ESSAYS ON INTERNATIONAL ECONOMICS

By

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To my parents, wherever they are ...

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Contents

List of Figures

List of Tables

Chapter 1

Overview

This dissertation consists of three chapters. Each chapter addresses a different issue in the strand of literature on international macroeconomics, broadly defined.

The *first* chapter addresses the question as to how a surprise movement in stock market volatility affects our forecasts of future output across countries. In particular, the chapter studies the time series and cross-sectional responses of output to variation in stock market volatility across 27 countries over 40 years, controlling for a number of country-specific characteristics. One important contribution of the chapter is to study the forecasting power of stock market volatility, thereby extending what has been almost exclusively single country investigations to a panel framework. We find that high levels of stock market volatility are detrimental to future output growth not only after financial crises as previously emphasized in the literature, but also in non-crisis periods. Output growth and interest rates react negatively to a random shock to volatility and revert to their means quickly thereafter. Moreover, these results are robust after controlling for economic policy uncertainty, the level of financial development, and the direction of the market.

The *second* chapter studies the question as to what the effects of government spending are when individual firms' pricing decisions are subject to the possibility that nominal interest rates are at the lower bound? This chapter studies a small open economy model with discrete choice state-dependent pricing where individual firms are subject to both idiosyncratic productivity and government spending shocks that may drive the nominal interest rate to the zero lower bound endogenously. Two patterns emerge. First, high fiscal volatility drives the economy to the lower bound more often, thus further limiting the effects of expansionary monetary policy. Second, output response to a random shock to government spending is transient because firms can respond promptly to aggregate shocks to the economy. Empirically, the model captures salient features of the Japanese economy from 1975 to 2006 along multiple dimensions.

The *third* chapter, joint with Siraj Bawa, studies an incomplete markets two-country model with corporate taxes and international financial frictions. Recent empirical studies have shown that workers tend to bear the lion's share of the burden from increases in corporate income tax. Yet existing theory on the subject implies that we should expect the burden of an increase in corporate taxes to fall more heavily on investors, who own most of the firms' assets. Our model is an attempt to reconcile these two seemingly contrasting strands of literature on the asymmetric effects of corporate taxes on agents who hold assets and those who do not. We show that increases in corporate income taxes can create asymmetric welfare benefits across agents who hold assets and those who do not. Specifically, while building on some elements of the current theoretical literature, our model implies that corporate tax burdens tend to fall more heavily on workers, a result that is congruent with the empirical findings. Furthermore, investors do suffer from an increase in corporate taxes, but such negative effect is considerably less persistent than that of the workers.

Chapter 2

Stock Market Volatility and International Business Cycle Dynamics: Evidence from OECD Economies

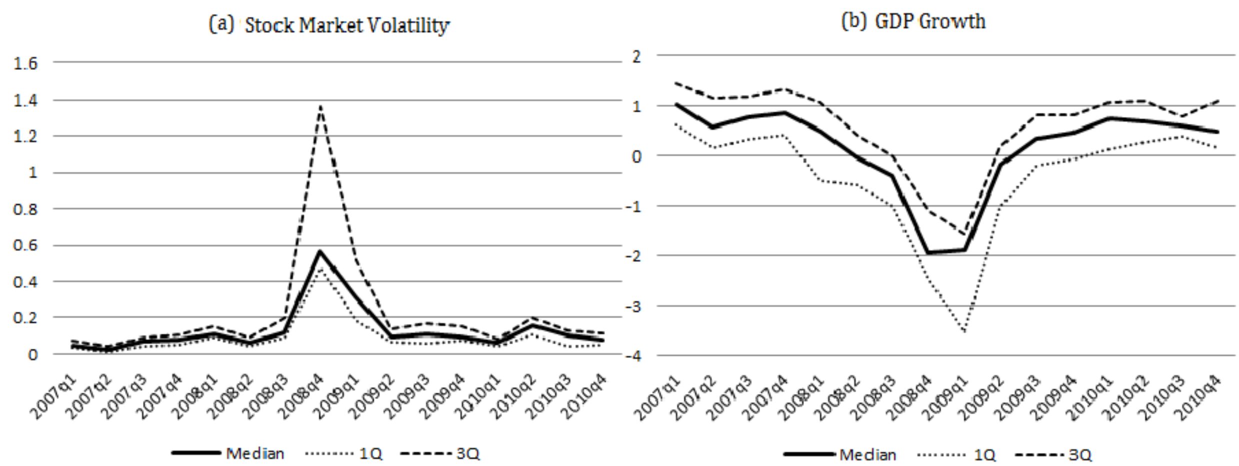
How does a surprise movement in stock market volatility affect our forecasts of future output across countries? This paper studies the time series and cross-sectional responses of output to variation in stock market volatility across 27 countries over 40 years, controlling for a number of country-specific characteristics. High levels of stock market volatility are detrimental to future output growth not only after financial crises as previously emphasized in the literature, but also in non-crisis periods. Output growth and interest rates react negatively to a random shock to volatility and revert to their means quickly thereafter. Moreover, these results are robust after controlling for economic policy uncertainty, the level of financial development, and the direction of the market.

Keywords: Stock market volatility; Output growth; Heterogeneous panel causality.
JEL Classification Numbers: E4, E6, C23

2.1. Introduction

Figure 2.1 plots both the quarterly variance of the Morgan Stanley Capital International (MSCI) standard country equity index and real output growth. Two patterns are visible. First, output growth shrinks following spikes in stock market volatility. Second, the 2007 recession is undeniably among the most devastating since the Great Depression with prolonged output growth stagnancy and stark cross-country spillovers. How does a surprise movement in stock market volatility affect our forecasts of future output? I address this question using quarterly and monthly data across 27 countries from 1970 to 2012.

Figure 2.1.: Stock Market Volatility and Output Growth (2007.Q1 - 2010.Q4)



Note: This figure presents the median, 1^{st} quartile (denoted $1Q$), and 3^{rd} quartile (denoted $3Q$) of stock market volatility and output growth across 27 countries from 2007.Q1 to 2010.Q4. Data are seasonally adjusted. The official NBER recession dates for the US are from 2007.Q2 to 2009.Q2, or 18 months.

While there are a plethora of studies linking increases in stock market volatility to declines in real output growth, they often abstract from incorporating cross-country dynamics. Given that many macroeconomic fundamentals are known to be driven by a variety of common world factors (see, for example, Gregory et al. (1997) and Crucini et al. (2011)), the analysis presented here thus fits in by accounting for these dynamics. Another source of novelty is the combined use of dynamic panel, panel vector autoregressive, and Granger-style panel causality analyses. These approaches are desirable because they allow for the analysis of the interaction of random shocks to real output growth and stock market volatility.

Before proceeding further, let us take a step back and review some of the most important works in the related literature. Using US data from 1834 to 1987, Schwert (1989) confirms that stock market volatility rose and interest rates fell on average during recessions in the pre-1987 period. As emphasized by Reinhart and Rogoff (2008), the aftermath of a financial crisis is typically associated with a large and persistent decline in real output growth. This paper complements Reinhart and Rogoff (2008) by suggesting that future output growth reacts negatively and consistently to high stock market volatility in the previous period in both crisis *and* non-crisis periods. More recently, using a time-series VAR and multi-step Granger causality approach on Australian data, Rahman (2009) suggests that the volatility of the stock market tended to be associated with profound declines in real output growth and increases in both inflation and the unemployment rate. Similarly, Kanas and Ioannidis (2010) observe a strong relationship between stock market volatility and real activity in the UK over the period 1946-2002.

The research presented here also builds upon a growing literature that concerns the forecasting power of stock market volatility for future real economic activity, by incorporating international stock markets.[1] From a theoretical perspective, our results are supported by a strand of literature concerning the role of financial frictions in amplifying the response of the macroeconomic aggregates to various types of shocks. (e.g., Bernanke et al. (1999)). Most recently, Jermann and Quadrini (2012) attempt to explain such a mechanism using a DSGE framework in which firms cut back on hiring and investment when faced with stricter financial constraints. To preview the results, (1) a high level of stock market volatility corresponds to declines in real output growth during both crisis *and* non-crisis periods *regardless* of the direction of the market, (2) real output growth reacts negatively to a random shock to stock market volatility and reverts to its mean quickly thereafter, (3) all US recessions from 1970 to 2010 exhibit stark spill-over effects to other countries, and (4) economic policy uncertainty has a significant negative effect on output growth in the next period, but not to the extent that it undermines the effect of stock market volatility.

The paper is organized as follows. Section 2.2 estimates the effect of stock market volatility on output growth using a dynamic panel framework, controlling for a variety of sources of cross-country heterogeneity. Section 2.3, the focus of this paper, studies the interactions between output growth and stock market volatility in a panel VAR framework with impulse response analysis. Section 2.4 concludes.

[1] See, for example, Campbell et al. (2011), Chauvet et al. (2012), and Fornari and Mele (2011).

2.2. Dynamic Panel Analysis

Table 2.1 presents descriptive statistics on stock market volatility and output growth across the 27 countries in our sample. Since past growth and stock market volatility may also contain certain characteristics of the state of the economy in the short run, lags of output growth and stock market volatility are included in the baseline specification in table 2.2. Stock market volatility is measured by the quarterly and monthly variance of the average daily MSCI country stock market index. With the exception of the MSCI index, all data series are from the *OECD Stats* database.[2]

2.2.1. Estimation

Carlstrom and Fuerst (2003) characterize a reduced form of the Taylor rule in which the Federal Reserve changes interest rates in response to deviations of outputs growth and inflation from their expected growth paths. Following the literature, here we control for short-term interest rates as a proxy for monetary policy; two lags are included to allow for delays in implementation and effectiveness of monetary policy. Dummies that correspond to official US recessions from 1970 to 2010 are also included. Intuitively, these dummies account for spillovers from US recessions to other countries in our sample.[3]

Specifications (1)-(3) from table 2.2 present the baseline specifications with output as dependent variable and stock market volatility and interest rates as independent variables. Two measures of output are considered: the growth rate of industrial production and real GDP growth. Including industrial production as an alternative measure of output strengthens the results presented here as it allows our analysis to be carried on at the monthly frequency as well as the quarterly frequency.

While our measure of stock market volatility can capture changes in uncertainty in one country's stock market, valid criticism is that it ignores the direction of recent movements of stock prices and returns. Here we address this problem by including the log of the level of the MSCI index (at both monthly and quarterly frequencies) to account for the direction of the market.[4] Specifications (4)-(6)

[2] Data are seasonally adjusted using the standard X-12-ARIMA procedure, unless otherwise specified.

[3] Official NBER business cycle dates, excluding the one from December 1969(IV) to November 1970 (IV). Another exception is the 2007 crisis, which is dated six months before the official NBER beginning date and continues until the end of 2010 (According the NBER, the peak was in 4^{th} quarter 2007 technically, the recession lasted from January 2008 until June 2009, or 18 months). Recession dates are at http://www.nber.org/cycles.html, last accessed March 23, 2012.

[4] An alternative to MSCI index as a measure of market direction is market returns. The dynamic panel regression results with this measure is presented in table 2.3 in the technical appendix. One key result is that our conclusions remain

from table 2.2 present the results with the level of MSCI index. Since countries with better developed financial sectors tend to have higher and more sustained output growth, as widely supported in the literature, it is important to control for country-specific levels of financial development. To measure financial development, this paper follows Rousseau (2003) in using the ratio of broad money to real output. Table 2.2 presents the results with financial development in specifications (7)-(9).

Changes in economic policy also matter. Consider, for example, how firms have stronger incentives to invest in countries where corporate tax rates are comparably lower. Here we employ two proxies for changes in economic policy. Specifications (7)-(9) from table 2.2 control for a measure of overall tax levels, i.e., the ratio of tax revenue as a percentage of a country's real output. Table 2.3 (see, specifications (3)-(5)) extends the baseline results in table 2.2 to include a proxy for economic policy uncertainty index developed by Baker et al. (2013). Since the U.S. is the biggest economy in terms of real outputs in the sample, our results might be dominated by U.S. dynamics. This is, however, simply not the case. The results presented in Table 2.2 are consistent in terms of magnitude and sign without U.S. data in the sample. Given the nature of the time-series and cross-section dimensions of the dataset, all specifications are estimated using the Arellano-Bond GMM procedure with the first and second differences as instruments. Country-specific fixed effects are removed in the process of differencing as they do not vary over time.

2.2.2. Discussion

A key novel result from table 2.2 is that the first lag of stock market volatility has strong predictive power for output growth, even when controlling for country-specific effects. This result supports the idea that financial crises can negatively impact output growth in the next one or two quarters. On the one hand, stock market volatility only has a very short-term effect on growth as lags beyond one quarter do not show any significance, even at the 15% level. On the other hand, removing our measure of stock market volatility from the baseline specification in table 2.2 reduces our forecasting power approximately 5 percent.[5]

qualitatively and quantitatively consistent regardless of which measure of market direction is employed.

[5] There is no consensus in the literature as to how R^2 should be reported for the Arellano and Bond dynamic panel procedure due to complication in the dynamics of cross-sectional heterogeneity. On the other hand, as noted by Judson and Owen (2011), when the number of time-series dimension is large, the Arellano and Bond (1991) procedure can produce results that are equivalent to those of a fixed effects panel regression, which is reported in table A.2. Thus, the values of R^2 obtained from the fixed effects panel regression can be interpreted as a rough estimation of R^2 for the Arellano and Bond procedure. Under this interpretation, moving from the specification without to the one with our measure of stock market

One common pattern across all specifications is that stock market volatility consistently has a *negative* effect on output growth, *regardless* of market direction, data frequency, and measure of output growth. In particular, whether the market is bullish or bearish does matter (as seen with the significance of the respective coefficients), but not to the extent that it takes away all the effects of our measure of uncertainty, i.e., stock market volatility. Quantitatively (see, table 2.2, specification (1)), a one percent increase in our volatility measure is expected to produce a 10.61 point decrease in industrial production index. High past interest rates correspond to declines in future output growth. In particular, a one percent increase in interest rate is expected to decrease output growth rate by approximately 2.15 percent with a two-month lag. This result is consistent with the perception that monetary policy changes are delayed in their effects on the economy. However, since each country has a different monetary and fiscal system, it is difficult to determine whether such a decrease is indeed attributable to the actions of the monetary authority.

The continued significance of the U.S. recession dummies across all specifications considered suggests that these recessions are not unique to the U.S. economy. This result is not surprising, given conclusions in the literature on world business cycles that macroeconomic fundamentals tend to share a common driving factor across nations.[6] Turning to Table 2.2 with an additional control for changes in tax policy overtime, the negative coefficients on taxes suggest a strong negative effect of changes in the tax rate on output growth. Consider, for example, the case with industrial production as the dependent variable, a one percent increase in tax rate corresponds to roughly a 0.174 percent decrease in real output growth.

Since a potential short-coming of the dynamic panel analysis is that causality can run in both directions, we next consider a three-step approach inspired by Hurlin (2005) to test potential causal relationships between market volatility and output growth. The results are presented in Table 2.5.[7] The causality running from stock market volatility to output growth is positive and significant. The magnitudes of the adjusted test statistics suggest that the direction of stock market volatility affecting growth is much *stronger* than the other way around, meaning that there is a potentially causal relationship from stock market volatility to output growth running in some cross sections. This result dovetails nicely with the dynamic panel analysis, which suggests that stock market volatility strongly

volatility (from specification 1 to specification 2) increases R^2 by approximately 5 percent.

[6]See, for example, Gregory et al. (1997) and Crucini et al. (2011).

[7]The results and the corresponding technical details of the test are provided in the Appendix.

predicts future output growth.

2.3. Impulse Responses

So far we have established the robust effects of increases in stock market volatility on future output growth. A natural question then arises concerning the dynamic effects of a random shock to stock market volatility on output growth forecasts at different horizons. Here we address this question using the impulse responses generated from a panel VAR framework.

2.3.1. Estimation

Assuming all variables of interest are endogenous, panel VAR builds upon and extends the traditional VAR approach to a panel setting that allows for individual unobserved heterogeneity (Holtz-Eakin et al. (1988)). As a standard precursor to estimating the panel VAR, panel unit root tests are performed and the null of a unit root is rejected for the series employed here. These test results are reported in the statistical appendix. The approach of this section is similar to that of Love and Zicchino (2006), which focuses on the impulse response analysis of financial development and investment dynamics. Mathematically, a p-order VAR model is specified as follows:

$$Y_{i,t} = \alpha + \sum_{j=1}^{p} \beta_j Y_{i,t-j} + f_i + d_{c,t} + \varepsilon_t \tag{2.1}$$

where $Y_{i,t}$ represents the three-variable vector of stock market volatility, interest rates, and GDP growth at time t for country i. This specification controls for cross-country heterogeneity using a country-specific dummy $d_{c,t}$ and assumes that the shocks to current growth and stock market volatility can propagate through the dependent variables, which will become part of the explanatory variable set in the next period.

Similar to Love and Zicchino (2006), Monte Carlo simulations are used to calculate standard errors and generate confidence intervals.[8] Variance decompositions are reported over the course of twenty quarters, which covers the length of most recessions.[9] The panel VAR procedure requires that the

[8]To isolate the macro shocks and avoid taking into account the spillovers of shocks to impulse response function analysis requires the ability to decompose the residuals in a way that they become orthogonal. This section thus follows the convention by using Choleski decomposition to decompose the variance-covariance matrix of residuals Hamilton (1993). 2,000 replications are used for the Monte Carlo simulations to obtain the 5% error band for impulse response analysis.

[9]With the exception of the 2007 recession, past recessions often have a duration that is far shorter than five years.

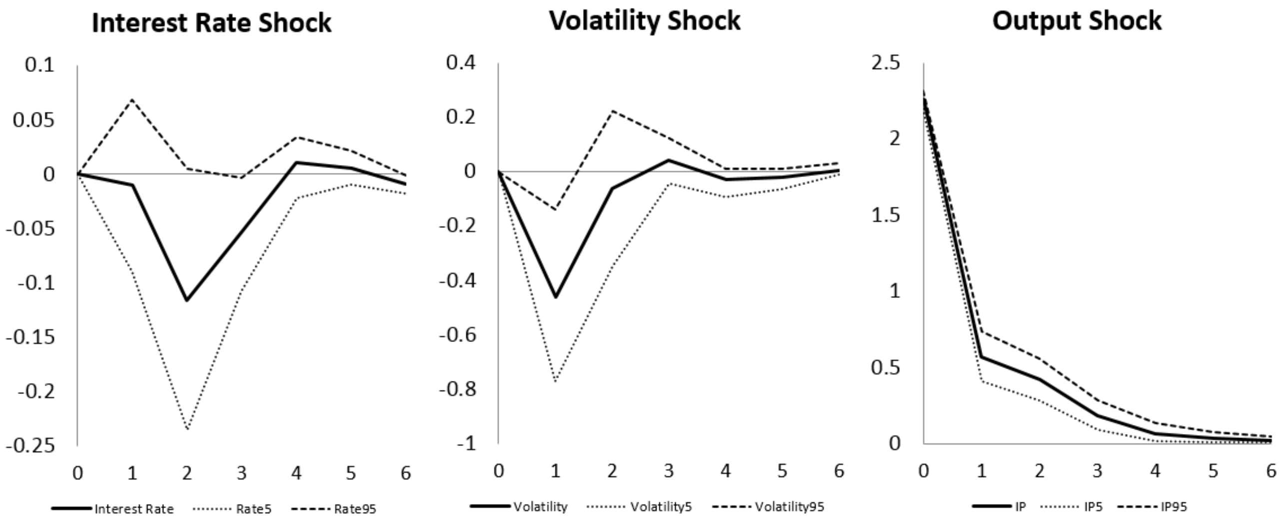
underlying structure is homogeneous across each cross-section unit, which can be achieved by allowing for the fixed effects f_i. However, as emphasized by Love and Zicchino (2006), the fixed effects are often correlated with the regressors, which can be corrected by forward mean-differencing, which is referred to as the "Helmert" procedure Arellano and Bover (1995). Such a procedure allows for the use of lagged regressors as instruments to estimate the coefficients using GMM. Identification follows the literature in assuming long-run restrictions with lower triangular matrix and Cholesky decomposition.

2.3.2. Main Results

To maintain consistency with the dynamic panel analysis, here we also include output growth, interest rates, and stock market volatility with two lags. Two measures of output are employed as in Section 2. Industrial production is first-differenced, other variables are estimated in levels. Because of the lower-triangular matrix assumption, the order of the three-variable vector matters. Figure 2.2 present the impulses responses of industrial production to one-standard deviation shock to each of the three variables, with (a) stock market volatility ordered first, and (b) with stock market volatility ordered last. Figure 2.3 differs from Figure 2.2 in the sense that we replace industrial production with real GDP growth.

One common theme across our two measures of outputs is that innovations to market volatility have a significant dampening effect on output in the next quarter with output growth returning toward its mean quickly thereafter. Turning to Figure 2.3 with real GDP growth, for example, a one-standard-deviation increase in the innovation to stock market volatility leads to a trough in output growth of 0.2 percent and a full growth recovery by the fourth quarter. Furthermore, since the responses of output to stock market volatility is significant at the 95% level in a short time window, stock market volatility contains important information about future output short horizons. Table 2.4 presents the fraction of the variance of the three variables accounted for by stock market volatility. Stock market volatility explains approximately 2.7% of the total variance of growth while interest rates explain about 8.8% of the variation over a ten-quarter window. Past stock market volatility accounts for approximately 98% of variations in its future values; that is, information contained in past output and interest rates is almost exogenous to future market volatility. Given that country-specific effects are controlled for in the panel VAR system, this result is in fact, consistent with others in the literature on the determinants

(a) Volatility ordered first



(b) Volatility ordered last

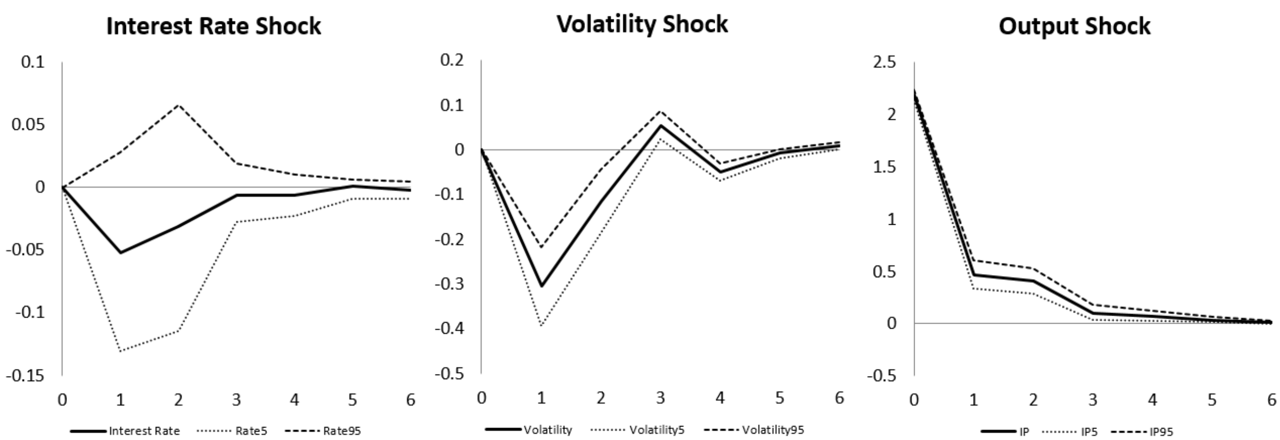


Figure 2.2.: **Responses of Industrial Production**

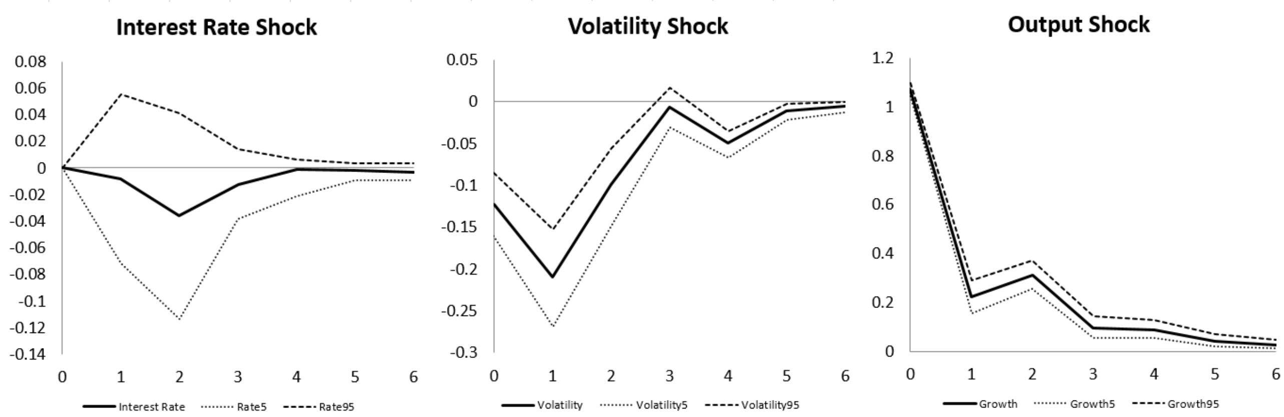
Note: Impulse responses of quarterly industrial production growth to innovations of, from left to right, interest rates, stock market volatility, and industrial production (output) growth (p=2). Lower triangular matrix is assumed for identification purpose. Order of the VAR system in the upper triplet: stock market volatility, interest rates, and output growth. Order of the VAR system in the lower triplet: interest rates, output growth, and stock market volatility. Dotted lines represent the 95% confidence bands.

of international stock markets.[10]

One open question remains in terms of whether the innovations in stock market volatility are simply reflective of information already contained in real output and interest rates. The identification

[10]King and Wadhwani (1990) study the transmission of volatility between stock markets and suggest a strong co-movements among international stock markets despite "widely differing economic circumstances." Along this dimension, King et al. (1994) analyze data from sixteen national stock markets and conclude that "only a small proportion of the time variation in the covariances between national stock markets can be accounted for by observable economic variables."

