model, but because of the difficulty in instrumenting for total trade, all empirical studies omit it from the regression, leading to omitted variables bias.

To correct for this third country effect, we recalculate the channels implied by the model, but now we assume that an exogenous increase in trade integration does not just involve an increase in bilateral trade between countries one and two but and increase in trade with the rest of the world as well. Similarly, an exogenous increase in financial integration involves not only an increase in bilateral cross-border portfolio holdings, but an increase in cross-border portfolio holdings with the rest of the world. The results from altering the model to account for this third country effect are found in the second column of table 5. Qualitatively the results are identical when we include trade and financial integration with the rest of the world. For some channels, accounting for trade and financial integration with the rest of the world significantly improves the quantitative predictions of the model. As in Kose and Yi (2006) accounting for trade with the rest of the world greatly improves the model's ability to quantitatively predict the effect of trade integration on cyclical correlation (channel a).

Summary and Conclusion

In this paper, we endogenize bilateral trade integration, financial integration, and industrial specialization in order to find the causal channels between these three real variables and their effect on bilateral business cycle correlation. We first replicated the results of previous empirical studies, then we built an international real business cycle model that could (potentially) replicate each one of these channels. Some of these channels have been modeled before in either the trade or the business cycle literatures, some have not.

The model is able to replicate the effects of trade, finance, and specialization on business cycle correlation. The model is also able to replicate the positive effect of bilateral financial integration on industrial specialization and the positive effect of specialization on finance, but in a few cases the model failed to reproduce the effects from the data.

Empirical studies show that bilateral trade integration has a negative effect on bilateral industrial specialization and vice versa. This result, which is contrary to trade theory, is attributed to the increasing importance of intra-industry trade. In the model, our exogenous increase in trade integration did not emphasize *intra-industry* trade, and thus we found the common result from trade theory. The failure of this model to account for the negative effects of trade on specialization and vice versa show that any attempt to endogenize both trade and industrial specialization needs to account for the role of intra-industry trade.

Empirical studies also show that bilateral financial integration has a positive effect on bilateral trade integration and vice versa. The effect of finance on trade is due to the fact that the vast majority of world trade relies on trade finance, especially trade credits. Financing constraints were not built into this real business cycle model, so the model couldn't replicate the positive effect of finance on trade.

Also, recent studies show that cross-country heterogeneity in financial development is the primary driver of cross-border capital flows and can be responsible for the positive effect of bilateral trade integration on bilateral financial integration. In this real business cycle model there is no cross-country heterogeneity in financial development, so the model is not able to replicate the positive effect of trade on finance. The failure of this model to account for the positive effects of trade on finance and vice versa show that any attempt to endogenize both trade and financial integration needs to account for the role of financing constraints and cross-country differences in financial development.

CHAPTER III

GLOBALIZATION AND THE PHILLIPS CURVE

Introduction

When discussing the macroeconomic impacts of globalization, one question that arises is what effect will globalization have on inflation, specifically the dynamics of the inflation process? Will globalization reduce a central bank's control over domestic inflation?

Economists agree that in a country with a floating currency, the central bank has complete control over the long run rate of inflation. However short term frictions may mean that in the short run inflation is not always a monetary phenomenon, and factors like domestic and foreign excess capacity may have a role in short run fluctuations in inflation.

The effect of globalization on the short run trade-off between output and inflation has been the subject of recent policy discussion.[1] This debate revolves around two related questions. Will globalization reduce the sensitivity of domestic inflation to movements in the domestic output gap (the flattening of the Phillips Curve) and will globalization increase the sensitivity of domestic inflation to movements in the foreign output gap?

In response to the first question Roberts (2006), The International Monetary Fund (2006), Ball (2006), and Mishkin (2007) all claim that the impact of the domestic output gap on domestic inflation has declined in recent years. However they disagree as to what caused this flattening of the Phillips Curve. Roberts and Mishkin argue that it is entirely

[1]See remarks by Vice Chairman of the Federal Reserve Donald Kohn (2006), Deputy Governor of the Bank of England Charlie Bean (2006), Chairman of the Federal Reserve Ben Bernanke (2007), Governor of the Bank of Japan Toshihiko Fukui (2007), and President of the European Central Bank Jean-Claude Trichet (2008). In addition, this topic was the subject of a recent academic speech by former Fed Governor Frederic Mishkin (2009).

due to improved monetary policy. The IMF argues that it is due to increased globalization and trade integration, however Ball disputes this.

In response to the second question, Tootell (1998) and Ball (2006) argue that the foreign output gap plays little or no role in determining domestic inflation. Gamber and Huang (2001) argue that the foreign output gap does play a role in determining U.S. inflation, and they argue that excess foreign capacity is responsible for the "missing inflation" of the 1990's. Wynne and Kertsing (2007) extend Tootell's study with an extra ten years of data and find some evidence that measures of foreign slack play a role in determining U.S. inflation.

The papers that most directly address the two questions listed above are Pain, Koske and Sollie (2006), Borio and Filardo (2007) and Ihrig, Kamin, Linder, and Marquez (2007). Borio and Filardo argue that for a range of countries, domestic inflation has become less responsive to movements in the domestic output gap. Pain et al. and Ihrig et al. do not dispute this, but question whether this "flattening of the Phillips curve" has anything to do with globalization.

As for the role of foreign slack in determining domestic inflation, Borio and Filardo argue that, even after controlling for import price inflation, the coefficient on the foreign output gap in a Phillips curve regression is positive and significant. They also argue that this coefficient is increasing over time. Pain et al. and Ihrig et al. directly challenge this result. They argue that the Borio and Filardo regressions are misspecified, and once certain corrections are made, the foreign output gap is an insignificant determinate of domestic inflation. Pain et al. find that domestic inflation is sensitive to movements in the foreign output gap, but this is entirely due to movements in import prices. Thus the foreign output gap does not contain any new information for inflation that is not already captured by import price inflation.

Woodford (2007) addresses this issue in a theoretical model. Using the open-economy monetary model of Clarida, Gali, and Gertler (2002), he shows that trade integration will have little effect on domestic output-inflation dynamics.

Like Woodford, this paper addresses this question with a theoretical model. This paper will repeat the tests from the empirical literature, using a DSGE model as the data generating process. Using the model to generate the data for the empirical estimation allows us to do two things. First, with the model we can change the degree of trade integration while keeping everything else fixed. This allows us to single out the effect of increased trade integration on the slope of the Phillips curve. Second, when a model is used as a data generating process, there are no limits to data availability. This is important since variables like the foreign output gap may have a small but positive effect on domestic inflation but because of limited data availability leading to high standard errors the effect is labeled insignificant in empirical studies.

The model used to generate this inflation and output data is described in the second section. The calibration of the model and the exogenous shock process are described in the third section. The results are presented in the fourth section. To gain an intuitive understanding of the model and the role of the exogenous shocks, we start with some impulse responses. Then we consider the Phillips curve regression that is used to measure the impact of domestic and foreign slack on domestic inflation. First we consider how the trade integration of the past 30 years has affected the Phillips curve, then we consider how the Phillips curve is affected as we move from complete autarky to free trade. Finally, the fifth section concludes with a summary and a prescription for policy makers.

Model

The model used in this paper follows the New Open Economy Macro approach of Obstfeld and Rogoff (1995) and incorporates many of the variations reviewed by Lane (2001). In this model there are two types of firms, firms that produce traded goods and firms that produce non-traded goods. Traded goods firms are engaged in imperfect competition while non-traded goods firms are engaged in perfect competition. Both types of firms use country specific capital and labor as inputs.

Households supply a household specific type of labor. This imperfect competition in the labor market and in the market for traded goods is a necessary condition for wage and price rigidity. Nominal wages and the nominal prices are fixed for a length of time as in Calvo (1983).

Business cycles are driven by government spending shocks. The government spending shock can be thought of as a pure demand shock that leads to movements *along* the Phillips curve.

Production

There are two countries, home and foreign. The equations describing technology and preferences are *nearly* identical, but foreign variables and parameters are written with a "$*$". The corresponding preference or technology equations for the foreign country are omitted when the only difference is one of notation. When there is a more substantive difference, the corresponding equation for the foreign country is presented. Production by the traded goods firm indexed i is a function of country specific capital and labor:

$$X_t(i) = h_t^x(i)^{1-\alpha} K_t^x(i)^{\alpha} - \psi \tag{III.1}$$

where $h_t^x(i)$ is the labor input into production by traded goods firm i, $K_t^x(i)$ is the capital input, and ψ is a fixed cost parameter that is calibrated to ensure that firms earn zero profit in the steady state.

The output of firm i can be sold domestically or exported:

$$X_t(i) = x_t^d(i) + x_t^x(i) \tag{III.2}$$

Home country firms are indexed $i \in [0, n]$, and foreign country firms are indexed $i \in (n, 1]$, where the parameter n describes the relative size of the home country and is used later to evaluate how country size affects the slope of the short run Phillips curve.

There is an iceberg cost to international trade, implying that when one unit of a good is shipped internationally, only $1 - c$ units arrive. Thus $x_t^{m*}(i) = (1-c)\, x_t^x(i)$, where $x_t^x(i)$ represents exports from the home country and $x_t^{m*}(i)$ represents imports into the foreign country.

Traded goods from domestic and foreign firms are then combined into one aggregate traded good. As in Chari, Kehoe, and McGrattan (1998), domestically supplied and imported traded inputs are aggregated by the following:

$$x_t = \left[\left[\left(\int_0^n x_t^d(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \right]^{\frac{\rho-1}{\rho}} + \left[\left(\int_n^1 x_t^m(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \right]^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \tag{III.3}$$

where σ is the elasticity of substitution between domestic traded goods varieties and ρ is the elasticity of substitution between home and foreign varieties.

If we assume that the domestic elasticity of substitution is equal to the international elasticity of substitution, $\sigma = \rho$, then this aggregation equation is identical to that in Obstfeld and Rogoff (1995):

$$x_t = \left[\left(\int_0^n x_t^d (i)^{\frac{\sigma-1}{\sigma}} di \right) + \left(\int_n^1 x_t^m (i)^{\frac{\sigma-1}{\sigma}} di \right) \right]^{\frac{\sigma}{\sigma-1}} \tag{III.4}$$

This aggregate traded good is combined with the output from non-traded goods firms to create the final good. Output from non-traded goods firms is simply a function of domestic labor and capital, $y_t = (h_t^y)^{1-\alpha} (K_t^y)^{\alpha}$, where h_t^y is the labor input into production of non-traded goods, and K_t^y is the capital input. The combination of traded and non-traded goods into one final good is:

$$Y_t = \left[(\gamma)^{\frac{1}{\mu}} (y_t)^{\frac{\mu-1}{\mu}} + (1-\gamma)^{\frac{1}{\mu}} (x_t)^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \tag{III.5}$$

where μ is the elasticity of substitution between traded and non-traded goods and γ is the relative size of non-traded goods in gross output.

Households

Households in the home country are indexed $j \in [0, n]$ and in the foreign country they are indexed $j \in (n, 1]$. The household derives utility from private consumption, $C_t(j)$, and disutility from labor, $h_t(j)$. Household j will maximize the discounted value of future utility given by the following:

$$U(j) = E\sum_{t=0}^{\infty}\beta^t U\left[C_t(j), h_t(j); C_{t-1}\right] \tag{III.6}$$

where

$$U\left[C_t(j), h_t(j); C_{t-1}\right] = \ln\left(C_t(j) - bC_{t-1}\right) - \psi\left(h_t(j)\right)^2 \tag{III.7}$$

subject to the household's budget constraint:

$$\begin{aligned} & P_t\left(C_t(j) + I_t(j) + T_t(j)\right) + \\ & B_t(j) - (1+i_{t-1})B_{t-1}(j) + E_t\left(B_t^F(j) - (1+i_{t-1}^*)B_{t-1}^F(j)\right) \\ = \; & W_t(j)\, h_t(j) + R_t k_t^s(j) + \int_0^n \Pi_t(j,i)di - P_t\frac{\chi^{bf}}{2}\left(\frac{E_t B_t^F(j)}{P_t} - nfa_{ss}^F\right)^2 \end{aligned} \tag{III.8}$$

where C_{t-1} is the previous period's per capita consumption (taken as exogenous by the household), $I_t(j)$ is investment in household j's stock of physical capital, $T_t(j)$ is a lump sum tax paid by household j, which finances government spending, $nG_t = \int_0^n T_t(j)dj$, $B_t(j)$ is the household's stock of nominal bonds denominated in the home currency, $B_t^F(j)$ is a stock of foreign currency nominal bonds, E_t is the nominal exchange rate, $W_t(j)$ is the household's nominal wage rate, R_t is the rental rate on capital, $k_t^s(j)$ is capital supplied by the household to domestic firms, and χ^{bf} represents a small quadratic cost to holding foreign bonds.[2]

A capital appreciation function with quadratic adjustment costs describes the evo-

[2]This quadratic cost term is a reduced form representation of a debt-elastic interest premium. For simplicity we keep the interest rate paid on bonds equal to the nominal risk free rate, i_t, and the fact that the risk premium on bonds is a function of indebtedness is instead captured by the quadratic cost term. Schmitt-Grohe and Uribe (2003) show that the two modeling techniques are nearly quantitatively identical.

lution of the household's capital stock:

$$K_{t+1}(j) = [1 - \delta(z_t(j))] K_t(j) + \phi\left(\frac{I_t(j)}{K_t(j)}\right) K_t(j) \tag{III.9}$$

where $\phi' > 0$ and $\phi'' < 0$.

Households not only choose a capital stock but they also choose a capital utilization rate. The depreciation rate is a function of the utilization rate, $z_t(j)$, $\delta(z_t(j)) = \delta + \frac{\kappa}{1+\zeta}\left[(z_t(j))^{1+\zeta} - 1\right]$ where $\kappa = \frac{1}{\beta} - 1 + \delta$ is derived from the first order condition with respect to the utilization rate. Capital is perfectly substitutable across households, so the aggregate capital supplied in the home country is:

$$K_t^s = \int_0^n k_t^s(j)\, dj = \int_0^n z_t(j) K_{t-1}(j)\, dj = n z_t K_{t-1} \tag{III.10}$$

Households also supply a differentiated type of labor. The per capita labor supplied by household j is $h(j)$. The aggregate labor supply is given by:

$$h_t^s = \left(\int_0^n h_t(j)^{\frac{\theta-1}{\theta}}\, dj\right)^{\frac{\theta}{\theta-1}} \tag{III.11}$$

where θ is the elasticity of substitution across households of their differentiated labor.

Market Clearing Conditions

The gross output in the home country, Y_t, is used for private consumption, investment, and government spending. If $C(j)$ and $I(j)$ are consumption and investment by household j, and G_t is per capital government spending:

$$Y_t = \int_0^n \left(C_t(j) + I_t(j)\right) dj + nG_t = n\left(C_t + I_t + G_t\right) \tag{III.12}$$

Labor and capital are both supplied to domestic traded and non-traded good firms.

$$\begin{aligned} h_t^s &= \int_0^n h_t^x(i)\, di + h_t^y \\ K_t^s &= \int_0^n K_t^x(i)\, di + K_t^y \end{aligned} \tag{III.13}$$

The only financial assets traded internationally are non-contingent bonds denominated in units of the home currency, B, and units of the foreign currency, B^F. The bond markets must clear internationally:

$$\begin{aligned} \int_0^n B_t(j)\, dj + \int_n^1 B_t^*(j)\, dj &= 0 \\ \int_0^n B_t^F(j)\, dj + \int_n^1 B_t^{F*}(j)\, dj &= 0 \end{aligned} \tag{III.14}$$

Monetary Policy

The central bank in each country follows a Taylor rule with smoothing and the supply of money is perfectly elastic at the desired nominal interest rate, i_t.

$$\frac{1+i_t}{1+i^{ss}} = \left(\frac{1+i_{t-1}}{1+i^{ss}}\right)^{\theta_i} \left\{\left(\Pi_{t-1}\right)^{\theta_p}\left(1+OG_t\right)^{\theta_y}\right\}^{1-\theta_i}$$

where $\Pi_t = \frac{P_t}{P_{t-4}}$ and $OG_t = \frac{GDP_t}{GDP_{ss}} - 1$.

Nominal Rigidities

In the model, wages and traded goods prices are sticky. We use a Calvo price and wage setting framework, as in Christiano, Eichenbaum, and Evans (2005).

Sticky Wages

In any given period, household j faces a probability of $1-\xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t(j) = \pi_{t-1}W_{t-1}(j)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

If household j is allowed to reset their wages in period t they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

$$E_t \sum_{l=0}^{\infty} \beta^l (\xi_w)^l \left\{ \upsilon_{t+l}\Pi_{t,t+l}W_t(j)\, h^s_{t+l}(j) - \psi \left(h^s_{t+l}(j)\right)^2 \right\} \tag{III.15}$$

where υ_{t+l} is the marginal utility of consumption in period $t+l$.[3]

$$\Pi_{t,t+l} = \begin{cases} 1 & \text{if } l = 0 \\ \pi_{t+l-1}\Pi_{t,t+l-1} & \text{if } l > 0 \end{cases}$$

The imperfect combination of labor from different households is described in (III.11). Use this function to derive the demand function for labor from a specific household:

$$h^s_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\theta} h^s_t \tag{III.16}$$

[3] We assume complete contingent claims markets within a country. This implies that the marginal utility of consumption is the same across all households within a country, regardless of their income. Therefore the total utility from the consumption of labor income in any period is simply the country specific marginal utility of income, υ_t, multiplied by the household's labor income, $W_t(j)\, h^s_t(j)$.

where $W_t = \left(\int_0^n W_t(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$ is the average wage across households, and h_t^s is aggregate labor supplied by domestic households.

The household will choose $\tilde{W}_t(j)$ to maximize (III.15) subject to (III.16). Details from the solution to this maximization problem and the derivation of $\tilde{W}_t(j)$ can be found in the appendix.

If we substitute $\tilde{W}_t(j)$ into the expression for the average wage rate W_t, we can derive an expression for the evolution of the average wage. With this expression it is clear how the Calvo framework makes wages sticky:

$$W_t = \left(\xi_w \left(\Pi_{t-1,t} W_{t-1}\right)^{1-\theta} + (1-\xi_w)\left(\tilde{W}_t\right)^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{III.17}$$

Sticky Prices

In the model, traded goods prices are sticky. The output from traded goods firms is both sold domestically and exported. Therefore the firm sets prices for both the domestic market and the foreign market.

In period t, the firm will be able to change it's price with probability $1-\xi_p$. If the firm cannot change prices then domestic prices are indexed by the previous period's domestic inflation rate, and export prices are indexed by the previous period's foreign inflation rate.

The firm that can reset prices in period t will choose $P_t^d(i)$ and $P_t^x(i)$ to maximize discounted future profits from both the domestic and foreign markets given by:

$$\max_{P_t^d(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{ \Pi_{t,t+l} P_t^d(i)\, x_{t+l}^d(i) - MC_{t+l} x_{t+l}^d(i) \right\}$$
$$+ \max_{P_t^x(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{ \Pi_{t,t+l}^* P_t^x(i)\, x_{t+l}^x(i) - MC_{t+l} x_{t+l}^x(i) \right\} - MC_{t+l}\psi$$

where MC_{t+l} is marginal cost of production in period $t+l$.

The degree to which traded goods firms are able to price discriminate, and thus charge different prices for the domestic and export markets, has potential implications for cross-country price dynamics. Therefore, we follow Betts and Devereux (2000) and assume that a fraction s of traded goods producing firms can set different prices for the domestic and export markets (i.e. they can Price to Market), while the other $1-s$ cannot. Without loss of generality assume that firms indexed $i \in [0, ns]$ can price-to-market and those indexed $i \in (ns, n]$ cannot.

The key difference between firms that can price-to-market and those that cannot is that the firms that can price-to-market choose both $P_t^d(i)$ and $P_t^x(i)$. Firms that cannot price-to-market can only choose $P_t^d(i) = P_t^x(i)$.

Details from the solution to these maximization problems can be found in the appendix.

Model Calibration

Parameter Values

The various parameters used in the model and their values are listed in table 6.

The first seven parameters, including the discount factor, the elasticity of sub-

Table 6. Parameter values for the model in chapter III

Symbol	Value	Description
β	$\sqrt[4]{1.03}$	discount factor
σ	6	elasticity of substitution (eos) between traded goods
b	.65	coefficient on lagged consumption in the utility function
α	.36	capital share in production of value added
θ	21	eos between labor from different households
ξ_p	0.6	probability that a traded goods firm cannot reset prices
ξ_w	0.64	probability that a household cannot reset wages
θ_i	0.9	smoothing parameter in the Taylor rule
θ_p	1.5	exponent on inflation in the Taylor rule
θ_y	0.5	exponent on the output gap in the Taylor rule
χ^b	0.02	quadratic cost of holding foreign bonds
ρ	5	eos between domestic and imported goods
ζ	1	elasticity of the depreciation rate with respect to the utilization rate
δ	0.025	capital depreciation rate
μ	2	eos between traded and non-traded goods
s	0.5	share of firms that can price-to-market
γ	.75	share of non-traded goods in final goods
n	0.25	country size parameter, U.S.
n	0.05	country size parameter, UK

stitution between traded goods from domestic firms, the coefficient that describes habit formation in consumption, the capital share, the elasticity of substitution across differentiated labor, and the two Calvo price setting parameters, are all taken from Christiano, Eichenbaum, and Evans (2005). The next four parameters, the three Taylor rule parameters and the quadratic cost to holding foreign bonds, are from the Bank of England Quarterly Model (47). The elasticity of substitution between domestic and imported goods, ρ, is from Imbs and Mejean (2008). The next two parameters, the elasticity of the depreciation rate with respect to the utilization rate, ζ, and the steady state depreciation rate, δ, are from Baxter and Farr (2005). The share of firms that can price-to-market, s, is from Choudhri, Faruqee and Hakura (2005). Finally, the share of non-traded goods in the consumption basket, γ, and the country size parameters for both the U.S. and the UK, n, are from the author's own calculations.

Shock Process

Since we use the model as a data generating process to estimate the parameters of the Phillips curve, we want to restrict the shocks driving the model to shocks that lead to a movement along the Phillips curve.

Shocks to total factor productivity, the driving process of most real business cycle models, can affect the marginal cost of production and lead to shifts in the short-run Phillips curve. Similarly, money supply shocks[4], a common feature of many new Keynesian DSGE models, can affect inflation expectations and lead to shifts in the short-run Phillips curve. To concentrate on movements along the Phillips curve, we restrict our attention to real demand shocks, which can be represented by government spending shocks.

To ensure that any measured effect of foreign output on domestic inflation is endogenous and not due to the exogenous shock process, we model shocks to home and foreign government spending as independent AR(1) processes:

$$\begin{aligned} \hat{G}_t &= \lambda \hat{G}_{t-1} + g_t \\ \hat{G}^*_t &= \lambda \hat{G}^*_{t-1} + g^*_t \end{aligned}$$

where $\lambda = 0.65$ is from Ravn, Schmitt-Grohe and Uribe (2008). Given that the shock processes are identical across the two countries and the model is solved using a first order approximation, the variance of the innovations to government spending, g_t and g^*_t, is simply normalized to one.

[4]which in this model with a central bank with a Taylor rule could be represented as monetary policy shocks.

Results

Impulse Responses

In order to gain intuition for how trade openness affects inflation dynamics, we will calculate some impulse responses for domestic output and inflation in response to a government spending shock, both at home and abroad.

Figure 2 presents the responses of home inflation and output to a home government spending shock. In figure 2 the model has been calibrated such that the home country has the same relative size as the U.S., about 25% of world GDP. This figure shows the response of inflation and output under two scenarios. One of trade autarky and one of costless international trade. They key point to notice is that output follows nearly the same path regardless of trade openness, however home inflation is noticeably less responsive to the shock under costless international trade. This suggests that trade openness may lower the coefficient on the domestic output gap in the Phillips curve.

Figure 3 presents the responses of consumer price inflation and import inflation to a foreign government spending shock. The model is still calibrated for a large country, and we again present the responses under both autarky and costless trade. Not surprisingly, domestic inflation doesn't respond to the foreign shock under autarky. The top panel in figure 3 shows that under costless trade, domestic inflation responds positively to a positive foreign demand shock. However this does not necessarily imply that under costless trade domestic inflation responds to measures of foreign slack. The bottom panel in the figure charts the path of domestic import price inflation to the same foreign demand shock. The paths of consumer price inflation and import inflation are qualitatively similar. This implies that in a Phillips curve regression, there may not be any information in the foreign output

Figure 2. Response of home inflation and output to a home government spending shock. Calibrated for a large country.

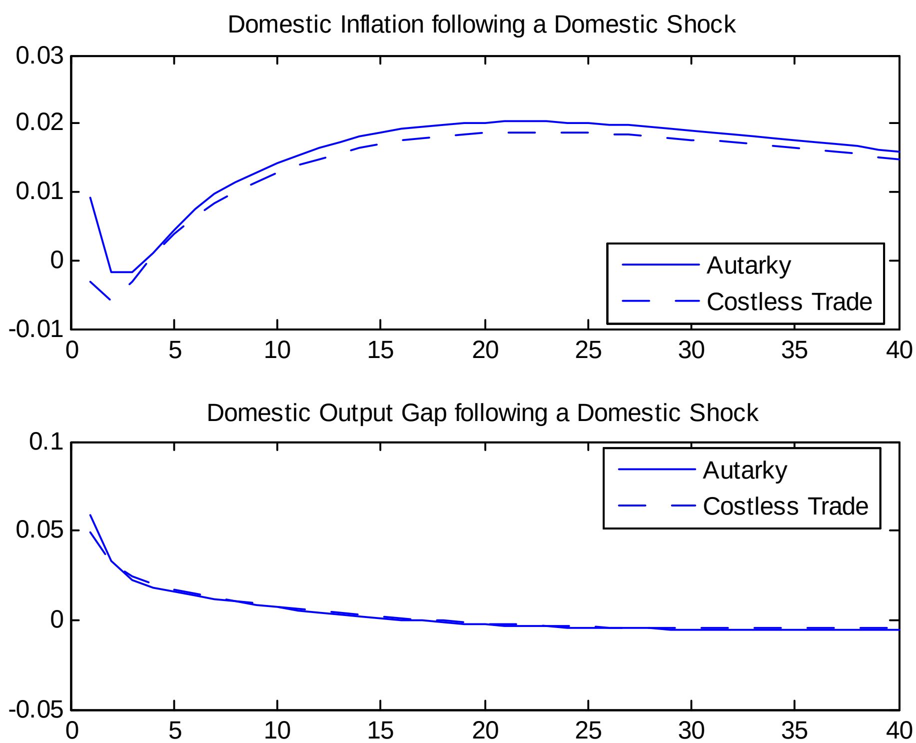
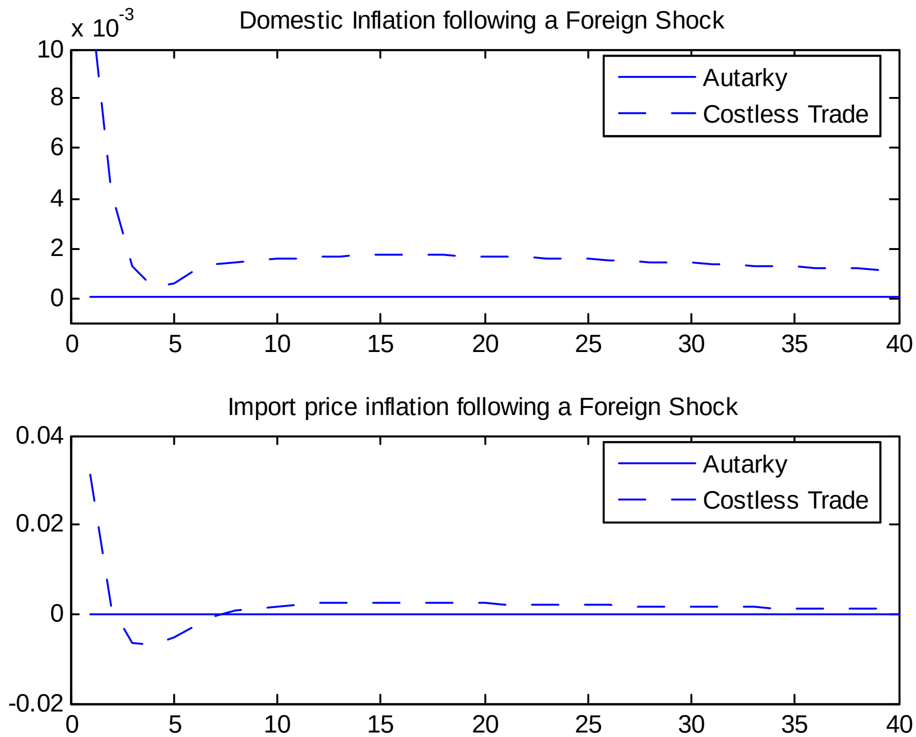


Figure 3. Response of home consumer price inflation and import price inflation to a foreign government spending shock. Calibrated for a large country.



gap that is not already captured by import price inflation. Therefore in a regression that already contains import prices, the foreign output gap may not be significant.

Figures 4 and 5 present the same impulse responses, just now the model is calibrated such that the home country has the same size as the UK, about 5% of world GDP. The response of inflation and output to a home shock seems to be independent of country size, for figures 2 and 4 are nearly identical. This suggests that any effect of globalization on the slope of the Phillips curve does not depend on country size. A comparison of figures 3 and 5 shows that the response of consumer price inflation and import inflation to a foreign demand shock are smaller in a small country, but for the small country we see again that the paths of consumer price inflation and import inflation are qualitatively similar, questioning how much new information about domestic inflation is contained in the foreign output gap.

Figure 4. Response of home inflation and output to a home government spending shock. Calibrated for a small country.

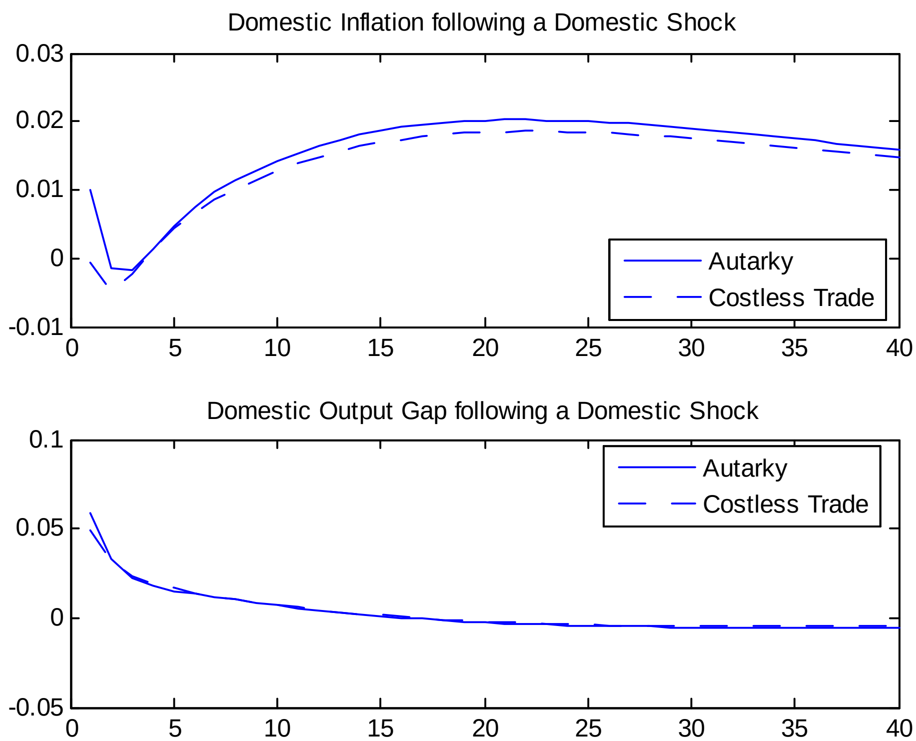
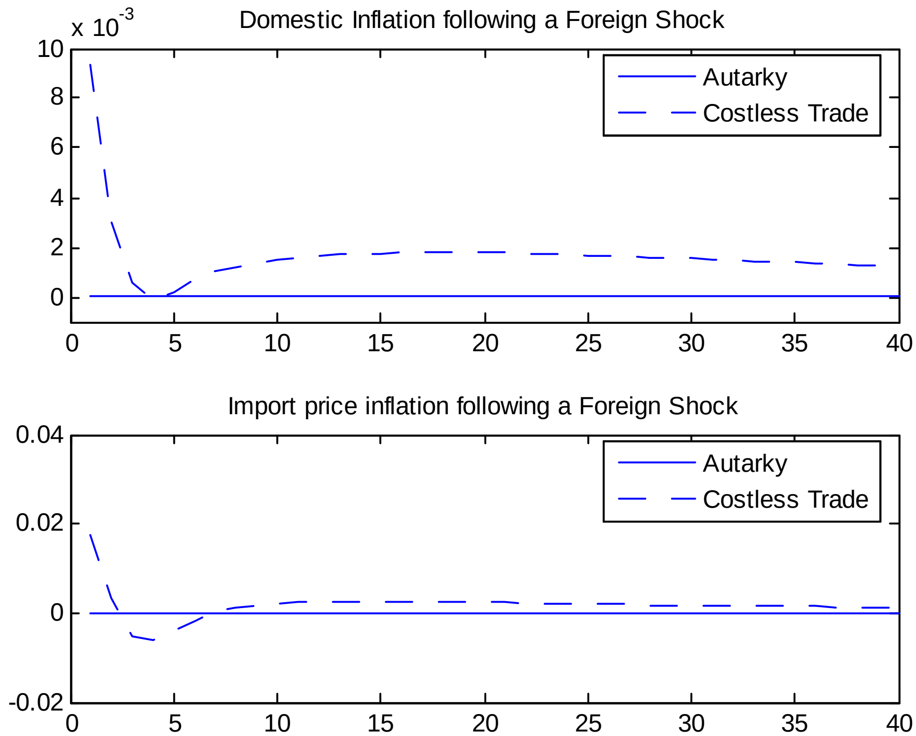


Figure 5. Response of home consumer price inflation and import price inflation to a foreign government spending shock. Calibrated for a small country.



A Phillips Curve Regression

Impulse responses give a good visual interpretation of the effect of globalization on inflation dynamics, but in order to quantify any effect, we need to turn to Phillips curve regressions.

There are two issues that plague empirical studies that attempt to find the effect of globalization on the Phillips curve.

The first is a problem with identifying the root cause of any empirical results. If your empirical results show that domestic inflation is becoming less responsive to movements in the domestic output gap and at the same time it is becoming more responsive to movements in the foreign output gap, how do you know that these effects are being driven by globalization? Equally plausible theories for the flattening of the Phillips curve cite the changing nature of shocks, or better monetary policy which serves to better anchor inflation expectations.

The second is a problem with data availability, which can make it difficult to separately identify the effects of both the domestic output gap and the foreign output gap on domestic inflation. This is especially true when lags of inflation are included in the regression model in order to correct for any serial correlation in the data.

The DSGE model presented in this paper is used to generate data. The simulated model can produce time series observations of inflation and output that can then be used to estimate a Phillips curve, as in previous empirical studies. Using a model to generate data ensures that data availability is not an issue.

Also with the model we can preform a type of comparative statics exercise. We can generate data and estimate a Phillips curve under one level of trade integration, and then repeat after changing the trade cost parameter c while holding everything else constant.

Thus we see how the estimated Phillips curve coefficients change when only the level of trade integration changes.

We use the Phillips curve regression framework from Ihrig et al. (2007). This contains sufficient lags of inflation in order to correct for any serial correlation in the error term.

$$\pi_t = \alpha + \sum_{i=1}^{6} \beta_i \pi_{t-i} + \sum_{i=0}^{5} \theta_i \left(p_{m,t-i} - \pi_{t-i-1}\right) + \delta OG_t + \gamma OG_t^* + \varepsilon_t \qquad \text{(III.18)}$$

where $\pi_t = 4\left(\frac{P_t}{P_{t-1}} - 1\right)$ is the annualized quarterly inflation rate, $p_{m,t}$ is the annualized quarterly import price inflation rate, OG_t is the domestic output gap, and OG_t^* is the foreign output gap.

We use a Monte Carlo methods to estimate the Phillips curve parameters in (III.18) and their standard errors. This not only allows us to find the true Phillips curve coefficients but also find confidence bands and thus compare our results to those from previous empirical papers. For instance, some previous empirical studies found that the foreign output gap has an insignificant effect on domestic inflation, γ in (III.18) is insignificant. This can happen if the true γ is zero, or if the true γ is positive but small and the relatively short time series of observations leads to wide confidence bands.

For each iteration in our Monte Carlo estimation, a time series of 100 observations is generated[5]. With these observations, we estimate (III.18) using OLS. This process is repeated 1000 times. The 1000 different estimates of the Phillips curve parameters are averaged to find a true values of each parameter, and the 97.5 and 2.5 percentiles of each parameter are calculated in order to construct 95% confidence bands.

[5] The model is calibrated for quarterly frequency, so 100 observations corresponds to a time series of 25 years of observations. In their empirical studies, Borio and Filardo (2007) use 21-26 years of observations and Ihrig, et al. (2007) use 29 years of observations.

To answer the question of how will globalization affect the Phillips curve, we use our model and this Phillips curve regression framework in two ways. First, we calibrate the model to match historical levels of trade integration in the U.S. and the UK. Thus we can calculate how the globalization of the past 30 years has affected the Phillips curve. Then we estimate how the Phillips curve is affected as we vary the level of trade integration from complete autarky to free trade, and thus see how future globalization might affect the relationship between output and inflation.

The Phillips curve over the last thirty years

The model is calibrated to reflect levels of trade integration in the U.S. and the UK in both the late 1970's and in 2000. Since both traded and non-traded goods are present in the model, trade integration is defined as the import penetration ratio among traded goods. These import penetration ratios and their corresponding trade cost parameters are found in table 7.[6]

Table 7. Historical import ratios and their corresponding trade cost parameters.

	US		UK	
	Import Ratio	Trade Cost	Import ratio	Trade Cost
2000	0.261	0.381	0.439	0.478
1970's	0.094	0.545	0.256	0.575

Notes: The import ratios are converted into trade costs assuming a relative country size of 0.25 for the US and 0.05 for the UK. The exact calculation of how import ratios are converted into trade costs can be found in a footnote in the text.

The estimated Phillips curves under our four model calibrations are presented in table 8. The first four columns in the table report the regression results from using the

[6]The demand functions in (A.17) and (A.18) in the appendix can be used to find the implied trade cost for a given import penetration ratio and country size. If s is the import penetration ratio, defined as total expenditure on imports divided by total expenditure on imports plus total expenditure on domestic goods, then $c = 1 - \left(\frac{s}{1-s}\right)^{\frac{1}{\rho-1}} \left(\frac{n}{1-n}\right)^{\frac{1}{\sigma-1}}$

model as the data generating process. In the first two columns, the model is calibrated to match the relative size of the U.S.. In the third and fourth columns the model is calibrated to match the relative size of the UK. The empirical estimation results from Ihrig et al. are reproduced in the fifth and sixth columns. These empirical results are reported to show that the data generating process in the model yields Phillips curve estimates that are quantitatively similar to those found in the data.

Table 8. Phillips curve regression results, using the model as the data generating process.