(a) Volatility ordered first



(b) Volatility ordered last

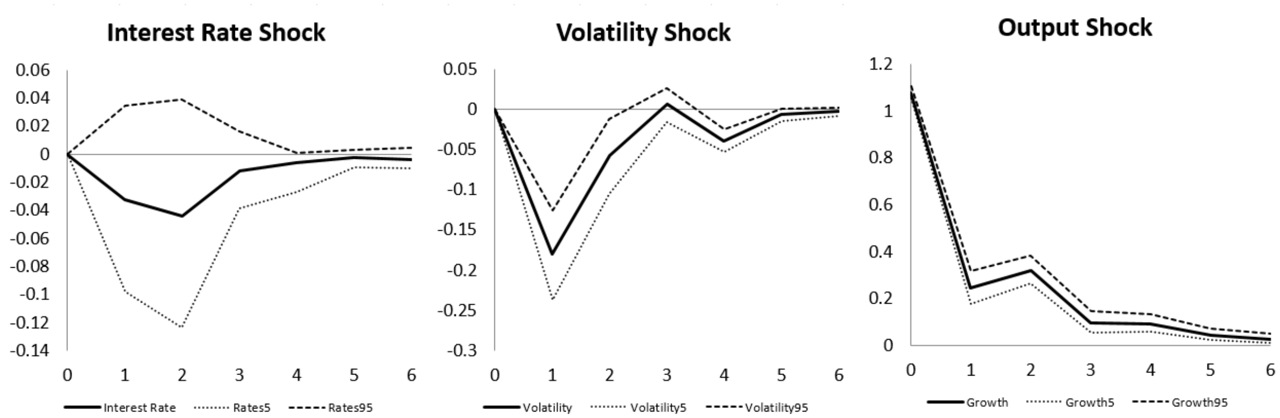


Figure 2.3.: **Responses of Real GDP Growth**

Note: Impulse responses of quarterly real GDP growth to innovations of, from left to right, interest rates, stock market volatility, and real GDP (output) growth (p=2). Lower triangular matrix is assumed for identification purpose. Order of the VAR system in the upper triplet: stock market volatility, interest rates, and output growth. Order of the VAR system in the lower triplet: interest rates, output growth, and stock market volatility. Dotted lines represent the 95% confidence bands.

assumption of lower triangular matrix provides the perfect tool to address this question. In particular, here stock market volatility is ordered in a way such that it is orthogonal with respect to real output and responses of interest rates. In this sense, stock market volatility is the most exogenous among the three variables. Qualitatively, re-ordering of stock market volatility has virtually no impact on the results. Quantitatively, the impact of an innovation to stock market volatility is much higher on output when industrial production is used as a measure for real output and remains the same otherwise. The fact that the qualitative results presented here hold under both orthogonalizations dovetails nicely with the results from the Granger causality analysis that the direction of stock market volatility affecting output growth is much *stronger* than the other way around.

2.3.3. Extensions: Political Uncertainty, Oil Prices Volatility and Other Leading Index

So far we have established that past movements of stock market volatility contain significant information about next period output growth. In particular, output growth decreases when there is news about an increase in current stock market volatility. While stock market itself contains a wide range of information on economic uncertainty, one natural question remains to what degree such information contained in our measure of market volatility simply reflects that of other indicators of uncertainty.[11] This section attempts to answer this question by incorporating three measures of macroeconomic uncertainty into the panel VAR system as presented in section 2.3.2.[12]

The first measure, the leading indicator index from the OECD, is constructed from a wide range of macroeconomic indicators, one of which is the industrial production index. Since this measure combines information on macroeconomic events from a variety of sources, its behavior provides the answer to the question as to whether stock market volatility can provide *additional* information about next period output, in excess of other, perhaps more conventional, measures of future level of output. Table 2.3 in the appendix presents the dynamic panel regressions that include this leading index from the OECD. The continued significance of the coefficients on stock market volatility suggests that our results are robust even with the presence of such an indicator. Figure 2.4a plots the impulse responses of output to a one standard deviation increase in the innovation in stock market volatility, interest rates, and the OECD leading indicator. On the one hand, output growth responds negatively to an orthogonal shock to stock market volatility and reverts to its mean quickly thereafter, which is consistent to the main results presented in section 2.3.2. On the other hand, this result also suggests that our measure of cross-country stock market volatility can provide additional forecasting information, even in the presence of a major leading indicator, such as the OECD leading index.

The second measure is oil price volatility, defined as the variance of the daily prices of one barrel

[11] The author thanks an anonymous referee for suggesting these robustness checks.

[12] Unless otherwise noted, all impulse responses are generated from a four-variable panel VAR system with output growth, stock market volatility, interest rates, and each of the three extra measures of economic uncertainty. The order of each corresponding Cholesky decomposition is presented under each figure. The 95% confidence bands are generated using Monte Carlo simulations with 2,000 repetitions.

of crude oil over a month, or a quarter.[13] One natural question arises as to whether the our measure of stock market volatility simply contains the information provided by the volatility of oil prices. This is not necessarily the case since stock market volatility can provide significant *additional* information for the forecast of output growth, as evidenced in the table 2.3 and the impulse responses of output growth in figure 2.4b. One common feature between stock market and oil prices volatility is that the effects of a one-time shock to their innovations tend to be short-lived, peaking approximately two months after the shocks and returning to the corresponding trends shortly thereafter.

The third measure is the economic policy uncertainty indices developed by Baker et al. (2013), which are constructed using micro data from a variety of newspapers sources.[14] Here we consider two indices, one for the US and one that covers most major economies in the European Union. Table 2.3 presents the results of the dynamic panel regression with these two measures of economic policy uncertainty. Figure 2.4c and 2.4d plot the impulse responses of output growth to a one-standard-deviation shock to stock market volatility, interest rates, and these two measures of economic policy uncertainty. As in the cases of the first two measures, our main results for stock market volatility presented in section 2.2.2 and 2.3.2 are robust, even with the inclusion of these economic policy uncertainty indices. It is interesting to note that a one-standard-deviation increase in US and European Union economic policy uncertainty decreases output growth, peaking at two and three months following the shocks with slow reversion back to their long-run growth paths. On the other hand, the effect of a random shock to political uncertainty peaks in around the same time as does a positive shock to stock market volatility but reverts to its corresponding mean far more slowly.

Three insights arise from incorporating these measures into our baseline specification. First, stock market volatility tends to exhibit significant forecasting power, even after controlling for more direct measures of uncertainty, such as oil prices volatility and the Baker et al. (2013) economic policy uncertainty indices. This result strengthens and extends the second insight that a positive increase in the innovation to stock market volatility dampens next period output growth, peaks after two months, and returns to its long-run trajectory quickly thereafter. Third, an increase in economic policy uncertainty and stock market volatility tends to have similar effects on the forecast of next period output growth in terms of timing of the peaks (i.e., around two to three months), but the effects of

[13] Data on oil prices were collected from the OECD website. Last accessed: Dec. 14, 2013.

[14] See the appendix for a more elaborate description of the construction of the index.

the former revert to their means far more slowly than do the effects of the latter.

2.4. Conclusion

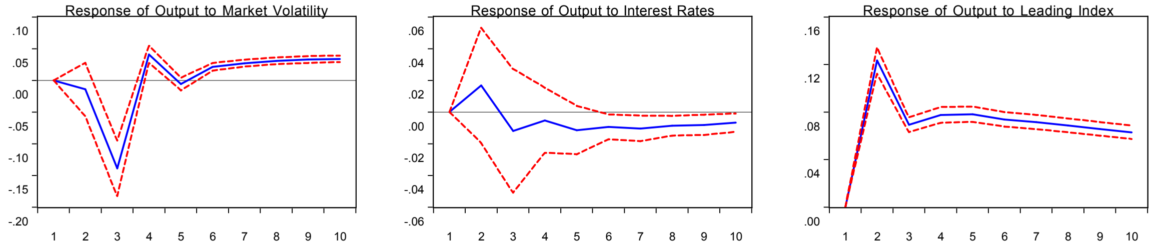
This paper finds that movements in output growth can be predicted to innovations in stock market volatility in a sample of 27 countries, even when controlling for a number of cross-country characteristics. Stock market volatility appears to be a strong predictor of output growth in the succeeding one or two quarters; this result extends a growing literature on the forecasting power of stock market volatility on output growth by extending to the case of international stock markets. The analysis presented here also contributes the recent literature on financial crises and output growth by showing that output growth rate falls not only after a financial crises as previously emphasized by Reinhart and Rogoff (2008), but also in non-crisis periods with high stock market volatility. These results are robust after controlling for the levels of financial development and the direction of the market. It is also important to note that all US recessions from 1970 to 2010 exhibit strong spill-over effects to other countries, even when the US dynamics are removed. This result is consistent with the literature that documents strong co-movements of macroeconomic fundamentals across countries.

Table 2.1.: Descriptive Statistics at Monthly Frequency

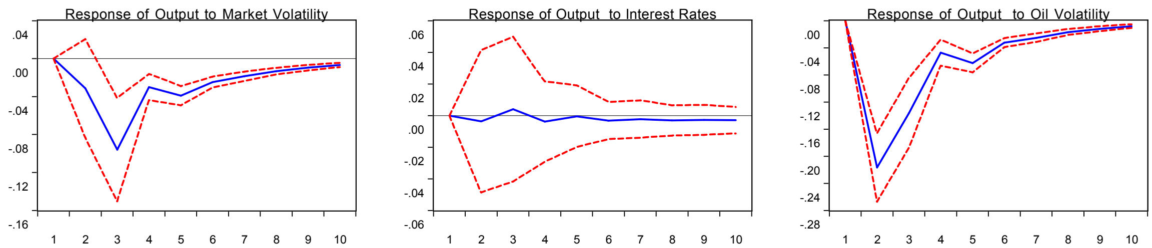
	Output		**Stock Market Volatility**		
Country	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Obs.**
Austria	0.26	1.89	0.025	0.019	273
Belgium	0.16	2.14	0.018	0.015	506
Canada	0.16	1.10	0.013	0.010	506
Czech	0.21	2.73	0.029	0.017	206
Denmark	0.05	3.18	0.021	0.012	302
Estonia	0.03	2.30	0.033	0.023	117
Finland	0.19	2.50	0.031	0.018	302
France	0.07	1.36	0.020	0.013	506
Germany	0.12	1.71	0.019	0.013	506
Greece	-0.29	2.91	0.033	0.023	134
Hungary	0.41	2.68	0.037	0.026	206
Iceland	0.90	4.75	0.078	0.234	62
Ireland	0.46	4.98	0.023	0.016	290
Italy	0.03	1.69	0.025	0.014	401
Japan	0.03	2.78	0.020	0.010	119
Korea	0.57	2.30	0.035	0.023	254
Luxembourg	0.36	3.33	0.043	0.028	39
Netherlands	0.12	2.80	0.020	0.013	314
Norway	0.08	4.50	0.027	0.017	398
Poland	0.53	2.32	0.040	0.028	230
Portugal	0.00	2.65	0.022	0.013	290
Slovak	0.36	3.31	0.029	0.018	200
Spain	0.04	1.89	0.023	0.014	422
Sweden	0.17	1.85	0.026	0.015	362
Turkey	0.13	5.28	0.052	0.030	231
UK	0.03	1.23	0.019	0.011	410
USA	0.18	0.76	0.014	0.010	506
Total	**0.17**	**2.60**	**0.025**	**0.028**	**8,209**

Note: Stock market volatility is the log of the level of the respective variables, seasonally adjusted. Output is the real GDP growth rate compared to the previous month, obtained from the OECD stats, seasonally adjusted. Market volatility is the variance of the MSCI index over the period of a month.

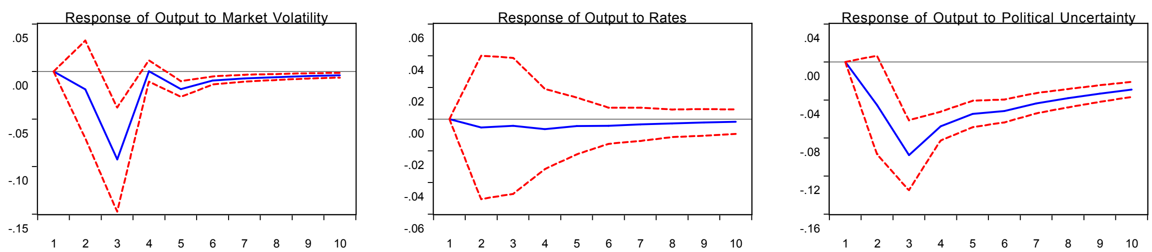
(a) Output, Stock Market Volatility, Interest Rates, and Leading Index



(b) Output, Stock Market Volatility, Interest Rates, and Oil Price Volatility



(c) Output, Stock Market Volatility, Interest Rates, and US Political Uncertainty



(d) Output, Stock Market Volatility, Interest Rates, and EU Political Uncertainty

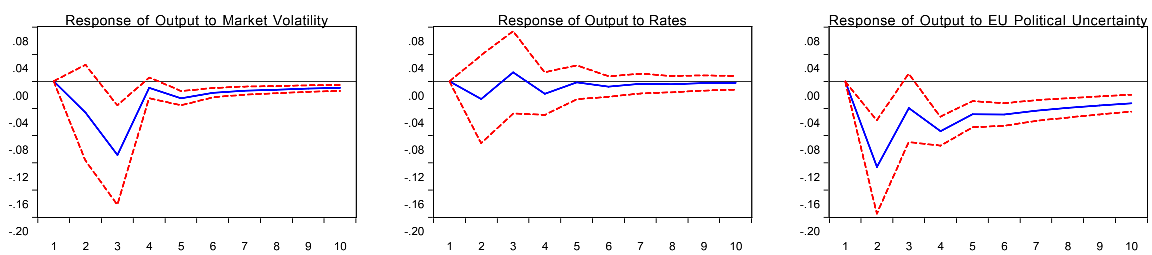


Figure 2.4.: Responses of Output to Innovations of Uncertainty

Note: Monthly responses of industrial production in the 4-variable VAR system with industrial production, market volatility, interest rates, and an extra measure of volatility (p=2). From up to down, that extra measure is OECD Leading Index, Oil Price Volatility, and the Baker et al. (2013) political uncertainty measure. Cholesky decomposition order is noted above the corresponding figure. Following section 2.3.2, the impulse responses are also re-ordered such that stock market volatility is ordered last. The results presented in this figure remain consistent. The dotted lines denote the 95 % confidence bands.

Table 2.2.: **Stock Market Volatility and Output**

Specifications		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		IP		**GDP**	**IP**		**GDP**	**IP**		**GDP**
	Lag	**Monthly**	**Quarterly**	**Quarterly**	**Monthly**	**Quarterly**		**Monthly**	**Quarterly**	
Dep. Var	1	-0.449***	0.138***	-0.0121	-0.448***	0.0827***	-0.0134	-0.244***	0.100**	0.0672
		[0.0118]	[0.0244]	[0.0257]	[0.0119]	[0.0216]	[0.0254]	[0.0371]	[0.0373]	[0.0407]
	2	-0.149***	-0.00334	0.0296	-0.149***	0.012	0.0228	-0.0565	0.0209	0.0971*
		[0.0118]	[0.0240]	[0.0245]	[0.0118]	[0.0212]	[0.0243]	[0.0352]	[0.0374]	[0.0389]
Volatility	1	**-10.61*** **	**-44.91*** **	**-27.25*** **	**-9.966*** **	**-33.57*** **	**-24.38*** **	**-13.54*** **	**-48.36*** **	**-28.13*** **
		[1.850]	[7.250]	[3.254]	[1.887]	[6.383]	[3.265]	[2.313]	[9.873]	[4.676]
	2	-16.00***	-5.267	-7.871*	-15.38***	2.945	-5.784	-15.11***	10.62	-1.672
		[1.873]	[7.382]	[3.370]	[1.891]	[6.365]	[3.361]	[2.324]	[10.22]	[4.943]
Rates	1	-0.0135**	0.00316	0.00279	-0.0152**	-0.0107	-0.00201	-0.00989	0.000471	0.00958
		[0.0048]	[0.0247]	[0.0112]	[0.00578]	[0.012]	[0.0112]	[0.00515]	[0.0258]	[0.0122]
	2	-0.0215***	-0.0326	-0.0036	-0.0167**	-0.00913	-0.00851	-0.00601	-0.028	-0.00211
		[0.0048]	[0.0229]	[0.010]	[0.0058]	[0.011]	[0.0103]	[0.00519]	[0.0242]	[0.0114]
Finan. Acco.	1							**20.47*** **	-3.382	2.158
								[3.084]	[4.306]	[2.170]
	2							**10.10*** **	7.862	**7.340*** **
								[2.924]	[4.221]	[2.105]
Market Level					**0.783***	**2.122*** **	**0.756*** **	-0.112	0.381	0.0854
					[0.305]	[0.273]	[0.109]	[0.194]	[0.222]	[0.0982]
Tax									-0.174**	-0.123***
									[0.0624]	[0.0287]
Recession		**-0.431** **	**-1.364*** **	**-0.775*** **	**-0.370***	**-1.315*** **	**-0.777*** **	**-0.434** **	**-1.678*** **	**-0.922*** **
		[0.156]	[0.184]	[0.0820]	[0.158]	[0.161]	[0.0813]	[0.155]	[0.248]	[0.115]
Constant		0.950***	1.143***	1.093***	-3.599	-11.97***	-3.693***	1.765	-1.307	0.454
		[0.0737]	[0.129]	[0.0694]	[1.878]	[1.686]	[0.694]	[1.258]	[1.454]	[0.654]
Obs.		8,039	2,618	2,142	8,039	2,618	2,142	3,545	1,023	1,023

Standard errors in brackets
* p<0.05, ** p<0.01, *** p<0.001

Table 2.3.: **Regression Results using Monthly Data**

Specifications		(1)	(2)	(3)	(4)	(5)
	Lag	**Output**	**Output**	**Output**	**Output**	**Output**
Output	1	0.458***	0.458***	0.425***	0.386***	0.381***
		(0.011)	(0.011)	(0.012)	(0.015)	(0.015)
	2	0.369***	0.369***	0.336***	0.314***	0.319***
		(0.011)	(0.011)	(0.012)	(0.015)	(0.015)
Leading Indicator	1	1.780***	1.832***	1.232***	0.737***	0.553**
		(0.133)	(0.142)	(0.158)	(0.195)	(0.199)
	2	-1.637***	-1.689***	-1.027***	-0.505*	-0.327
		(0.135)	(0.143)	(0.161)	(0.199)	(0.203)
Rates	1	0.00640	0.00640	0.00909	0.0267**	0.0238**
		(0.005)	(0.005)	(0.005)	(0.009)	(0.009)
	2	-0.00311	-0.00301	0.00255	0.0294**	0.0288**
		(0.005)	(0.005)	(0.005)	(0.009)	(0.009)
Volatility	1	-10.61***	-10.65***	-5.354**	-6.467**	-4.300
		(1.640)	(1.663)	(1.869)	(2.395)	(2.441)
	2	-21.56***	-21.24***	-17.80***	-19.18***	-17.88***
		(1.622)	(1.627)	(1.791)	(2.310)	(2.329)
Recession		0.0241	0.0215	0.141*	-0.00534	0.0652
		(0.060)	(0.060)	(0.071)	(0.078)	(0.080)
Market Return	1		-17.98*	-30.40***	-33.99***	-33.23**
			(7.147)	(7.902)	(10.106)	(10.119)
	2		8.571	-4.515	-1.397	-3.046
			(7.250)	(8.021)	(10.327)	(10.345)
Political Uncertainty	USA			-0.0147***	-0.00407*	-0.00474*
				(0.001)	(0.002)	(0.002)
	EUR				-0.0184***	-0.0167***
					(0.002)	(0.002)
Oil Price Volatility						-8.744***
						(1.839)
Constant		4.314***	4.306***	6.243***	10.43***	11.11***
		(0.327)	(0.327)	(0.394)	(0.652)	(0.668)
Obs.		7,644	7,644	6,391	4,059	4,059

Standard errors in brackets
* p<0.05, ** p<0.01, *** p<0.001

Table 2.4.: **Variance Decompositions for 20 quarters**

	Past Periods	Growth	Market volatility	Interest Rate
Output Growth	10	0.97281	0.02702	0.00017
Market volatility	10	0.00132	0.99858	0.00009
Interest Rate	10	0.08833	0.00805	0.90361
Output Growth	20	0.97268	0.02702	0.00031
Market volatility	20	0.00133	0.99850	0.00017
Interest Rate	20	0.09348	0.00723	0.89929

Table 2.5.: **Panel Causality Test**

Lags	Z
Market volatility weakens growth	
1	38.18
2	12.49
3	5.58
Growth increases stock market volatility	
1	12.16
2	5.85
3	4.47

Note: The adjusted Z-statistics follows the N(0,1) standard normal distribution.

Chapter 3

Accounting for the Japanese Fiscal Multiplier: Ss Interpretation meets the Zero Lower Bound?

What are the effects of government spending when individual firms' pricing decisions are subject to the possibility that nominal interest rates are at the lower bound? This chapter studies a small open economy model with discrete choice state-dependent pricing where individual firms are subject to both idiosyncratic productivity and government spending shocks that may drive the nominal interest rate to the zero lower bound endogenously. Two patterns emerge. First, high fiscal volatility drives the economy to the lower bound more often, thus further limiting the effects of expansionary monetary policy. Second, output response to a random shock to government spending is transient because firms can respond promptly to aggregate shocks to the economy. Empirically, the model captures salient features of the Japanese economy from 1975 to 2006 along multiple dimensions.

Keywords: Fiscal Multipliers, Japan, Ss pricing, Heterogeneous Agents
JEL Classification Numbers: E02, E62

3.1. Introduction

The zero-lower bound - that undesired lower limit of nominal interest rate, at which expansionary monetary policy becomes fruitless - has rekindled an interest in studying the determinants of the size of fiscal multipliers in recent years.[1] 'Rekindled' because, for the majority of the past century, the average interest rate of U.S. treasury bills - conventionally referred to as the nominal interest rate - has stayed well above the zero. While a near zero nominal interest rate has gained attention in the US only since the 'Great Recession' in 2008, it has, unfortunately, been the cornerstone of the so-called 'Japanese economic malaise' since the early 1990s. A leading paper in the related theoretical literature is Christiano et al. (2011), who argue that the size of the fiscal multipliers can be very large when the zero lower bound on nominal interest rates binds. Moreover, as critiqued by Golosov and Lucas (2007), most models in the related literature assume firms' (re)pricing decisions are exogenous, which makes them hard to square with micro-price facts.[2]

This paper shows that while fiscal spending is transitory in its impact, its volatility can be detrimental when firms' pricing decisions are subject to the possibility that the nominal interest rates are at the lower bound. First, high fiscal volatility can drive the economy to the lower bound more often, which further limits the impact of expansionary monetary policy. Second, output response to a random shock to government spending is transient, both in data and in the model. While the responses of real aggregates to monetary policy are known to be transient in menu costs models, less is known about the same responses to changes in government spending.

The dynamic model presented here extends two branches of literature. The first branch studies the effects of monetary policy when firms' pricing decisions depend on idiosyncratic shock, and to a larger extent, on the aggregate shock. This branch of the literature relies on the Ss-style state-dependent pricing assumption, a famous result of which is that expansionary monetary policy is highly transient in its effects.[3] The second branch studies the effects of fiscal spending when the economy is at the

[1] See, for example, Farhi and Werning (2012), Christiano et al. (2011), Fernandez-Villaverde et al. (2012),and Woodford (2010)

[2] This result is well-documented in the literature, for example, by Golosov and Lucas (2007) and Gagnon (2009).

[3] Leading papers in this literature include, but are not limited to, Gagnon (2009), Golosov and Lucas (2007), and Nakamura and Steinsson (2010). Nakamura and Steinsson (2010) calibrate a menu cost model using U.S. retail data and report a degree of monetary non-neutrality that is three times larger in a multi-sector setting than in a single sector setting. This conclusion dovetails nicely with Caplin and Leahy (1991), who suggest that changes in monetary policies often have no effects on real aggregate demands in the short run. Gagnon (2009) calibrates a menu-cost model in the spirit of Golosov and Lucas (2007) using Mexican retail data. The high volatility of retail price in this data-set poses a challenge to the

bound. While inspired by recent advances in this second branch of research, this paper deviates by considering the macroeconomic implications when firms consider the possibility of the economy hitting the bound endogenously.

Another source of novelty lies in the solution method of the model along two aspects. First, this paper uses a globally non-linear method which helps retain full non-linearities of the model. In contrast, a common approach in the literature on the zero lower bound is to first log-linearize the model everywhere except at the zero lower bound.[4] This approach ignores important information that may have influenced the possibility of the economy reaching the bound.[5] Second, this paper incorporates a heterogeneous agent method in the spirit of Krusell and Smith (1998) into a dynamic environment with multiple non-linearities. This feature is important because the model presented here assumes firms' pricing decisions are discrete by nature, thereby having one more dimension of non-linearity over recent studies.

We next take the model to the data, showing that it can capture salient features of the Japanese economy along two main dimensions. At the macro level, we show that the model can match the empirical distribution of a measure of short-term nominal interest rates from 1975-2006. In addition to documenting fiscal multipliers of size less than one, this paper also shows, using military procurement data, that the effect of Japanese government spending on output growth is transient, both in model and in data. At the micro level, we show that the model can produce hazard functions that are congruent with a novel Japanese micro-price dataset from 1975 to 2006, therefore satisfying the critique by Golosov and Lucas (2007). We also show that the conventional assumption of time-dependent pricing, which often serves as the workhorse of the current literature on fiscal multipliers, is difficult to sustain in the case of Japan.

Intuitively, the pricing assumption applied here entails implications markedly different from its (exogenous) time-dependent pricing counterpart. This assumption accentuates the effects of idiosyncratic productivity distribution on the persistence of inflation response, and ultimately of output response, to a random increase in government spending. When prices are flexible, firms at the lower end of the optimal price distribution have more tendency to change prices. They adjust prices more promptly

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conventional time-dependent and state-dependent pricing models because those models tend to perform poorly when prices are highly volatile.

[4] See, for example, Adam and Billi (2007).

[5] See, for example, Fernandez-Villaverde et al. (2012) who solved dynamic model with the zero-lower bound under time-dependent pricing.

than when firms across the whole distribution are randomly selected to change price under a time-dependent pricing assumption. Therefore, a model under time-dependent pricing may under-estimate the effects of government spending on the expected inflation rate, a key determinant of the size and dynamics of the fiscal multipliers.

This technical schism is even more pronounced as we incorporate the zero interest rate lower bound. Because this possibility is endogenous to the model, individual firm's decision to change prices depends not only on the joint distribution of last period price and individual productivity, but also on the future possibility of hitting the bound. In stark contrast, under the conventional exogenous Calvo pricing, whether the economy is at the bound has no influence on firms' decisions whether to change price.

There are two channels through which an increase in fiscal volatility can affect the frequency of the economy hitting the zero lower bound for nominal interest rates. In the first channel, or the *direct* channel, an increase in the variance of the innovation to fiscal spending process implies an increase in the variance of aggregate demand. This first channel induces an increase in the dispersion of firms' decisions to change price in the next period; hence the second, indirect channel through which an increase in government spending leads to an increase in the second moment of aggregate inflation. A combination of these two channels sub-sequentially leads to an increase in the expected variance of the unconstrained nominal interest rates.

The fact that the model explicitly accounts for the lower bound extends its application beyond the Japanese economic malaise. In particular, the analysis presented here can be applied to economies that face the curse of the zero lower bound. One notable, and perhaps unfortunate, fact is that many developed economies have started to experience nominal interest rates that are near or at the bound lately. This paper can be a step toward a better understanding of the question as to what is the optimal fiscal policy under this rather unfortunate circumstance.

This paper is organized as follows. Section 3.2 documents key empirical facts to support our modeling choices. Section 3.3 describes the model. Individual firms are subject to both idiosyncratic productivity shocks and aggregate government spending shocks that may drive the nominal interest rate to the zero lower bound endogenously. Section 3.4 takes the model to the data, calibrating it to key features of the Japanese economy from 1975 to 2006. Section 3.5 presents the main results, showing that the model can fit the Japanese economy from 1975 to 2006 along some important dimensions. Section 3.6 summarizes our results.

3.2. Japan: Some Empirical Foundation

This section documents two empirical findings. First, Japanese fiscal multipliers are typically less than one. Second, using a novel dataset on Japanese consumer prices from 1975 to 2006, we show that the assumption of exogenous time-dependent pricing - the work-horse of the current literature on fiscal multipliers - is difficult to sustain.

3.2.1. Japanese Fiscal Multipliers

We define fiscal multipliers as the ratio of the first difference of real output over the first difference of a measure of government spending; particularly,

$$a_t = \frac{\Delta Y_t}{\Delta G_t}$$

Here we use military spending as a proxy for government spending for two reasons. First, since the end of World War II, Japan's constitution has confined its military to defensive purposes, a consequence of which is that Japan spends a significant portion of its military spending on maintaining the occupying U.S. bases. Therefore, military spending can be considered reasonably exogenous. Indeed, such a proxy has been widely used in the related literature studying the empirical size of the fiscal multiplier.[6] Second, other general measures of government spending are often considered endogenous to economic conditions.

To determine the size of the Japanese fiscal multipliers, we regress real output on military spending as an exogenous proxy for government spending using three specifications. The first specification regresses real output on military spending as a proxy for government spending. The second specification regresses real output growth on military spending as a measure of government spending and inflation rates. Because general government spending is often endogenous to economic conditions, open criticism remains that the economic information included in military spending may also be included in general government spending.[7] One consequence is that military spending may also be endogenous, which can invalidate the regression results. To test for this possibility, the third specification regresses

[6] See, for example, Auerbach (2014) or Nakamura and Steinsson (2014).

[7] This paper is not the first to use military spending as a proxy for government spending. An example of this approach in the literature is Nakamura and Steinsson (2014).

output growth on the previous two independent variables and total government spending.

The variables used for these three specifications are expressed in first differences and standard errors are adjusted for heteroscedasticity. As a result, the coefficient on military spending can be interpreted as an estimate for the size of the fiscal multipliers.[8] Data on military spending are from the *Statistics Bureau of Japan*, while data on other variables are from the *OECD Stats* database.[9]

The effects of government spending on output growth are small and robust across specifications. For example, the marginal effects of military spending are statistically significant across all three specifications with values from 0.59 to 0.89 (see table 3.1). These numbers imply a fiscal multiplier ranging from 0.59 to 0.89 and agree with the current literature on Japanese government spending.[10] We interpret the fiscal multiplier value of 0.89 as an *upper-bound* in this case because the corresponding specification does not take into account the effects of general (total) government spending, a measure often considered endogenous with real output growth. More importantly, while reducing the implied fiscal multiplier to 0.59, including this measure does not make military spending insignificant. This result confirms the robustness of military spending as an exogenous proxy to measure the effects of fiscal stimulus across all regression specifications considered.

3.2.2. Micro-price Evidence

This section documents the key features of Japanese consumer prices from 1975 to 2006. In particular, section 3.2.2 describes the dataset. Section 3.2.2 provides empirical evidence to advocate the use of a state-dependent pricing framework for Japan, using a conditional logit model.

Japan's Micro-price Data: Overview

This section uses two datasets to characterize Japanese micro-price evidence. The first dataset is the annual series, "Annual Report on the Retail Price Survey," published by the Statistics Bureau, Management and Coordination Agency, Japan. This dataset covers more than 650 goods and 70 cities from 2000 to 2006. The second dataset is a three-dimension panel of monthly Japanese consumer

[8]This assumption is well-supported in the literature. See, for example, Nakamura and Steinsson (2014) and Farhi and Werning (2012) for a summary of recent literature that uses military spending as a proxy for government spending.

[9]Data for military spending are collected from the website of the Statistics Bureau of Japan at www.stat.go.jp/english/. Data last accessed: March 21, 2014.

[10]See, for example, Auerbach (2014); Auerbach and Gorodnichenko (2012) and Bruckner and Tuladhar (2013).

prices from 1975 to 1999, covering 65 goods and more than 70 cities.[11] Table B.1 shows that the datasets feature a remarkable level of diversity and consistency because it covers both coastal and inland cities and therefore, is geographically balanced. Turning to the columns with the number of goods, the dataset also exhibits a strong consistency in terms of the number of goods across cities.

We classify the dataset into traded and non-traded goods because the prices of the former are more integrated and thus more flexible than the latter.[12] A traded good, as its name implies, is a good that can be traded across locations; for example, an apple.[13] A non-traded good is a good that must be produced and consumed locally; for example, a hair-cut. Open criticism remains that certain goods are regulated by the government and their prices are rarely changed. We exclude these goods from our analysis.

Overall, price changes are relatively frequent. Across all cities, the median and the average frequency of prices changes is around 37% and 35%, respectively. These numbers are in stark contrast with the equivalents often found in the US data, in which the median frequency of price change is approximately 8 percent.[14] Price increases are more frequent (42%) and are smaller than price decreases, a feature consistent with Japan's distinctively low inflation rates since 2000. We obtain the frequency of price changes as follows. For every unique combination of city and good, we calculate the number of price changes from one month to another over the entire span of the dataset. Next, we take the mean and median across all combinations.

State-dependent Pricing Assumption: Some Empirical Foundation

This section presents empirical evidence from Japanese micro-price data to support the use of a state-dependent pricing assumption. To do so, we construct the probability that a price change lasts until the next period, conditional on the history of price changes and other information on past macroeconomic aggregates. Because price changes are costly and sometimes firms have to wait a fixed period before they can change prices, these past price changes are classified into fixed horizons. These horizons are one month, three months, six months, nine months, and twelve months. This

[11] I am grateful for support from the Center for International Price Research at Vanderbilt University. This second dataset is originally used in Parsley and Wei (2001).

[12] See, for example, Crucini et al. (2010), for a detailed discussion.

[13] Strictly speaking, an apple consumed at a local restaurant is not a traded good. However, here we avoid this problem by assuming that unless further described in the good name, goods similar to apples are classified as traded goods.

[14] See, for example, Nakamura and Steinsson (2010)

assumption that firms can only adjust in fixed period is well-supported in the literature. Many models assume that firms can only change price given a fixed probability γ. At time t, only a fraction γ of firms can change price, while the rest have to wait until the next period.

To account for cross-sectional heterogeneity, we use a conditional logit regression in the spirit of Chamberlain (1980); that is,

$$\Pr(p^{+}|\mathbf{x}) = \frac{\exp(\mathbf{x}\beta)}{1+\exp\mathbf{x}\beta},$$

where $\Pr(p^{+}|\mathbf{x})$ denotes the probability of having a price increase, conditional on the set of co-variates $\mathbf{x}$; the probability of price decreases $\Pr(p^{-}|\mathbf{x})$ is similarly defined. The set of co-variates $\mathbf{x}$ contains (1) past inflation rates, (2) real output growth measured by the industrial production index, (3) trade dummies, (4) a set of dummy variables indicating last price changes, (4) the magnitude of last price changes, (5) a set of dummy variables for locations and time, and (6) exchange rate between USD and Yen. Because pricing decision can differ significantly between traded and non-traded goods as suggested by the non-parametric analysis, a trade dummy is included in $\mathbf{x}$. Because the probability of changing price depends on the magnitude and frequency of last prices changes, we also include these in the set of co-variates $\mathbf{x}$.[15] Data for exchange rate, industrial production, and inflation rate are collected by the OECD, seasonally adjusted, and are of monthly frequency. Data for industrial production is transformed such that they represent the percentage change from last period. Table 3.2 presents the results for the probability of price going up and down, the sum of which constitutes the probability of price changes.

Table 3.2 shows strong support for the use of a state-dependent pricing framework over its time-dependent pricing counterpart, which has been the workhorse of the recent literature on fiscal multipliers. First, the coefficients on output growth and other state variables are significant. This result is robust for both the probability of price increase (p^{+}) and the probability of price decrease (p^{-}). Second, the coefficients for the timing of the last price change are mostly insignificant. The only exception to this result - that is, the case of non-traded goods for the sample between 2000-2006 - accounts for only less than 13% of the overall sample size.

[15] The setup presented here bears much resemblance to some recent works in the literature concerning micro-price data. In particular, the set of co-variates are similar to the ones used in Gagnon (2009).

3.3. A Menu Cost Model accounting for the Zero Lower Bound

Given the preceding two empirical facts on Japan, an empirically plausible model should: (1) allow firm's pricing decisions to be based on the state of the economy; (2) explicitly incorporate the possibility of hitting the lower bound as an endogenous event that may arise depending on the condition of the economy; (3) be able to match the dynamic responses of output to an increase in government spending and the patterns of the nominal interest rates; and (4) be able to capture the salient features of Japanese micro-prices. The first two targets are the theoretical features we want to incorporate. The remaining two features are the empirical dimensions that are used to assess the performance of the model.

The model presented here benefits from advances in two branches of literature. The first branch studies the effects of monetary policy when firms' pricing decisions depend on the realization of idiosyncratic shock, and to a larger extent, on the realization of the aggregate shock. The second branch studies the effects of fiscal spending when the economy is *at* the bound. While inspired by recent advances in this second branch of research, this paper deviates by considering the macroeconomic implications when firms incorporate the *possibility* of the economy hitting the bound.

The assumption that firms' pricing decisions depend on the states of the economy, and implicitly along with the possibility of the economy reaching the bound, has marked effects on the role of government spending. Intuitively, an increase (decrease) in government spending can be thought of as an increase (decrease) in aggregate demand. When pricing decisions are endogenous, firms at the lower end of the economy can optimally change their price, which generates a secondary effect on the demands for intermediate goods. Overall, the effect is that aggregate production may respond promptly to an increase in government spending. Therefore, one prediction from the model is that an increase in government spending has a transitory effect on aggregate output.

Let us turn to some details of the model. Consumers buy both goods of home and foreign varieties. Output from home country needs to meet the demands of both domestic and foreign consumption, and government spending. The model extends recent works by Gali (2005) to allow for Ss-style state-dependent pricing and zero lower bound in nominal interest rate.

3.3.1. Households

The households gain utility from consuming both home and foreign goods. To finance consumption, they work at a domestically prevailing wage W_t. In particular, they maximize the following utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U[C_t, N_t],$$

in which the consumption aggregate C_t follows the functional form:

$$C_t = [(1-\alpha)^{\frac{1}{\varepsilon}} C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} + \alpha^{\frac{1}{\varepsilon}} C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3.1}$$

subject to the budget constraint

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + Q_{t,t+1}D_{t+1} \leq D_t + W_t N_t + \int_0^1 \Pi_t(j)\,dj$$

In terms of notation, here $C_{H,t}$ and $C_{F,t}$ denote the consumption of home and foreign goods at time t, respectively; N_t denotes the amount of hours worked at a prevailing wage W_t; $\int_0^1 \Pi_t(j)dj$ denotes the total profits transferred to the households by all domestic firms; D_{t+1} denotes the quantity of one-period risk-less discounted bonds, which are purchased at time t and will pay one unit of money at time $t+1$.

Consumers in both home and the rest of the world maximize the discounted values of an additively separable utility function; that is, $U(C_t, N_t) \equiv \frac{C_t^{1-\sigma}}{1-\sigma} - \psi \frac{N_t^{1+\varphi}}{1+\varphi}$, in which ψ controls the dis-utility of working and φ is the inverse of the Frisch elasticity of labor supply. The price of these discounted nominal bonds D_{t+1} is $Q_{t,t+1}$. These bonds can also be traded internationally and are linked to the international bond market via the global risk-sharing condition defined in section 3.3.2.

The cost minimization problem from the households implies the aggregate domestic price index $P_t = \left[(1-\alpha)P_{H,t}^{1-\varepsilon} + \alpha P_{F,t}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$, in which individual goods of home and foreign varieties obey $C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\varepsilon} C_t$ and $C_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t}\right)^{-\varepsilon} C_t$, in which ε denotes the elasticity of substitution between good of home and foreign origins. Therefore, the first order conditions for consumption, labor, and bonds write

$$\frac{W_t}{P_t} = -\frac{U_{N,t}}{U_{C,t}} \tag{3.2}$$

$$Q_{t,t+1} = \beta E_t\left[\frac{U_{C,t+1}}{U_{C,t}}\frac{P_t}{P_{t+1}}\right] \tag{3.3}$$

Equation 3.2 describes the labor supply while equation 3.3 describes the relationship between the price of bonds and the time path of consumption. For convenience, we define the nominal interest rate R_t as $1/Q_{t,t+1}$; therefore, the inter-temporal condition for consumer 3.3 writes

$$1 = \beta E_t\left[R_t\frac{U_{C,t+1}}{U_{C,t}}\frac{P_t}{P_{t+1}}\right] \tag{3.4}$$

3.3.2. Trade, Risk Sharing, and the Rest of the World

Following Gali (2005), the rest of the world is almost symmetric to the home economy. In particular, consumers from the rest of the world maximize an utility function with identical functional form and are subject to an identical (but with a * superscript) budget constraint. The aggregate price index for the rest of the world P_t^* has the form of a CES aggregator of (1) the price index for goods produced in the rest of the world to be consumed in the rest the world $P_{F,t}^*$ and (2) the price index for goods produced at the home country to be consumed in the rest of the world $P_{H,t}^*$.

Because the rest of the world is, approximately, a closed economy, $P_{H,t}^*$ is negligible in comparison with $P_{F,t}^*$ and P_t^*. Therefore, the price of the foreign goods in terms of foreign currency $P_{F,t}^*$ is the same as the price index of all foreign goods P_t^* in foreign currency.

The law of one price holds and there exists a nominal exchange rate X_t such that the price of foreign goods sell at home and in foreign country only differ as a result of X_t; that is, $P_{F,t} = X_t P_{F,t}^*$. There is a complete global securities market and the stochastic discount factor for home country $Q_{t,t+1}$ also prevails in the international securities market; that is,

$$\beta E_t\left[\frac{U_{C,t+1}^*}{U_{C,t}^*}\frac{1}{1+\pi_{t+1}^*}\frac{X_t}{X_{t+1}}\right] = Q_{t,t+1}$$

Initially, the relative consumption and prices between the home and foreign countries are related via a constant $\Xi = (C_0/C_0^*)\left(P_0/P_0^*\right)^{\frac{1}{\sigma}}$. We also define the real exchange rate X_t^R as $X_t^R \equiv \dfrac{X_t P_t^*}{P_t}$. Combing the inter-temporal conditions for both the international and domestic securities markets recursively yields

$$C_t = \Xi C_t^* \left(X_t^R \right)^{\frac{1}{\sigma}} \tag{3.5}$$

For convenience, we define the terms of trade between home and foreign goods S_t as $P_{F,t}/P_{H,t}$. From the implied aggregate domestic price index, it follows that

$$1+\pi_{t+1} = 1+\pi_{H,t+1}\left[\frac{(1-\alpha)+\alpha S_{t+1}^{1-\varepsilon}}{(1-\alpha)+\alpha S_t^{1-\varepsilon}}\right]^{1/(1-\varepsilon)} \tag{3.6}$$

Pricing Decision in the Rest of the World Pricing decisions in the rest of the world are flexible. Under monopolistic competition, firms select a price equal to the marginal cost times a markup under flexible prices. In particular, the pricing decision of firms from the rest of the world is $P_{F,t}^* = \frac{\theta^*}{\theta^*-1} MC_t^*$. Firms in the rest of the world produce using a production technology linear in labor; that is, $Y_t^* = A^* N_t^*$. Taking the first order condition under the firm's cost minimizing problem yields the corresponding marginal cost $MC_t^* = \frac{W_t^*}{A^*}$.

Because consumers from the rest of the world solve a problem almost identical to one solved by the home agents, their labor supply condition is almost identical to one by the home country. In particular, such a condition writes $\frac{W_t^*}{P_t^*} = -\frac{U_{N,t}^*}{U_{C,t}^*}$. From the perspective of the home country, government spending in the rest of the world all sum up to a constant G^*. This value equals to a fraction α^g of the steady state value of foreign consumption C^*. Thus, combining the optimal pricing decision and real marginal cost for firms from the rest of the world yields a relationship between the rest of the world output and productivity level as follows

$$\frac{\theta^*-1}{\theta^*} = \frac{\left(Y_t^*\right)^{\varphi+\sigma}}{(A^*)^{1+\varphi}} \tag{3.7}$$

3.3.3. Firms and Pricing Decisions in the Small Open Economy

There are two types of firms in the domestic market: intermediate goods and final goods firms. The final good firm bundles the goods produced by intermediate goods firms to meet the aggregate demand Y_t; that is,

$$Y_t = \left(\int_0^1 [Y_t(j)]^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}$$

The cost minimization problem for the final goods firm problem yields the demand for goods produced by intermediate firm j by the final goods firm

$$Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta} Y_t$$

A continuum of intermediate goods firms use labor as the only production factor to meet inputs demands of the final goods firms. In particular, each intermediate firm j produces using the following technology

$$Y_t(j) = A_t(j) N_t(j),$$

where $Y_t(j)$ denotes the output of firm j in period t, $A_t(j)$ denotes the firm's draw of technology, and $N_t(j)$ denotes the quantity of labor the firm demands for production purpose. The production technology of firm j follows a standard (log) normal AR(1) process of the form

$$\log(A_t(j)) = \rho_A \log(A_{t-1}(j)) + \varepsilon_t(j) \tag{3.8}$$

Each firm j seeks to maximize the value of its discounted profit at time t as follows

$$E_t \sum_{k=0}^{\infty} Q_{t,t+k} \Pi_{t+k}(j), \tag{3.9}$$

in which profits in period t are given by

$$\Pi_t(j) = P_{H,t}(j) Y_t(j) - W_t N_t(j) - \chi \Gamma_t(j) W_t, \tag{3.10}$$

in which $\Gamma_t(j)$ is an indicator function which takes the value of 1 if firm decides to change the price it offers to the final goods firm and 0 otherwise.

The firm first chooses the amount of labor to employ given the demand by the final good firm and then decides on which price to charge. In the latter phase, the firm must first decide whether to change price at time t or not. It does so only when the expected discounted stream of profits of doing so (which is denoted as V^C) is greater than the expected discounted stream of profits of keeping the price it offers in the previous period (which is denoted as V^K). Following the recent literature on menu costs (see, for example, Gagnon (2009)), if an intermediate firm decides to change its price at period t, it has to pay a menu cost χW_t equal to a fraction χ of the prevailing wage W_t.

Here the choice of changing prices for intermediate firms is endogenous because it depends on the draw of productivity it receives at time t, as well as on the magnitude of the menu costs of changing prices. The pricing decision by firm j at time t is given by

$$p_{H,t}(j) = \begin{cases} p_{H,t-1}(j) & if \quad V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) \leq V^K\left(p_{H,t-1}(j);\bar{\Omega}_t, A_t(j)\right) \\ p^c_{H,t}(j) & if \quad V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) > V^K\left(p_{H,t-1}(j);\bar{\Omega}_t, A_t(j)\right) \end{cases}, \tag{3.11}$$

in which $p_{H,t}(j) = \dfrac{P_{H,t}(j)}{P_{H,t-1}(j)}$ denotes the real price selected by intermediate firm j at time t; $\bar{\Omega}_t$ is a set of the aggregate states of the economy; $p^c_{H,t}(j) \equiv \arg\max_{p_{H,t}(j)}\left\{V^C\left(p_{H,t}(j);\bar{\Omega}_t, A_t(j)\right)\right\}$ denotes the optimal choice of prices, conditional on the decision to change price by intermediate firm j. Equivalently, in terms of notation in equation 3.10, $\Gamma_t(j)$ is equal to 1 when $V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) \leq V^K\left(p_{H,t-1}(j);\bar{\Omega}_t, A_t(j)\right)$ and is equal to 0 otherwise.

Here V^C is value function when intermediate firm j changes it currently offered price, conditional on the draws of productivity and government spending. Similarly, V^K is the value function when intermediate firm j decides to keep the price it offers at period $t-1$. In this latter case, the firm needs not pay any menu cost. Given V^C and V^K, firm j's value function V is simply the bigger of the two. We thus can express these value functions for intermediate firm j recursively as follows

$$\begin{aligned}
V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \max_{p(j)}\left\{\Pi^C_t\left(p(j);A(j),\bar{\Omega}_t\right) + E\left\{Q_{t,t+1}\right\}V'\left(p^{`}_{H,t}(j);\bar{\Omega}^{`}_t, A^{`}_t(j)\right)\right\} \\
V^K\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \Pi^K_t\left(p(j);A(j),\bar{\Omega}_t\right) + E\left\{Q_{t,t+1}\right\}V'\left(p^{`}_{H,t}(j);\bar{\Omega}^{`}_t, A^{`}_t(j)\right) \\
V\left(p_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \max\left\{V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right), V^K\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right)\right\},
\end{aligned}$$

in which V^C and V^K denote the corresponding value functions when intermediate firm j decides to change or keep its current prices.

3.3.4. Market Clearing Conditions

Production in the small open economy must meet both domestic and foreign demand for consumption, as well as government spending. In particular,

$$Y_t = G_t + C_{H,t} + C^*_{H,t},$$

in which $C^*_{H,t}$ denotes the export from home country to the rest of the world. Combining the market clearing condition for home country and the demand function for home good and foreign varieties in terms of the aggregate consumption index yields the expression

$$Y_t = G_t + (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\varepsilon} C_t + \alpha^* \left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\varepsilon} C^*_t \tag{3.12}$$

given that government spending in the rest of the world is constant in that sense that it does not have any effect on the small open economy; that is, $Y^*_t = C^*_t + G^*$ and $C^*_t = [(1-\alpha^*)^{\frac{1}{\varepsilon}} C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}} + \alpha^{*\frac{1}{\varepsilon}} C_{F,t}^{*\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}}$ for the good market in the rest of the world to be cleared. The labor market must also be clear; that is $N_t = \int_0^1 N_t(j)dj$, or $N_t = \dfrac{Y_t}{A_t}\vartheta_t$, in which $\vartheta_t = \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta} dj$ denotes the level of price dispersion. Government spending is an AR(1) process (in log) as follows:

$$\log(G_t) = \log(\bar{G})\left(1-\rho^G\right) + \rho^G \log(G_{t-1}) + \varepsilon^G_t \tag{3.13}$$

Turning to the market for the rest of the world, the government spending in the rest of the world is negligible from the perspective of home country. The small open economy (the home economy) is 'small,' in the sense that production in the home economy is negligible from the perspective of the rest of the world. As a result of these simplifying assumptions, production from the rest of the world needs to satisfy both demand for consumption goods from home and the rest of the world itself; that is, $Y^*_t = C^*_t + G^*$.

3.3.5. Nominal Interest Rates at the Bound

Nominal interest rates are constrained by a lower-bound, because Japan has followed an aggressive expansionary policy since the 1990s. In particular, the nominal interest rate, when not binding, is

$$\tilde{R}_t = \bar{R}\left(R_{t-1}\right)^{1-\rho_r}\left[\left(\frac{Y_{t+1}}{\bar{Y}}\right)^{b_1}\left(\frac{1+\pi_{t+1}}{1+\bar{\pi}}\right)^{b_2}\right]^{\rho_r}, \tag{3.14}$$

in which $1+\bar{\pi}$ denotes the target inflation rates; ρ_r is a parameter governing monetary inertia; b_1 and b_2 dictate how monetary reacts to changes in expectation of future output growth and inflation rates, respectively. Under the zero-bound condition, nominal interest rate thus writes

$$R_t = \max\left(\tilde{R}_t, 1\right)$$

Here the nominal interest rate is also related to the inter-temporal condition via equation 3.4. Therefore, any equilibrium would contain a pair of (1) a consumption decision which satisfies the inter-temporal condition and (2) a nominal interest rate which either binds or is greater than unity.[16] I solve the model non-linearly using a method similar to that of Maliar et al. (2010) and Krusell and Smith (1998). In particular, here I discretize the state space and posit a guess of aggregate law of motion using the first moment on inflation. To improve the accuracy of the policy function, I also use cubic splines interpolation when the differences between iterations are sufficiently small. Appendix B.1 provides further details.

3.4. Model Calibration

This section estimates key parameters for the model. We pay special attention to estimating the monetary policy reaction function because the prolonged nominal interest rates at the bound is a key feature of the Japanese economy since the 1990s.

[16] Some early papers (for example, Willis (2000) and Knotek and Terry (2008)) in the state-dependent pricing literature model monetary policy using an AR(1) process for the growth rate of money supply. While not pursuing this approach, we can connect to this early literature by defining the money supply as $M_t = P_t C_t$ and the growth rate of money supply ΔM_t as $\Delta M_t = \log(M_t) - \log(M_{t-1})$. See appendix B.2 for more details.