	US		UK		Ihrig et al.	
	1977	2000	1979	2000	US	UK
Lagged Inflation, sum	1.008	1.014	1.014	1.018	0.976	0.918
SE	(0.025)	(0.027)	(0.029)	(0.031)	(0.031)	(0.054)
Import price, sum	0.112	0.199	0.157	0.234	0.024	−0.035
SE	(0.050)	(0.074)	(0.061)	(0.091)	(0.025)	(0.051)
Domestic Output Gap	0.094	0.076	0.092	0.079	0.179	0.245
SE	(0.030)	(0.025)	(0.032)	(0.028)	(0.052)	(0.113)
Foreign Output Gap	−0.014	0.002	−0.004	0.006	−0.157	−0.081
SE	(0.021)	(0.018)	(0.024)	(0.021)	(0.087)	(0.211)
Adj R^2	0.969	0.972	0.967	0.971	0.958	0.868

Notes: Model calibrated to match country size and import ratio for U.S. in 1977 and 2000, and for UK in 1979 and 2000. Monte Carlo estimated standard errors in parentheses. The Ihrig, et al. regressions also include lagged food and energy price inflation and dummy variables to account for tax changes.

Turning to the first four columns, the coefficient on the domestic output gap falls with greater trade integration. This is true regardless of whether the model is calibrated for a large country or whether it is calibrated for a small country. Thus increased trade integration since the late 1970's has caused a flattening of the Phillips curve. The magnitude of the change is small, less than one standard deviation. Therefore it is not surprising that empirical studies would find that trade integration has no role in the flattening of the

Phillips curve.

Similarly, the coefficient on the foreign output gap is small and insignificant in every case. While there is a slight increase in the coefficient on the foreign output gap, it is so small that under current levels of trade integration, the foreign output gap doesn't contain any new information for inflation dynamics that is not already captured by import price inflation.

The Phillips curve over the full range of trade integration

The Phillips curve results presented thus far confirm the empirical findings in Ihrig et al. (2007). Globalization over the past 30 years has not significantly altered inflation dynamics. The Phillips curve has gotten flatter, but not noticeably so. The foreign output gap contains no information that is not already conveyed by import price inflation. These results are found from calibrating the model to reflect trade integration in the late 1970's and 2000. What if the model is simulated over the entire range of trade integration, from autarky to free trade?

Figures 6 and 7 plot the coefficients on the domestic and foreign output gaps across the full range of trade integration. Specifically, we simulate the model under various trade cost parameters, c, ranging from c close to one (autarky) to $c = 0$ (free trade in tradeable goods). The two vertical lines in each plot refer to the trade cost parameters in the late 1970's and in 2000 that were used to calculate the regression results in table 8.

The top panel in both figures shows that as trade costs decrease, the coefficient on the domestic output gap will decrease. Thus increased trade integration causes a slight flattening of the Phillips curve. However to put this in perspective, the two vertical lines show how little the Phillips curve has flattened given the trade integration of the past 30

Figure 6. Phillips curve coefficients on the domestic and foreign output gaps over a range of trade integration. Dashed lines represent 95% confidence intervals. Calibrated for a large country.

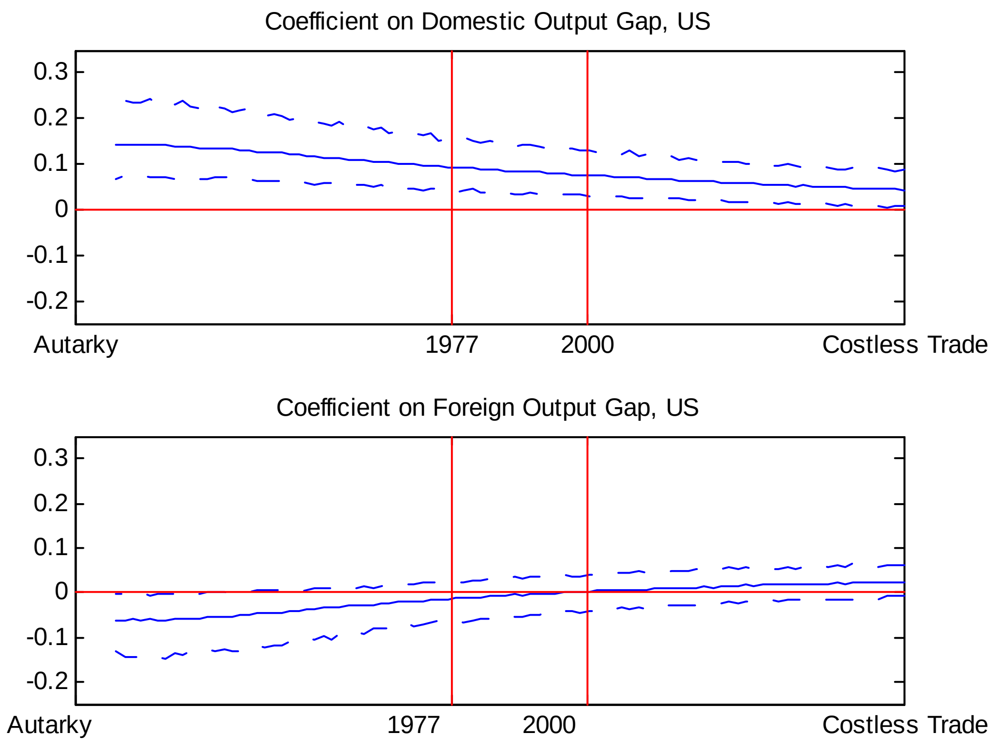
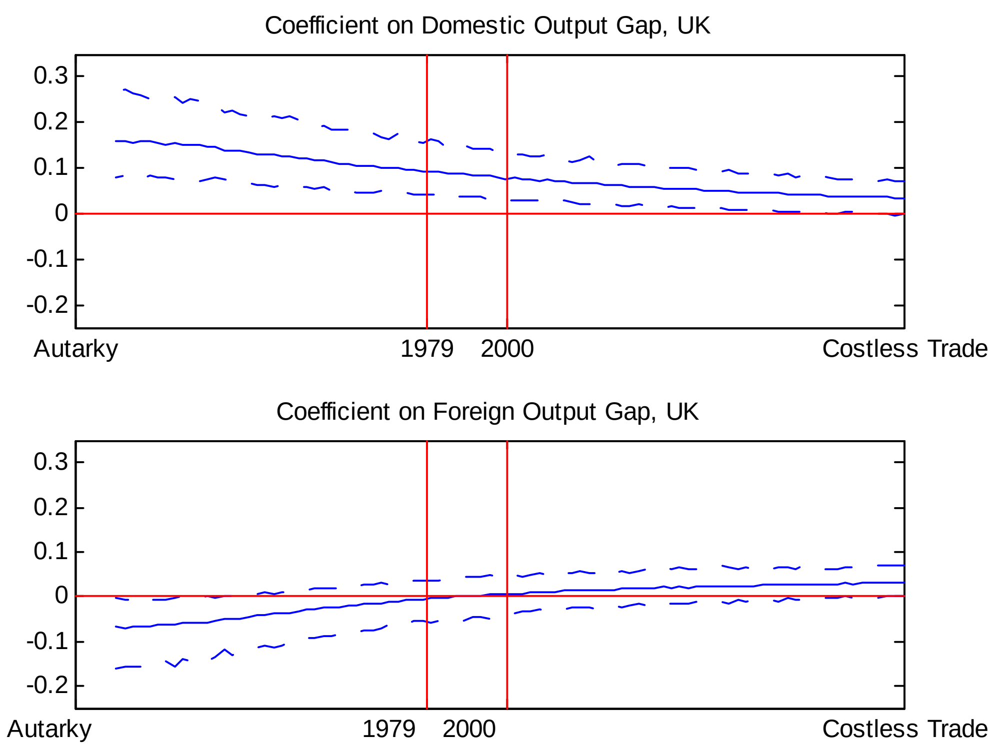


Figure 7. Phillips curve coefficients on the domestic and foreign output gaps over a range of trade integration. Dashed lines represent 95% confidence intervals. Calibrated for a small country.



years, and the figures show that even moving from the current level of trade integration to costless trade would not have a great effect on the slope of the Phillips curve.

The bottom panel of both figures shows that as trade costs decrease, the coefficient on the foreign output gap increases. However the two vertical lines show that under current levels of trade integration, it is for all practical purposes zero. Furthermore the confidence bands show that in an estimation using 25 years of observations, the coefficient is insignificant across the entire range of trade costs. Therefore, regardless of the level of trade integration, an empirical study would conclude that the foreign output gap conveys no information about inflation dynamics that is not already captured by import price inflation.

A comparison across the two figures shows how globalization may affect the Phillips curve differently in a small country than in a large country. The plots are slightly steeper in the UK than in the U.S., implying that trade integration has a somewhat greater effect on the coefficients of the Phillips curve in a small country. But the plots are still very similar, implying that country size plays little role in the effect of globalization on the Phillips curve.

Summary and Conclusion

The sensitivity of inflation to movements in the domestic and foreign output gaps is of paramount importance to monetary policy makers. Understanding how measures of domestic and foreign slack affect inflation allows for a better inflation forecast. Also, the sensitivity of inflation to movements in domestic output determines the sacrifice ratio, the short run trade off between inflation and output that the central bank must keep in mind when determining monetary policy. It is for these reasons that the effects of globalization on the sensitivity of inflation to domestic and foreign output conditions has garnered so much attention both among academic researchers and policy makers.

This paper set out to answer with a quantitative model, what is the effect of increased trade integration on the sensitivity of inflation to domestic and foreign output conditions. The results clearly show that as an economy moves from a state of autarky to costless trade, inflation becomes less sensitive to movements in the domestic output gap. However, the quantitative impact is small. When we use as a benchmark the trade integration of the past 30 years, the Phillips curve has flattened only slightly, and certainly not enough to be picked up by empirical studies.

Furthermore, we find that increased trade integration will increase the sensitivity of inflation to the foreign output gap, but again, the quantitative impact is small. Under current levels of trade integration, the foreign output gap provides no information about domestic inflation that is not already conveyed by the movements in import prices. Moving to a state of costless trade, the foreign output gap has a small role in the determination of domestic inflation, but Monte Carlo simulations show that the effect is so small that it would be deemed insignificant by most empirical studies.

The implications for monetary policy are clear. Don't worry about the effect of globalization on the Phillips curve. Increased trade integration will lessen the sensitivity of inflation to movements in the domestic output gap, but the effect is small. Too small to have any statistical significance, and thus too small to have an effect on either inflation forecasting or the sacrifice ratio. Similarly, increased trade integration will increase the sensitivity of inflation to foreign output, but this effect is small, and when we control for import prices, the foreign output gap provides no significant information about domestic inflation. Thus, if import price inflation is included in the Phillips curve, there is no need to include the foreign output gap.

CHAPTER IV

VARIABLE MARKUPS INTERNATIONAL BUSINESS CYCLE CO-MOVEMENT

Introduction

In the lead up to the introduction of the euro, a number of authors began to empirically measure the effect of bilateral trade intensity on bilateral business cycle correlation. The goal was to find if the increased trade arising from the introduction of a common currency would help the members of a currency union meet Mundell's Optimum Currency Area Criteria. A number of papers, including Frankel and Rose (1998), Clark and van Wincoop (2001), Imbs (2004 and 2006), Baxter and Kouparitsas (2005), and Calderon et al. (2007) have all measured the effect of bilateral trade on bilateral business cycle correlation and found that trade has a positive and significant effect on cyclical co-movement.

This robust and intuitive empirical finding is rather difficult to reproduce with a model. The international real business cycle model (IRBC) from Backus et al. (1992) actually predicts that trade has a negative effect on cyclical co-movement, as trade allows production to be located in the country that enjoys temporarily higher relative productivity. By restricting the international asset market, Baxter and Crucini (1995), Heathcote and Perri (2002), and Kose and Yi (2001 and 2006) show that the IRBC model can replicate the positive effect of trade on co-movement. Similarly, Ambler et al. (2002) show that when trade consists of intermediate goods, the model can also replicate the positive effect of trade on co-movement.

These models all assume that firms face a constant elasticity of demand, and thus price is a constant markup over marginal cost. The effect of variable demand elasticities and thus variable markups on output co-movement has thus far been neglected in the literature.[1]

The model in this paper is a discretized version of the Dixit and Stiglitz (1977) monopolistic competition model. This was introduced in the closed economy case by Yang and Heijdra (1993), and has been used in recent macro applications by Eckel (2008), Jaimovich and Floetto (2008), and Atkeson and Burstein (2008).

The model predicts that a firm's pricing power is an increasing function of its market share. We apply this model in an international setting. The mechanism that drives the results of this paper is that the pricing power of a domestic firm is a decreasing function of the import share. This intuitive result has support in both the industrial organization and international trade literatures.

Tybout (2003) provides a comprehensive survey of the evidence on how markups generally fall with the degree of import competition.[2]

Melitz and Ottaviano (2008) show the (short run) significance of the pro-competitive effect of trade in a model that incorporates the selection effect of trade featured in Melitz (2003). Chen et al. (2009) empirically test the model's predictions. Using EU manufacturing data from the 1990's they find in accordance with the theoretical model that increased trade openness has a negative effect on domestic markups in the short run.[3]

At business cycle frequencies, country specific business cycle fluctuations can lead

[1]Since variable markups are a type of real rigidity that prevent changes in real marginal costs from passing through into prices, models with variable markups have tended to focus on prices and exchange rates. See Dotsey and King (2005), Gust et al. (2006), Bouakez (2006) and Sbordone (2007)

[2]See also Katics and Peterson (1994), Tribble (1995), Becarello (1997), Konings and Vandenbussche (2005), and Blonigen et al. (2007)

[3]The Melitz and Ottaviano model also contains a long run channel whereby the selection effect of trade in a heterogeneous firm model can actually lead to higher markups in the long run. Chen et al. confirm this by finding that trade may have an ambiguous effect on markups in the long run. However, this paper is concerned with the cyclical effects of trade on markups, so we are not concerned with the long-run effects due to heterogeneous firms.

to cyclical changes in the import share, which can lead to cyclical changes in domestic and foreign firms' pricing power, and thus their markup.

This markup variability leads to greater international business cycle correlation. The intuition is as follows. Suppose there is a positive shock to foreign productivity. Then foreign marginal costs fall. The relative price of foreign products decreases. Foreign producers will increase production and domestic producers will cut production. Thus the foreign shock leads to business cycle divergence.

Foreign producers will gain market share at the expense of domestic producers, and thus foreign markups increase while domestic markups fall. These changes in markups cause the relative price of foreign goods to increase. Thus variability in markups causes a change in relative prices that is exactly opposite to the change due to the initial productivity shock. Home and foreign business cycles will diverge less than they would have without variable markups.

Thus markup variability has a qualitative effect on business cycle correlation. In this paper we will quantify that effect and show that markup variability has a significant effect on cyclical correlation. Furthermore we show that a real business cycle model with endogenous markup variability can reproduce the positive effect of trade on co-movement.

This paper will proceed as follows. In the next section the model is described and a part of the model is solved in order to find a closed form expression for a firm's elasticity of demand as a function of its market share. The parameterization of the model and the exogenous shock process is described in the third section. The results from the model are presented in the fourth section. First we log linearize part of the model to provide some intuition for how markup variability should affect co-movement. Then we simulate the model to show the quantitative effect of endogenous markup variability on cyclical co-movement. Finally, the fifth section concludes.

The Model

Technology

There are two countries, home and foreign. Foreign variables are written with a $*$ and home variables are not. In the following description of the model, foreign equations are omitted for brevity.

A final aggregate good is used by households for consumption and investment, C_t and I_t. This final good, y_t, is formed by aggregating goods from different sectors, y_t^j. The sector level outputs are combined using the Dixit and Stiglitz (1977) aggregator:

$$C_t + I_t = y_t = \left[\int_0^1 \left(y_t^j\right)^{\frac{\gamma-1}{\gamma}} dj\right]^{\frac{\gamma}{\gamma-1}}. \tag{IV.1}$$

where γ is the elasticity of substitution across goods from different sectors.

Household expenditure minimization can be used to find the demand for the aggregate consumer good in sector j as a function of aggregate consumption:

$$y_t^j = \left(p_t^j\right)^{-\gamma} y_t. \tag{IV.2}$$

where p_t^j is the price of output from sector j relative to the price of final output. From this demand function, we can find the real exchange rate between the two countries. The price of the foreign consumption good in terms of the home consumption good is $q_t = \left(\frac{\int_0^1 \left(p_t^{j*}\right)^{1-\gamma} dj}{\int_0^1 \left(p_t^j\right)^{1-\gamma} dj}\right)^{\frac{1}{1-\gamma}}$.

Final output in sector j is the combination of domestic and imported goods from sector j. The two are combined with an Armington (1969) aggregator function:

$$y_t^j = \left[\left(\frac{1}{2}\right)^{\frac{1}{\rho}}\left(y_{D,t}^j\right)^{\frac{\rho-1}{\rho}} + \left(\frac{1}{2}\right)^{\frac{1}{\rho}}\left(y_{M,t}^j\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}. \tag{IV.3}$$

where $y_{D,t}^j$ is the domestic variety, $y_{M,t}^j$ is imported, and ρ is the elasticity of substitution between them. We assume $\rho > \gamma$. Thus home and foreign varieties from the same sector are more substitutable than goods from different sectors.[4]

This aggregation function is used to find the demands for the imported and domestic varieties of the good from sector j:

$$\begin{aligned} y_{D,t}^j &= \frac{1}{2}\left(\frac{p_{D,t}^j}{p_t^j}\right)^{-\rho} y_t^j \\ y_{M,t}^j &= \frac{1}{2}\left(\frac{p_{M,t}^j}{p_t^j}\right)^{-\rho} y_t^j. \end{aligned} \tag{IV.4}$$

where $p_{D,t}^j$ and $p_{M,t}^j$ are the relative prices of domestically supplied and imported goods from sector j and $p_t^j = \left[\frac{1}{2}\left(p_{D,t}^j\right)^{1-\rho} + \frac{1}{2}\left(p_{M,t}^j\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}$.

Goods shipped internationally are subject to an iceberg trade cost, so when 1 unit of a good is shipped, only $1-c$ units arrive. Thus $y_{X,t}^j = \frac{y_{M,t}^{j*}}{(1-c)}$ and $y_{X,t}^{j*} = \frac{y_{M,t}^j}{(1-c)}$, where $y_{X,t}^j$ and $y_{X,t}^{j*}$ are home and foreign exports in sector j. We assume that transport firms are perfectly competitive, so $p_{M,t}^j = q_t\frac{p_{X,t}^{j*}}{1-c}$, where $p_{X,t}^{j*}$ is the relative price of foreign exported goods.

The domestically supplied good from sector j, $y_{D,t}^j$, is formed from the combination

[4]We assume that there is no exogenous home bias, commonly refered to as ω in the Armington aggregator function. The iceberg trade costs will bias consumers towards home goods, and the trade cost parameter is calibrated so that the model reflects trade volumes observed in the data, so it would be superfluous to include an exogenous home bias parameter.

of firm level varieties from the N domestic firms in sector j.

$$y^{j}_{D,t} = \left[\sum_{i=1}^{N} \left(\frac{1}{N}\right)^{\frac{1}{\sigma}} y^{j}_{D,t}\left(i\right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{IV.5}$$

where $y^{j}_{D,t}(i)$ is the domestic output from firm i in sector j and σ is the elasticity of substitution between varieties from different firms. There is also a corresponding aggregation function for exports that yields $y^{j}_{X,t}$.

We assume that the N different varieties are imperfect substitutes, thus $\sigma < \infty$. We also assume that $\sigma \geq \rho$, and thus there is greater substitutability across domestic varieties than between domestic and foreign varieties.

Given this aggregation function, the demand for output from firm i in sector j is:

$$\begin{aligned} y^{j}_{D,t}(i) &= \frac{1}{N}\left(\frac{p^{j}_{D,t}(i)}{p^{j}_{D,t}}\right)^{-\sigma} y^{j}_{D} \\ y^{j}_{X,t}(i) &= \frac{1}{N}\left(\frac{p^{j}_{X,t}(i)}{p^{j}_{X,t}}\right)^{-\sigma} y^{j}_{X} \end{aligned} \tag{IV.6}$$

where $p^{j}_{D}(i)$ and $p^{j}_{X}(i)$ are the domestic and export prices for output from firm i in sector j. Furthermore, $p^{j}_{D,t} = \left[\sum_{i=1}^{N}\left(\frac{1}{N}\right) p^{j}_{D,t}(i)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ and $p^{j}_{X,t} = \left[\sum_{i=1}^{N}\left(\frac{1}{N}\right) p^{j}_{X,t}(i)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$

Firm i in sector j combines domestic capital and labor to make a good that can be sold domestically or exported.

$$y^{j}_{D,t}(i) + y^{j}_{X,t}(i) = A_t \left(N^{j}_{t}(i)\right)^{1-\alpha} \left(K^{j}_{t}(i)\right)^{\alpha} - \psi \tag{IV.7}$$

where $N^{j}_{t}(i)$ and $K^{j}_{t}(i)$ is labor and capital employed by firm i in sector j, A_t is an exogenous country specific productivity shock, and ψ is a fixed cost which ensures that firms earn zero profit in the steady state..

Households

The one representative household per country derives utility from consumption and leisure. The household in the home country maximizes expected lifetime utility given by:

$$E_0 \sum_{t=o}^{\infty} \beta_t \frac{1}{1-\zeta} \left[(1-N_t)^{\theta} (C_t)^{1-\theta} \right]^{1-\zeta} \tag{IV.8}$$

where ζ is the coefficient of relative risk aversion and $N_t = \int_0^1 \sum_{i=1}^{N} N_t^j(i)\, dj$ is aggregate labor supplied by the domestic household to all firms i in all sectors j.

We assume that international asset markets are complete. We can model this by assuming households share one worldwide budget constraint:

$$C_t+I_t+q_t\left(C_t^*+I_t^*\right) = w_tN_t+r_tK_t+\int_0^1 \sum_{i=1}^{N} \Pi_t^j(i)\, dj+q_t\left(w_t^*N_t^*+r_t^*K_t^*+\int_0^1 \sum_{i=1}^{N} \Pi_t^{j*}(i)\, dj\right) \tag{IV.9}$$

where w_t is the home wage rate (in terms of the home consumption good), r_t is the rental rate of home capital, $K_t = \int_0^1 \sum_{i=1}^{N} K_t^j(i)\, dj$, and $\Pi_t^j(i) = p_{D,t}^j(i)\, y_{D,t}^j(i) + p_{X,t}^j(i)\, y_{X,t}^j(i) - w_tN_t^j(i) - r_tK_t^j(i)$ is the profit at time t of the home firm i in sector j.

Finally, the home capital stock evolves according to the following:

$$K_{t+1} = (1-\delta) K_t + I_t \tag{IV.10}$$

where δ is the one-period depreciation rate of capital.

The firm's maximization problem

Firm i in sector j chooses $p^j_{D,t}(i)$, $p^j_{X,t}(i)$, $y^j_{D,t}(i)$, and $y^j_{X,t}(i)$ to solve the following static maximization problem:

$$\max\left(p^j_{D,t}(i)\, y^j_{D,t}(i) + p^j_{X,t}(i)\, y^j_{X,t}(i) - w_t N^j_t(i) - r_t K^j_t(i)\right) \tag{IV.11}$$

This profit can be rewritten as:

$$\max\left[\left(p^j_{D,t}(i) - MC_t\right) y^j_{D,t}(i) + \left(p^j_{X,t}(i) - MC_t\right) y^j_{X,t}(i) - MC_t\psi\right] \tag{IV.12}$$

where $MC_t = \frac{1}{A_t}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t}{\alpha}\right)^{\alpha}$.

We assume a sufficient degree of market segmentation such that firms can price to market, i.e. the firm is able to set a different price for goods sold domestically versus those that are exported.[5]

If firms are engaged in quantity competition then the firm chooses domestic and export quantities according to:

$$\begin{aligned}
y^j_{D,t}(i) &= \underset{y^j_{D,t}(i)}{\operatorname{argmax}}\left\{\left(p^j_{D,t}(i) - MC_t\right) y^j_{D,t}(i)\right\} \\
y^j_{X,t}(i) &= \underset{y^j_{X,t}(i)}{\operatorname{argmax}}\left\{\left(p^j_{X,t}(i) - MC_t\right) y^j_{X,t}(i)\right\}
\end{aligned} \tag{IV.13}$$

subject to the inverse demand functions:

[5] We assume market segmentation in the benchmark case, but when we test the sensitivity of the main results, we will consider one case where firms must set the same price for both the domestic and export markets.

$$p^j_{D,t}(i) = \left(N\frac{y^j_{D,t}(i)}{y^j_D}\right)^{\frac{-1}{\sigma}} \left(2\frac{y^j_{D,t}}{y^j_t}\right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t}\right)^{\frac{-1}{\gamma}} \tag{IV.14}$$

$$p^j_{X,t}(i) = \frac{1-c}{q_t}\left(N\frac{y^j_{X,t}(i)}{y^j_X}\right)^{\frac{-1}{\sigma}} \left(2\frac{y^{j*}_{M,t}}{y^{j*}_t}\right)^{\frac{-1}{\rho}} \left(\frac{y^{j*}_t}{y^*_t}\right)^{\frac{-1}{\gamma}}$$

Thus the domestic and export elasticities of demand faced by the firm are:

$$\varepsilon^d = \left[\frac{1}{\sigma}\left(1-s^j_t\right) + s^j_t\left(\frac{1}{\rho}m_t + \frac{1}{\gamma}(1-m_t)\right)\right]^{-1} \tag{IV.15}$$

$$\varepsilon^x = \left[\frac{1}{\sigma}\left(1-s^j_t\right) + s^j_t\left(\frac{1}{\rho}\left(1-m^{j*}_t\right) + \frac{1}{\gamma}m^*_t\right)\right]^{-1}$$

where $s^j_t = \frac{p^j_{D,t}(i)y^j_{D,t}(i)}{\sum_{j=1}^N p^j_{D,t}(j)y^j_{D,t}(j)}$ is the firm's market share among its domestic competitors, $m_t = \frac{p^j_{M,t}y^j_{M,t}}{p^j_{D,t}y^j_{D,t}+p^j_{M,t}y^j_{M,t}}$ is the import share in the home market, and m^*_t is the import share in the foreign market. In equilibrium all domestic firms are identical, so $s^j_t = \frac{1}{N}$.

If instead firms engaged in price competition the demand elasticities would be the following:

$$\varepsilon^d = \sigma\left(1-s^j_t\right) + s^j_t\left(\rho m_t + \gamma(1-m_t)\right) \tag{IV.16}$$

$$\varepsilon^x = \sigma\left(1-s^j_t\right) + s^j_t\left(\rho(1-m^*_t) + \gamma m^*_t\right)$$

Details of the solution to the firm's problem and how these elasticities are derived can be found in the appendix.

This expression for demand elasticity is simply one convex combination of elasticities nested inside another convex combination of elasticities. The inner convex combination, $\rho m_t + \gamma(1-m_t)$, describes the demand elasticity faced by the domestic industry. This elasticity is a weighted average of the elasticity of substitution across home and foreign varieties and the elasticity of substitution across goods from different sectors. The weight is the import share. In a relatively closed economy, the domestic producers in sector j compete mainly with producers in other sectors, and the elasticity of substitution between goods from different sectors is γ. As the economy becomes more open and the import share increases, domestic producers in sector j face greater competition from foreign producers in the same sector, and the elasticity of substitution between home and foreign varieties is ρ. Since $\gamma < \rho$, the domestic industry loses pricing power as they face greater foreign competition.

The outer convex combination describes the pricing power of the individual firm. If the firm faces a lot of domestic competition and their relative share among domestic producers is low, then the firm's main competitors are not foreign producers or producers in other sectors, but other domestic firms in the same sector. In this case the demand elasticity is close to the elasticity of substitution between varieties from different domestic firms, σ. As s_t^j increases then the firm can base their pricing decisions less on competition with domestic firms in the same industry and more on competition with foreign producers and other industries. If $\sigma \geq \rho > \gamma$, then $\sigma > \rho m_t + \gamma (1 - m_t)$, so as s_t^j increases, the firm faces less domestic competition, the elasticity of demand falls, and the firm gains pricing power.

Parameterization

The model's parameters and their benchmark values are found in table 9.

The three parameters that describe the elasticity of substitution across goods are σ, γ, and ρ. σ is the elasticity of substitution across domestic goods in the same sector.

Table 9. Parameter values for the model in chapter IV

Symbol	Value	Description
σ	21	elasticity of substitution across domestic varieties
γ	1.01	elasticity of substitution across different sectors
ρ	7.5	elasticity of substitution across home and foreign goods
θ	0.7	weight on leisure in the utility function
ζ	2	coefficient of relative risk aversion
α	0.36	capital's share of income
β	0.99	discount factor
δ	0.025	capital depreciation rate
ψ	0.321	fixed cost parameter (benchmark)
c	0.221	trade cost (benchmark)
μ^d	20%	steady state domestic markup

We set this elasticity equal to 21. Therefore as the number of firms in an industry, N, approaches infinity, our model predicts a 5% markup as in Basu and Fernald (2002).

γ is the elasticity of substitution between goods from different sectors. We follow Atkeson and Burstein (2008) and set this parameter equal to 1.01. An elasticity of substitution close to one ensures that sectoral expenditure shares are roughly constant.

The elasticity of substitution between home and foreign goods, ρ, can also be thought of as the import demand elasticity. In a survey, Anderson and van Wincoop (2004), conclude that this elasticity is somewhere between 5 and 10. In the benchmark parameterization $\rho = 7.5$. We will also test the model using $\rho = 10$ and $\rho = 5$.

The next five parameters: θ, the exponent on leisure in the Cobb-Douglas utility function, ζ, the coefficient of relative risk aversion, α, capital's share of income, β, the discount factor, and δ, the capital depreciation rate, are all set to values commonly found in the real business cycle literature.

The benchmark fixed cost parameter, ψ, from the firm's production function, is set such that firms earn zero profit in the steady state.

The benchmark trade cost parameter, c, is set such that the import share is equal to 25% in the steady state.

The steady state domestic markup is equal to 20%. With this steady state domestic markup, the number of firms, N, can be backed out of the elasticity expressions in (IV.15) and (IV.16).[6]

Finally, in this real business cycle model, fluctuations in total factor productivity drive business cycle fluctuations. The A_t and A_t^* variables in (IV.7) are exogenous country specific shocks that evolve according to the following VAR(1) process:

$$\begin{bmatrix} A_{t+1} \\ A_{t+1}^* \end{bmatrix} = \begin{bmatrix} 0.9 & 0 \\ 0 & 0.9 \end{bmatrix} \begin{bmatrix} A_t \\ A_t^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix}$$

where $\text{var}(\varepsilon_t) = \text{var}(\varepsilon_t^*) = .00852^2$ and $\text{corr}(\varepsilon_t, \varepsilon_t^*) = .258$

Results

Conceptual Issues

To see how variable markups affect the cyclical fluctuations in output, consider the log linearization of the demand function for goods from domestic firms in (IV.4):

$$\hat{y}_{D,t} = -\rho \hat{p}_{D,t} + \rho \hat{p}_t + \hat{y}_t \qquad \text{(IV.17)}$$

Note that the sectoral superscripts j have been omitted for clarity.

If we log linearize the function that aggregates domestic and imported prices, then

[6] $\mu = \frac{\varepsilon}{\varepsilon - 1} - 1$. Under quantity competition, $\varepsilon = \left(\frac{1}{\sigma}\left(1 - \frac{1}{N}\right) + \frac{1}{N}\left(\frac{1}{\rho}m_t + \frac{1}{\gamma}(1 - m_t)\right)\right)^{-1}$, thus $N = \frac{(\mu+1)\left(\frac{1}{\sigma} - \left(\frac{1}{\rho}m_t + \frac{1}{\gamma}(1-m_t)\right)\right)}{1-(\mu+1)\left(1-\frac{1}{\sigma}\right)}$.Under price competition, $\varepsilon = \sigma\left(1 - \frac{1}{N}\right) + \frac{1}{N}\left(\rho m_t + \gamma(1 - m_t)\right)$, thus $N = \frac{\mu(\sigma - (\rho m_t + \gamma(1-m_t)))}{\mu + 1 - \mu\sigma}$

the sectoral price level $\hat{p}_t$ can be expressed as:

$$\hat{p}_t = (1-m)\,\hat{p}_{D,t} + m\hat{p}_{M,t} \tag{IV.18}$$

where m is the steady state import share.

Substituting equation (IV.18) into (IV.17) yields the following:

$$\hat{y}_{D,t} = \rho m\left(\hat{p}_{M,t} - \hat{p}_{D,t}\right) + \hat{y}_t \tag{IV.19}$$

The domestic price is simply equal to a markup over the domestic marginal cost of production, $p_{D,t} = \mu_{D,t} MC_t$. The import price is equal to a markup multiplied by the foreign marginal cost of production adjusted for trade costs and the real exchange rate, $p_{M,t} = \frac{q_t}{1-c}\mu^*_{X,t} MC^*_t$. After log-linearizing these pricing formulas, the log-linearizaed demand function in (IV.19) is:

$$\hat{y}_{D,t} = \rho m\left(\hat{q}_t + \hat{\mu}^*_{X,t} + M\hat{C}^*_t - \hat{\mu}_{D,t} - M\hat{C}_t\right) + \hat{y}_t \tag{IV.20}$$

Suppose that there is an exogenous change in the foreign marginal cost of production, MC^*_t. Equation (IV.20) shows that the elasticity of domestic demand with respect to changes in foreign marginal cost is:

$$\frac{\hat{y}_{D,t}}{M\hat{C}^*_t} = \rho m\left(\frac{\hat{q}_t}{M\hat{C}^*_t} + \frac{\hat{\mu}^*_{X,t}}{M\hat{C}^*_t} + 1 - \frac{\hat{\mu}_{D,t}}{M\hat{C}^*_t} - \frac{M\hat{C}_t}{M\hat{C}^*_t}\right) + \frac{\hat{y}_t}{M\hat{C}^*_t} \tag{IV.21}$$

Suppose markups are constant, then $\frac{\hat{\mu}^*_{X,t}}{M\hat{C}^*_t} = \frac{\hat{\mu}_{D,t}}{M\hat{C}^*_t} = 0$. Then the elasticity in (IV.21) can be rewritten as:

$$\frac{\hat{y}_{D,t}}{M\hat{C}_t^*} = \rho m \left(\frac{\hat{q}_t}{M\hat{C}_t^*} + 1 - \frac{MC_t}{M\hat{C}_t^*} \right) + \frac{\hat{y}_t}{M\hat{C}_t^*} \tag{IV.22}$$

Therefore equations (IV.21) and (IV.22) show how the variability of markups can affect the cyclical fluctuations in output. Define $\Delta \frac{\hat{y}_{D,t}}{M\hat{C}_t^*}$ to be the change in elasticity when the variability of markups is taken into account[7]:

$$\Delta \frac{\hat{y}_{D,t}}{M\hat{C}_t^*} = \rho m \left(\frac{\hat{\mu}_{X,t}^*}{M\hat{C}_t^*} - \frac{\hat{\mu}_{D,t}}{M\hat{C}_t^*} \right) \tag{IV.23}$$

In this model markup is an increasing function of market share. Therefore when foreign costs increase, foreign producers lose market share in the domestic market and thus their markup falls, $\frac{\hat{\mu}_{X,t}^*}{M\hat{C}_t^*} < 0$. Similarly when foreign cost increase, domestic producers gain market share and thus their markup increases, $\frac{\hat{\mu}_{D,t}}{M\hat{C}_t^*} > 0$. This implies that $\Delta \frac{\hat{y}_{D,t}}{M\hat{C}_t^*} < 0$.

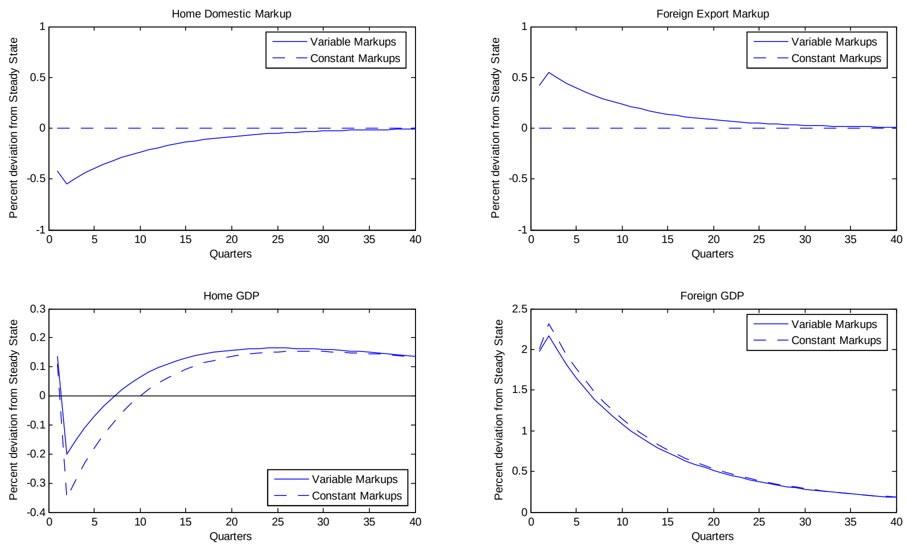
The key result from this paper is summarized in equation (IV.23).

Markup variability should lead to greater international business cycle correlation. Suppose there is a positive shock to foreign productivity. Then foreign marginal costs fall. The relative price of foreign products decreases. Foreign producers will increase production and domestic producers will cut production. Thus the foreign shock leads to business cycle divergence.

Foreign producers will gain market share at the expense of domestic producers, and thus foreign markups increase while domestic markups fall. These changes in markups cause the relative price of foreign goods to increase. Thus variability in markups causes a

[7]This expression for $\Delta \frac{\hat{y}_{D,t}}{M\hat{C}_t^*}$ is an approximation. Other elasticities like the elasticity of the real exchange rate with respect to changes in foreign marginal costs, $\frac{\hat{q}_t}{M\hat{C}_t^*}$, the elasticity of home marginal costs, $\frac{M\hat{C}_t}{M\hat{C}_t^*}$, and the elasticity of home gross output, $\frac{\hat{y}_t}{M\hat{C}_t^*}$, should all be affected by the variability of markups.

Figure 8. Response of home and foreign markups and GDP to a positive shock to foreign productivity.



change in relative prices that is exactly opposite to the change due to the initial productivity shock. Home and foreign business cycles will diverge less than they would have without variable markups.

This sequence of events is illustrated in figure 8. The figure plots the response of home domestic markups and foreign export markups, and the response of home and foreign GDP to a positive foreign productivity shock. The dotted line in each plot refers to the path of markups and GDP when markups are constant. The solid line refers to the path of markups and GDP in the model with variable markups arising from firms engaged in quantity competition, as in (IV.15).[8]

The plots in figure 8 clearly show how markup variability tempers the response of both home and foreign GDP. Following the positive foreign shock, home markups fall and foreign markups increase. With these changes in markups, domestic prices are lower than they would have been under constant markups. Therefore domestic production is higher

[8] In both cases the steady state markup is 20%.

than it would have been without variable markups. Endogenous markup variability means that the initial negative response to home GDP is less negative, and the initial positive response of foreign GDP is less positive.

Quantitative impact of variable markups

The last section clearly shows the qualitative effects of variable markups. The inclusion of variable markups in an international real business cycle model should lead to greater international business cycle correlation. However the quantitative impact can only be found by simulating the model and calculating business cycle correlations with and without variable markups.

First we will show how markup variability affects the elasticity of output co-movement with respect to changes in trade integration. This elasticity is the variable of interest in Frankel and Rose (1998) and other empirical studies. Then we will show how markup variability affects cyclical co-movement across the entire range of trade integration, from autarky to free trade. We also show how the steady state markup, the type of competition (quantity or price), the substitutability of home and foreign goods, and the degree of market segmentation can affect the importance of markup variability.