3.4.1. Monetary Rules for Japan

This section estimates the monetary reaction rule for Japan using following baseline specification:

$$\hat{i}_t = \bar{i} + \bar{b}_1 \hat{y}_t + \bar{b}_2 \hat{\pi}_t$$

in which $\hat{i}_t$ denotes a measure of nominal short-term interest rate, $\hat{y}_t$ denotes a proxy for real output growth, and $\hat{\pi}_t$ denotes inflation rate. We use the monthly series '3-Month or 90-day Rates and Yields: Certificates of Deposit for Japan' from 1979M1 to 2013M12 by the *St Louis Fed FRED* database. All variables are seasonally adjusted accordingly. Because there is no real GDP measure at the monthly frequency, here I use the growth rate of industrial production as a proxy for real output growth.

One difficulty of estimating Japanese monetary policy is that the unconstrained nominal interest rate are not observable at the bound. We overcome this problem by estimating this policy function using data from the periods in which the nominal interest rates are not binding. The starting points of these periods are determined by a rolling structural break detection procedure, proposed by Verbesselt et al. (2010) and Bai and Perron (2003). A residuals-based MOving SUM (MOSUM) test is first used to test for the existence of one or more breakpoints. Conditional on significance of the test, we use the method proposed by Bai and Perron (2003) to calculate the number of breaks, locations of each break, and the corresponding confidence intervals.[17]

Figure 3.1 presents two structural breaks in 1989 and 1996. The latter break marks the beginning of the prolonged period during which the nominal interest rates are near or at the bound. We use these two break points to determine the data windows for estimating the monetary policy rule for Japan.

Japan's nominal interest rates since the mid-1990s have been, for the most part, at or near the zero lower bound. This phenomenon makes it difficult to estimate the monetary reaction rule for Japan because because it is not possible to estimate a reaction function of the policy rate when the rate is fixed at the lower bound. Therefore, we restrict our attention to the periods before 1995, after which the Japanese nominal interest rates started to touch the lower bound (see, for example, figure 3.1). Heteroscedasticity-robust standard errors are calculated.

Table 3.3 shows that the nominal interest rate exhibits significant correlation with changes in expectation of future inflation rates. The estimated coefficients for the effects of inflation rates on the

[17] See Verbesselt et al. (2010) for a detailed discussion of the procedure.

nominal interest rates range from 0.9 to 2.0, which corresponds to the first and last specifications. For the model, we pick the value $b_2 = 1.5$, which is between these two extremes.

3.4.2. Other Parameters

We calibrate the remaining parameters to Japanese data. In particular, β equals to 0.98, which reflects Japan's sustainably low level of nominal interest rates; the parameter on home bias α for the small open economy is 0.33; the parameter on home bias for the rest of the world α^* has the same value as α. The parameter ψ that dictates the dis-utility of labor is 3.5. The inverse of the Frisch elasticity of labor φ is 0, which is similar to those set by Nakamura and Steinsson (2010) and Golosov and Lucas (2007).

The elasticity of substitution between varieties θ of the same origin (i.e., either produced by the home country or imported) is 3.5, while the same elasticity between home and foreign goods ε is 3. One difficulty of selecting the elasticity of substitution between different varieties of goods θ for Japan is that there has not been any attempt, to my best knowledge, to estimate this parameter using scanner data on a similar scale as the ones using US data (for example, Nevo (2001)). Here we estimate this parameter using Bayesian methods on a similarly calibrated model under Calvo pricing.

This estimation yields a θ of 3.5, implying a 1.4 markup, which is consistent with some earlier studies using micro-price data in the literature (for example, Nevo (2001) estimates the parameter to fall within a range of 1.4 to 2.1, Midrigan (2007) uses θ=3, Nakamura and Steinsson (2010) use θ=4.5). As noted by Golosov and Lucas (2007), to generate the sizes of price change that are congruent with the data often requires that the innovation of the random shock process for idiosyncratic productivity has a relatively large variance. The standard deviation of the innovation to productivity σ^A equals to 0.03 for the model to replicate an average size of price changes of around 0.04, which is consistent with Japanese data.[18]

The markup for fixed menu costs μ is such that the median of price rigidity γ matches micro-price evidence. In particular, in the baseline specification, γ is 0.67, which coincides with the median level of price rigidity in the Japanese micro-price data. We calculate the persistence of the process for government spending using an AR(1) process with first differences of military spending used in section 3.2. This exercise yields a persistence coefficient for the government spending process of

[18] See B.1 for a list of average size of price changes, classified by Japanese prefectures.

0.78. Turning to the coefficients that govern the zero-bound interest rate rule in Japan, b_1 is 1. We choose ρ_r - the parameter that control the level of inertia in monetary policy - to be one to save one dimension of the state space. This simplifying assumption is the same as in Christiano et al. (2011) and Fernandez-Villaverde et al. (2012). Table (3.4) summarizes all parameters under this calibration.

3.5. Results

This section documents two main results of the paper. First, high fiscal volatility drives the economy to the lower bound more often, thus further limiting the effects of expansionary monetary policy. Second, output response to a random shock to government spending is transitory. Moreover, the size of menu costs and the distribution of firms' productivity are important determinants of the size of fiscal multipliers. We also show that the model can capture salient features of the Japanese economy from 1975 to 2006 along multiple dimensions.

3.5.1. The Level Effects of Fiscal Spending: Model and Data

This section shows that the effects of fiscal spending under the state-dependent pricing assumption are transitory. It also shows that this behavior is along the line of the Japanese economy from 1975 to 2006.

To that end, we begin by generating the impulse responses from the model. Upon obtaining the policy function such that the distribution of idiosyncratic pricing decisions converge, we generate a finite sample using both the aggregate stochastic shock (i.e., government spending) and the idiosyncratic shocks (i.e., productivity draws) for T periods and N firms. We simulate the model for $N = 10,000$ and $T = 1,000$, discard the first 200 periods, pick the middle 50 from the remaining periods, and plot these series in figure $B.2$. Keeping the same idiosyncratic shocks, we initiate a one-standard deviation shock to the innovation process of government spending at time $t = 200$ and plot 40 periods thereafter. This first 200 periods are considered burn-ins. We calibrate the model to the baseline specification as in section 3.4. Since the model is non-linear, the point at which the shock is initiated matters. We assume that the economy is very close to, but not at the bound when the impact of government spending hits. The choice of β reflects the historical trends in Japanese nominal interest rates and implies a small steady state level of zero-inflation nominal interest rate.

Figure 3.2 compares the effects of government spending on output, both in the model and in the data. In terms of methodology, figure 3.2 overlays the impulse responses from the data over one generated by the model.[19] These impulses respond to a one-standard deviation increase in government spending. A insight from the model-generated impulse responses is that the impact of an increase to the innovation of government spending tends to have a relatively transient effect on output growth. In particular, output rises upon impact but decreases quickly after only three periods thereafter. These dynamics are consistent between model and data.

3.5.2. Fiscal Volatility and the Frequency of Binding

This section shows that high fiscal volatility is unfavorable in the sense that it drives the nominal interest rates to the bound more often, thereby limiting the possibility of expansionary monetary policy. We also show that this prediction is consistent with the Japanese economy from 1975 to 2006.

To do so, we construct the kernel density distribution for the nominal interest rates under the baseline model with varying levels of fiscal volatility. Here we use the standard deviation σ_G of the innovation ε_t^G to the government spending process as a measure of fiscal volatility. To obtain the simulated nominal interest rates from the model, we first obtain a policy function such that the aggregate law of motion converges. We next simulate the model for 250 periods with 10,000 firms, discarding the first 50 periods as burn-ins. Because the nominal interest rate depends on both the inter-temporal conditions and the monetary rule under the zero lower bound, it is endogenous by construction. Figure 3.4 plots the distributions of nominal interest rates under different level of fiscal volatility while figure 3.4 plots the conditional probability of the interest rates hitting the bound against the sizes of the standard deviation to the innovation of the government spending process.

Figure 3.4 shows that the probability of binding increases with fiscal volatility. For example, in figure 3.4, moving from $\sigma_G = 0.01$ to 0.02 almost triples the probability of binding. The same effect applies as we increase the degree of fiscal volatility to other levels. Because conventional quantitative easing tends to lose effectiveness when the nominal interest rates are near or at the bound, an increase in fiscal volatility can further limit the role of accommodative monetary policy when the economy is near

[19] To do so, we estimate a tri-variate VAR with 3 lags. This tri-variate system includes real output growth, inflation rates, and military spending as a proxy for government spending. The choice of three lags specifications follows Akaike's information criterion. The choice of variables resembles the log-linearized version of standard New-Keynesian models with government spending and time-dependent pricing. All series are in first differences of log, except inflation rates.

the lower bound. Therefore, high fiscal volatility can cause unfavorable effects on the ability of the central bank to support the economy.

$$\tilde{R}_t = \bar{R}\,(R_{t-1})^{1-\rho_r}\left[\left(\frac{Y_{t+1}}{\bar{Y}}\right)^{b_1}\left(\frac{1+\pi_{t+1}}{1+\bar{\pi}}\right)^{b_2}\right]^{\rho_r}$$

There are two channels through which an increase in fiscal volatility can affect the frequency of the economy hitting the zero lower bound for nominal interest rates. In the first channel, or the *direct* channel, an increase in the variance of the innovation to fiscal spending process implies an increase in the variance of aggregate demand. This first channel induces an increase in the dispersion of firms' decisions to change price in the next period (figure B.1); hence the second, indirect channel through which an increase in government spending leads to an increase in the second moment of aggregate inflation. A combination of these two channels subsequentially leads to an increase in the expected variance of the unconstrained nominal interest rates. When the nominal interest rates are near the zero lower bound, as in the case for Japan since the 1990s, this increase in expected variance implies an increase in the frequency of hitting the zero lower bound.

This theoretical result that fiscal volatility is unfavorable in the sense that it tends to drive the economy to the zero lower bound more often is empirically supported by Japanese evidence. Figure 3.3 plots the kernel density distribution of the nominal interest generated by the model versus the same distributions using actual Japanese data. Here we use the series '3-Month or 90-day Rates' from the St. Louis Fed's FRED database as a measure for the nominal interest rates. Data are of monthly frequency and are seasonally adjusted. Next, we split the dataset into two separate periods: one from 1979 to 1990 and one from 1990 to 2013. The rationale for doing so is that the year of 1990 is the start of the so-called 'Japanese economic malaise.' One key result is that the model under the baseline specification (with $\sigma_G = 0.01$) dovetails nicely with the behavior of Japanese nominal interest rates distribution from 1990 to 2013. However, it overshoots the distribution of the nominal interest rates from 1979 to 2013. This result is expected because until 1990, Japan had not experienced near zero nominal interest rates. Therefore, the distribution of the nominal interest rates is expected to be less concentrated near the bound.

3.5.3. Model's Fit: Menu Cost and Firm Distribution Do Matter

We compare the impulse responses of the model under different levels of price flexibility by varying the size of the menu costs multiplier χ. Figure 3.8 plots the impulse responses of aggregate output, inflation, wage, and real exchange rates to a one standard deviation increase to the innovation to the government spending process.

We generate the impulse responses as follows. We initiate a random draw for the idiosyncratic shocks, simulate the model, and apply these shocks to a baseline path. We generate another identical path, but initiate a one standard deviation increase to the innovation term of government spending at time T=40. The first 40 periods of both series are discarded.

Let us turn to some details of figure 3.8, which plots the impulse responses that correspond to four different degrees of price flexibility. Of these four, the level of price flexibility $\gamma = 0.67$ corresponds to the same level of price flexibility in our baseline calibration and in the data. One important insight from figure 3.8 is that when the menu costs multiplier χ varies with different levels of price flexibility, the model fails to match the empirical dynamics of fiscal multipliers that we have seen in section 3.2. Therefore, the size of menu costs, and implicitly the joint distribution of past price changes and idiosyncratic productivity, is an important determinants of the size and dynamics of fiscal spending.

Open criticism remains whether our results are sensitive to the choices of parameters other than the ones that relates to price flexibility. Figure 3.8 implies that such criticism is difficult to sustain. In particular, when calibrated to match a lower degree of price rigidity, the model fails to re-create such ineffectiveness of fiscal policy, as seen in the case of empirical Japanese VAR. These contrasting results thus suggest that, since other parameters remain unchanged, a unique micro-price pattern is one important factor for the ineffectiveness of Japanese government spending.

As the degree of price rigidity γ goes up, the response of real output tend to revert to its corresponding mean much faster thereafter. In comparison, Golosov and Lucas (2007) suggest that monetary policies tend to have a rather transient effect under a dynamic model with menu costs and Nakamura and Steinsson (2010) suggest that monetary policy can have a more robust effect on real aggregates when allowing for heterogeneity in the menu costs across different goods. Therefore, our finding here complements this literature in the sense that government spending also exhibits transient effects on other real aggregates under state-dependent pricing.

3.5.4. Model's Implication: Model versus Micro-price Evidence

As previously noted in the literature, one key advantage of a state-dependent pricing model with discrete choice price setting is the ability to capture micro-price evidence along some important dimensions. This section assesses this claim by comparing the empirical hazard function with the one generated by the model. In particular, we compare the hazard functions from the data to the ones generated by the model under the calibration strategy presented in section 3.4.

This section begins by constructing the hazard functions for micro-price. In particular, we construct the cumulative distribution function of duration of price changes over different time horizons. Let T be a random variable that measures the time of price changes and let $F(t)$ be the corresponding cumulative distribution function. The hazard function $S(t)$ is defined as $S(t) = P(T \geq t) = 1 - F(t)$. We construct the hazard functions for both empirical and model-generated data using kernel density estimation. Figure 3.6a plots the smoothed hazard function for traded and non-traded goods.

Goods under different classification shows markedly different behaviors. Traded goods tend to have a steeper hazard function; that is, price changes are more often than their non-traded counterparts. This result is consistent with the idea that traded goods are more integrated and thus are more likely to change. This conclusion agrees with other papers in the micro-price literature; for example, Crucini et al. (2010) report that traded good prices tend to have a shorter half-life than do non-traded goods. Intuitively, since non-traded goods are often location-specific, they are less likely to be affected by, say, a random shock from another location. The shapes of these hazard functions are in line with what we typically expect from the classical dichotomy between the two types of goods. Turning to figure 3.6b, regulated goods show more rigidity than unregulated goods.

We next compare these micro-price patterns with ones generated by the model. In particular, upon obtaining the relevant policy functions under the baseline specification, we simulate the model with 10,000 firms and 300 periods. The first 200 periods are considered burn-ins and are discarded. We apply the same procedure on data generated by the model as on empirical data.[20] To match the monthly frequency observed in the micro-price dataset, here the discount factor β is $0.98^{1/12}$.

Figure 3.7 shows that the model can capture features of the Japanese empirical hazard function along some important dimensions. In particular, the underlying micro-price patterns generated by the

[20]For the underlying kernel smoothing, we use the Silverman rule of thumb for bandwidth selection criteria. (See Silverman (1998) for details.)

model dovetail nicely with ones from empirical data. When calibrated to Japan's median frequency and size of price change, the model generates a survivor function that is between that of traded goods and that of non-traded goods. It is helpful to note that the classification of traded versus non-traded is interchangeable for a selected number of goods. The two survivor functions presented here can be thought of as two extremes of a wide variety of goods. Under this interpretation, our model-generated pricing behavior fits in between these two extremes.

Intuitively, this result comes as a result of the state-dependent pricing assumption. In particular, the implications under a state-dependent pricing are markedly different from ones generated by a time-dependent pricing framework. The former implies that the hazard function generated from the model often exhibits an upward trend, while the latter implies that the corresponding hazard function will be flat.

3.6. Conclusion

This paper has studied the dynamic responses of Japanese output to changes in government spending using a small open economy model with menu costs and zero lower bound. Two implications emerged. First, high fiscal volatility drives the economy to the lower bound more often, therefore further limits the effects of expansionary monetary policy. Second, output responses to an increase in government spending are transient, returning to their pre-shock path quickly upon impact, both in data and in the model. The model not only can match the empirical sizes of Japanese fiscal multipliers, but also can generate an empirical hazard function consistent with micro-price evidence.

Despite its focus on Japan's economic stagnation, this paper is also a step toward a more comprehensive understanding of the question on the ineffectiveness of fiscal spending. In particular, under the forward-looking monetary rule, an increase in fiscal spending can reinforce, not crowd out, private spending when the nominal interest rate is at the bound. Its effect is however transitory, especially when firms base their pricing decisions on the state. Thus, establishing a credible and persistent belief of accommodative monetary policy is even more important in elongating the effect of fiscal spending.

Table 3.1.: Fiscal Multipliers - Size

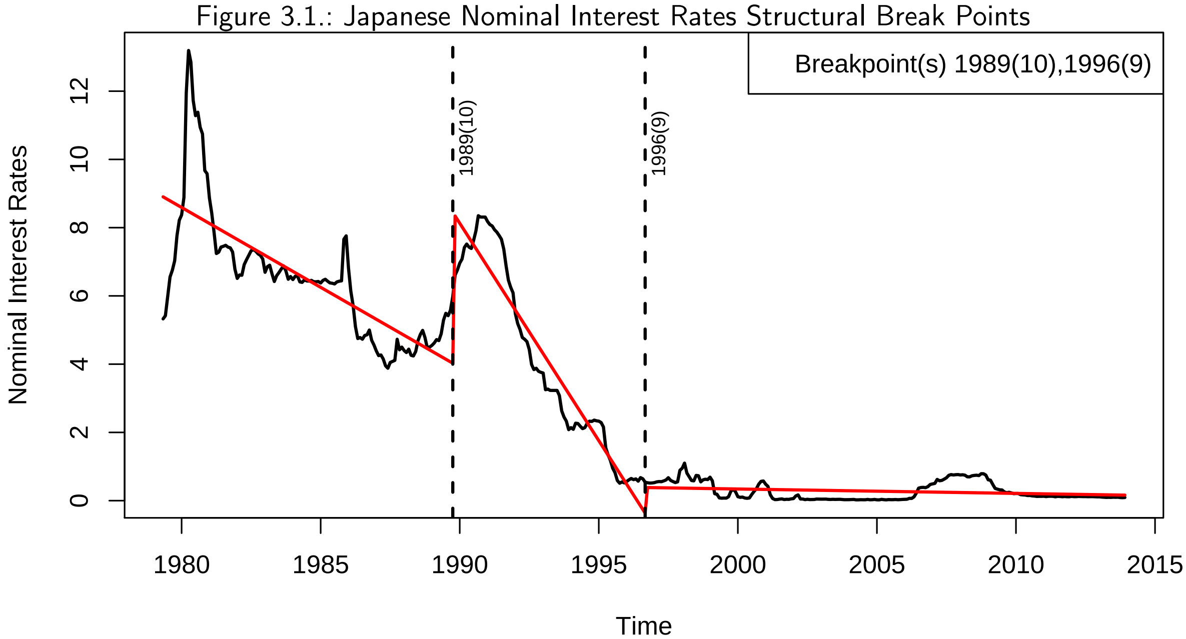
	(1) Output (ΔY_t)	(2) Output (ΔY_t)	(3) Output (ΔY_t)
Military Spending (ΔMS_t)	0.885***	0.633***	0.589***
	(0.0716)	(0.118)	(0.142)
Inflation (π_t)		0.329*	0.227
		(0.128)	(0.218)
General Government Spending (ΔG_t)			0.124
			(0.214)
Constant	0.00270	0.00563	0.00344
	(0.00533)	(0.00505)	(0.00635)
Observations	34	34	34
Adjusted R^2	0.822	0.848	0.845

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: We use OLS and standard errors are heteroscedasticity-robust. Specification (1) is $\Delta Y_t = \beta_0 + \beta_1 \Delta MS_t + \varepsilon_t$. Specification (2) is $\Delta Y_t = \beta_0 + \beta_1 \Delta MS_t + \beta_2 \pi_t + \varepsilon_t$. Specification (3) is $\Delta Y_t = \beta_0 + \beta_1 \Delta MS_t + \beta_2 \pi_t + \beta_3 \Delta G_t + \varepsilon_t$.

Figure 3.1.: Japanese Nominal Interest Rates Structural Break Points



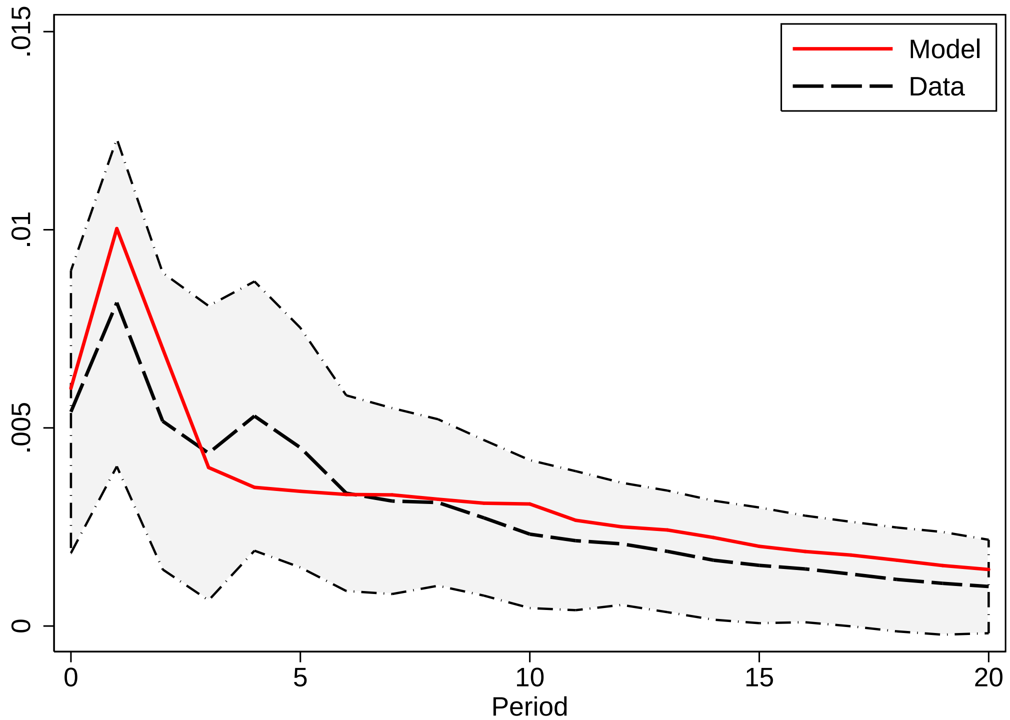
Note: This figure plots the structural breaks in the Japanese nominal interest rates. I use a rolling windows procedure by Verbesselt et al. (2010) to estimate these breaks.

Table 3.2.: Conditional Logit Regression Results for p^+ and p^-

	Price Up			Price Down		
Period	**2000-2006**	**2000-2006**	**1975-1999**	**2000-2006**	**2000-2006**	**1975-1999**
Output	0.00161	0.00368	-0.0280***	0.00554***	0.0240***	0.0119***
	(1.56)	(0.89)	(-15.04)	(5.48)	(5.61)	(5.90)
Inflation	0.0413**	0.200***	-0.0418***	-0.0283*	0.273***	0.118***
	(3.29)	(3.99)	(-3.57)	(-2.30)	(5.07)	(9.29)
Exchange Rate	-0.00217***	0.00537*	0.000753	0.00416***	0.0132***	-0.00522***
	(-3.75)	(2.30)	(1.79)	(7.43)	(5.33)	(-11.39)
LastD3	25.82	6.125***	24.75	24.78	23.91	22.76
	(0.01)	(40.75)	(0.02)	(0.02)	(0.02)	(0.04)
LastD6	1.544	3.285***	0.621	1.499	1.396	0.624
	(0.00)	(20.90)	(0.00)	(0.00)	(0.00)	(0.00)
LastD9	1.113	3.197***	0.429	1.096	0.949	0.464
	(0.00)	(20.08)	(0.00)	(0.00)	(0.00)	(0.00)
LastD12	0.796	2.639***	0.330	0.764	0.580	0.334
	(0.00)	(15.47)	(0.00)	(0.00)	(0.00)	(0.00)
Unregulated	Yes	Yes	Both	Yes	Yes	Both
Traded	Yes	No	Both	Yes	No	Both
N	1,877,447	317,982	606,291	1,877,447	317,982	606,291

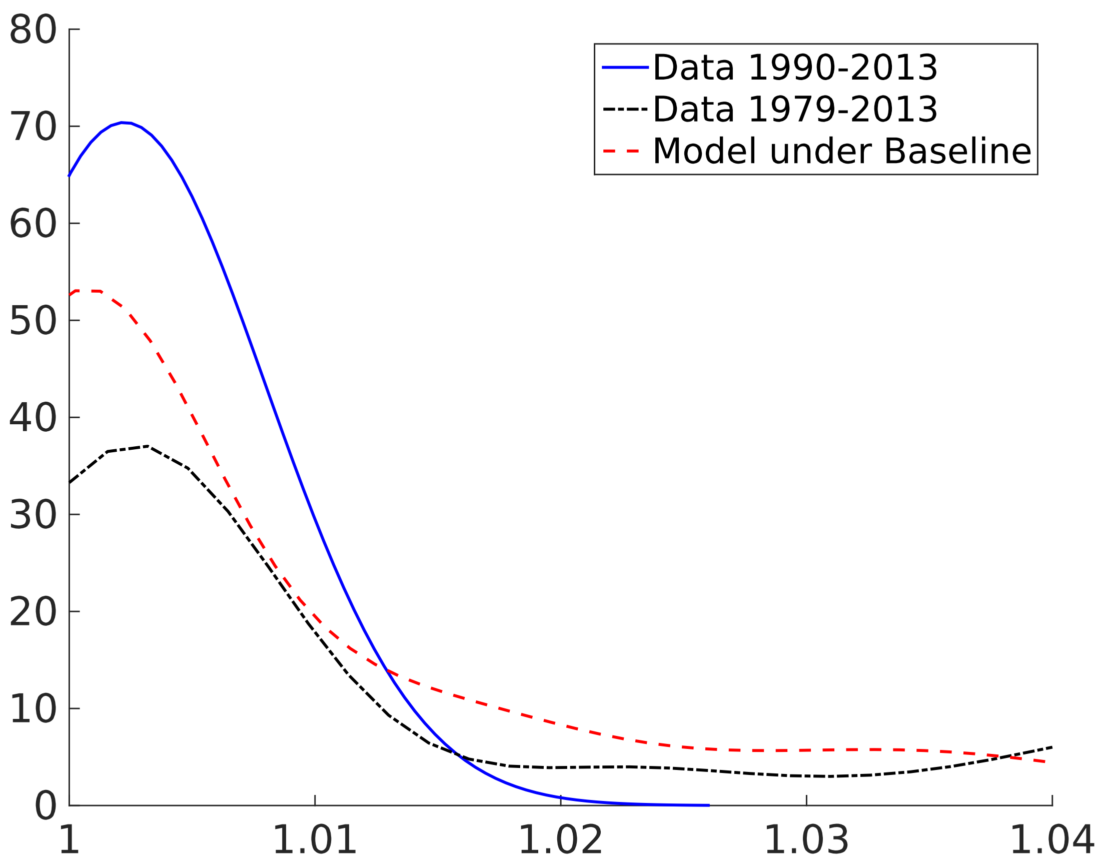
Note: t-statistics in parentheses. Dummies for year, month, good, and city are included for all regression specification. I obtain the marginal effects at the median after the fixed-effects conditional logit regression. The significance of estimates is labelled as follows: *** p<0.001,** p<0.01, * p<0.05.