The effects of trade on co-movement

In a seminal paper, Frankel and Rose (1998) measure the increase in bilateral GDP correlation resulting from a change in bilateral trade intensity. This cross-sectional regression method is common in the empirical literature that measures the effect of trade on co-movement.[9]

[9] See Clark and van Wincoop (2001), Imbs (2004 and 2006), Kose and Yi (2006), and Calderon et al. (2007).

T is a measure of bilateral trade intensity and ρ is a measure of bilateral GDP correlation. T_1 and T_2 represent two levels of bilateral trade intensity, assume without loss of generality that $T_2 > T_1$. ρ_1 and ρ_2 are measures of bilateral GDP correlation arising from the two levels of trade intensity, T_1 and T_2. The parameter that Frankel and Rose and others measure using a cross-sectional regression is:

$$\Theta = \frac{\rho_2 - \rho_1}{\ln T_2 - \ln T_1} \tag{IV.24}$$

Since trade intensity is usually endogenous, this parameter can be difficult to measure empirically. However, in a model, the degree of trade intensity can be altered with the exogenous trade cost parameter c. Thus in a model, a decrease in the trade cost parameter c causes an increase in trade intensity from T_1 to T_2. When the model is solved using a first order approximation, the theoretical moments ρ_1 and ρ_2 can be calculated.

Kose and Yi (2001 and 2006) measure the parameter Θ in a simulated real business cycle model. They show that this parameter is negative under the assumption of complete international asset markets.

In the previous section we discussed the intuition behind why endogenous markup variability should lead to greater business cycle co-movement. To quantify this effect, we can simulate the international real business cycle model with and without variable markups and calculate the Θ term in (IV.24).

The parameter Θ implied by the model is reported in table 10. This table reports the Θ implied by the model under various situations relating to different steady state markups, different types of competition (price or quantity), differences in the import demand elasticity (the elasticity of substitution between home and foreign goods), and differences in market segmentation. To calculate Θ, we set T_1 equal to the benchmark level of trade integration, a 25% import share. T_2 is the import share under costless trade, 50%. Thus Θ measures the effect of doubling the degree of trade intensity.

The benchmark parameterization is listed in the first two columns of the top row of table 10. The first column lists the effect of trade on correlation when markups are variable, while markups are held constant in the second column.

The Θ implied by the model under the assumption of constant markups is negative. When endogenous markup variability is introduced in the model, Θ becomes positive. Thus the IRBC model with endogenous markup variability can produce the positive effect of trade on co-movement.

The first two columns in table 10 report the results for the benchmark parameterization of the model. The remaining columns in the top row and the first two columns in the second row report the model's implied Θ assuming different values for the steady state markup. When the markup is only 15%, Θ is still negative even after introducing variable markups, but in all cases, introducing markup variability increases Θ. Thus endogenous markup variability causes trade to have a greater effect on business cycle co-movement.

Table 10. Elasticity of output co-movement with respect to changes in trade intensity with and without variable markups

Steady state markup	20%		15%	
Competition:	Quantity		Quantity	
Pricing to Market or Not:	PTM		PTM	
Import demand elasticity:	7.5		7.5	
Markups, Variable or Constant:	Variable	Constant	Variable	Constant
Effect of trade on correlation:	0.014	−0.036	−0.016	−0.051

Steady state markup	25%		20%	
Competition:	Quantity		Price	
Pricing to Market or Not:	PTM		PTM	
Import demand elasticity:	7.5		7.5	
Markups, Variable or Constant:	Variable	Constant	Variable	Constant
Effect of trade on correlation:	0.040	−0.023	−0.002	−0.048

Steady state markup	20%		20%	
Competition:	Quantity		Quantity	
Pricing to Market or Not:	PTM		PTM	
Import demand elasticity:	10		5	
Markups, Variable or Constant:	Variable	Constant	Variable	Constant
Effect of trade on correlation:	−0.014	−0.071	0.085	0.048

Steady state markup	20%	
Competition:	Quantity	
Pricing to Market or Not:	No PTM	
Import demand elasticity:	7.5	
Markups, Variable or Constant:	Variable	Constant
Effect of trade on correlation:	0.006	−0.081

The remaining entries in table 10 report the Θ implied by the model with and without variable markups under different assumptions about competition, international goods substitutability, and domestic and export market segmentation (e.g. can firms price to market or not). The first two columns in the bottom row report the model's prediction of Θ assuming that firms are engaged in price competition. The results show that endogenous market variability still has a sizeable positive impact on Θ even when firms are engaged in price competition. Introducing variable markups increases Θ by about 0.05.

In columns three and four, the elasticity of substitution between home and foreign goods is equal to ten. If we compare these results to those in the benchmark, we see that introducing markup variability has a greater effect on Θ when goods are more substitutable across borders.

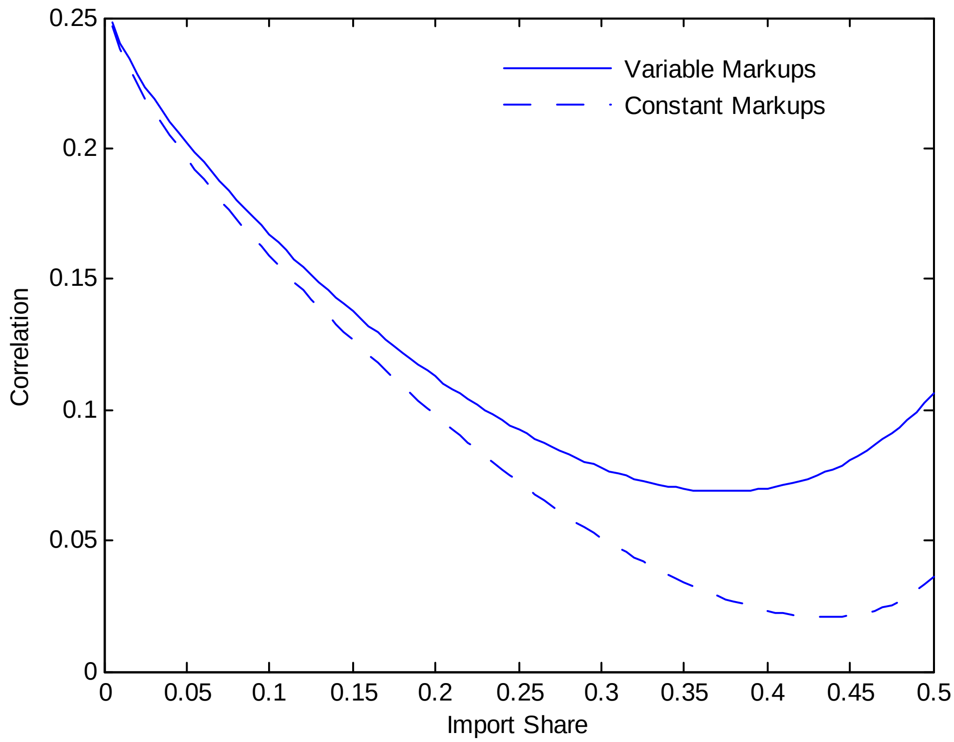
In columns five and six the elasticity of substitution between home and foreign goods is set to 5. Here we see that trade has a much greater effect on cyclical correlation when home and foreign goods are less substitutable, for Θ is positive even when markups are constant. A comparison of columns five and six shows that introducing markup variability still increases Θ by about 0.04.

Finally, in columns seven and eight we assume firms must set the same price for both the domestic and export markets (i.e. they cannot price to market). Here we see that when firms cannot price to market endogenous markup variability has the greatest effect on Θ. Introducing markup variability increases Θ by almost 0.09.

Markup variability and cyclical co-movement across the entire range of trade integration, from autarky to free trade

The cross-country correlation of GDP fluctuations as a function of the import share is presented in figure 9. This figure compares the bilateral correlation under the assumption

Figure 9. Cross-country GDP correlation as a function of the import share, for variable and constant markups.

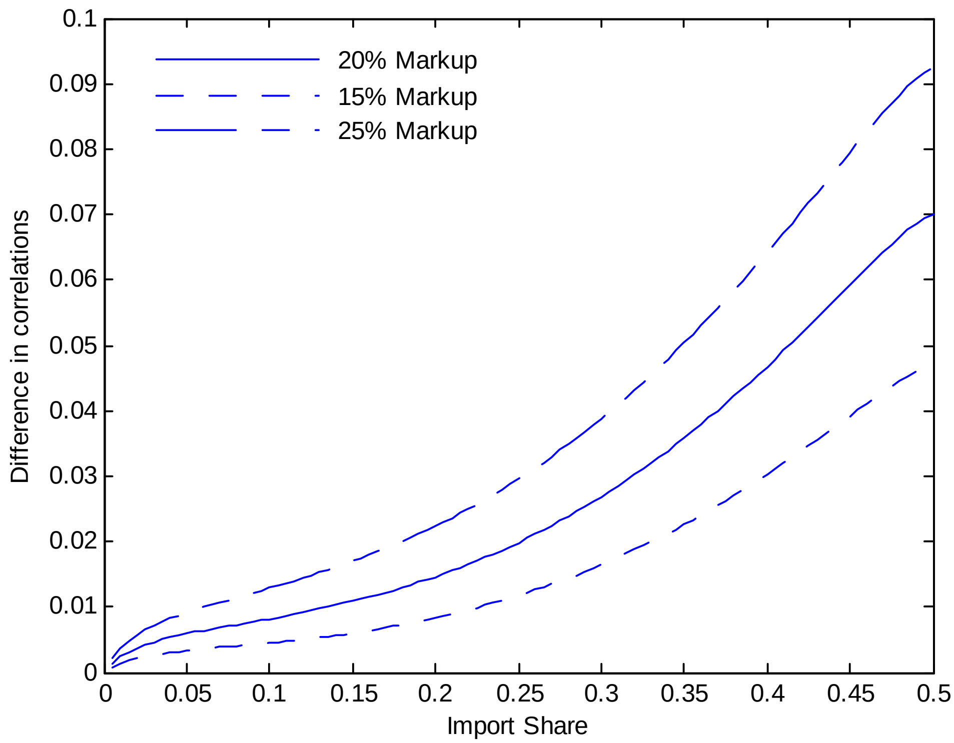


of variable markups arising from firms engaged in quantity competition to the correlation assuming a constant markup.

As predicted in an earlier section, cross-country GDP fluctuations are more correlated in the model assuming a variable markup than in the model with a constant markup. Introducing markup variability increases GDP correlation as much as seven percentage points at high levels of trade integration.

The results in figure 9 are calculated assuming a steady state markup of 20%. Figure 10 presents the difference between GDP correlation in the model with variable markups and GDP correlation in the model with constant markups as a function of the import share. Thus the solid line in figure 10 is the difference between the two lines in figure 9. The figure presents the results assuming a 15%, 20%, or 25% markup. As the steady state markup in-

Figure 10. Difference in the cross-country GDP correlation between the model with variable markups and in the model with constant markups as a function of the import share. Calculated assuming a steady state markup of 15%, 20%, or 25%.



creases, markup variability has a greater effect on cyclical co-movement. With a 25% steady state markup, markup variability adds nearly ten percentage points to GDP correlation at high levels of trade integration.

The results presented thus far assume the import demand elasticity, $\rho = 7.5$. As discussed earlier, empirical studies have found that at a sectoral level of disaggregation, this elasticity lies between five and ten. The effect of introducing variable markups and how it depends on the import demand elasticity is presented in figure 11. This figure plots the difference between GDP correlation in the model with variable markups and GDP correlation in the model with constant markups as a function of the import share assuming that $\rho = 7.5$, $\rho = 5$ or $\rho = 10$. Scale is the only difference between the three lines in the

Figure 11. Difference in the cross-country GDP correlation between the model with variable markups and in the model with constant markups as a function of the import share. Calculated assuming different values for the elasticity of substitution between home and foreign goods.

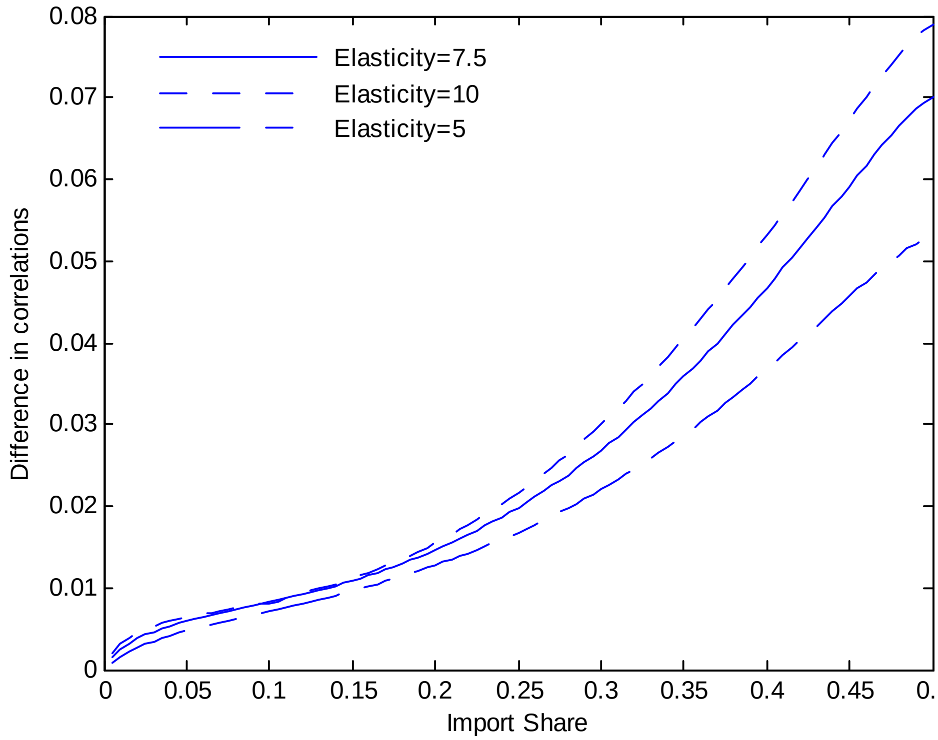


figure. When the import demand elasticity is higher, markup variability has a greater effect on cyclical correlation.

So far we have assumed that firms are engaged in quantity competition. Figure 12 plots the difference between GDP correlation in the model with variable markups and GDP correlation in the model with constant markups as a function of the import share assuming that firms are engaged in price or quantity competition. The figure shows that endogenous markup variability has less of an effect on cyclical correlation when firms are engaged in price competition, but the effect is still significant. At high levels of trade integration, endogenous markup variability adds five percentage points to GDP correlation when firms are engaged in price competition.

Figure 12. Difference in the cross-country GDP correlation between the model with variable markups and in the model with constant markups as a function of the import share. Calculated under the assumption of price competition and the assumption of quantity competition.

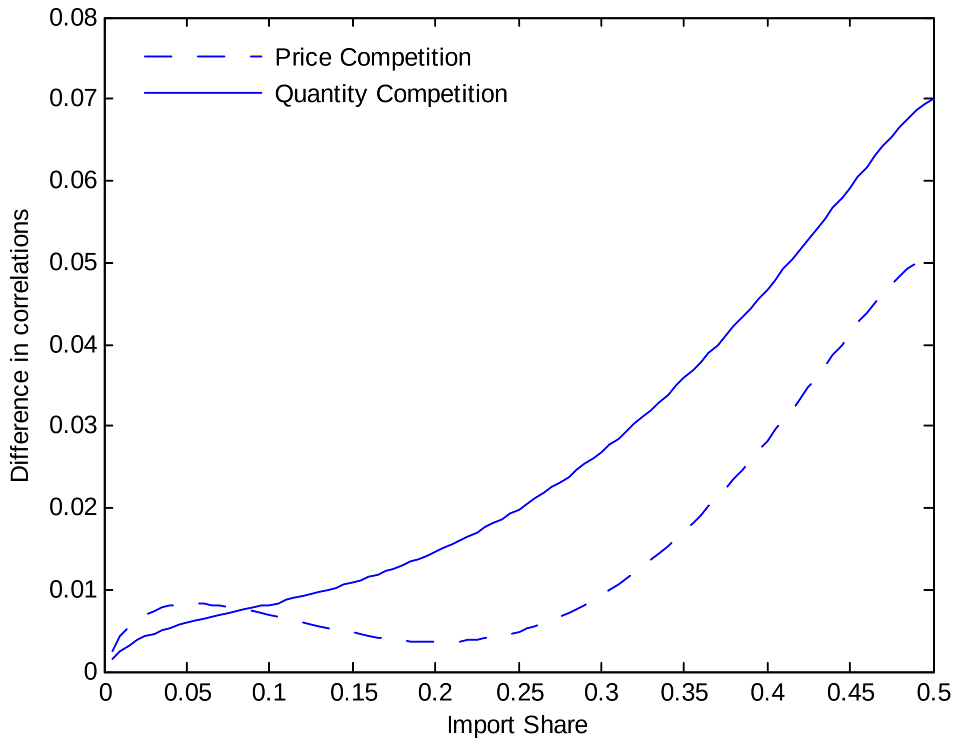
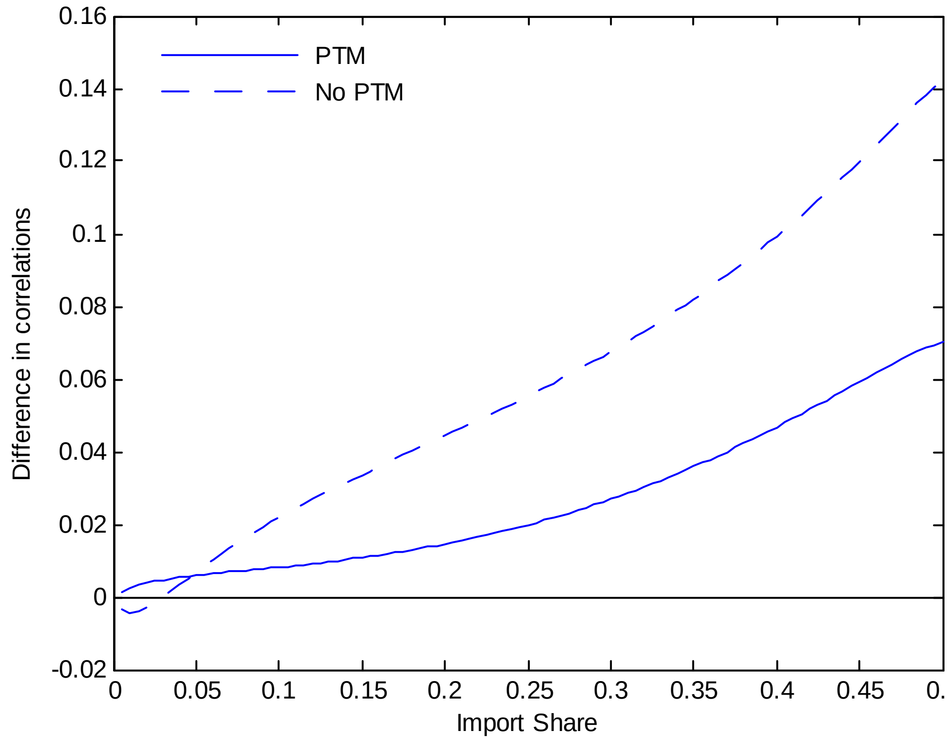


Figure 13. Difference in the cross-country GDP correlation between the model with variable markups and in the model with constant markups as a function of the import share. Calculated under the assumption that domestic and export markets are segmented and under the assumption that they are not.



Finally in figure 13 we relax the assumption that markets are segmented and that firms can choose separate prices for the domestic and export markets. We can see that assuming firms cannot price to market actually increases the effect of variable markups, but otherwise the results of the model do not depend on the assumption of market segmentation.

Summary and Conclusion

This paper introduces endogenous markup variability into the international real business cycle model. Specifically this paper examines how endogenous markup variability can affect international business cycle co-movement.

The intuition here is simple. Endogenous markup variations lead to a change in home and foreign relative prices that is exactly opposite to the change caused by a country specific productivity shock. Thus a country specific productivity shock should lead to business cycle divergence in a real business cycle model. When markups are variable, the same shock leads to less divergence.

The qualitative effect of variable markups on business cycle correlation are clear. This paper set out to quantify those effects.

We found that the introduction of markup variability into the international real business cycle model leads to about a ten percentage point increase in business cycle correlation. Furthermore, we found that introducing markup variability can help reconcile the effect of trade intensity on business cycle correlation found in a model with the effect found in the data.

This paper fits into the young but growing literature that applies the microeconomic issue of endogenous markup variability to macroeconomic questions. Up to this point, endogenous markup variability has been mostly used to study macroeconomic issues related to prices and exchange rates. However this paper shows that the effect of endogenous markup variability on cross-country business cycle correlation is not trivial. The effect of markup variability on other questions pertaining to quantities and production allocation is a promising avenue for further research.

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APPENDIX A

APPENDIX

Technical Appendix to Chapter II

Model Solution

Solution to the Firm's Problem

In this model, production technology is complicated, with multiple sectors, multiple countries, and multiple stages of production. However most of the input and output demand functions can simply be expressed as the solution to a within period optimization problem. Only when discussing investment do we have to consider a multi-period solution to the firm's problem. Since the technologies are identical for each of the three countries (only the parameters are different) we will only solve the model for one of the two small countries, country 1.

Within period Optimization Problems - Demand functions and price indices

The solution to the household's optimization problem (latter in this appendix) will give us the demand for the consumption good, C_{1t}. The solution of the firm's intertemporal optimization problem will give us the demand for investment goods, I_{1t}^i for $i = n, d$. Thus aggregate output is $y_{1t} = C_{1t} + \sum_{i \in n,d} I_{1t}^i$. From here we can use the principle of cost minimization by household's and firms to find the demand functions for all intermediate goods and primary factors of production in the model. This same analysis will allow us to write the price of every good in terms of wage rates and rental rates in both countries.

To begin, consider (II.18), the function that described the imperfect combination of the two final goods, y^i_{1t} for $i = n, d$, into one aggregate good, y_{1t}. Intratemporal optimization requires that in equilibrium the marginal contribution to y_{1t} from one more unit of y^i_{1t} divided by the price of y^i_{1t}, p^{yi}_{1t}, is equal for all i:

$$\frac{\frac{\partial y_{1t}}{\partial y^n_{1t}}}{p^{yn}_{1t}} = \frac{\frac{\partial y_{1t}}{\partial y^d_{1t}}}{p^{yd}_{1t}}$$

We can then rearrange this expression into a demand function for y^i_{1t}:

$$y^i_{1t} = \left(\frac{1}{2}\right)^{\sigma^f} \left(p^{yi}_{1t}\right)^{-\sigma^f} y_{1t}$$

The prices p^{yi}_{1t} for $i = n, d$ are in terms of units of the final consumption good. Thus we can use the demand functions y^i_{1t} in both sectors and in all three countries to define the real exchange rates. This exchange rate is simply the price of the final consumption/investment good in country h, where $h = 2, w$ divided by its corresponding price in country 1:

$$rx^{h1}_t = \frac{\left[\sum_{i \in n,d} \left(\frac{1}{2}\right)^{\sigma^f} \left(p^{yi}_{ht}\right)^{1-\sigma^f}\right]^{\frac{1}{1-\sigma^f}}}{\left[\sum_{i \in n,d} \left(\frac{1}{2}\right)^{\sigma^f} \left(p^{yi}_{1t}\right)^{1-\sigma^f}\right]^{\frac{1}{1-\sigma^f}}}$$

The final goods, y^i_{1t} for $i = n, d$, are composites of domestically produced and imported final goods. We can use the aggregator function (II.17) and again the principle of cost minimization to derive demand functions for both the domestic and imported varieties of the final good from sector i:

$$
\begin{aligned}
y^i_{11t} &= (\omega^y_{11})^{\sigma^y} \left(\frac{mc^{yi}_{1t}}{p^{yi}_{1t}}\right)^{-\sigma^y} y^i_{1t} \\
y^i_{h1t} &= (\omega^y_{h1})^{\sigma^y} \left(\frac{rx^{h1}_t mc^{yi}_{ht}}{p^{yi}_{1t}}\right)^{-\sigma^y} y^i_{1t}
\end{aligned}
\tag{A.1}
$$

where $h = 2, w$, mc^{yi}_{ht} is the marginal cost of producing a unit of final output from sector i in country h. Here we are using the assumption that firm's operate in perfectly competitive markets, and thus the sale price of a good is equal to its marginal cost. Notice that since the foreign marginal cost, mc^{yi}_{ht}, is in terms of the foreign consumption good, we multiply it by the real exchange rate to put in it terms of the home consumption good.

The price index describing the price of final output from sector i, p^{yi}_{1t}, can be derived by using the demand functions (A.1) and the expenditure shares. The price of final output from sector i is given by:

$$
p^{yi}_{1t} = \left[(\omega^y_{11})^{\sigma^y} \left(mc^{yi}_{1t}\right)^{1-\sigma^y} + \sum_{h=2,w} (\omega^y_{h1})^{\sigma^y} \left(rx^{h1}_t mc^{yi}_{ht}\right)^{1-\sigma^y}\right]^{\frac{1}{1-\sigma^y}}
$$

After we have derived the demands for y^i_{11t} and y^i_{h1t} for $i = n, d$, we can use the resource constraint for the distribution of final goods to find the demand for final goods production in each sector and each country , Y^i_{1t}. Once we know the demand for final goods production, we can find the demand for inputs. We need to turn to (II.15) to derive the demand for value added and intermediate inputs in the production of Y^i_{1t}.

$$
\begin{aligned}
VA_{1t}^{i} &= \gamma^{\sigma^{VI}} \left(\frac{mc_{1t}^{vai}}{mc_{1t}^{yi}}\right)^{-\sigma^{VI}} Y_{1t}^{i} \\
x_{1t}^{i} &= (1-\gamma)^{\sigma^{VI}} \left(\frac{p_{1t}^{Xi}}{mc_{1t}^{yi}}\right)^{-\sigma^{VI}} Y_{1t}^{i}
\end{aligned}
$$

where mc_{1t}^{vai} is the marginal cost of the value added component and p_{1t}^{Xi} is the price index of intermediate inputs into production in sector i. Using these demand functions we can derive an expression for the marginal cost of production for a firm producing the final good in sector i in country 1:

$$
mc_{1t}^{yi} = \left[(\gamma)^{\sigma^{VI}} \left(mc_{1t}^{vai}\right)^{1-\sigma^{VI}} + (1-\gamma)^{\sigma^{VI}} \left(p_{1t}^{Xi}\right)^{1-\sigma^{VI}}\right]^{\frac{1}{1-\sigma^{VI}}}
$$

Once we know the demand for value added inputs into the production of final goods, we can derive the demand for capital and labor inputs into the production of final goods. These are derived, just as before, from the value added aggregator function (II.14). Therefore the demand for capital and labor inputs into final goods production in sector i is:

$$
\begin{aligned}
N_{1t}^{yi} &= \theta \frac{mc_{1t}^{vai}}{w_{1t}} VA_{1t}^{i} \\
K_{1t}^{yi} &= (1-\theta) \frac{mc_{1t}^{vai}}{r_{1t}^{i}} VA_{1t}^{i}
\end{aligned}
$$

where MC_{1t}^{vai} is the marginal cost of the value added component to production. We can write it in the following way:

$$mc_{1t}^{vai} = \frac{1}{A_{1t}^{i}} \left(\frac{W_{1t}}{\theta}\right)^{\theta} \left(\frac{R_{1t}^{i}}{1-\theta}\right)^{1-\theta}$$

Notice that our exogenous productivity parameter, A_{1t}^{i}, affects the marginal cost of value added. This is the only place where the exogenous productivity parameter is involved in either the demand functions or price indices of the model. In the steady state, industrial specialization is caused by one country having an absolute advantage in one particular sector. In terms of the model, if we wanted to say that country 1 had an absolute advantage in sector i then we would say $A_{1t}^{i} > A_{ht}^{i}$. Since this productivity parameter factors into the marginal cost of the value added part of the production process, this would say that the firm in sector i in country 1 can produce the good at a lower unit cost than its counterpart in country h.[1]

The demand for capital and labor inputs are important and we will return to those shortly, but we turn now to the demand for intermediate inputs into production in sector i, x_{1t}^{i}. Equation (II.13) describes how the quantity of intermediate inputs into sector i, x_{1t}^{i}, is an imperfect combination of intermediate inputs supplied to sector i from all sectors $k = n, d$. We can use this aggregator function to derive the demand for intermediate inputs into sector i from sector k.

[1]Saying that the firm in country 1 can produce at a lower unit cost than the firm in country h assumes that wages rates and shadow prices of capital are equal across countries in the steady state. The two countries are symmetric, so wages are equal. However if this absolute advantage leads country j to specialize in sector i then the presence of risk and risk premia will make the shadow price of capital in sector i and country j, r_{jt}^{i}, higher than the shadow price in country h, r_{ht}^{i}. This means that difference across countries in unit costs are not as great as would be implied by the differences in the productivity parameter, but in all but very extreme cases of risk and risk aversion, the country with the absolute advantage will have the lower unit costs.

$$x^{ii}_{1t} = (\eta)^{\sigma^{II}} \left(\frac{p^{Xii}_{1t}}{p^{Xi}_{1t}}\right)^{-\sigma^{II}} x^{i}_{1t}$$
$$x^{ki}_{1t} = (1-\eta)^{\sigma^{II}} \left(\frac{p^{Xki}_{1t}}{p^{Xi}_{1t}}\right)^{-\sigma^{II}} x^{i}_{1t} \text{ where } k \neq i$$

where p^{ki}_{1t} is the price index describing the price of intermediate inputs from sector k into sector i. These price indices can then be combined into the price index of all intermediate inputs into sector i.

$$p^{Xi}_{1t} = \left[(\eta)^{\sigma^{II}} \left(p^{Xii}_{1t}\right)^{1-\sigma^{II}} + (1-\eta)^{\sigma^{II}} \left(p^{Xki}_{1t}\right)^{1-\sigma^{II}}\right]^{\frac{1}{1-\sigma^{II}}}$$

The term describing inputs from sector k into sector i, x^{ki}_{1t}, is an imperfect combination of domestically produced and imported inputs. Equation (II.12) describes this imperfect combination. From this function we can derive demand functions for intermediate inputs produced both at home and in the other two countries:

$$x^{ki}_{11t} = (\omega^{x}_{11})^{\sigma^{x}} \left(\frac{mc^{vak}_{1t}}{p^{Xki}_{1t}}\right)^{-\sigma^{x}} x^{ki}_{1t}$$
$$x^{ki}_{h1t} = (\omega^{x}_{h1})^{\sigma^{x}} \left(\frac{rx^{h1}_{t} mc^{vak}_{ht}}{p^{Xki}_{1t}}\right)^{-\sigma^{x}} x^{ki}_{1t}$$

where $h = 2, w$, and mc^{vak}_{1t} is the marginal cost of producing a unit of the intermediate good from sector k. Notice, as before when we derived foreign and domestic demand of final goods, that when a good is shipped internationally the real exchange rate, rx^{h1}_{t}, is included in the price. With these demand functions we can write the price of inputs to sector i from sector k, p^{ki}_{1t}, as a function of the marginal costs,the trade cost, and the real exchange rate.

$$p_{1t}^{Xki} = \left[(\omega_{11}^{x})^{\sigma^x} \left(mc_{1t}^{vak} \right)^{1-\sigma^x} + \sum_{h=2,w} (\omega_{h1}^{x})^{\sigma^x} \left(rx_t^{h1} mc_{ht}^{vak} \right)^{1-\sigma^x} \right]^{\frac{1}{1-\sigma^x}}$$

Once we know the demand for the inputs x_{11t}^{ki} and x_{h1t}^{ki} for $k, i = n, d$, we can use the resource constraint for the distribution of intermediate goods to find the demand for intermediate goods production in sector i and country 1, X_{1t}^{i}. Once we know these production demands we can use the production function in (II.10) to find the demand for the inputs into the production of X_{1t}^{i}. The only inputs into the production of intermediate goods are capital and labor, thus the demand for capital and labor by intermediate goods producing firms is:

$$\begin{aligned} N_{1t}^{xi} &= \theta \left(\frac{mc_{1t}^{vai}}{w_{1t}} \right) X_{1t}^{i} \\ K_{1t}^{xi} &= (1-\theta) \left(\frac{mc_{1t}^{vai}}{r_{1t}^{i}} \right) X_{1t}^{i} \end{aligned}$$

Notice that while the various price indices in the model are complicated functions involving elasticities of substitution, they are simply functions of the wage rates in both countries and the rental rates in both sectors and both countries.

The intertemporal solution to the firm's problem As discussed in the main body of the paper, the firm in sector i in country 1 maximizes its stock price by maximizing the expected discounted value of future dividend payments:

$$\mathcal{P}_{1t}^{i} = E_t \sum_{\tau=1}^{\infty} Q_{1t+\tau}^{i} d_{1t+\tau}^{i}$$

where:

$$d^i_{1t} = r^i_{1t} K^i_{1t} - I^i_{1t}$$

subject to various output and input demand functions, and the capital accumulation constraint:

$$K^i_{jt+1} = (1-\delta) K^i_{jt} + \phi\left(\frac{I^i_{jt}}{K^i_{jt}}\right) K^i_{jt}$$

At time t the firm will choose I^i_{1t} and K^i_{1t} to maximize the following Lagrangian:

$$\mathcal{L} = E_t \sum_{\tau=1}^{\infty} \left\{ \begin{array}{c} Q^i_{1t+\tau}\left(r^i_{1t+\tau} K^i_{1t+\tau} - I^i_{1t+\tau}\right) \\ -\mu^i_{1t+\tau}\left(K^i_{jt+1} - (1-\delta) K^i_{jt} - \phi\left(\frac{I^i_{jt}}{K^i_{jt}}\right) K^i_{jt}\right) \end{array} \right\}$$

The first order conditions with respect to I^i_{1t} and K^i_{1t} are:

$$Q^i_{1t} = \mu^i_{1t} \phi'\left(\frac{I^i_{jt}}{K^i_{jt}}\right) \tag{A.2}$$

$$E_t \left\{ \mu^i_{1t+1}\left(1 - \delta + \phi\left(\frac{I^i_{jt+1}}{K^i_{jt+1}}\right) - \phi'\left(\frac{I^i_{jt+1}}{K^i_{jt+1}}\right)\frac{I^i_{jt+1}}{K^i_{jt+1}}\right) + Q^i_{1t+1} r^i_{1t+1} \right\} = \mu^i_{1t}$$

Solution to the Household's Problem

As discussed in the main body of the paper, the household maximizes the expected discounted value of future utility, which is an increasing function of consumption and a decreasing function of labor supplied. At the beginning of period 0 the household owns

100% of both domestic firms and none of the foreign firms. In period 0 the household sells shares in the domestic firms and buys shares in the foreign firms in an attempt to diversify risk and smooth future income fluctuations.

In period 0 the household in country 1 will choose $C_{1,0}, N_{1,0}, \lambda_{11}^i, \lambda_{h1}^i$, for $i = n, d$ and $h = 2, w$, and $C_{1t}, N_{1t}\ \forall\ t \geq 1$ to maximize the expected discounted value of future utility subject to their period 0 budget constraint and all future budget constraints. There is also the constraint that the household cannot take a short position on foreign stocks, $\lambda_{h1}^i \geq 0$. The household's problem can be expressed as the following Lagrangian:

$$
\begin{aligned}
\mathcal{L} \;=\; & \max E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} \left(C_{1t}\right)^{1-\sigma} - (\kappa) \frac{\sigma^h}{\sigma^h + 1} \left(N_{1t}\right)^{\frac{\sigma^h+1}{\sigma^h}} \right] \\
& - \upsilon_{1,0} \left[C_{1,0} + \sum_{i \in n,d} \lambda_{11}^i \mathcal{P}_1^i + \sum_{h=2,w} \sum_{i \in n,d} \lambda_{h1}^i \mathcal{P}_h^i - w_{1,0} N_{1,0} - \sum_{i \in n,d} \left(\mathcal{P}_1^i + d_{1,0}^i \right) \right] \\
& - E_0 \sum_{t=1}^{\infty} \beta^t \upsilon_{1t} \left[C_{1t} - w_{1t} N_{1t} - \sum_{i \in n,d} \lambda_{11}^i d_{1t}^i - \sum_{h=2,w} \sum_{i \in n,d} (1-\tau) \lambda_{h1}^i r x_t^{h1} d_{ht}^i \right] \\
& + \sum_{h=2,w} \sum_{i \in n,d} \chi_1^i \lambda_{h1}^i
\end{aligned}
$$

The first order conditions of the household's problem with respect to $C_{1,0}, N_{1,0}, \lambda_{11}^i, \lambda_{h1}^i$ and $C_{1t}, N_{1t}\ \forall\ t \geq 1$ are:

$$
\begin{aligned}
(C_{1,0})^{-\sigma} &= \upsilon_{1,0} \qquad (A.3)\\
\kappa\,(N_{1,0})^{\frac{1}{\sigma^h}} &= w_{1,0}\upsilon_{1,0}\\
\upsilon_{1,0}\mathcal{P}_1^i &= E_0\sum_{t=1}^{\infty}\beta^t\upsilon_{1t}d_{1t}^i\\
\upsilon_{1,0}\mathcal{P}_h^{i*} &= \chi_1^i + E_0\sum_{t=1}^{\infty}\beta^t\upsilon_{1t}\,(1-\tau)\,rx_t d_{ht}^i\\
(C_{1t})^{-\sigma} &= \upsilon_{1t}\\
\kappa\,(N_{1t})^{\frac{1}{\sigma^h}} &= w_{1t}\upsilon_{1t}
\end{aligned}
$$

Numerical Solution Method

In this model the steady state levels of financial integration and the steady state risk premia on capital depend on the variances and covariance of certain real variables. These variances and covariances are found through a stochastic approximation of the model. This approximation is only good in the neighborhood of the steady state. Thus the moments of certain real variables are needed to find the steady state, which is needed to find the moments of certain real variables.

Since these moments are used to find the optimal portfolio holdings and risk premia on capital returns, we need to consider three first order conditions, which are all listed in the text and the previous section of this appendix. Let's consider the first order condition of the domestic household's problem with respect to domestic equity shares and the first order condition of the foreign household's problem with respect to domestic portfolio shares in equation (A.3), and the first order condition of the firm's problem with respect to next period's capital stock in equation (A.2). We follow Devereux and Sutherland (2006) and take a second order approximation of these first order conditions to find an expression for asset prices and the risk premium on capital returns as a function of steady state values and second moments of certain real variables. For intuition these were included in the text in equations (II.31) and (II.33).

The iterative method we use to find the equilibrium is similar to the method in Heathcote and Perri (2007). We begin with an initial guess of the variances and covariances of certain real variables. We use this initial guess to solve for a steady state. We then take a first order approximation around this steady state and find the variances and covariance of the same real variables that we were forced to guess at initially. We take these new moments and use them to find a new steady state around which to take another first order approximation. We repeat this process until the moments we used to calculate a steady state are nearly identical to the moments from the first order approximation of the model.

In reality the model converges rather quickly, never needing more than a few iterations.

Details from the empirical estimations

Alternate measures of trade and financial integration

Since accurate and complete data on bilateral financial flows does not exist for a broad set of countries, we are forced to rely on a proxies for bilateral financial integration. We use four measures of financial integration. The first two are "volume based" measures financial integration. These actually measure the volume of financial flows between two countries. The last two measures are "effective" measures of financial integration, which proxy the degree of financial integration by looking at the effects of this integration, as seen through similarities in interest rates or the extent of risk sharing.

The primary measure is found in equation (II.1) in the text.