Figure 3.2.: Impulse Responses: Model vs. Data



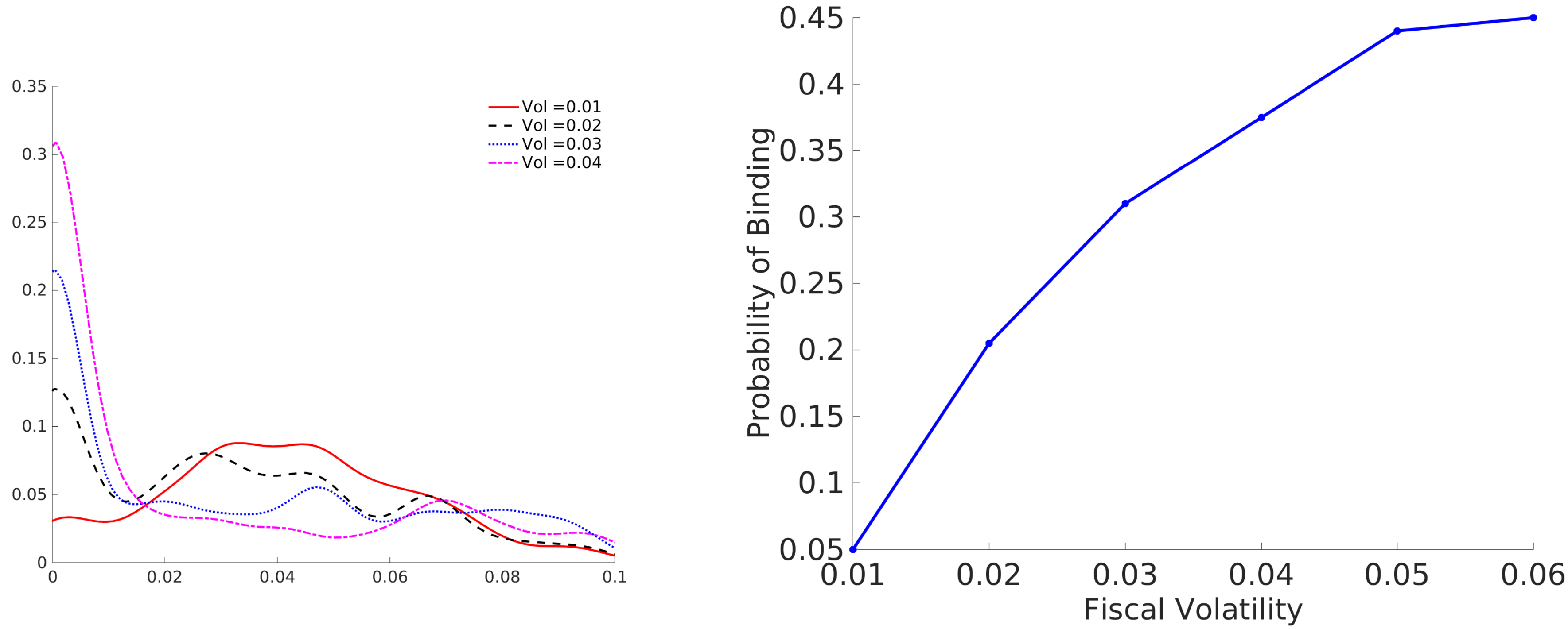
Note: This figure plots the impulse reponses generated by the tri-variate VAR system versus the one generated by the model. We plot the 95% confidence bands for the impulse responses by the data and overlay the impulse responses from the model. For the model impulse responses, we simulate two paths with the same set of idiosyncratic shocks. We initiate a one standard-deviation increase to the innovation term of the government spending process at time t=40 and plot the differences 20 periods thereafter.

Figure 3.3.: Nominal Interest Rates: Model vs. Data



Note: I simulate the model for 250 periods and 10,000 firms and discard the first 50 observations. I next plot the kernel density estimation for the nominal interest rates generated by the model along side the ones generated by the data. Data for nominal interest rates are the series '3-Month or 90-day Rates and Yields: Certificates of Deposit for Japan.'

Figure 3.4.: High Fiscal Volatility vs Frequency of ZLB Binding



Note: Upon obtaining the policy function such that the aggregate law of motion converges, I simulate the model for 250 periods and 10,000 firms and discard the first 50 observations. I next plot the kernel density estimations for the nominal interest rates.

Table 3.3.: Monetary Rules for Japan: Regression Results

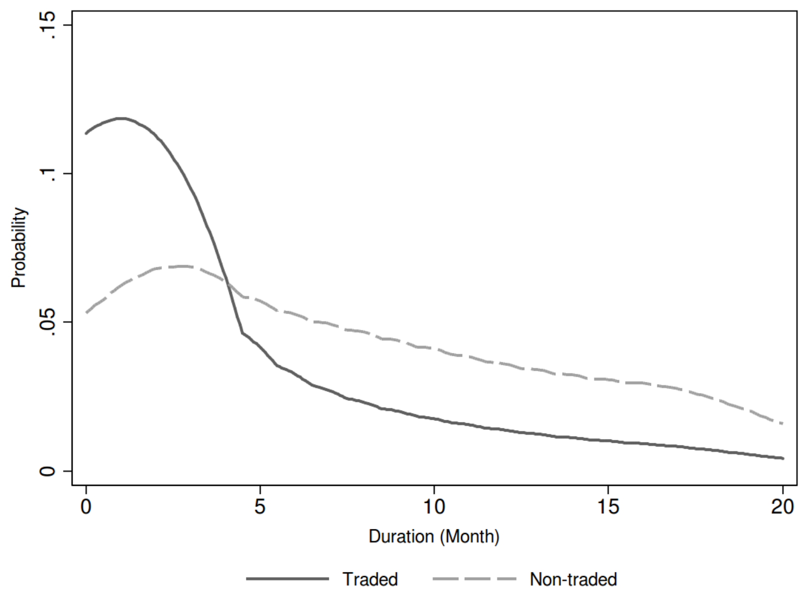
	Dependent variable:			
	Nominal Interest Rates			
	1979-1989	1989-1996	1996-2013	All
	(1)	(2)	(3)	(4)
Growth Rates	−0.147	−0.034	−0.024***	0.066
	(0.127)	(0.185)	(0.009)	(0.084)
Inflation	0.899***	1.134**	0.057	2.006***
	(0.303)	(0.565)	(0.056)	(0.336)
Constant	6.453***	4.331***	0.269***	2.721***
	(0.189)	(0.270)	(0.018)	(0.152)
Observations	116	84	204	416
R^2	0.091	0.048	0.040	0.081
Adjusted R^2	0.075	0.024	0.031	0.076
Residual Std. Error	1.847 (df = 113)	2.372 (df = 81)	0.262 (df = 201)	3.049 (df = 413)
Note:				*p<0.1; **p<0.05; ***p<0.01

Note: We use OLS and standard errors are heteroscedasticity-robust. We regress nominal interest rates on real output growth and inflation rates. Data are from the OECD stats database.

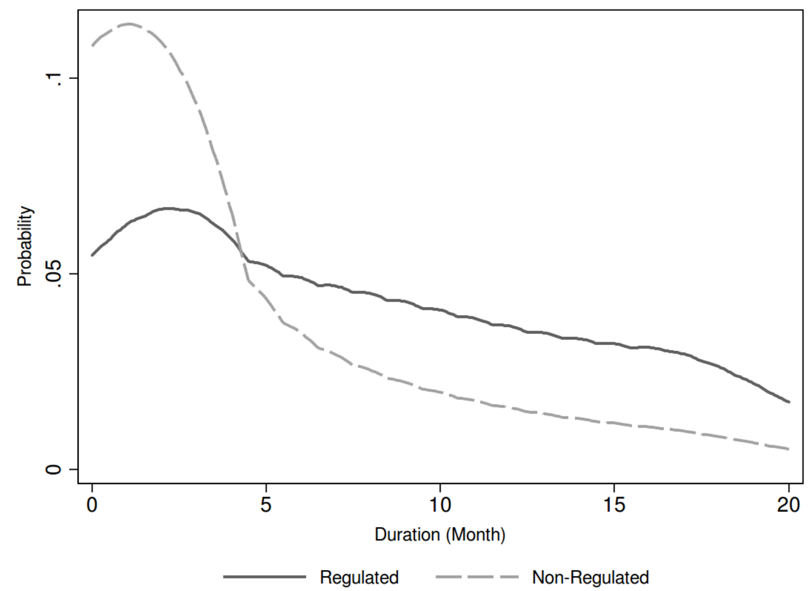
Table 3.4.: Summary of Parameters

Par.	**Val.**	**Notes**	**Description**
α	0.330	Backus et al. (1992)	Home bias for Home
β	0.98	Backus et al. (1992)	Discount rates for annual data
α^*	0.33	Our calibration	Home bias for the ROTW
ε	2	Dedola and Nakov; Gali	Elasticity of sub. H vs F
θ	4.5	Nakamura and Steinsson (2010)	Elasticity of substitution
ψ	3	Nakamura and Steinsson (2010)	Labor dis-utility
σ	3	Nakamura and Steinsson (2010)	Elasticity of substitution
φ	0	Nakamura and Steinsson (2010)	Inverse of Frisch elasticity
ρ_A	0.7	Backus et al.	Persistence of productivity
ρ_G	0.78	Our calibration	Persistence of gov. spending
b_1	1	Our calibration	Monetary rule
b_2	1.5	Our calibration	Monetary rule
Ξ	1	Gali; Gali et al.	Initial welfare dist.

Figure 3.5.: Empirical Hazard Functions



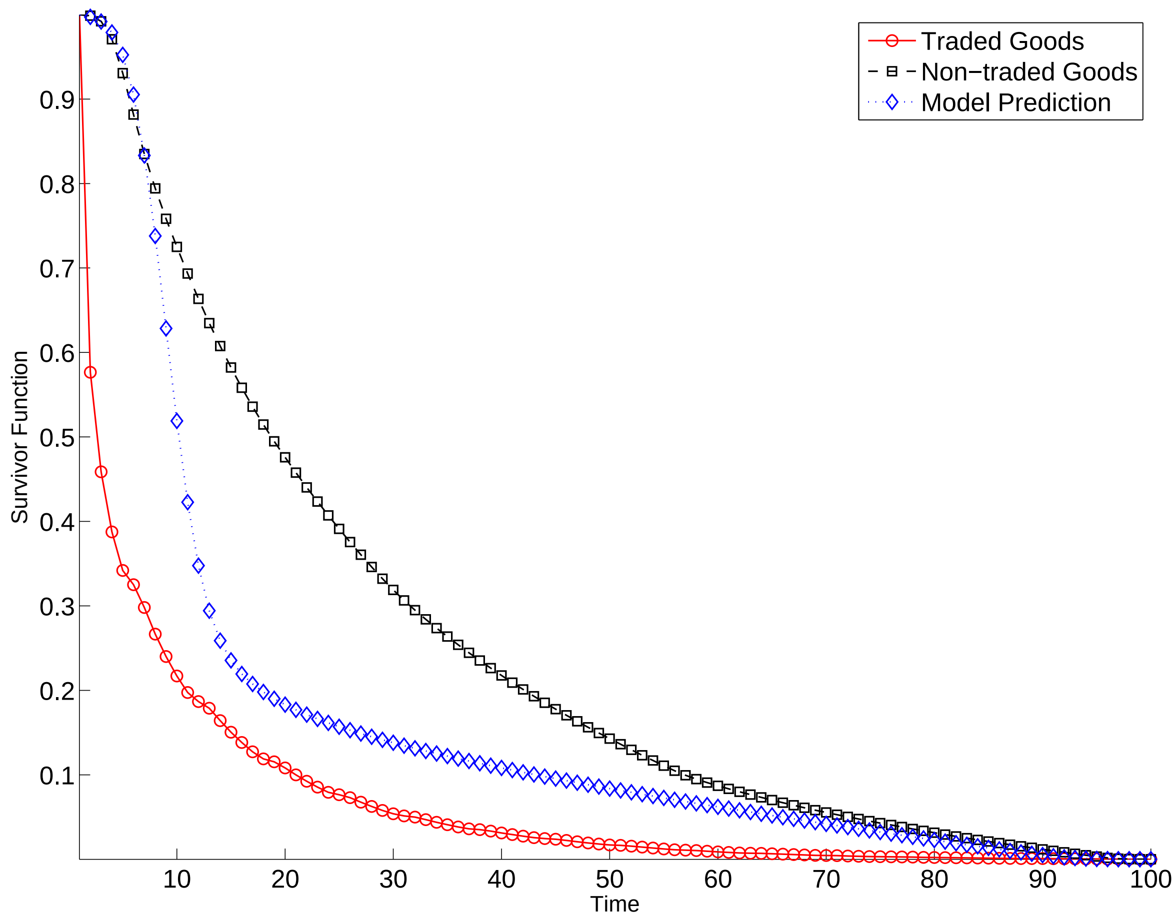
(a) Traded vs Non Traded



(b) Regulated vs Non-reg.

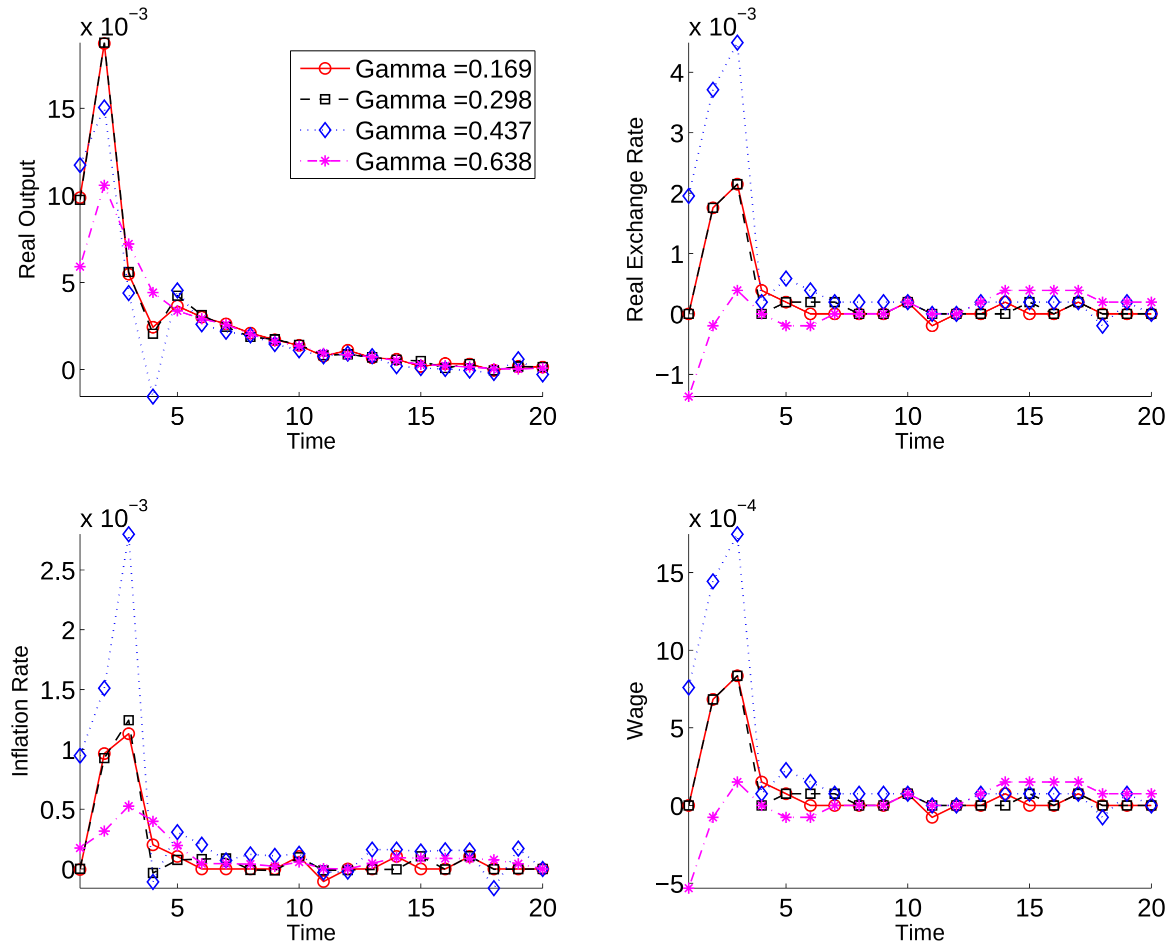
Note: This figure plots the empirical hazard functions across all good using Japanese data from 1975 to 2006. Data are pooled based on (1) whether the goods are traded and (2) whether the goods are government-regulated. Here I select the bandwidth for the kernel density estimator using the Silverman rule of thumb.

Figure 3.7.: Micro-price Evidence: Model prediction versus Data



Note: This figure compares the survivor function generated by the data and ones generated by the model. We simulated the model for 1,000 periods with 10,000 firms, removing the first 50 periods.

Figure 3.8.: Impulse responses of Output and Inflation



Note: This figure plots the impulse responses of selected aggregate variables to an increase of one standard deviation in government spending (0.01 under baseline). Output responses are normalized by the absolute magnitude of government spending. As a result, an increase of 0.01 in the plot of the response of output corresponds to a fiscal multiplier of size unity. The responses of real exchange rate and wage are normalized by their corresponding steady state values.

Chapter 4

David versus Goliath: Who Bears the Burden of Corporate Tax?

Recent empirical studies have shown that workers tend to bear the lion's share of the burden from increases in corporate income tax. This paper studies an incomplete markets two-country model with corporate taxes and international financial frictions. We show that increases in corporate income taxes can create asymmetric welfare benefits across agents who hold assets and those who do not. Specifically, while building on some elements of the current theoretical literature, our model implies that corporate tax burdens tend to fall more heavily on workers, a result that is congruent with the empirical findings. Furthermore, investors do suffer from an increase in corporate taxes, but such negative effect is considerably less persistent than that of the workers.

Keywords: Incomplete markets, cross-country investment costs, and corporate tax policy.
JEL Classification Numbers: F38, F23, D63.

4.1. Introduction

The welfare effects of corporate taxes have been a central issue in economic debate. Raising corporate taxes provides governments with the financial flexibility they need to build and maintain basic components of the economy. But doing so may impose significant welfare costs on the economy. This long-enduring schism has posed a dilemma for governments seeking to raise corporate taxes.

Yet the literature on the welfare effects of corporate taxes has been rather divided. One strand of literature (for example, Harberger (1962), and subsequent works) has argued, theoretically, that we should expect the burden of an increase in corporate taxes to fall more heavily on investors, who own most of the firms' assets. However, recent empirical studies such as Arulampalam et al. (2007), Felix (2007), and to a larger extent Desai et al. (2007)), have shown that workers bear the lion's share of the burden from increases in corporate income tax. More recent theoretical literature has attempted to reconcile such a dichotomy between past theory and empirics by introducing more realistic assumptions to the model, an example of which is the use of open economy frameworks to study the effects of corporate taxes changes.

The paper presented here seeks to provide further insight into the short-run effects of corporate taxation while maintaining the long-run properties consistent with salient features of the data. To this purpose we study a dynamic open economy framework that contains financial frictions across countries, trade costs, and corporate taxation. In particular, we propose a two-country model in which a representative household worker provides labor and consumes goods from both countries. The second agent is a representative capitalist who provides capital to firms across the globe for a claim in their after tax profits. Unlike in standard real business cycle models, firms in our model engage in monopolistic competition which allows them to charge consumers a mark-up over the marginal cost; hence the positive profits, which are subject to a corporate tax at source that is used to finance government expenditures. We adopt the Ramsey framework in which government expenditure is exogenously determined. Furthermore, we assume that such expenditure has no direct effect on the utility of the agents in the economy. Trade between countries and capital transfers across borders are costly, relative to their domestic equivalents.

Our source of novelty also hinges on several other aspects. In particular, the model not only generates the dynamics and long run effects that are in line with some previous theories, but also exhibits properties consistent with the empirical studies. Increases in corporate taxes reduce output and capital stock in the country that raises the tax while output and capital stock follow the opposite path in the other country. While output decreases only in one country, the capitalists in both countries suffer from the impacts of an unexpected tax increase. These spillover effects become more pronounced as countries become more integrated.

Workers' wages in the long run are negatively related to international finance costs; that is, long run wages increase when its openness to foreign investment increases. While our result is quite striking for an inverse relationship is usually expected, it is well-supported by the empirical evidence in the literature. For example, Chari et al. (2012) find that in countries that liberalize to inflows of foreign capital, the manufacturing wages increase by a fifth, three years following the liberalization. Corporate taxes negatively affect the wages of workers at source in the long run as well as the short run. In the short run, wages decrease because a portion of the financial burden of the firm owners, also called the capitalists in our model, is shifted to workers; moreover, another part of this burden is also exported to workers in the other country. The burden transfer property is found in Kotlikoff and Summers (1987) and Harberger (1995); while Gravelle and Smetters (2001) argue that in the long run the burden either falls on domestic capital, or is exported.

This property of the model results in another contribution in terms of providing a theoretical foundation for the idea that raising corporate taxes affects individuals asymmetrically. In particular, we show that an increase in corporate taxes result in distinct effects on individuals whose income depends solely on wages and those whose income does not. Individuals who claim ownership in firms recover *far* quicker than individuals who depend solely on wages as their main sources of income.

Our paper is also related to the literature on law of one price deviations in the sense that it provides a theoretical foundation to support the plethora of empirical evidence in the literature on deviation from the law of one price, or the lack thereof. In particular, we show, for example in propositions 4.4.4 and 4.4.5, that it is difficult to sustain the law of one price under plausible model restrictions, a conclusion that dovetails nicely with the current empirical literature on the law of one price.[1]

We proceed as follows. Section 4.2 provides a brief literature review. Section 4.3 describes the baseline set-up of the model, in which we also discuss the features that set ours apart from other two-country models in the literature. Section 4.4 examines the properties of the steady-state conditions of

[1] See, for example, Crucini and Shintani (2008) for a detailed discussion on the topic.

the model, evaluating the link between these properties and the current policy debate on the role of financial integration and corporate taxes policy on income inequality. Section 4.5 studies the short-run dynamics of the model. Specifically, we examine the properties of the impulse responses of selected macroeconomic aggregates to random shocks to corporate tax rates and financial frictions. Section 4.6 concludes.

4.2. Related Literature

This paper is related to the literature on corporate taxation, more specifically, to the literature analyzing the allocation of the burdens of corporate taxes. A widely used theoretical framework for this literature is the seminal paper by Harberger (1962), which used a closed economy setting. Subsequent papers based on Harberger (1962) have extended such an environment into a more realistic open economy setting (Harberger (1995, 2008), Randolph (2006), Gravelle and Smetters (2006) among others). Most of these papers agree that the open economy is necessary for generating the implication that corporate tax burden falls more heavily on workers; though, as argued by Harberger (1995), this result can also be obtained under certain parameters on his closed economy model. Our paper deviates from this large literature by assuming incomplete capital mobility across borders in an open dynamic setting. The empirical evidence supporting this assumption on incomplete markets is overwhelming (see, for example, Kollmann et al. (2014), or Hall (2011)).

Recent empirical studies have shown that workers bear a lion's share of the corporate tax burdens (for example, Arulampalam et al. (2007), Felix (2007), and to a larger extent Desai et al. (2007)). Yet the mechanism for this result is unclear. Specifically, Clausing (2013) conducts a VAR analysis of OECD countries, showing no robust linkages between wages and corporate income taxes; this result implies no conclusive evidence that corporate taxes have a negative impact on workers welfare. A source of their contrasting results lies in the dynamic nature of their analysis while most of the earlier studies (both empirical and theoretical) have based their conclusions on long-run properties. To this purpose, our model provides a structural model in a dynamic setting that can be used for analysis along both the long-run and the short-run dimensions. Specifically, both the long-run and the short-run implications of our model are not only consistent with empirical studies, but also dovetail nicely with salient features in other aspects of the trade economic literature.

Our paper is also related to the vast literature on the international business cycle (for example, Backus et al. (1992) and Baxter and Crucini (1995)). In particular, the model presented here deviates from this literature by allowing for cross-border frictions and the asymmetry in the types of agents; that is, ones that hold assets and the other does not. Therefore, another source of novelty in our approach lies in its application of an extension of a well-established type of dynamic model to the study of the asymmetric effects of corporate taxes.

4.3. Model

Our model assumes two types of households in each country: one household provides labor to firms and has access to basic financial instruments (bonds) and a capitalist who does not provide physical labor but relies in its capital investments to generate income. The capitalist has access to a worldwide financial market in which she can invest in the producing firms of any country; such an investment grants her a claim into a share of after tax profits for the next period that is proportional to her ownership of the firm.