The second measure of bilateral financial integration, F_{jh}^{cpis}, comes the closest to a true measure of direct financial flows between countries j and h. This is based on the Coordinated Portfolio Investment Survey (CPIS) conducted by the IMF and featured in Imbs (2006). This measure involves portfolio assets, both debt and equity, issued by residents of country j and owned by residents of country h, f_{jh}. The proxy of bilateral financial integration, F_{jh}^{cpis}, is simply the sum of bilateral asset holdings normalized by the sum of the two countries' GDPs:

$$F_{jh}^{cpis} = \frac{f_{jh} + f_{hj}}{GDP_j + GDP_h} \tag{A.4}$$

The effective measures of financial integration proxy integration by interest rate differentials and the degree of risk sharing. The first effective measure, called F_{jh}^{mad}, uses the mean absolute deviation of the real rates of return in country j and h. We calculate the mean absolute deviation of both stock and bond returns and sum them to get F_{jh}^{mad}.

$$F_{jh}^{mad} = \sum_{i=1}^{N} \frac{1}{T} \sum_{t=1}^{T} \left| r_{jt}^{i} - r_{kt}^{i} \right| \tag{A.5}$$

where r_{jt}^{i} is the real rate of return on financial asset i in country j in period t. If country j and country h are integrated financially, then arbitrage conditions require that their real rates of return are equal. Thus F_{jh}^{mad} should be small for financially integrated economies.

The fourth measure of financial integration F_{jh}^{rs} measures the extent of income and consumption risk sharing in countries j and h, $F_{jh}^{rs} = \beta_j + \beta_h$, where the risk sharing measure β is introduced in Asdrubali, Sorensen, and Yosha (1996) and used as a measure of financial integration in Kalemli-Ozcan, Sorensen, and Yosha (2003). β_j is the coefficient in a regression involving time series of gross domestic product and consumption in country j, GDP_{jt} and C_{jt}:

$$\Delta \log (GDP_{jt}) - \Delta \log (C_{jt}) = \alpha_t + \beta_j \Delta \log (GDP_{jt}) + \varepsilon_{jt} \tag{A.6}$$

where α_t are time fixed effects, and thus capture the effect of non-diversifiable aggregate production risk.

In the case of no risk sharing, $\beta_j = 0$, fluctuations in GDP_{jt} translate directly into fluctuations in C_{jt} (up to some idiosyncratic error, ε_{jt}). In the case of perfect risk sharing, $\beta_j = 1$, fluctuations in GDP_{jt} do not carry through into fluctuations in C_{jt}, and C_{jt} is a constant (again, up to some idiosyncratic error, ε_{jt}). Integration in international financial markets leads to this risk sharing. Thus if $F^{rs}_{jh} = \beta_j + \beta_h$ is high then countries j and h are well integrated into the international financial system. This makes it likely that the degree of bilateral financial integration between countries j and h is high.

In addition to the primary measure of trade integration found in (II.2), for robustness we will also use the measure of bilateral trade intensity from Frankel and Rose (1998).

$$T^2_{jh} = \sum_{i \in \mathcal{N}} \frac{X^i_{jh} + M^i_{jh}}{GDP_j + GDP_h} \tag{A.7}$$

The estimation results in this paper hold when using our three alternate measures of financial integration, our one alternative measure of trade integration, and when we calculate GDP correlation using our two alternate detrending methods. The details from these alternate regressions can be found on the author's website.

Countries in the estimations

Argentina; Australia; Austria; Belgium-Luxembourg; Brazil; Bulgaria; Canada; Chile; China; Colombia; Czech Rep.; Denmark; Ecuador; Egypt; Finland; France; Germany; Greece; Hong Kong; Hungary; India; Indonesia; Ireland; Israel; Italy; Japan; Jordan; Kenya; Korea; Latvia; Malaysia; Mexico; Netherlands; New Zealand; Nigeria; Norway; Pakistan; Peru; Philippines; Poland; Portugal; Romania; Russia; Singapore; Slovakia; Slovenia; South Africa; Spain; Sri Lanka; Sweden; Switzerland; Taiwan; Thailand; Turkey; UK; Uruguay; USA; Venezuela

Technical Appendix to Chapter III

In this appendix, we discuss the solution to the model. We start with the household's maximization problem, and then derive the various demand functions and price indices. We then discuss the solution to the household's wage setting problem and the firm's price setting problem, the two sources of nominal rigidity in the model.

Household Maximization Problem

Each household will maximize the present value of future utility given by (III.6) subject to their budget constraint in (III.8). The Lagrangian that describes the household's problem is the following:

$$\mathcal{L} = E\sum_{t=0}^{\infty}\beta^t \left\{ \begin{array}{c} \left[\ln\left(C_t\left(j\right) - bC_{t-1}\left(j\right)\right) - \psi_o\left(h_t^s\left(j\right)\right)^2\right] \\ -\upsilon_t \left[\begin{array}{c} P_tC_t(j) + P_tI_t(j) + P_tT_t(j) \\ +B_t(j) - (1+i_{t-1})B_{t-1}(j) + E_t\left(B_t^F(j) - (1+i_{t-1}^*)B_{t-1}^F(j)\right) \\ -W_t\left(j\right)h_t^s(j) - R_tz_t\left(j\right)K_{t-1}\left(j\right) \\ -\int_0^n \Pi_t(j,i)di + \frac{\chi^{bf}}{2}\left(\frac{E_tB_t^F(j)}{P_t} - nfa_{ss}^F\right)^2 \end{array} \right] \\ -\eta_t\left[K_t - \left(1-\delta-\frac{\kappa}{1+\zeta}\left(z_t\left(j\right)\right)^{1+\zeta}\right)K_{t-1} - \phi\left(\frac{I_t}{K_{t-1}}\right)K_{t-1}\right] \end{array} \right\} \tag{A.8}$$

The first order conditions with respect to $C_t(j)$, $I_t\left(j\right)$, $K_t\left(j\right)$, $z_t\left(j\right)$, $B_t\left(j\right)$, and $B_t^F\left(j\right)$ are:

$$\begin{aligned} \frac{1}{C_t\left(j\right) - bC_{t-1}} &= P_t\upsilon_t \qquad \text{(A.9)} \\ \eta_t\phi'\left(\frac{I_t}{K_{t-1}}\right) &= P_t\upsilon_t \\ \frac{\eta_t}{\beta} &= \upsilon_{t+1}R_{t+1}z_{t+1}\left(j\right) + \eta_{t+1}\left[\left(1-\delta\left(z_{t+1}\right)\right) + \phi\left(\frac{I_{t+1}}{K_t}\right) - \phi'\left(\frac{I_{t+1}}{K_t}\right)\frac{I_{t+1}}{K_t}\right] \\ \upsilon_tR_tK_{t-1}\left(j\right) &= \eta_t\kappa z_t\left(j\right)^{\zeta}K_{t-1}\left(j\right) \\ \frac{\upsilon_{t+1}}{\upsilon_t} &= \frac{1}{\beta(1+i_t)} \\ \frac{\upsilon_{t+1}}{\upsilon_t} &= \left[1+\chi^{bf*}\left(\frac{B_t^{F*}(j)}{P_t^*} - nfa_{ss}^{F*}\right)\right]\frac{E_t}{E_{t+1}\beta\left(1+i_t^*\right)} \end{aligned}$$

A combination of the two first order conditions with respect to bonds yields the uncovered interest parity condition:

$$\frac{(1+i_t^*)}{(1+i_t)} = \frac{E_t}{E_{t+1}}\left[1+\chi^{bf*}\left(\frac{B_t^{F*}(j)}{P_t^*} - nfa_{ss}^{F*}\right)\right] \tag{A.10}$$

Demand Functions and Price Indices

The demand for private consumption and investment can be derived from the various first order conditions. This, along with exogenous government spending gives us aggregate final demand, Y_t, by (III.12). From there we can derive the demand for both traded and nontraded goods using the final good aggregator function in (III.5):

$$y_t = \gamma \left(\frac{MC_t}{P_t} \right)^{-\mu} Y_t \tag{A.11}$$

$$x_t = (1-\gamma) \left(\frac{P_t^T}{P_t} \right)^{-\mu} Y_t \tag{A.12}$$

where MC is the marginal cost of production, P^T is an index of the price of traded goods, and P is the consumer price index:

$$P_t = \left[\gamma \left(MC_t \right)^{1-\mu} + (1-\gamma) \left(P_t^T \right)^{1-\mu} \right]^{\frac{1}{1-\mu}} \tag{A.13}$$

Use the non-traded goods production function and the demand for non traded goods, y_t, to derive the demand for labor and capital by non-traded goods producing firms:

$$h_t^y = (1-\alpha) \frac{MC_t}{W_t \left(1 + i_{t-1}\right)} y_t \tag{A.14}$$

$$K_t^y = \alpha \frac{MC_t}{R_t} y_t \tag{A.15}$$

The demand for labor shows that we are adopting the working capital assumption from Christiano, Eichenbaum, and Evans (2005). Workers must be paid in advance, and thus the wage rate paid by the firm is $W_t\left(1+i_{t-1}\right)$ where W_t is the actual wage paid to the employee, but since the wage is paid in advance the time value, $(1+i_{t-1})$, of that wage must be internalized by the firm. This is simply a way to incorporate that firms must hold working capital (like inventory, cash, accounts receivable), and thus there is a time value cost. Given these factor demand functions, the marginal cost of production, MC_t, is:

$$MC_t = \left(\frac{W_t\left(1+i_{t-1}\right)}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t}{\alpha}\right)^{\alpha} \tag{A.16}$$

If we define $x_t^d = \left(\left(\frac{1}{n}\right)^{\frac{1}{\sigma}}\int_0^n x_t^d\left(i\right)^{\frac{\sigma-1}{\sigma}}di\right)^{\frac{\sigma}{\sigma-1}}$ and $x_t^{m*} = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}}\int_n^1 x_t^{m*}\left(i\right)^{\frac{\sigma-1}{\sigma}}di\right)^{\frac{\sigma}{\sigma-1}}$ as aggregate domestically supplied and imported traded goods, then the traded goods aggregator function in (III.3) can be rewritten as:

$$x_t = \left[\left(n^{\frac{\rho-1}{\sigma-1}}\right)^{\frac{1}{\rho}}\left[x_t^d\right]^{\frac{\rho-1}{\rho}} + \left(\left(1-n\right)^{\frac{\rho-1}{\sigma-1}}\right)^{\frac{1}{\rho}}\left[x_t^{m*}\right]^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}$$

Use this aggregator function to derive the demands for domestic and imported goods:

$$x_t^d = \left(n\right)^{\frac{1-\rho}{1-\sigma}}\left(\frac{P_t^d}{P_t^T}\right)^{-\rho}x_t \tag{A.17}$$

$$x_t^m = \left(1-n\right)^{\frac{1-\rho}{1-\sigma}}\left(\frac{P_t^m}{P_t^T}\right)^{-\rho}x_t \tag{A.18}$$

where P^d is a price index for domestic goods, and P^m is an import price index. With domestic and imported prices, the index for the price of all traded goods is:

$$P_t^T = \left[(n)^{\frac{1-\rho}{1-\sigma}} \left(P_t^d \right)^{1-\rho} + (1-n)^{\frac{1-\rho}{1-\sigma}} \left(P_t^m \right)^{1-\rho} \right]^{\frac{1}{1-\rho}} \tag{A.19}$$

The market clearing condition linking one country's exports with another country's imports is simply $x_t^{m*} = (1-c)\, x_t^x$, and this combined with the assumption that transporting firms earn zero profit, links the export prices in one country with the import in another:

$$P_t^m = \frac{P_t^{x*}}{(1-c)\, E_t} \tag{A.20}$$

where E_t is the nominal exchange rate denoted in units of the foreign currency per units of the home currency.

Since firms that can price-to-market are indexed $i \in (0, ns]$ and those that cannot are indexed $i \in (ns, n]$, the goods output from firms that can price-to-market can be written as $x_t^{ad} = \left(\left(\frac{1}{ns}\right)^{\frac{1}{\sigma}} \int_0^{ns} x_t^d(i)^{\frac{\sigma-1}{\sigma}}\, di \right)^{\frac{\sigma}{\sigma-1}}$ and the output of the firms that cannot price-to-market can be written as $x_t^{bd} = \left(\left(\frac{1}{n(1-s)} \right)^{\frac{1}{\sigma}} \int_{ns}^{n} x_t^d(i)^{\frac{\sigma-1}{\sigma}}\, di \right)^{\frac{\sigma}{\sigma-1}}$. Therefore the aggregator of domestically supplied traded goods can be written as:

$$x_t^d = \left((s)^{\frac{1}{\sigma}} \left(x_t^{ad} \right)^{\frac{\sigma-1}{\sigma}} + (1-s)^{\frac{1}{\sigma}} \left(x_t^{bd} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

Use this to derive the demands for goods from firms that cannot price-to-market and those that can:

$$x_t^{ad} = s \left(\frac{P_t^{ad}}{P_t^d} \right)^{-\sigma} x_t^d \tag{A.21}$$

$$x_t^{bd} = (1-s)\left(\frac{P_t^b}{P_t^d}\right)^{-\sigma} x_t^d \tag{A.22}$$

where P^{ad} is the index of prices among domestic goods firms that can price-to-market, and P^b is the price index for firms that cannot. With these price indices, the price index for all domestic traded goods is:

$$P_t^d = \left[(s)\left(P_t^{ad}\right)^{1-\sigma} + (1-s)\left(P_t^b\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{A.23}$$

The demands and price indices in the export market are the same, just all superscripts d are replaced with superscripts x.

Use the functions for x_t^{ad} and x_t^{bd} to derive the demand functions facing the individual firm:

$$x_t^{ad}(i) = \frac{1}{ns}\left(\frac{P_t^{ad}(i)}{P_t^{ad}}\right)^{-\sigma} x_t^{ad} \tag{A.24}$$

$$x_t^{bd}(i) = \frac{1}{n(1-s)}\left(\frac{P_t^b(i)}{P_t^b}\right)^{-\sigma} x_t^{bd} \tag{A.25}$$

where $P_t^{ad}(i)$ and $P_t^b(i)$ is the price set by the individual firm that can and cannot price-to-market, respectively. P_t^{ad} and P_t^b are price indices given by:

$$P_t^{ad} = \left(\frac{1}{ns}\int_0^{ns}\left(P_t^{ad}(i)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}} \tag{A.26}$$

$$P_t^b = \left(\frac{1}{n(1-s)} \int_{ns}^{n} \left(P_t^b(i) \right)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \tag{A.27}$$

Nominal Price Setting

Wage Setting

In any given period, household j faces a probability of $1-\xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t(j) = \pi_{t-1} W_{t-1}(j)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

If household j is allowed to reset their wages in period t they will set a wage to maximize the expected present value of consumption from real labor income minus the disutility of labor.

$$E_t \sum_{l=0}^{\infty} \beta^l (\xi_w)^l \left\{ \upsilon_{t+l} \Pi_{t,t+l} W_t(j) h_{t+l}^s(j) - \psi \left(h_{t+l}^s(j) \right)^2 \right\}$$

where υ_{t+l} is the marginal utility of consumption in period $t+l$

$$\Pi_{t,t+l} = \begin{cases} 1 & \text{if } l = 0 \\ \pi_{t+l-1} \Pi_{t,t+l-1} & \text{if } l > 0 \end{cases}$$

The imperfect combination of labor from different households is described in (III.11). Use this function to derive the demand function for labor from a specific household:

$$h_t^s(j) = \left(\frac{W_t(j)}{W_t} \right)^{-\theta} h_t^s$$

where $W_t = \left(\int_0^n W_t(j)^{1-\theta} dj \right)^{\frac{1}{1-\theta}}$ is the average wage rate across households, and h_t^s is aggregate labor supplied by domestic households.

Substitute the labor demand function into the maximization problem to express the maximization problem as a function of one choice variable, the wage rate, $W_t(j)$:

$$E_t \sum_{l=0}^{\infty} \beta^l (\xi_w)^l \left\{ \upsilon_{t+l} \Pi_{t,t+l} W_t(j) \left(\frac{W_t(j)}{W_t} \right)^{-\theta} h_t^s - \psi \left(\left(\frac{W_t(j)}{W_t} \right)^{-\theta} h_t^s \right)^2 \right\}$$

After some rearranging, the first order condition of this problem is:

$$(W_t(j))^{\theta+1} = \frac{\theta}{(\theta-1)} 2\psi (W_t)^{\theta} \frac{E_t \sum_{l=0}^{\infty} \left\{ \beta^l (\xi_w)^l \left(\frac{W_{t+l}}{\Pi_{t,t+l} W_t} \right)^{2\theta} \left(h_{t+l}^s \right)^2 \right\}}{E_t \sum_{l=0}^{\infty} \left\{ \beta^l (\xi_w)^l \upsilon_{t+l} (\Pi_{t,t+l}) \left(\frac{W_{t+l}}{\Pi_{t,t+l} W_t} \right)^{\theta} h_{t+l}^s \right\}}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t(j) = \frac{\theta}{(\theta-1)} \frac{2\psi h_t^s}{\upsilon_t}$$

Thus when wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{(\theta-1)}$, multiplied by the marginal disutility of labor, $2\psi h_t^s$, divided by the marginal utility of consumption, υ_t.

Write the wage rate for the household that can reset wages in period t, $W_t(j)$, as $\tilde{W}_t(j)$ to denote it as an optimal wage. Also note that all households that can reset wages in period t will reset to the same wage rate, so $\tilde{W}_t(j) = \tilde{W}_t$.

All households face a probability of $(1 - \xi_w)$ of being able to reset their wages in a given period, so by the law of large numbers $(1 - \xi_w)$ of households can reset their wages in a given period. The wages of the other ξ_w will automatically reset by the previous periods inflation rate.

So substitute $\tilde{W}_t$ into the expression for the average wage rate $W_t = \left(\int_0^n W_t(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the average wage. With this expression it is clear how the Calvo framework makes wages sticky:

$$W_t = \left(\xi_w \left(\Pi_{t-1,t} W_{t-1}\right)^{1-\theta} + (1-\xi_w)\left(\tilde{W}_t\right)^{1-\theta}\right)^{\frac{1}{1-\theta}}$$

Price Setting

In the model, traded goods prices are sticky. The output from traded goods firms is both sold domestically and exported. Therefore the firm sets prices for both the domestic market and the foreign market.

In period t, the firm will be able to change it's price with probability $1-\xi_p$. If the firm cannot change prices then domestic prices are indexed by the previous period's domestic inflation rate, and export prices are indexed by the previous period's foreign inflation rate.

The firm that can reset prices in period t will choose $P_t^d(i)$ and $P_t^x(i)$ to maximize discounted future profits from both the domestic and foreign markets:

$$\begin{aligned} &\max_{P_t^d(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{\Pi_{t,t+l} P_t^d(i)\, x_{t+l}^d(i) - MC_{t+l} x_{t+l}^d(i)\right\} \\ &+ \max_{P_t^x(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{\Pi_{t,t+l}^* P_t^x(i)\, x_{t+l}^x(i) - MC_{t+l} x_{t+l}^x(i)\right\} - MC_{t+l}\psi \end{aligned}$$

where MC_{t+l} is marginal cost of production in period $t+l$.

The only difference between firms that can price-to-market, indexed $i \in [0, ns]$, and those that cannot, indexed $i \in (ns, n]$, is that the firms that can price-to-market choose both $P_t^d(i)$ and $P_t^x(i)$. Firms that cannot price-to-market can only choose $P_t^d(i) = P_t^x(i)$.

First, we will derive the pricing rules for the firms that can price-to-market. The rule for the firms that cannot are similar, but since there is an extra constraint they are slightly more complicated.

The domestic and export demand functions facing the firm are given in (A.24). Substitute these demand functions into the maximization problem to express this problem as a function of two choice variables, $P_t^d(i)$ and $P_t^x(i)$:

$$\max_{P_t^d(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{ \begin{array}{c} \Pi_{t,t+l} P_t^d(i) \frac{1}{ns} \left(\frac{P_t^{ad}(i)}{P_t^{ad}}\right)^{-\sigma} x_t^{ad} \\ -MC_{t+l} \frac{1}{ns} \left(\frac{P_t^{ad}(i)}{P_t^{ad}}\right)^{-\sigma} x_t^{ad} \end{array} \right\}$$
$$+ \max_{P_t^x(i)} E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \left\{ \begin{array}{c} \Pi^*_{t,t+l} P_t^x(i) \frac{1}{ns} \left(\frac{P^{ax}(i)}{P^{ax}}\right)^{-\sigma} x_t^{ax} \\ -MC_{t+l} \frac{1}{ns} \left(\frac{P^{ax}(i)}{P^{ax}}\right)^{-\sigma} x_t^{ax} \end{array} \right\} \tag{A.28}$$

After some rearranging, the first order condition with respect to $P_t^d(i)$ is:

$$P_t^{ad}(i) = \frac{\sigma}{\sigma - 1} \frac{E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} MC_{t+l} \left(\frac{\Pi_{t,t+l}}{P_{t+l}^{ad}}\right)^{-\sigma} x_{t+l}^{ad}}{E_t \sum_{l=0}^{\infty} \beta^l \left(\xi_p\right)^l \upsilon_{t+l} \Pi_{t,t+l} \left(\frac{\Pi_{t,t+l}}{P_{t+l}^{ad}}\right)^{-\sigma} x_{t+l}^{ad}}$$

The first order condition with respect to $P_t^x(i)$ is the same, just the superscripts d are replaced with superscripts x and the home inflation index variable $\Pi_{t,t+l}$ is replaced with the foreign inflation index variable $\Pi^*_{t,t+l}$.

If prices are flexible, and thus $\xi_p = 0$, then this expression for price reduces to:

$$P_t^{ad}(i) = \frac{\sigma}{\sigma - 1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Write the price set by the firm that can reset prices in period t as $\tilde{P}_t^{ad}(i)$ to denote that it is an optimal price. Firms that can reset prices in period t will all reset to the same level, so $\tilde{P}_t^{ad}(i) = \tilde{P}_t^{ad}$. Substitute this optimal price into the price index in (A.26) and use the fact that in any period $1-\xi_p$ firms will reoptimize prices, and the prices of ξ_p firms will be automatically reset using the previous periods inflation rate to derive an expression for the price index, P_t^{ad}:

$$P_t^{ad} = \left(\xi_p \left(\Pi_{t-1,t} P_{t-1}^{ad}\right)^{1-\sigma} + (1-\xi_p)\left(\tilde{P}_t^{ad}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

As before, the expression for export prices, P_t^{ax}, is nearly identical, all d's are replaced with x's, and instead of automatically indexing by the home inflation rate, $\Pi_{t-1,t}$, prices are indexed by the foreign inflation rate, $\Pi_{t-1,t}^*$.

If we impose the constraint that $P_t^d(i) = P_t^x(i)$, then we can use the same steps to derive the optimal price for firms that cannot price-to-market. The the first order condition of (A.28) with respect to $P_t^b(i) = P_t^d(i) = P_t^x(i)$ is:

$$P_t^b(i) = \frac{\sigma}{\sigma-1} \frac{E_t \sum_{l=0}^{\infty} \beta^l (\xi_p)^l \upsilon_{t+l} MC_{t+l} \left\{ \left(\frac{\Pi_{t,t+l}}{P_{t+l}^b}\right)^{-\sigma} x_{t+l}^{bd} + \left(\frac{\Pi_{t,t+l}}{P_{t+l}^b}\right)^{-\sigma} x_{t+l}^{bx} \right\}}{E_t \sum_{l=0}^{\infty} \beta^l (\xi_p)^l \upsilon_{t+l} \left\{ \Pi_{t,t+l} \left(\frac{\Pi_{t,t+l}}{P_{t+l}^b}\right)^{-\sigma} x_{t+l}^{bd} + \Pi_{t,t+l}^* \left(\frac{\Pi_{t,t+l}}{P_{t+l}^b}\right)^{-\sigma} x_{t+l}^{bx} \right\}}$$

This expression is slightly more complicated than the earlier price setting equations, but when prices are flexible, $\xi_p = 0$, it reduces to the familiar rule that price is a constant mark-up over marginal cost.

Technical Appendix to Chapter IV

The household's maximization problem

The household will maximize the expected present value of lifetime utility, (IV.8), subject to their budget constraint in (IV.9), and capital accumulation equation, (IV.10).

Under complete international financial markets, the home and foreign households' problems are solved as one maximization problem subject to one worldwide budget constraint and two capital accumulation equations:

$$\mathcal{L} = E_0 \sum_{t=o}^{\infty} \beta^t \left[\begin{array}{c} \frac{1}{1-\zeta} \left[(1-N_t)^{\theta} (C_t)^{1-\theta} \right]^{1-\zeta} + \frac{1}{1-\zeta} \left[(1-N_t^*)^{\theta} (C_t^*)^{1-\theta} \right]^{1-\zeta} \\ -\lambda_t \left(\begin{array}{c} C_t + I_t + q_t (C_t^* + I_t^*) \\ -w_t N_t - r_t K_t - \int_0^1 \sum_{i=1}^{N} \Pi_t^j (i)\, dj \\ -q_t \left(w_t^* N_t^* - r_t^* K_t^* - \int_0^1 \sum_{i=1}^{N} \Pi_t^{j*} (i)\, dj \right) \end{array} \right) \\ -\upsilon_t \left(K_{t+1} - (1-\delta) K_t - I_t \right) \\ -\upsilon_t^* \left(K_{t+1}^* - (1-\delta) K_t^* - I_t^* \right) \end{array} \right]$$

The first order conditions with respect to $C_t, C_t^*, N_t, N_t^*, I_t, I_t^*, K_{t+1}$ and K_{t+1}^* are:

$$
\begin{aligned}
\lambda_t &= (1-\theta)\left[(1-N_t)^{\theta}(C_t)^{1-\theta}\right]^{1-\zeta}(C_t)^{-\theta} \\
\lambda_t q_t &= (1-\theta)\left[(1-N_t^*)^{\theta}(C_t^*)^{1-\theta}\right]^{1-\zeta}(C_t^*)^{-\theta} \\
\lambda_t w_t &= \theta\left[(1-N_t)^{\theta}(C_t)^{1-\theta}\right]^{1-\zeta}(1-N_t)^{-1} \\
\lambda_t w_t^* q_t &= \theta\left[(1-N_t^*)^{\theta}(C_t^*)^{1-\theta}\right]^{1-\zeta}(1-N_t^*)^{-1} \\
\lambda_t &= \upsilon_t \\
\lambda_t q_t &= \upsilon_t^* \\
\frac{\upsilon_t}{\beta} &= (1-\delta)\,\upsilon_{t+1}+\lambda_{t+1}r_{t+1} \\
\frac{\upsilon_t^*}{\beta} &= (1-\delta)\,\upsilon_{t+1}^*+\lambda_{t+1}r_{t+1}^*q_{t+1}
\end{aligned}
\tag{A.29}
$$

The firm's maximization problem

Firm i in sector j will choose a prices and quantities to maximize profit given by:

$$
\Pi_t^j(i) = p_{D,t}^j(i)\,y_{D,t}^j(i) + p_{X,t}^j(i)\,y_{X,t}^j(i) - w_t N_t^j(i) - r_t K_t^j(i) \tag{A.30}
$$

This profit can be rewritten as:

$$
\Pi_t^j(i) = \left(p_{D,t}^j(i) - MC_t\right) y_{D,t}^j(i) + \left(p_{X,t}^j(i) - MC_t\right) y_{X,t}^j(i) - MC_t\psi \tag{A.31}
$$

where $MC_t = \frac{1}{A_t}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t}{\alpha}\right)^{\alpha}$.

Quantity Competition

The firm engaged in quantity competition will choose quantities $y^j_{D,t}(i)$ and $y^j_{X,t}(i)$ to maximize (IV.13) subject to the inverse demand functions in (IV.14). After substituting the inverse demand function into the profit maximization problem, the firm's univariate maximization problem to choose $y^j_{D,t}(i)$ is:

$$y^j_{D,t}(i) = \underset{y^j_{D,t}(i)}{\operatorname{argmax}} \left\{ \left(\left(N\frac{y^j_{D,t}(i)}{y^j_{D,t}} \right)^{\frac{-1}{\sigma}} \left(2\frac{y^j_{D,t}}{y^j_t} \right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t} \right)^{\frac{-1}{\gamma}} - MC_t \right) y^j_{D,t}(i) \right\} \tag{A.32}$$

The individual firm's choice of $y^j_{D,t}(i)$ can influence total production within sector j, $y^j_{D,t}$ and y^j_t, but not aggregate production y_t or marginal cost, MC_t. Using the fact that $\frac{d\ln y^j_{D,t}}{d\ln y^j_{D,t}(i)} = s^j_t = \frac{1}{N}$ and $\frac{d\ln y^j_t}{d\ln y^j_{D,t}(i)} = (1-m_t)\frac{1}{N}$ the first order condition of the firm's problem is:

$$\left(N\frac{y^j_{D,t}(i)}{y^j_{D,t}} \right)^{\frac{-1}{\sigma}} \left(2\frac{y^j_{D,t}}{y^j_t} \right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t} \right)^{\frac{-1}{\gamma}} = \frac{(MC_t)}{\left(1-\frac{1}{\sigma}\left(1-\frac{1}{N}\right)-\frac{1}{N}\left(\frac{1}{\rho}m_t+\frac{1}{\gamma}(1-m_t)\right)\right)} \tag{A.33}$$

If this first order condition is substituted into the inverse demand function in (IV.14), then the price set by the firm engaging in quantity competition is:

$$p_{D,t}(i) = \frac{1}{1-\frac{1}{\sigma}\left(1-\frac{1}{N}\right)-\frac{1}{N}\left(\frac{1}{\rho}m_t+\frac{1}{\gamma}(1-m_t)\right)} MC_t \tag{A.34}$$

Thus the domestic elasticity of demand for the firm engaged in quantity competition is:

$$\varepsilon^d = \left[\frac{1}{\sigma}\left(1-\frac{1}{N}\right) + \frac{1}{N}\left(\frac{1}{\rho}m_t + \frac{1}{\gamma}(1-m_t)\right) \right]^{-1}$$

If the firm cannot price-to-market, there is one additional constraint that $p^j_{D,t}(i) = p^j_{X,t}(i) = p^j_t(i)$. Therefore after substituting the inverse demand functions in (IV.14) into the firm's maximization problems in (IV.13), the firm's univariate maximization problem to choose $y^j_{D,t}(i)$ is:

$$y^j_{D,t}(i) = \underset{y^j_{D,t}(i)}{\operatorname{argmax}} \left[\left(\left(N \frac{y^j_{D,t}(i)}{y^j_D} \right)^{\frac{-1}{\sigma}} \left(2 \frac{y^j_{D,t}}{y^j_t} \right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t} \right)^{\frac{-1}{\gamma}} - MC_t \right) \left(y^j_{D,t}(i) + y^j_{X,t}(i) \right) \right] \tag{A.35}$$

Using the fact that $\frac{d \ln y^j_{D,t}}{d \ln y^j_{D,t}(i)} = s^j_t = \frac{1}{N}$ and $\frac{d \ln y^j_t}{d \ln y^j_{D,t}(i)} = (1 - m_t) \frac{1}{N}$, the first order condition of the firm's problem is:

$$\left(N \frac{y^j_{D,t}(i)}{y^j_D} \right)^{\frac{-1}{\sigma}} \left(2 \frac{y^j_{D,t}}{y^j_t} \right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t} \right)^{\frac{-1}{\gamma}} \tag{A.36}$$

$$= MC_t \frac{\left(1 + \frac{d \ln y^j_{X,t}(i)}{d \ln y^j_{D,t}(i)} \frac{y^j_{X,t}(i)}{y^j_{D,t}(i)} \right)}{\left[- \left(\frac{1}{\sigma} - \left(\frac{1}{\sigma} - \frac{1}{\rho} \right) \frac{1}{N} - \left(\frac{1}{\rho} - \frac{1}{\gamma} \right) \frac{1}{N} (1 - m) \right) \frac{y^j_{D,t}(i) + y^j_{X,t}(i)}{y^j_{D,t}(i)} + \left(1 + \frac{d \ln y^j_{X,t}(i)}{d \ln y^j_{D,t}(i)} \frac{y^j_{X,t}(i)}{y^j_{D,t}(i)} \right) \right]}$$

The condition that $p^j_{D,t}(i) = p^j_{X,t}(i)$ implies that:

$$y^j_{X,t}(i) = \left(\frac{q_t}{1 - c} \left(\frac{y^j_{D,t}(i)}{y^j_D} \right)^{\frac{-1}{\sigma}} \left(\frac{y^j_{D,t}}{y^j_t} \right)^{\frac{-1}{\rho}} \left(\frac{y^j_t}{y_t} \right)^{\frac{-1}{\gamma}} \left(\frac{1}{y^j_X} \right)^{\frac{1}{\sigma}} \left(\frac{y^{j*}_{M,t}}{y^{j*}_t} \right)^{\frac{1}{\rho}} \left(\frac{y^{j*}_t}{y^*_t} \right)^{\frac{1}{\gamma}} \right)^{-\sigma} \tag{A.37}$$

which implies:

$$\frac{d \ln y^j_{X,t}(i)}{d \ln y^j_{D,t}(i)} = \frac{\left(\frac{1}{\sigma} \right) - \left(\frac{1}{\sigma} - \frac{1}{\rho} \right) \frac{1}{N} - \left(\frac{1}{\rho} - \frac{1}{\gamma} \right) \frac{1}{N} (1 - m)}{\left(\frac{1}{\sigma} \right) - \left(\frac{1}{\sigma} - \frac{1}{\rho} \right) \frac{1}{N} - \left(\frac{1}{\rho} - \frac{1}{\gamma} \right) \frac{1}{N} m^*} \tag{A.38}$$

Thus the first order condition in (A.36) simplifies to:

$$p_t^j(i) = \frac{\varepsilon}{\varepsilon - 1} MC_t$$

where

$$\begin{aligned} \varepsilon &= \left[\frac{1}{\sigma}\left(1 - \frac{1}{N}\right) + \frac{1}{N}\left(\frac{1}{\rho} m_t + \frac{1}{\gamma}(1 - m_t)\right)\right]^{-1} s_{D,t} \\ &+ \left[\frac{1}{\sigma}\left(1 - \frac{1}{N}\right) + \frac{1}{N}\left(\frac{1}{\rho}(1 - m_t^*) + \frac{1}{\gamma} m_t^*\right)\right]^{-1} s_{X,t} \end{aligned}$$

and $s_{D,t} = \frac{y_{D,t}^j(i)}{y_{D,t}^j(i) + y_{X,t}^j(i)}$ and $s_{X,t} = 1 - s_{D,t}$.

Notice that this elasticity of demand is simply a convex combination of the domestic elasticity and the export elasticity.

Price Competition

The firm engaged in price competition will choose prices $p_{D,t}^j(i)$ and $p_{X,t}^j(i)$ to maximize:

$$\begin{aligned} p_{D,t}^j(i) &= \underset{p_{D,t}^j(i)}{\operatorname{argmax}} \left\{\left(p_{D,t}^j(i) - MC_t\right) y_{D,t}^j(i)\right\} \\ p_{X,t}^j(i) &= \underset{p_{X,t}^j(i)}{\operatorname{argmax}} \left\{\left(p_{X,t}^j(i) - MC_t\right) y_{X,t}^j(i)\right\} \end{aligned} \tag{A.39}$$

subject to the following demand functions:

$$\begin{aligned} y_{D,t}^j(i) &= \frac{1}{N}\left(\frac{p_{D,t}^j(i)}{p_{D,t}^j}\right)^{-\sigma}\left(\frac{p_{D,t}^j}{p_t^j}\right)^{-\rho}\left(p_t^j\right)^{-\gamma} y_t \\ y_{X,t}^j(i) &= \frac{1}{N}\left(\frac{p_{X,t}^j(i)}{p_{X,t}^j}\right)^{-\sigma}\frac{1}{(1-c)}\left(\frac{p_{M,t}^{j*}}{p_t^{j*}}\right)^{-\rho}\left(p_t^{j*}\right)^{-\gamma} y_t^* \end{aligned} \tag{A.40}$$

After substituting the demand function into the maximization problem, the firm's univariate maximization problem to choose its domestic price, $p^j_{D,t}(i)$, is:

$$p^j_{D,t}(i) = \underset{p^j_{D,t}(i)}{\operatorname{argmax}} \left\{ \left(p^j_{D,t}(i) - MC_t\right) \frac{1}{N} \left(\frac{p^j_{D,t}(i)}{p^j_{D,t}}\right)^{-\sigma} \left(\frac{p^j_{D,t}}{p^j_t}\right)^{-\rho} \left(p^j_t\right)^{-\gamma} y_t \right\} \quad \text{(A.41)}$$

The individual firm's choice of $p^j_{D,t}(i)$ can influence sectoral prices, $p^j_{D,t}$ and p^j_t, but not aggregate production y_t or marginal cost, MC_t. Using the fact that $\frac{d\ln p^j_{D,t}}{d\ln p^j_{D,t}(i)} = s^j_t = \frac{1}{N}$ and $\frac{d\ln p^j_t}{d\ln p^j_{D,t}(i)} = (1-m_t)\frac{1}{N}$ the first order condition of the firm's problem is:

$$p^j_{D,t}(i) = \frac{\sigma\left(1-\frac{1}{N}\right) + \frac{1}{N}\left(\rho m_t + \gamma(1-m_t)\right)}{\sigma\left(1-\frac{1}{N}\right) + \frac{1}{N}\left(\rho m_t + \gamma(1-m_t)\right) - 1} MC_t \quad \text{(A.42)}$$

Thus the domestic elasticity of demand for the firm engaged in price competition is:

$$\varepsilon^d = \sigma\left(1-\frac{1}{N}\right) + \frac{1}{N}\left(\rho m_t + \gamma(1-m_t)\right)$$

If the firm cannot price-to-market, there is one additional constraint that $p^j_{D,t}(i) = p^j_{X,t}(i) = p^j_t(i)$. Therefore after substituting the demand functions in (A.40) into the firm's maximization problems in (A.39), the firm's univariate maximization problem to choose $p^j_t(i)$ is:

$$p^j_t(i) = \underset{p^j_t(i)}{\operatorname{argmax}} \left\{ \begin{array}{c} \left(p^j_t(i) - MC_t\right)\frac{1}{N}\left(\frac{p^j_t(i)}{p^j_{D,t}}\right)^{-\sigma}\left(\frac{p^j_{D,t}}{p^j_t}\right)^{-\rho}\left(p^j_t\right)^{-\gamma} y_t \\ + \left(p^j_t(i) - MC_t\right)\frac{1}{N}\left(\frac{p^j_t(i)}{p^j_{X,t}}\right)^{-\sigma}\left(\frac{p^{j*}_{M,t}}{p^{j*}_t}\right)^{-\rho}\left(p^{j*}_t\right)^{-\gamma}\frac{y^*_t}{1-c} \end{array} \right\} \quad \text{(A.43)}$$

Using the fact that $\frac{d\ln p^j_D}{d\ln p^j(i)} = \frac{d\ln p^j_X}{d\ln p^j(i)} = s^j_i = \frac{1}{N}$, $\frac{d\ln p^j_t}{d\ln p^j_t(i)} = \frac{1}{N}\left(1-m^j\right)$, and $\frac{d\ln p^{j*}_t}{d\ln p^j_t(i)} = \frac{1}{N}m^{j*}$, the first order condition of the firm's problem is:

$$p_{b,t}^{j}(i) = \frac{\varepsilon}{\varepsilon - 1} MC_t \tag{A.44}$$

where $\varepsilon = \sigma\left(1 - \frac{1}{N}\right) + \frac{1}{N}\left(s_{D,t}\left(\rho m^{j} + \gamma\left(1 - m^{j}\right)\right) + s_{X,t}\left(\rho\left(1 - m^{j*}\right) + \gamma m^{j*}\right)\right)$ is the elasticity of demand and $s_{D,t} = \frac{y_{D,t}^{j}(i)}{y_{D,t}^{j}(i) + y_{X,t}^{j}(i)}$ and $s_{X,t} = 1 - s_{D,t}$.