Workers

A lifetime utility maximizing laborer lives in each country. He gets positive utility from consuming a composite good M, which is an Armington aggregation of the two available goods in this economy: one good produced by the firm in country H (the home good) and another good produced by the firm in country F (the foreign good). To afford his consumption he provides labor to the firm in the country where he resides; in exchange for his services he receives a wage ω_t. We assume labor is immobile, thus households born in H (F) can only offer their services to the home (foreign) firm at a market-prevailing wage rate ω_t^H (ω_t^F). The household worker can choose to save part of his income by holding bonds which pay him a default free interest rate $r_{b,t}^j$, where j is the country of residence of the worker. The household workers problem is to maximize

$$\max E \sum_{t=1}^{\infty} \beta^t \left[M_t^j + log(N_t^j) \right] \quad (4.1)$$

subject to

$$\sum_{i=1}^{N} p^j_{i,t} m^j_{i,t} + b^j_{w,t+1} = \omega^j_t L^j_t + (1 + r^j_{b,t}) b_{w,t} + T^j_t \tag{4.2}$$

$$1 = L^j_t + N^j_t \tag{4.3}$$

$$M^j_t = \left[\sum_{i=1}^{N} \left(m^j_i \right)^{\varepsilon} \right]^{1/\varepsilon} \tag{4.4}$$

Here $b^j_{w,t+1}$ is the amount of bonds purchased by the worker in country j at time t. Bonds mature after one period and yield interest income of $r^j_{b,t} b^j_{w,t}$ to the worker at time $t+1$. The term T^j_t is a lump sum transfer that the worker receives (gives) from (to) the government. The amount of the transfer is equal to the difference between the tax revenue from corporate taxes and government spending for the period (G^j_t).[2] Lastly, $p^j_{i,t}$ is the price of a good produced in country i and sold in country j; the notation for the quantity of goods m^j_i is define in a similar manner.

Let P^j be the implied price index of the preferences in country j, then the optimal consumption of each good can be written as:

$$m^j_{i,t} = \left(\frac{p^j_{i,t}}{P^j_t} \right)^{-\sigma} M^j_t \qquad \forall i \tag{4.5}$$

$$P^j_t = \left[\sum_{i=H,F} \left(p^j_i \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{4.6}$$

where σ is the elasticity of substitution between the goods.[3]

Capitalist

Another infinitely lived type of household lives in each country. While different from the worker type in terms of sources of income, her utility function is similar to that of the worker type household in the sense that their consumption indices both admit an Armington aggregation formula of goods produced at home and abroad. Instead of providing labor to firms, the capitalist provides the capital

[2] The transfer can be either or positive thus it some periods it can be a wealth transfer from the capitalist to the workers and in other periods it will be a lump sum tax to the worker. The baseline specification of the model is calibrated such that T^j_t is positive for all t and for both countries.

[3] $\sigma = \dfrac{1}{1-\varepsilon}$

needed for production of the consumption goods. The return for her investment is a share of after-tax profits from the firms in which she invested.

The timing of the capitalist problem can be summarized as follows. Take the capitalist in the home country as an example. First, she determines the levels of consumption of home c_H^H and foreign c_F^H goods, as well as the levels of investment in firms in both home I_H^H and foreign I_H^F countries. Her income comes from the return of investment made in the *previous* period, which depends on their level of ownership, that is determined by their corresponding share of capital in the home s_H^H and in the foreign s_H^F firms. It is helpful to recall that, in terms of notation, here we use superscript to denote the destination and under-script to denote the origin; for example, s_H^F reads the share of capital at *foreign* firms that are owned by capitalists from the *home* country.

Investment across border carries a cost of $\eta_j^i > 1$ for $i \neq j$ and it is identical to unity for investments originating and ending in the same country. In our model, the investment costs affect capital flows in the following way:

$$k_{i,t+1}^j = \frac{1}{\eta_i^j} I_{i,t}^j + (1-\delta) k_{i,t}^j \tag{4.7}$$

The international investment costs η_i^j from country i to country j are designed to capture all costs associate with investing overseas such as: monitoring the investment, and financial costs from finding agencies to carry the investment. For example, investors from the U.S. have to pay additional fees to buy stocks in exchanges from other countries. These fees lead to increases in the price of the same capital unit for the U.S. investors while investing abroad. Direct estimation of these cost is difficult as they encompass variables that are both quantitative (additional fees) and qualitative in nature (accessibility and ease of investment). Bribery may also increase the cost of investment abroad, especially in the case of emerging economies which tend to have higher rates of corruption; this is not to say that developed countries are free of this problem as lobbying could be considered a form of corruption.

The proportion of after-tax profits that belong to each capitalist depends on the proportion of its investment (net of cross country investment costs), with respect to the total capital provided to the firm from all sources for that period. This proportion is denoted by the variable $s_{j,t}^i \leq 1$ and the exact formula is given in equations 4.11 below. In what follows, we proceed by expressing the capitalist problem as well as the capital evolution equations.

$$\max E \sum_{t=1}^{\infty} \beta^t C_t^j \tag{4.8}$$

such that

$$\sum_{i=1}^{N} p_{i,t}^{j} c_{i,t}^{j} + \sum_{i=1}^{N} I_{j,t}^{i} = \sum_{i=1}^{N} s_{j,t}^{i} (1-\tau_t^i)\pi_t^i \tag{4.9}$$

$$C_t^j = \left[\sum_{i=1}^{N} \left(c_{i,t}^{j} \right)^{\varepsilon} \right]^{1/\varepsilon} \tag{4.10}$$

Here the budget constraint, that is, equation 4.9, implies that the capitalist type agents do not work, but rather finance their consumption and investment decision using incomes from the investment in home and foreign firms in the last period. One key insight from this equation is that, the income of the capitalists depend on both the share of ownership realized at time t (which is a state variable at time t) and the firms' profits realized at time t.

$$s_j^i = \frac{k_{j,t}^i}{K_t^i} \tag{4.11}$$

$$K_t^j = \sum_{i=1}^{N} k_{i,t}^{j} \tag{4.12}$$

4.3.1. Firms and Government

There is a representative firm in each country that is responsible for the production of a consumption good. The technology for the firm follows a Cobb-Douglas form with labor and capital as inputs. The firm sells its product in the home market as well as the foreign market. Both countries possess markets characterized by monopolistic competition. The representative firm of each country maximizes profits by choosing the optimal price after the cost minimization problem

$$\max \quad p_t Y_t - \omega_t L_t - r_t K_t \tag{4.13}$$

$$Y_t = A_t (K_t)^{\alpha} (N_t)^{1-\alpha} \tag{4.14}$$

where Y_t is the quantity supplied at t; ω_t and r_t denote wages and rental rates of capital. Here we omit the country subscripts for notational convenience. Profit maximization (under monopolistic competition) along with the cost minimization implies that the firm in country j charges an optimal price to residents of j of:

$$p_t^j = \frac{1}{\varepsilon}\Omega_t^j \tag{4.15}$$

$$\Omega_t^j = \frac{1}{A_t^j}\left(\frac{\omega_t^j}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^j}{\alpha}\right)^{\alpha}, \tag{4.16}$$

in which Ω_t^j denotes the marginal costs of firms in country j at time t. A firm in country j pays an iceberg trade cost of $\theta_j^i > 1$ for $j \neq i$ to ship to residents in country i. Thus prices as specified in the household section are given by:

$$p_{j,t}^i = \theta_{j,t}^i p_{j,t}^j \tag{4.17}$$

We use the Ramsey approach and assume that governments consumes an exogenous given amount G_t^j of the domestically produced good. This expenditure is financed by corporate tax revenue and any left over money is transfer to the workers. If the tax revenues is lower than governments expenditures at time t, then the government imposes a lump sum tax on workers to cover the deficit. Therefore the following equation holds in all periods

$$T_t^j = \tau_t^j \pi_t^j - G_t^j p_t^j, \tag{4.18}$$

and the rate of growth of government spending is exogenously driven by the following process:

$$\Delta \log G_t^j = \log G_t^j - \log G_{t-1}^j \tag{4.19}$$

$$\Delta \log G_t^j = (1-\rho_g)\Delta \log \bar{G} + \rho_g \Delta \log G_t^j + v_t^j \tag{4.20}$$

$$\tau_t^j = (1-\rho_\tau)\bar{\tau} + \rho_\tau \tau_t^j + \varepsilon_{G,t}^j \tag{4.21}$$

Here $v_t^j \sim N(0,\sigma_G^2)$ denotes the innovations to fiscal policy in country $j = H,F$ at time t, $\Delta \log G_t^j$ denotes the rate of growth of government spending as in equation (4.21). Turning to the details on the production process for intermediate goods firms, here we assume that productivity is exogenously driven in the following manner:

$$\log A_t^j = \rho \log A_{t-1}^j + u_t^j, \qquad (4.22)$$
$$\forall j = 1, \ldots, N$$

where the innovation term u_t^j is assumed to follow $N(0, \sigma_A^2)$.

4.3.2. Equilibrium

The equilibrium is a collection of prices and allocations of consumptions and output, such that

1. The problems for workers equations (4.2), (4.4), and (4.5) are satisfied.
2. The problems for capitalists as in equations (4.9), (4.11), (4.7), (4.12), and (4.10) are satisfied.
3. The profit maximizing problem for firms is satisfied; that is equations (4.15), (4.16), and (4.17).
4. Government's budget is balanced; that is, equations (4.18), (4.20), (4.19) and (4.21) are satisfied.

Additionally, the relative size of the economies is fixed in the steady state and is subject to a global macroeconomic shock. This condition ensures that the model reaches the steady state through one path; thus avoiding a sunspot solution.

$$\frac{Y_t^H}{Y_t^F} = \Xi + \epsilon_t \qquad (4.23)$$

4.4. Steady State Analysis

We continue our discussion by examining some key insights of the model presented in section 4.3 by studying its steady state. In particular, we put an emphasis on the capital allocation across countries and wages given a particular set of financial costs, trade costs and taxes for each country. We provide proofs to the propositions presented in the appendix.

Proposition 4.4.1. *Let $i \neq j$ then:*

- *An increase in τ^j increases r^j but has no effect on r^i.*
- *r^j does not depend on η_j^i.*

- *Increasing the financial cost of investing abroad raises the interest rate at the target country. Thus if η_H^F was to increase then r^F would also increase.*

- *The derivative of r^j w.r.t the country's corporate tax is greater than the derivative of such interest rate w.r.t the cross country investment cost (η_i^j).*

The first proposition concerns properties of the rental rates on capital. In particular, the long run properties of interest rates depend solely in variables decided at the country where the interest rate is paid.[4] Higher taxes along with higher cross border investment costs reduce the available capital in the economy which leads to raising interest rates by firms that wish to obtain their optimal capital stocks. This observation builds upon and results in a salient feature of the model in which financial integration is beneficial over the long term for interest rates. In particular, lowering financial transaction costs results in lower interest rates, a key channel in which the economy can expand and recover quickly upon a recession. Not only can a lower interest rate induce domestic production but also encourages investment from abroad. Further expanding this argument, the last bullet point shows the interaction between taxes and financial integration and show that these elements are important in order to correctly forecast the effects of government policies on key variables, such as the interest rate.

Next, we present and interpret the distribution of ownership of firms which are given by:

$$s_H^H = \frac{\eta_F^H}{1+\eta_F^H} \qquad s_F^H = \frac{1}{1+\eta_F^H}$$
$$s_F^F = \frac{\eta_H^F}{1+\eta_H^F} \qquad s_H^F = \frac{1}{1+\eta_H^F}$$

Interpreting these ownership shares becomes easier by noting that $\eta_j^j = 1$. In terms of notation, the numerator in all proportions represent the net cost to invest into the target country from the perspective of the other investor, while the denominator is the sum of the net costs for both investors. When the cost of investing into a country increases, the ownership of the firm shifts toward the domestic capitalist. Such effect occurs for two reasons. First, an increase in η_i^j decreases the net returns to investment made by capitalist at i, hence a reduction in their investments. Second, an increase in the

[4]Is quite likely that the financial costs to investing abroad are functions of variables from the source as well as the recipient country.

interest rates reduces profits and thus gives less incentives to invest in the firm for all investors alike. This second channel is complemented by the subsequent proposition:

Proposition 4.4.2. *Increases in financial cost of investment into a country raises the ownership of domestic investors in the firm while reducing the foreign ownership.*

Increases in ownership are driven by a reduction in the total K that firms require in equilibrium. This reduction in capital demand is a consequence of higher rental rates of capital resulting from a higher η. One natural implication from this result is that, when the international financial market is more integrated as a result of low financial costs, domestic firms can better position themselves in terms of attracting foreign investors. This increase in foreign flow of investment can further reduce the interest rates and enhance the effects that we have previously seen in proposition 4.4.1.

We next turn our attention to some propositions on the Purchasing Power Parity (PPP), which in the case of our model, boils down to the ratio of price indexes P^F/P^H. For notational convenience, we denote such a ratio as Q which, in the steady state, depends on *all* exogenous parameters of the model. The range of possible values for Q is pin down by the trade costs as illustrated in proposition 4.4.3. We begin our analysis of PPP and the law of one price by first establishing this theoretical range of possible values of the steady state equilibrium value(s) of Q in the following proposition:

Proposition 4.4.3. *Let θ_H^F ,θ_F^H be strictly greater than one. Then Q is bounded below by $\frac{1}{\theta_F^H}$ and bounded above by θ_H^F.*

The theoretical bounds on Q in proposition 4.4.3 suggest that higher trade costs can lead to greater divergence and variability in the aggregate price ratio across the two countries. Intuitively, increasing the cost of importing into the foreign country increases the upper limit for the solution of Q. Given the preferences of the consumers (in the case of no home bias in taste), the price index at the foreign country will increase relative to that of H, therefore a greater Q is a possible solution to the model, all else equal. On the other hand, increasing θ_F^H makes foreign goods at the home country more expensive, which raises P^H, *ceteris paribus*. In this case, P^F is less likely to increase and this result translates in to a decrease in the lower bound of Q.

It is important to note that this property holds given the assumption that consumers do not prefer (in a home-bias sense) domestic goods over foreign ones (or vice-versa). The range of the solution for a general case with asymmetric countries is plotted in figure 4.1 while figure 4.2 presents the case for symmetric countries. This last figure suggests that cross-country price equality ($Q = 1$) can be achieved achieved when countries are completely symmetric. In stark contrast, a large portion of the literature points to trade costs as the cause for PPP inequality. We present an alternative proposition in which PPP is possible even in the presence of trade costs.

Proposition 4.4.4. *If H and F are symmetric with respect to $\tau < 1$, $\eta \geq 1$, and θ; then $Q = 1$ is the solution to the equilibrium problem. Furthermore, the result is independent of trade cost being equal or larger than one.*

Specifically, proposition 4.4.4 implies that even in a world economy with no perfect trade in goods, PPP equalization is possible if all other parameters are symmetric, including shipping cost. This result is not surprising since it implies that countries are mirrors of each other and thus there is no reason to expect any price differential.

Proposition 4.4.5. *If trade cost are symmetric and greater than one and the two countries are asymmetrical with respect to taxes and international finance cost then $Q \neq 1$.*

Proposition 4.4.5 implies that a world with perfect trade in goods does not lead to PPP equalization. This proposition along with 4.4.4 imply that disparities in PPP are not a sole consequence of trade costs. In short, perfect trade in goods is neither a necessary nor sufficient condition for equal PPP across countries. This result provides an implicit theoretical foundation for a long-established empirical result in the international micro-price literature that the law of one price is rarely obeyed.

Proposition 4.4.6. *An increase in the real exchange rate Q leads to an increase in the ratio between the home and the foreign gross profits.*

In the context of our model, one natural question remains to what extent do these implications on the relative price ratio Q affect profit in each firm, one of the key channel that affects capitalists' incomes. Proposition 4.4.6 implies that the profit of the home country must increase relative to that of the Foreign firm when there is an increase in the cross-country price ratio $Q = P^F/P^H$. Intuitively, when the prices in the foreign country become more expensive relative to home, the ratio of the nominal profit between the home and the foreign firms increase.

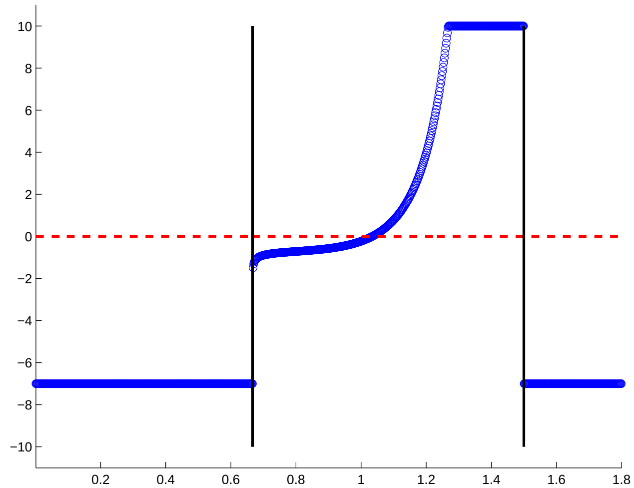


Figure 4.1.: Law of One Price: A General Case

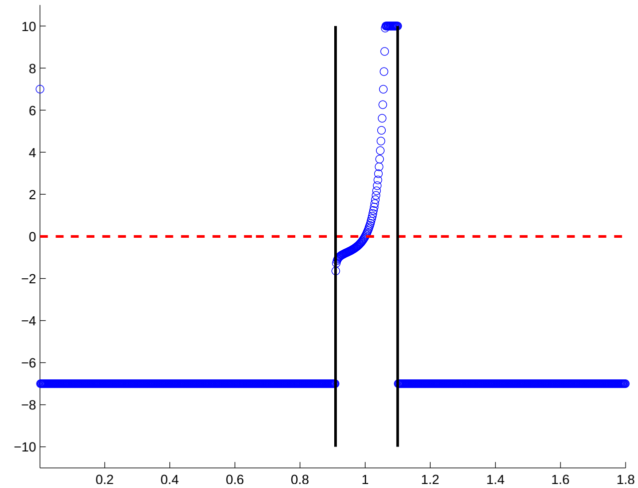


Figure 4.2.: Law of One Price Obeyed

Note: This figure plots the value for the cross-country relative price ratio Q in the steady state. Figure 4.1 uses the baseline calibration, the details of which are summarized in table 4.2. Figure 4.2 represents the case of complete symmetry; that is, the iceberg trade costs and the international finance costs to and from the two countries are identical. The horizontal axis denotes the values of the steady state terms of trade Q and the vertical axis denotes the absolute difference between left and right hand sides of the non-linear equation that we use to numerically calculate the steady state value of Q. The details of such an equation are provided in the appendix.

4.5. Main Results: Asymmetry in Consumption Responses to Corporate Tax Increases

We continue our discussion of the properties of the steady states with a focus on the interaction between an increase in corporate taxes and other macroeconomic aggregates. To do so, we first present our choice of reasonable parameters for the model with connection to some empirical data on corporate taxation in the U.S. and Germany in section 4.5.1. We next study the long-run implications of an asymmetric increase in corporate tax income in section 4.5.2. Turning to the short-run implications in section 4.5.3, we pay special attention to the properties of the impulse responses of aggregate variables, conditional on an asymmetric increase in the innovation to corporate income taxes.

4.5.1. Calibration

We select the target tax rate $\bar{\tau}^j$ for home and foreign countries such that they match the effective corporate tax rates from Germany (lowest effective corporate tax in our panel) and the US (high effective tax relative to Germany).[5] These countries are chosen for two reasons. First, they are large economies in the sense that a change in one country's policy will most likely influence the world

[5]Table 4.1 summarizes the effective tax rates for selected economies from 1990-2011.

economy. Second, having a low and a high tax country allows us to study the differences in impulse reactions under these two extremes. The literature does not provide any consensus for the values of η_F^H and η_H^F, thus for this particular exercise we chose a value of 1.2 for the baseline specification. In other words, it is ≈ 20% more costly to invest abroad than into one's own country.[6] Similarly, we consider symmetric ice-berg trade costs $\theta_F^H = \theta_H^F$ and set their value to 1.1; that is, for every unit of good sold abroad the producer must ship 1.1 units of the good.

Turning to the remaining parameters, we follow the existing literature. In particular, the discount rate is $\beta = 0.96$ for both countries; the share of capital in the production function α is 0.33; the depreciation rate is $\delta = 0.025$; the elasticity of substitution between home and foreign variety of one good σ is equal to 3, implying a mark-up $1/\varepsilon = 3/2$.[7] Table 4.2 summarizes the values for the baseline specification.

Upon obtaining the policy function using the method developed by Uhlig, we simulate the model for 2,000 periods and discard the first 200. We set the standard errors of the innovations to tax rate at 0.01; thus, we can interpret all the impulses as responses to one percent increase in the level of tax rates from home or foreign authority, depending on the figure. Since our focus is on the dynamic responses of effective tax rates, we pay special attention to studying the impulse responses of orthogonal innovations to tax rate from home and foreign countries. In particular, we first generate the dynamic responses of selected variables under the baseline specification as presented in table 4.2.

4.5.2. Asymmetry in Welfare in the Long Run: Some Steady State Implications

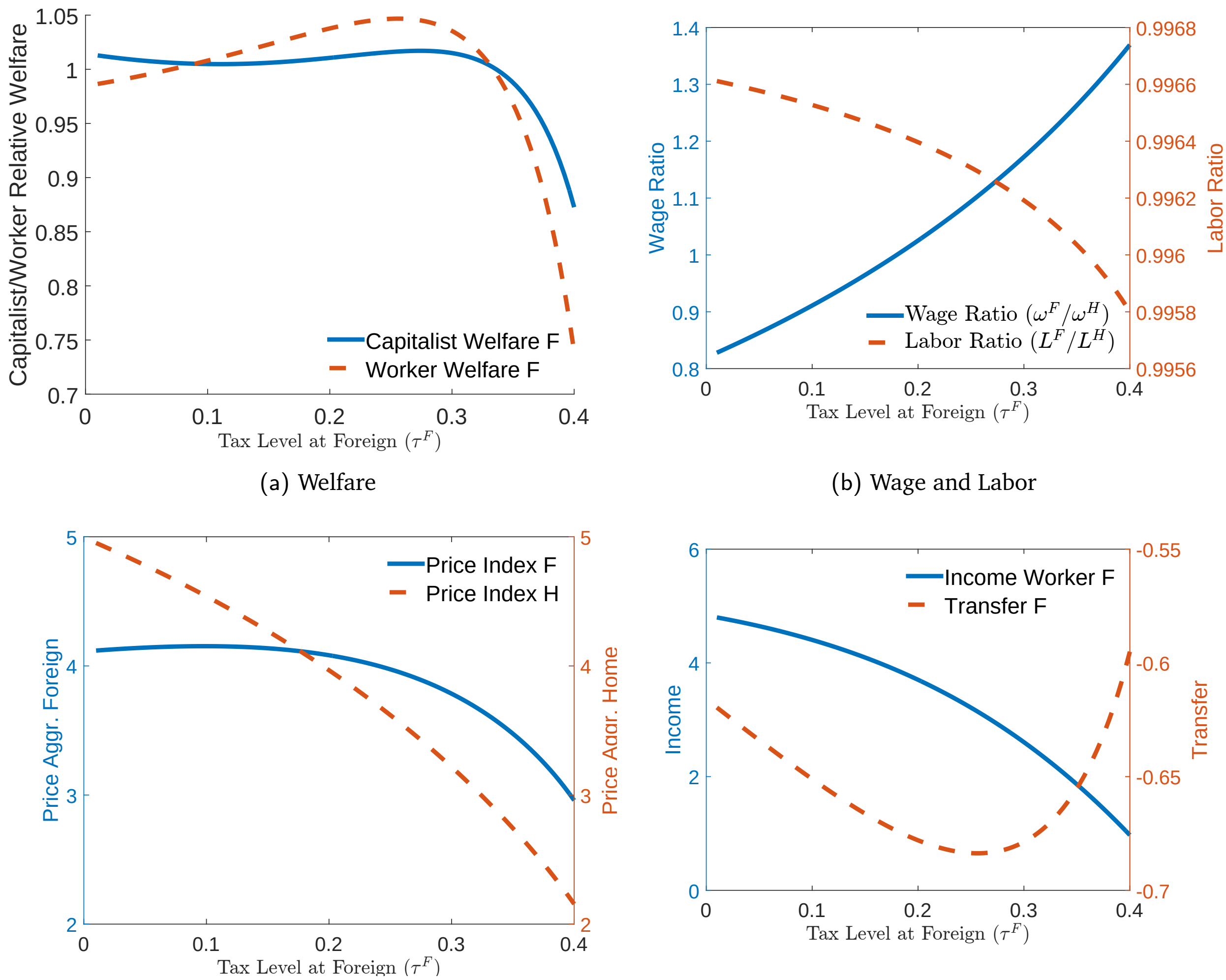
Figure 4.4a plots the level of welfare, defined as the post-transfer level of the aggregate consumption basket for workers and capitalists, under the baseline specification in table 4.2. One key take-away from the figure is that both capitalists and workers tend to suffer when there is an increase in corporate taxes. This result dovetails nicely with the recent empirical literature on the effects of corporate taxes (for example, Arulampalam et al. (2007), Felix (2007), and to a larger extent Desai et al. (2007)) in the sense that a large share of the welfare costs of corporate taxes falls on workers.

Another insight from figure 4.4a is that workers tend to experience a higher welfare loss than the

[6] As mentioned earlier, the "cost" could be monitoring cost and not necessarily just costs on the flow of investment. Here we do not consider a completely symmetric case because this case is trivial and has been well-studied in the literature and thus is not the focus of the study presented here.

[7] The value for the elasticity of substitution across goods ranges from 1.4 to 4.5 in the literature; see Nevo (2001) or Nakamura and Steinsson (2013) for details.

Figure 4.3.: Asymmetry in Welfare: Varying Corporate Taxes



(a) Welfare

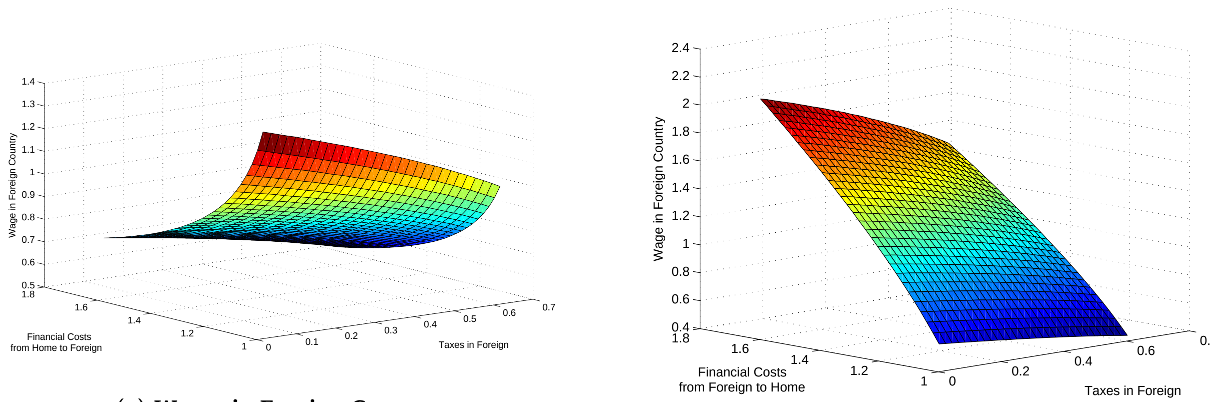
(b) Wage and Labor

(c) Price

(d) Income and Transfer

capitalists type. One key mechanism of this decrease in workers' welfare is illustrated in figure 4.4b, in which an increase in corporate taxes leads to an increase in the relative labor costs in the long run and hence, a decrease in employment. Because the only source of incomes for workers come from wages, such a decrease in labor tends to imply a decrease in workers income (as in figure 4.4d). It is helpful to note that while these workers do receive transfers from corporate tax revenues, the size of this transfer decreases with the level of corporate taxes. The overall effect, which tends to kick in when corporate tax is sufficiently high to offset transfers, is that workers are left with lower disposable income to spend on consumption and hence, a sharp decrease in the level of welfare (as seen in figure 4.4a).

Figure 4.5.: Wage: Sensitivity to Tax Level



(a) **Wages in Foreign Country**

Note: Here wage in the foreign country is a function of taxes in the foreign country and financial costs from the *home* to the *foreign* country.

(b) **Wages in Foreign Country**

Note: Here wage in the foreign country is a function of taxes in the foreign country and financial costs from the *foreign* to the *home* country.

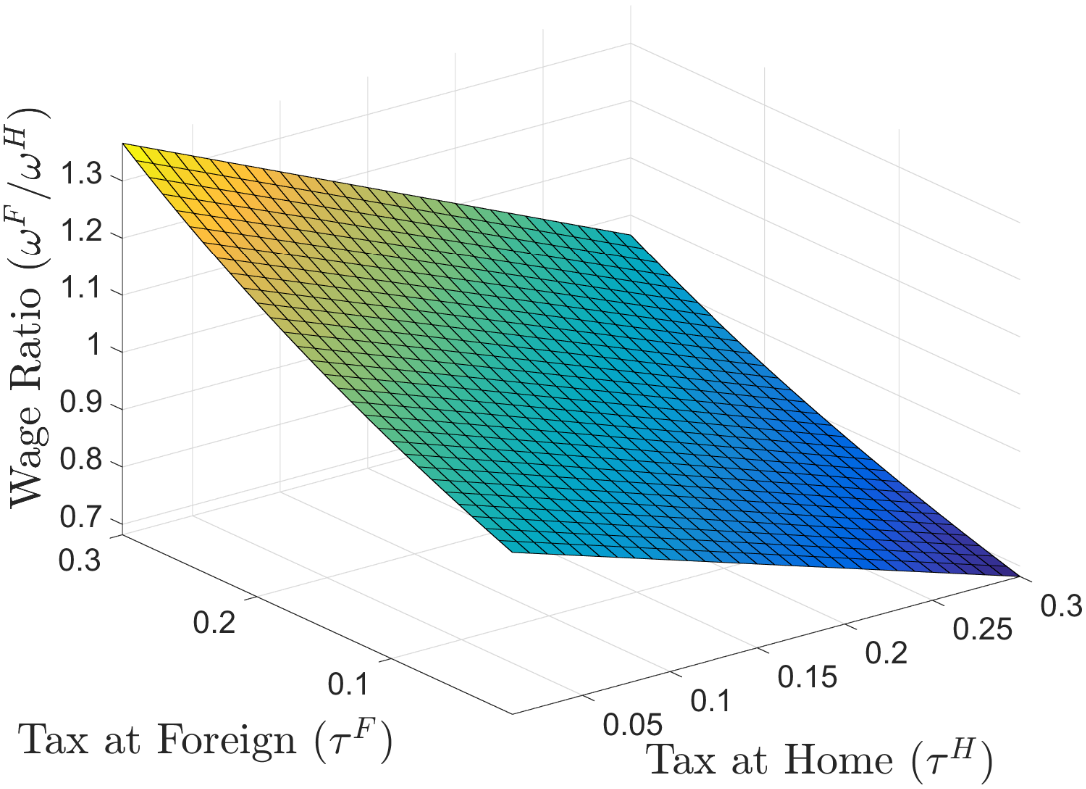
Turning to issues on the labor market, we note the following implication:

Remark 4.5.1. *The steady state ratio of wages ω^F/ω^H increases with τ^F and decreases with τ^H. Moreover, wages and international financial cost (into the country) posses a negative relationship in the long run.*

Remark 4.5.1 states that, in the long run, wages increase as a result of more financial integration; that is, when η_F^H is smaller. This result provides a theoretical basis for some empirical findings in the literature (see, for example, Chari et al. (2012)). In particular, under baseline case in which the two countries are more financially integrated, an orthogonal shock to both tax rates and exchange rate creates a more pronounced increase in wages than in the case of high financial costs. We illustrate the properties stated by remark 4.5.1 in figure 4.6a and figure 4.6b. In particular, we solve for wages in the foreign country as a function of taxes in the foreign country and (4.6a) financial costs from the home to the foreign country and (4.6b) financial costs from the foreign to the home country. Here we assume that financial costs of investing across domestic and foreign market are *asymmetric*. The intuition behind such an assumption is that investment costs tend to vary greatly across countries.

Figure 4.7 plots the ratio of equilibrium wages in foreign over home countries against the level of foreign and home tax rates, respectively. This ratio can be interpreted as the relative costs of labor between foreign and home countries. One key insight from the figure is that the relative costs of labor at the foreign country (ω^F/ω^H) is monotonically *increasing* in the level of corporate taxes in the

Figure 4.7.: Wage Ratio ω^F/ω^H: Sensitivity to Tax Level



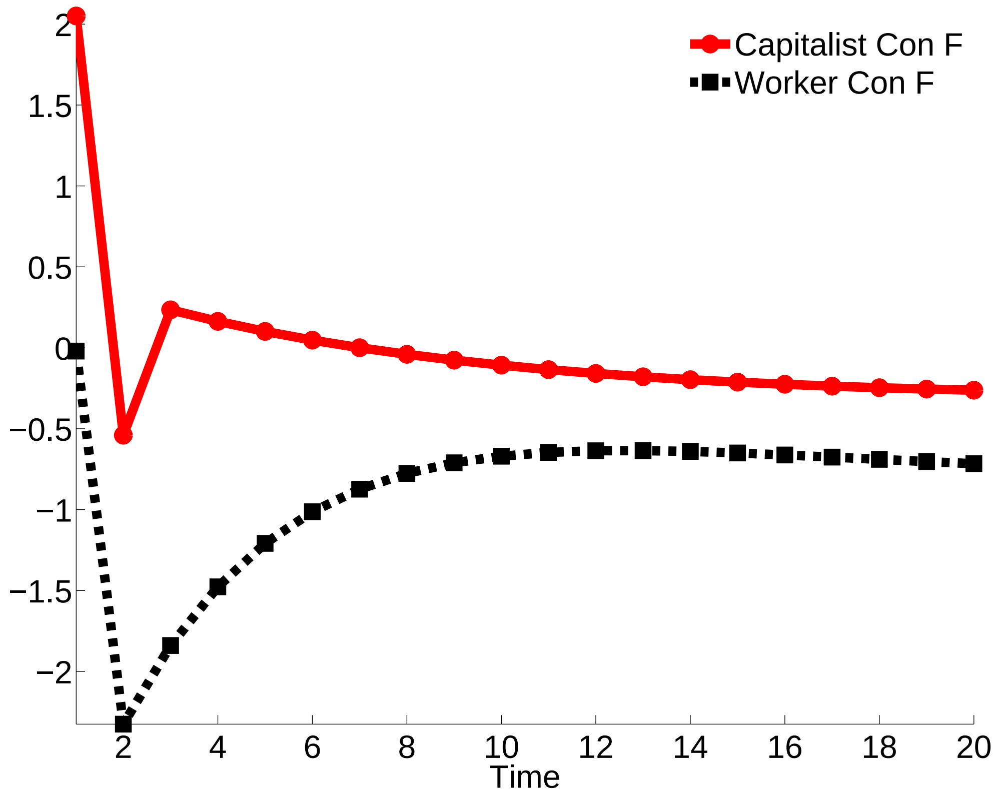
Note: This figure plots the wage in the foreign country over wage in the home country with respect to corporate taxes. Here we solve for the steady state equilibrium, conditional on the level of corporate tax at home and foreign countries. Other parameters are calibrated to the baseline specifications.

foreign country (τ^F) and is *decreasing* with respect to the level of tax at the home country (τ^H). In other words, an increase in tax level tends to make labor more costly, relative to the labor cost in the other country.

4.5.3. The Effects of Corporate Taxes in the Short Run: an Impulse Response Analysis

Figure 4.8 shows that when there is an increase in corporate tax, agents who hold assets, that is, capitalists, tend to be less worse off than agents who do not hold assets, that is, workers. Consumption by capitalists slightly decreases with a delay upon an increase in the innovation to corporate tax rates. This behavior is in stark contrast with the impulses responses of consumption by workers. Specifically, an one standard deviation increase in corporate tax rates (roughly 1 percent) leads to a 0.5 percent decrease in consumption for capitalists and this deviation quickly returns to its long-term

Figure 4.8.: Asymmetry in Consumption Responses



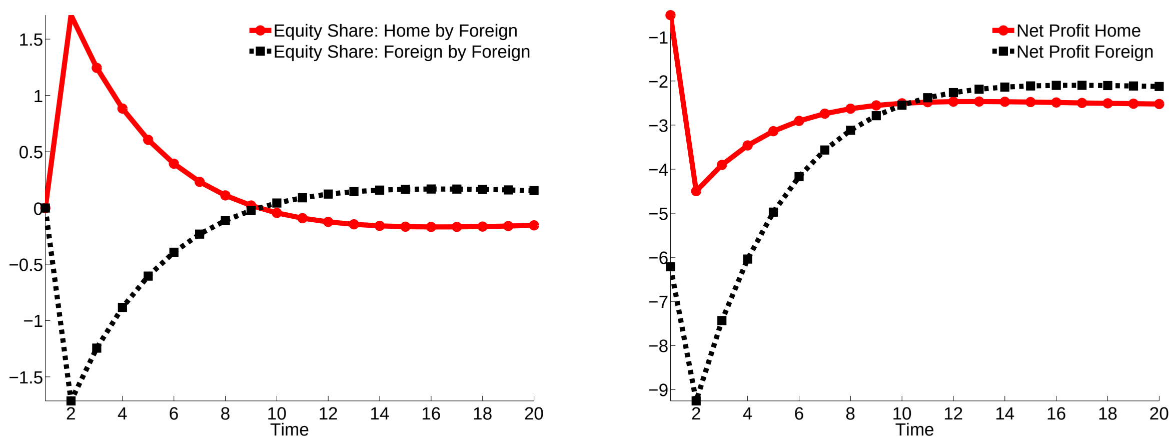
Note: Impulse responses of Workers and Capitalists consumption to innovations to foreign tax rates. Under baseline specification. The vertical axis denotes the percentage deviation from the steady states.

mean thereafter. In stark contrast, the consumption by workers decreases by more than two percent and the effects tends to last more than 10 quarters. One natural question thus arises in terms of what mechanism may have caused this dichotomy between the two types of workers.

The mechanism for the results in figure 4.8 is illustrated in figure 4.10a, which plots the impulse responses of equity share by foreign investor to home and foreign countries. One key take-away from this figure is that the foreign investors tend to decrease their ownership in their domestic market; that is, in the foreign firms. At the same time, they ramp up their ownership share in the home firms, thereby diverting their risk from the domestic market to the international market. This behavior is consistent with the mechanisms we have seen in the static analysis, in which capitalists tend to divert their ownerships share from the economy that has relatively high level of cross-border financial friction. Naturally, the magnitude of this shift depends on the relative level of corporate taxes across countries when such an increase in tax rate is initiated.

Figure 4.9.: Impulse Responses to Increase in Tax Rates

(a) **Asymmetry in Equity Shares Responses** (b) **Responses of After-tax Net Profit**

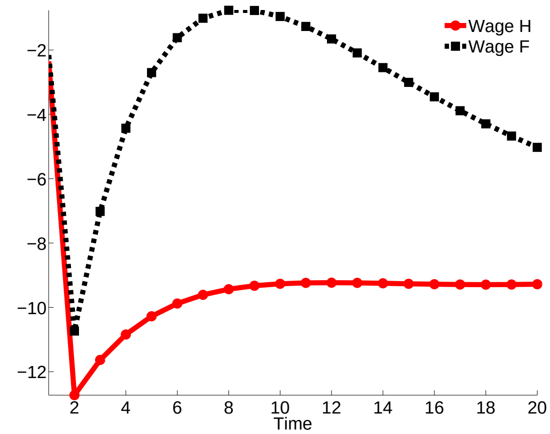


Note: [Left] Impulse responses of equity shares in the home and the foreign companies by foreign capitalists to an increase in foreign tax rates. Under baseline specification. The vertical axis denotes the percentage deviation from the steady states. [Right] Impulse responses of net profits to an increase in foreign tax rates. Under baseline specification. The vertical axis denotes the percentage deviation from the steady states.

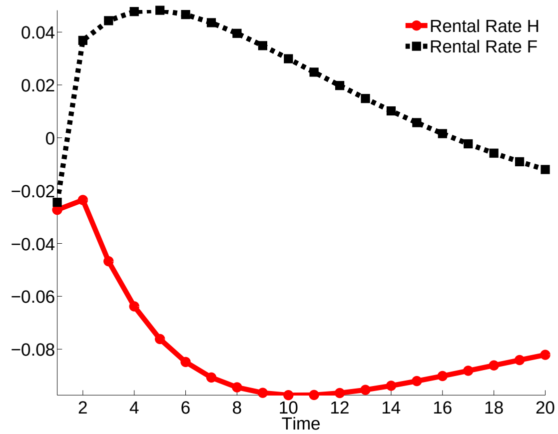
Another channel through which capitalists are affected by an increase in corporate taxes is through the reduction in after-tax profits. Figure 4.10b shows that net profit at home tends to suffer less from an increase in corporate taxes than net profit at the foreign firms does. These effects are more pronounced for country F due to $\tau^F > \tau^H$ at the baseline specification. One most striking feature from the impulse response functions is the co-movement across countries of rental rates and wages (figure 4.11). While this result contrasts the proposition that of the previous section in which steady state interest rates were found to be an increasing function of taxes at *source*, in the dynamic setting, the spillover effects are presented on the interest rates.

This spillover effect is an implication of the FOCs for the capitalists with respect to capital allocation. Investing abroad or domestically is discounted at the same stochastic rate λ_{t+1}/λ_t, which is a function of both tax rates and other exogenous variables. Hence a shock to τ^F changes this stochastic rate which changes the stochastic discount rate used. A more intuitive explanation goes as follows: investors realize an unexpected increase in corporate profit tax rate that effectively reduces their incomes; since both firms compete for capital in the world market, they pay higher interest since the capitalist now has fewer resources as well as lower expected returns. On the other hand, the movements of the aggregate capital stocks K^H and K^F are in line with the properties of the steady states in the sense

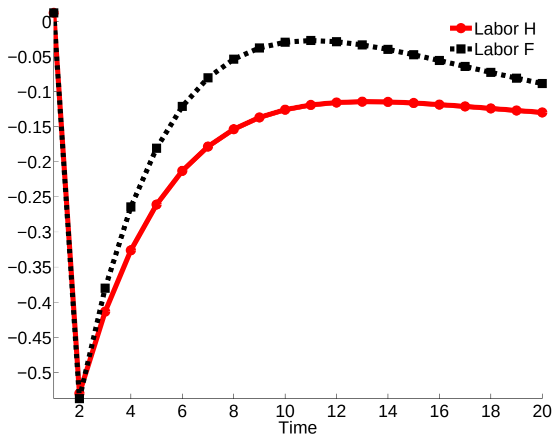
Figure 4.11.: Impulse Responses to Increase in Tax Rates



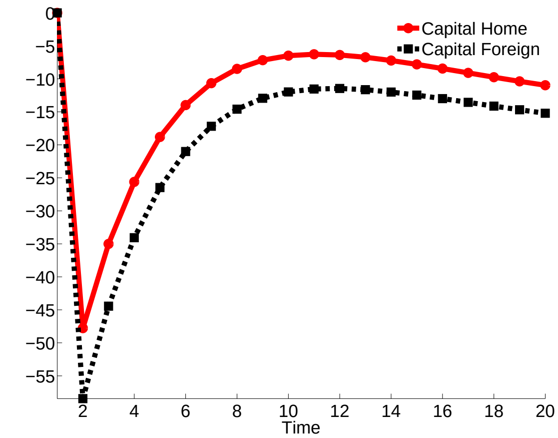
(a) Wage



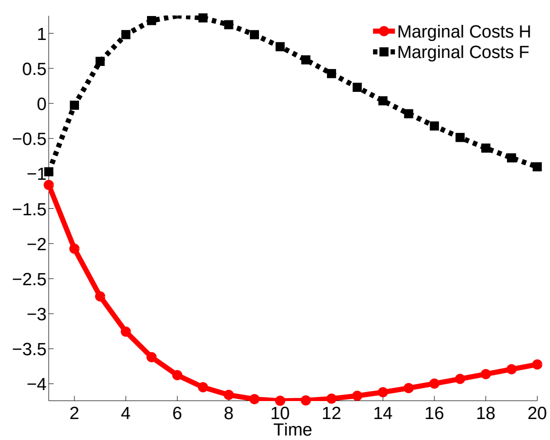
(b) Rental Rates



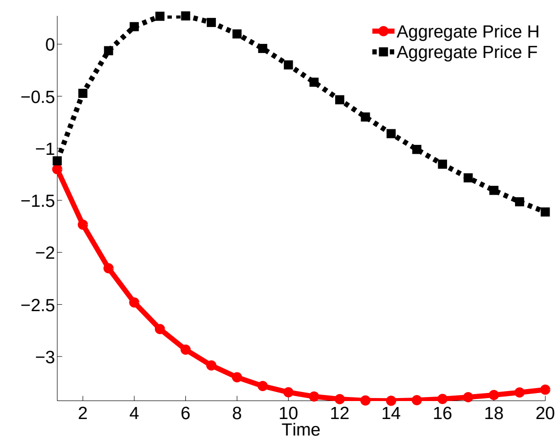
(c) Labor



(d) Capital



(e) Marginal Costs



(f) Price Level

that higher taxes reduced the level of capital stock in that country. Since our model abstracts from investment adjustment costs, the corresponding impulse responses tend to be less persistent.

The impulses responses of capital and labor in figure 4.12d and 4.12c confirm the convention that an increase in corporate tax rates can cause a significant decrease in employment and capital investment; a salient, yet undesirable, implication of which is a large decrease in real consumption in the country that initiates such a change in corporate tax, as evidenced in figure 4.8.

4.6. Conclusion

The recent Great Recession reminds us that financial integration can have a profound impact on trade patterns and outputs across countries. We re-evaluated this link, extending an otherwise standard two-country model to include cross-border financial frictions and corporate taxes. We found that the benefits of financial integration are not symmetric across different types of agents, which imply that financial integration may not necessarily lead to a preferable outcome for workers whose primary source of income is wages. This result is also deeply rooted in the debates whether financial openness is truly beneficial to developing countries, where most workers earn the majority of their incomes through salaried work.

Another contribution of the paper is to provide a theoretical foundation to support the empirical evidence that raising corporate taxes can result in distinctively different effects on individuals whose incomes depend solely on salaries and those who do not. In particular, we examined the properties of the model in both static and dynamic settings, showing that an orthogonalized increase in the innovation in corporate tax can result in a larger loss for capitalists in absolute value. However, these individuals who also claim ownership in firms tend to recover *far* quicker than individuals of the worker type.

One key feature of the recent Great Recession beginning in 2008 is that while investors lose money quickly, they also tend to recover much faster than do salaried workers. If an increase in corporate taxes can be considered equivalent to a shock in firm's profit, the theoretical results presented in our model can provide an alternative explanation to the varying degrees to which a shock to financial system can negatively affect individuals of different levels of dependence on salaries as their sole income. The message is thus that, while financial integration can help stimulate trade and financial flows across countries, such a perk does come at an unfortunate cost of potentially increasing the inequality between individuals who hold substantial capital and those who do not.

Table 4.1.: Summary Statistics for Statutory Tax Rate τ and Two Different EATRs.

	Means			Std. Deviation		Correlation	
	τ	τ^a_{nop}	τ^a_{gop}	τ^a_{nop}	τ^a_{gop}	$\rho_{n,g}$	$\rho_{s,g}$
Austria	32.06	17.41	9.31	2.51	1.36	0.97	0.19
Australia	33.05	32.99	21.01	5.19	3.60	0.97	-0.45
Belgium	37.52	24.92	12.92	6.19	2.56	0.98	-0.12
Canada	35.02	19.40	13.00	3.13	2.15	0.98	-0.21
Finland	28.64	22.09	12.42	8.68	4.43	0.66	0.09
France	35.57	26.84	14.71	5.66	2.94	0.95	0.33
Great Britain	30.73	21.24	14.01	3.53	2.53	0.92	-0.36
Germany	**45.70**	11.06	**6.74**	2.36	1.45	0.95	0.19
Italy	41.91	23.93	14.75	3.84	2.18	0.90	0.46
Japan	44.41	**37.74**	17.61	8.38	4.41	0.86	0.81
Netherlands	32.35	21.58	13.65	4.10	2.50	0.98	0.64
Norway	30.07	32.00	**22.10**	6.77	7.10	0.98	-0.39
Poland	28.65	30.92	16.04	16.86	6.68	0.96	0.90
Portugal	33.43	26.68	14.82	2.97	1.72	0.91	-0.15
Spain	33.98	24.80	14.33	9.35	4.96	0.99	0.30
Sweden	28.81	23.70	13.81	4.42	2.30	0.89	-0.49
Switzerland	30.15	21.02	10.25	4.39	1.82	0.89	-0.60
United States	39.36	25.71	**15.04**	3.01	2.19	0.97	-0.08
Overall (Panel)	34.55	24.73	14.36	8.72	5.02	0.84	-0.01

Note: Effective corporate tax rates computed under Mendoza et al. (1994) methodology. τ_{GOP} uses gross operating surplus while τ_{NOP} used net operating surplus. Data are restricted to 1990-2011 to ensure comparability. Data comes from the OECD National Accounting Tables.

Table 4.2.: Calibration under Baseline Specification

Parameters	Value	Notes	Description
α	0.33	Backus, Kydland, and Kehoe (1992)	Capital Share
β	0.98	Backus, Kydland, and Kehoe (1992)	Discount rates for annual data
δ	0.025	Backus, Kydland, and Kehoe (1992)	Depreciation rates for capitals
ϕ	3	Nakamura and Steisson (2007)	Labor dis-utility
θ_F^H	1.1	Our calibration	Ice-berg trade costs from Foreign to Home
θ_H^F	1.1	Our calibration	Ice-berg trade costs from Home to Foreign
η_F^H	1.2	Our calibration	Cross-country capital mark-ups from Foreign to Home
η_H^F	1.2	Our calibration	Cross-country capital mark-ups from Home to Foreign
$\bar{\tau}^H$	0.06	German effective tax	Steady-state corporate taxes rate at Home
$\bar{\tau}^F$	0.15	USA effective tax	Steady-state corporate taxes rate at Foreign
σ	3	Nakamura and Steisson (2007)	Elasticity of substitution between domestic and imported goods
ρ_H	0.7	Our calibration	Persistence of productivity process for Home
ρ_F	0.7	Our calibration	Persistence of productivity process for Foreign

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Appendices

Appendix A

Chapter 1

A.1. Data

The dataset covers 27 OECD countries across 40 years on a quarterly and monthly bases, seasonally adjusted. With the exception of stock market volatility, all data are from the *OECD Stats* database. The market data index comes from the Morgan Stanley Capital International (MSCI) standard country equity index that covers the majority of the country's stocks. The precise definition of the index is as follows:

> To construct a country index, every listed security in the market is identified. Securities are free float adjusted, classified in accordance with the Global Industry Classification Standard (GICS©), and screened by size, liquidity, and minimum free float.[1]

Market data are collected and reported daily. I obtain stock market volatility by taking the variance of the logarithm of the country specific market index over the course of one or three months. Interest rates are the short-term interest rate measure by the OECD. Taxes are the ratios of tax revenues over real outputs, which covers both corporate tax and personal income tax. Baker et al. (2013) construct a number of policy uncertainty indices using micro-data from a large number of newspaper articles. Two series are employed here: one for the US and one common index for the Euro zone. In terms of methodology, the index is constructed from three components, a description of which can be summarized as follows:[2]

> One component quantifies newspaper coverage of policy-related economic uncertainty. A second component reflects the number of federal tax code provisions set to expire in future years. The third component uses disagreement among economic forecasters as a proxy for uncertainty.

Here we calculate a measure of the market return by subtracting the log of MSCI index from the log of the same index in the succeeding period. The result that uses this measure of market returns is

[1] This definition is from http://www.msci.com/products/indices/tools/ and were accessed on April 12, 2012. All market data were collected using Thomson Reuters Datastream.

[2] The except was retrieved from http://www.policyuncertainty.com/methodology.html on Dec. 20, 2013. All corresponding data on the policy uncertainty index was also collected from the same website.

presented in Table 2.3.

A.2. Panel Unit Root Tests

To test for unit roots in heterogeneous panels, two procedures are often used: (1) Levin et al. (2002), LL hereafter and (2) Im et al. (2003), IPS hereafter. Under LL specification, the error terms are independent and the persistence parameter is the same across sections, which requires the presence of a strongly balanced panel. As in the literature, the tests are based on the following model:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \delta_i t + \sum_{p=1}^{P_i} \theta_i^{(p)} \Delta y_{i,t-p} + \varepsilon_{i,t} \tag{A.1}$$

where $y_{i,t}$ denotes the variable y observed for the i^{th} cross-sectional unit and time t unit.

Instead of assuming a common unit root process, the IPS procedure tests for individual unit roots processes, which means that the IPS test is more suitable for a less balanced dataset. Given the highly unbalanced nature of our dataset, this paper uses the IPS test; null hypothesis is that all panels contain unit roots, against the alternative hypothesis that some of the panel contains unit roots. By rejecting the hypothesis that all panels contain unit roots (as in table A.1), the test also satisfies the first requirement in the three-step panel Granger causality procedure in the next section.

Table A.1.: **IPS panel unit root test**

Variable	**Test statistics**
Stock Market Volatility	-21.2078
Output Growth (GDP)	-21.4656
Tax Level	-2.5173
Financial Accommodation	-3.9314
Interest Rate	-4.7784

Note: Significant values of the test statistics reject the null hypothesis. This specification does include time trend. Ho: All panels contain unit roots. Ha: Some panels are stationary.

A.3. Panel Causality Test

I test for potential causal relationship between market volatility and output growth using the specification by Hurlin and Venet (2001). Like the traditional Granger causality test, this procedure requires first and foremost the assumption that the variables under investigation are covariance-stationary. As a result, I adopt a three-step approach as follows:

- First, test for stationarity in the testing variables. Note that this is a requirement for the panel causality test to be valid.
- Second, obtain the individual Wald test for each panel by testing the hypothesis described in equation (6).
- Lastly, obtain the adjusted test statistics Z_{NL} for the *unbalanced* panel dataset that converges in distribution to the standard normal as shown in Hurlin (2005).

Upon verifying the stationarity of the growth and market volatility, the causality relationship between those two variables is tested by following Hurlin (2005), which assumes the following specification:

$$y_{i,t} = \alpha_i + \sum_{p=1}^{P} \gamma_i^{(p)} y_{i,t-k} + \sum_{p=1}^{P} \beta_i^{(p)} x_{i,t-k} + \varepsilon_{i,t} \tag{A.2}$$

where P denotes the number of maximum number of lags specified. The null hypothesis to be tested is:

$$H_o : \beta_i^{(1)} = \beta_i^{(2)} = \ldots = \beta_i^{(P)} = 0, \forall i = 1, \ldots, N \tag{A.3}$$

This *Homogenous Non-Causality* (HNC) hypothesis, allows for causality from x to y for some but no all individuals. This approach consists of two steps: (1) compute each individual i Wald statistics under the null, and (2) compute the average of the Wald statistics from the first step. Since the dataset is unbalanced, it is important to adjust the previously-obtained average statistics to account for this heterogeneity across the cross section dimension. Following Hurlin and Venet (2001), I adjust the average Wald statistics using the following formula[3]:

$$Z_{N,T} = \sqrt{N}\left(W - \frac{P}{N}\sum_{i=1}^{N}\frac{T_i - 2P - 1}{T_i - 2P - 3}\right) \times \left(\frac{2P}{N}\sum_{i=1}^{N}\frac{(T_i - 2P - 1)^2 \times (T_i - P - 3)}{(T_i - 2P - 3)^2 \times (T_i - 2P - 5)}\right) \tag{A.4}$$

where the adjusted $Z_{N,T}$ follows a standard normal distribution as shown in Hurlin (2005). A statistically significant value of $Z_{N,T}$ implies that we can reject the null hypothesis that there is no causality running in the direction of testing.

[3] One important technical requirement of the adjustment is that $T_i > 5 + 2P$, which are satisfied across the dataset.

A.4. Additional Tables and Figures

This section includes extra tables that have been previously mentioned in the main text of the paper. In particular, Tables 2.3 and A.2 present the regression results under dynamic panels and fixed effects least squares dummies regressions, respectively. In terms of notation, the prefix L. and L2. denote the first and second lag, respectively.

Table A.2.: **Regression Results using Monthly Data (Fixed Effects)**

Specifications		(1)	(2)	(3)	(4)	(5)
	Lag	**Output**	**Output**	**Output**	**Output**	**Output**
Output	1	-0.362***	-0.367***	-0.439***	-0.439***	-0.434***
		(-32.20)	(-32.70)	(-38.74)	(-38.73)	(-35.04)
	2	-0.0830***	-0.0870***	-0.147***	-0.147***	-0.148***
		(-7.38)	(-7.75)	(-12.98)	(-12.95)	(-11.96)
Rates	1	-0.00542	-0.00468	0.0000571	0.000198	-0.000758
		(-1.34)	(-1.16)	(0.01)	(0.05)	(-0.19)
	2	-0.00654	-0.00637	-0.00533	-0.00525	-0.00490
		(-1.62)	(-1.58)	(-1.40)	(-1.38)	(-1.21)
Recession		-0.529***	-0.467***	-0.274***	-0.271***	-0.283***
		(-9.58)	(-8.40)	(-5.03)	(-4.98)	(-4.43)
Volatility	1		-2.801**	-2.230	-1.630	-1.516
			(-3.17)	(-1.48)	(-1.07)	(-0.87)
	2		-5.389***	-10.80***	-10.50***	-10.81***
			(-6.08)	(-7.13)	(-6.92)	(-6.35)
Leading Indicator	1			0.411	0.355	0.497
				(1.13)	(0.96)	(1.24)
	2			1.647***	1.632***	1.438***
				(4.41)	(4.36)	(3.53)
Market Return	1				-3.745	-2.176
					(-0.55)	(-0.29)
	2				24.78***	25.11***
					(3.64)	(3.31)
Political Uncertainty	USA					-0.000251
						(-0.29)
Constant		0.407***	0.587***	0.320***	0.301***	0.361***
		(11.17)	(13.45)	(5.41)	(5.08)	(3.44)
Obs.		7,897	7,897	7,897	7,897	6,401

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Appendix B

Chapter 2

B.1. Solution Method

B.1.1. Defining the State-space

It is helpful to note that the true policy function for C_t must accompany a choice of R_t such that they satisfy (1) the inter-temporal condition, and (2) the zero lower bound condition; mathematically,

$$\begin{cases} R_t & = \frac{1}{\beta} E_t \left[(1+\pi_{t+1}) \frac{U_{C,t}}{U_{C,t+1}} \right] \\ R_t & = \max \{ \tilde{R}_t, 1 \} \\ \tilde{R}_t & = \bar{R} (R_{t-1})^{1-\rho_r} E_t \left[\left(\frac{Y_{t+1}}{\bar{Y}} \right)^{b_1} \left(\frac{1+\pi_{t+1}}{1+\bar{\pi}} \right)^{b_2} \right]^{\rho_r} \end{cases} \tag{B.1}$$

Combining the inter-temporal and the zero lower bound condition, noting the timing of the expectation and the fact that $\rho_R = 1$, yields

$$\frac{1}{\beta} \frac{C_{t-1}^{-\sigma}}{E_t \left[C_t^{-\sigma} / (1+\pi_t) \right]} = \max \left\{ 1, E_t \left[\left(\frac{Y_t}{\bar{Y}} \right)^{b_1} \left(\frac{1+\pi_t}{1+\bar{\pi}} \right)^{b_2} \right] \right\}$$

Therefore, the state-space of the problem is a four-dimension object that contains (1) last period individual real price $p_{t-1}(j)$, (2) idiosyncratic productivity level $A_t(j)$, (3) government spending g_t, (4) last period consumption level C_{t-1}. Note that we can write home consumption as a function of real exchange rate and foreign consumption via the global risk-sharing condition. We can thus replace the grids for last period consumptions with the grids for last period real exchange rate.

B.1.2. Defining the Aggregate Laws of Motions

Given the zero lower bound rule for nominal interest rates, intermediate firms still need information about this period real exchange rate X_t^R to decide whether to change its price. Following Krusell and Smith (1998), here I posit that intermediate firms forecast the state of the economy in the next period using a set of aggregate laws of motion $m^{'} = f(m; B, \xi)$, in which ξ denotes the set of state variables and B denotes the set of estimates for a selected numbers of forecasting moments.

It is helpful to recall that the firm can calculate next period real exchange rate X^R upon realizing the value of domestic good inflation $1+\pi_H$. Intermediate firms use the following statistics to forecast the distribution of ex-post decisions from other firms

$$\mu = \int_0^1 \log\left(\frac{p'_j}{p''_j}\right) dj, \tag{B.2}$$

in which p'_j and p''_j denote past pricing decisions for firm j.[1] Thus, the algorithm can be summarized as follows. I first make a guess of μ' and solve for the policy function given the state of the economy (Ω, μ').

I then discretize the state spaces and evolution process for government spending and idiosyncratic productivity using the discretization method by Tauchen (1986). I simulate the model by generating a random sample of stochastic shocks using a large number of firms and periods and obtain a new estimate of the distribution of idiosyncratic decision m''. I follow Maliar et al. (2010) in updating the next optimal guess μ for such a distribution using the following process:

$$\mu = \lambda^s \mu' + \left(1-\lambda^s\right)\mu'',$$

in which λ^s is a smoothing parameter.[2] I repeat the process until convergence of the distribution of idiosyncratic decision. To ensure optimal accuracy and to keep the state space tractable, I use an accelerating algorithm, combining value function iteration with cubic splines interpolation to obtain the policy function. In particular, I start with a moderate number of grids points of the state space and then perform the inner loop Bellman function iteration.

As the distance between the two consecutive iterations gets sufficiently small, I increase the number of grids points for real prices, while using the same number of grids points for productivity and other aggregate variables. Since there is no guarantee that the next period price given inflation exists on traditional discretized grids, we combine discretization with cubic splines interpolation. One natural advantage of this method is that we can always be sure that the price is on the grid. In terms of grids

[1] I find that this aggregate law of motion, similar to one used in Gagnon (2009), can characterize the distribution of individual firm's decision reasonably well. The algorithm using this law of motion is stable and requires a relatively small number of iterations to converge.

[2] I select this parameter to be 0.1. Changing the parameter only affects the speed of convergence, but not any quantitative and/or qualitative result of the model.

initialization, here we use about 300 points for the price grids, which is sufficiently fine to capture price changes of magnitude of at least 0.1%. This number is later doubled to 600 when convergence tolerance is sufficiently small. We provide further details of recursive formulation in section $B.2$.

B.2. A Summary of the Recursive Formulation

We proceed as follows:

1. Generate a set of random sample both idiosyncratic and aggregate shocks; in particular, we generate the matrices of random shocks for both government spending and productivity. Here we simulate a sample of $N = 10{,}000$ firms and $T = 1{,}000$, in which we discard the first 300 periods.
2. Initiate the set of grid points and initial value function. The grids for G and $A_t(j)$ depends on the standard deviations of government spending and productivity innovations. The grids for $\{p, X^R_{-1}\}$ is linearly spaced between 0.5 and 1.5 with 300 grid points on the price dimensions, fine enough to capture a change of 0.01% in real price level.
3. Initiate a set of aggregate law of motion for prices μ_t and back out the policy function via fixed point iterations
   a) Update the aggregate law of motion for intermediate firms $\mu_t = \int_0^1 \log\left(\frac{p(j)}{p_{-1}(j)}\right) dj$. This setup is similar to Maliar et al. (2010) in the sense that we can think of having a high G_t as a 'good aggregate shock' and having a low G_t as 'bad aggregate shock.'
   b) Given the ALM, we conduct a fixed point iteration to back out the policy function. Note that here the value function is a four dimensional object with p as the control variables and four state variables $\{p_{-1}, a, X^R_{-1}, g\}$

$$\begin{aligned} V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \max_{p(j)}\left\{\Pi^C_t\left(p(j), A(j), \bar{\Omega}_t\right) + E\left\{Q_{t,t+1}\right\} V'\left(p^{`}_{H,t}(j);\bar{\Omega}^{`}_t, A^{`}_t(j)\right)\right\} \\ V^K\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \Pi^K_t\left(p(j), A(j), \bar{\Omega}_t\right) + E\left\{Q_{t,t+1}\right\} V'\left(p^{`}_{H,t}(j);\bar{\Omega}^{`}_t, A^{`}_t(j)\right) \\ V\left(p_{H,t}(j);\bar{\Omega}_t, A_t(j)\right) &\equiv \max\left\{V^C\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right), V^K\left(p^c_{H,t}(j);\bar{\Omega}_t, A_t(j)\right)\right\}, \end{aligned}$$

   To keep computational costs manageable, we follow Gopinath et al. (2010) in terms of approximating $E\{Q_{t,t+1}\}$ as β. Comparing simulation results of the models using true

$E\{Q_{t,t+1}\}$ (with smaller grid sizes) and ones when approximating $E\{Q_{t,t+1}\}$ as β, we find that there is no discernible discrepancies under these two scenarios. It is important to note that because of the zero lower bound constraint, the real profit functions are not continuous when the firm decides to change or keep its price from last period. As noted by Coenen and Wieland (2003), while the projection method that uses Chebyshev polynomials often exhibits attractive quantitative accuracy when the value function is 'smooth,' it often exhibits worse performance than cubic splines interpolation. Because of this technical feature, here I use a combination of both discretization and cubic splines interpolation.

c) Given the policy function obtained in the previous step, we simulate the model using the shocks generated in step 1 and update the aggregate variable. In particular, we have price as a function of idiosyncratic and aggregate realizations over N firms and T periods. Given the realization of aggregate shock G_t and the current aggregate laws of motion $\mu = \int_0^1 \log\left(\frac{p(j)}{p_{-1}(j)}\right) dj$, we can calculate the aggregate demand at time t as follows

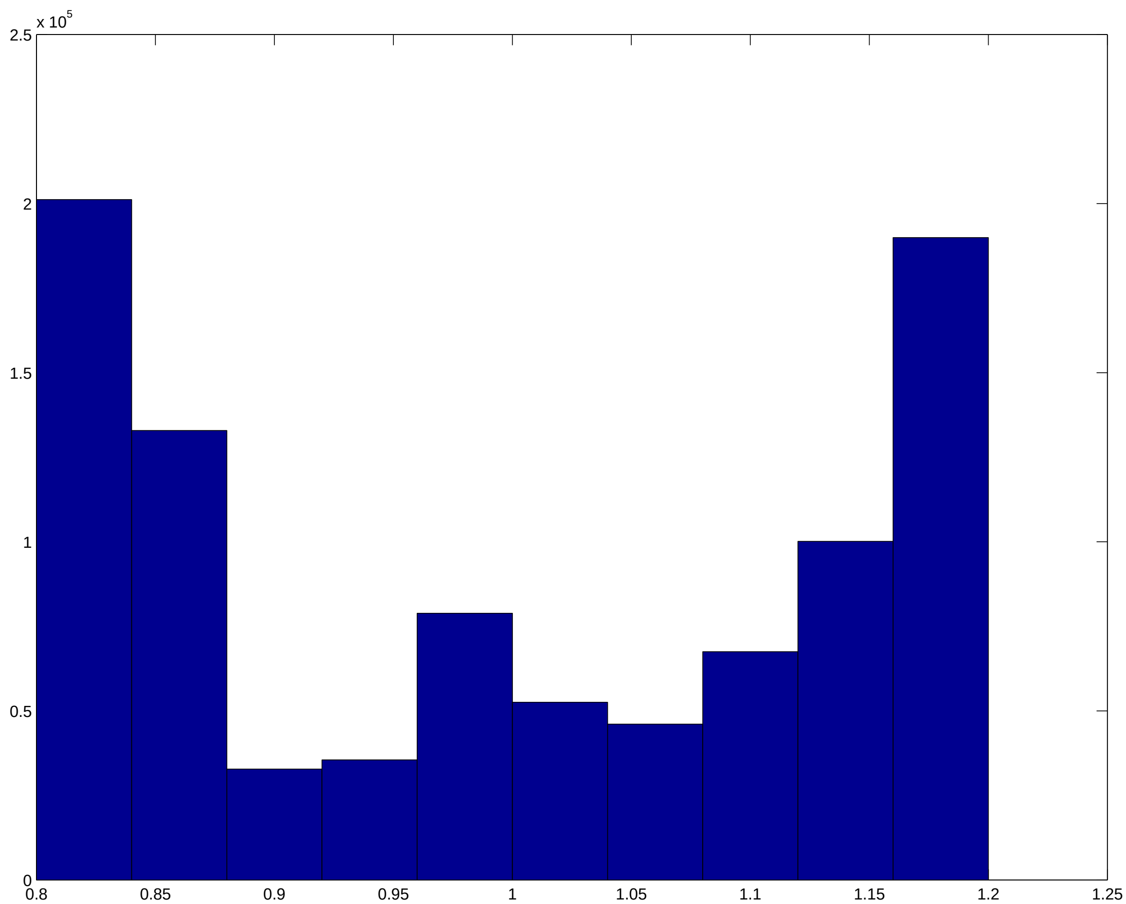
$$Y_t = G_t + C_t^* \left[(1-\alpha)\Xi \left(X_t^R\right)^{\frac{1}{\sigma}} + \alpha^* \left(X_t^R\right)^{\varepsilon} \right] \left((1-\alpha) + \alpha S_t^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}$$

in which X^R and $S(X^R)$ satisfies both the zero bound condition and the Euler equation for consumption.

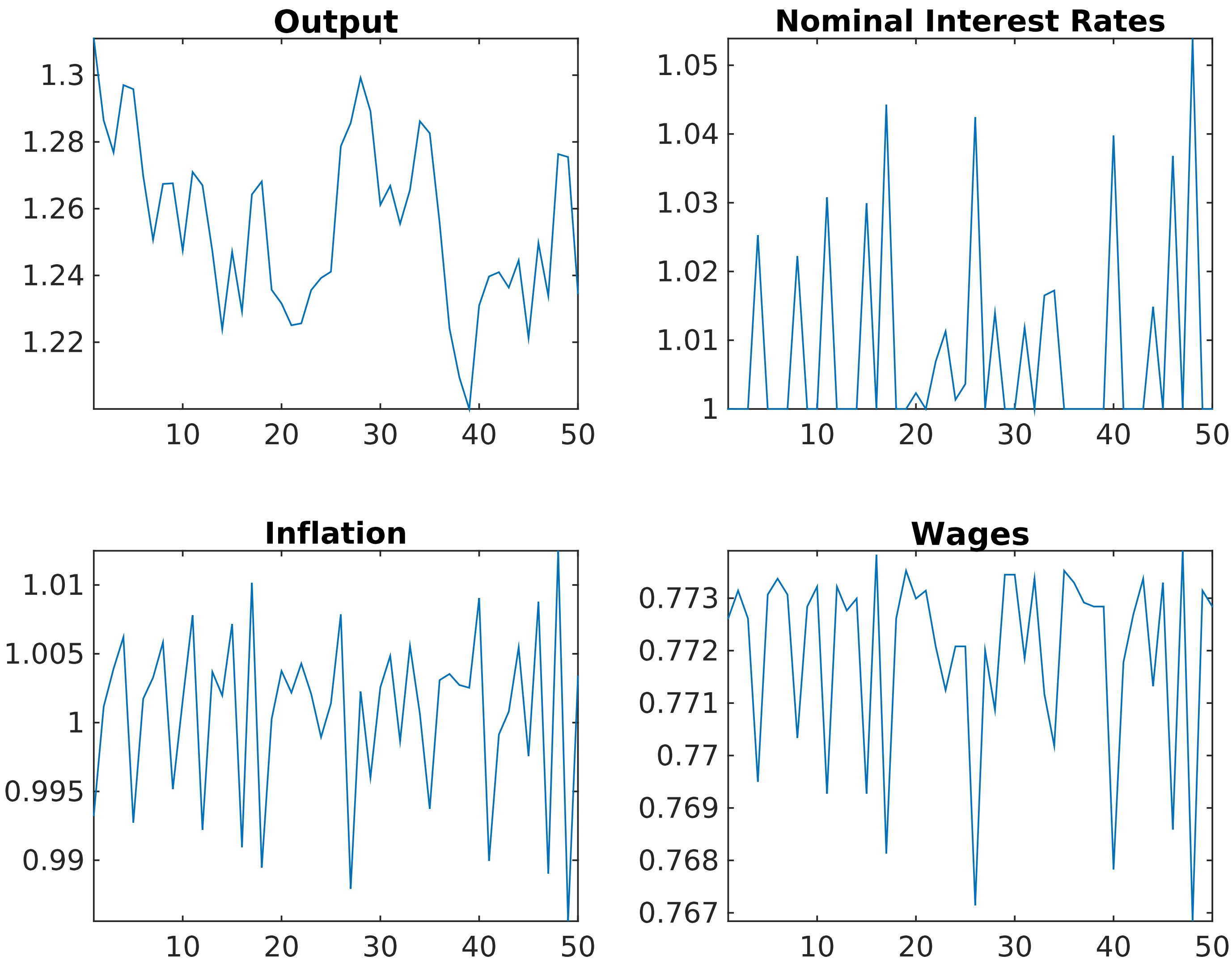
4. Given the updated aggregate variable, we obtain an update on the aggregate law of motions μ. Repeat until convergence of the aggregate laws of motion.

B.3. Additional Tables and Figures

Figure B.1.: Selection Effects of Firms' Idiosyncratic Responses



Note: This figure plots the distribution of individual firms' pricing decisions in the current period (the vertical axis), given the firm's real price last period (the horizontal axis). Here I simulate the model using N=10,000 firms and over T=400 periods, discarding the first 50 periods.



Note: This figure plots a typical simulated path for selected aggregate variables. We simulate the model for 250 periods with 10,000 firms, remove the first 50 periods, and plot the next 50 periods. It is helpful to note that here nominal interest rates are bounded below by the zero lower bound; this feature of the model is reflected in the simulated path for nominal interest rate in the sense that such an interest rate cannot go below zero.

Table B.1.: Locations

N	City	Δp	Goods	N	City	Δp	Goods
1	Akita	0.04	649	41	Miyazaki	0.04	649
2	Aomori	0.04	649	42	Moriguchi	0.06	573
3	Asahikawa	0.01	570	43	Morioka	0.04	649
4	Atsugi	0.01	570	44	Nagaika	0.01	570
5	Chiba	0.04	649	45	Nagana	0.02	538
6	Fuchu	0.04	649	46	Nagano	0.05	601
7	Fukui	0.04	649	47	Nagaoka	0.02	538
8	Fukuoka	0.04	649	48	Nagasaki	0.04	649
9	Fukushima	0.04	649	49	Nagoya	0.04	649
10	Fukuyama	0.00	570	50	Naha	0.02	648
11	Gifu	0.04	649	51	Nara	0.04	649
12	Hakodate	0.04	649	52	Niigata	0.04	649
13	Hamamatsu	0.04	649	53	Nishinomiya	0.04	649
14	Higashiosaka	0.04	649	54	Oita	0.02	535
15	Himeji	0.05	649	55	Okayama	0.04	649
16	Hirakata	0.01	570	56	Osaka	0.04	649
17	Hiroshima	0.04	649	57	Otsu	0.04	649
18	Itami	0.04	649	58	Qita	0.05	601
19	Kagoshima	0.04	648	59	Saga	0.04	649
20	Kamakura	0.01	538	60	Sakura	0.00	570
21	Kanazawa	0.04	649	61	Sapporo	0.04	649
22	Kasugai	0.04	649	62	Sasebo	0.04	649
23	Kawaguchi	0.04	649	63	Sendai	0.04	649
24	Kawasaki	0.04	649	64	Shizuoka	0.04	649
25	Kitakyushu	0.05	649	65	Tachikawa	0.00	570
26	Kobe	0.04	649	66	Takamatsu	0.04	649
27	Kochi	0.04	649	67	Tokorozawa	0.02	646
28	Kofu	0.04	649	68	Tokushima	0.04	649
29	Koriyama	0.04	649	69	Tottori	0.04	649
30	Kuarea of Tokyo	0.03	649	70	Toyama	0.04	649
31	Kumamoto	0.04	649	71	Toyohashi	0.08	337
32	Kure	0.05	649	72	Tsu	0.04	649
33	Kushiro	0.05	573	73	Ube	0.00	570
34	Kyoto	0.04	649	74	Urawa	0.04	649
35	Maebashi	0.04	649	75	Utsunomiya	0.04	649
36	Mastuyama	0.02	537	76	Wakayama	0.04	649
37	Matsue	0.04	649	77	Yamagata	0.04	649
38	Matsumoto	0.04	649	78	Yamaguchi	0.04	649
39	Matsuyama	0.05	601	79	Yokohama	0.04	649
40	Mito	0.04	649	80	Yokosuka	0.05	649

Appendix C

Chapter 3

C.1. Summary of Equations

C.1.1. For Workers

We consider the following utility function

$$\mathbb{E}\sum_{t=1}^{\infty}\beta^t\left[M_t^j + log(N_t)\right] \tag{C.1}$$

subject to

$$\sum_{i=1}^{N} p_i^j m_i^j + b_{w,t+1}^j = \omega_t^j L_t^j + (1+r_{b,t}^j)(b_{w,t}) + T_t^H \tag{C.2}$$

$$M_t^j = \left[\sum_{i=1}^{N}\left(m_i^j\right)^{\varepsilon}\right]^{1/\varepsilon} \tag{C.3}$$

$$1 = L_t + N_t \tag{C.4}$$

The set of variables for country $j = H, F$ for the worker type includes

1. Five (5) choice variables from the first orders condition; namely, $\{\lambda_w, m_H, m_F, b_w, L\}$.

$$\left[\sum_{i=1}^{N}\left(m_{i,t}^j\right)^{\varepsilon}\right]^{1/\varepsilon-1}\left(m_{i,t}^j\right)^{\varepsilon-1} = \lambda_{w,t}^j p_{i,t}^j \qquad \forall i = j \tag{C.5}$$

$$\left[\sum_{i=1}^{N}\left(m_{i,t}^j\right)^{\varepsilon}\right]^{1/\varepsilon-1}\left(m_{i,t}^j\right)^{\varepsilon-1} = \lambda_{w,t}^j p_{i,t}^j \qquad \forall i \neq j \tag{C.6}$$

$$\lambda_{w,t}^j \omega_t^j = N_t^{-1} \tag{C.7}$$

$$\lambda_{w,t+1}^j \beta(1+r_{b,t+1}^j) = \lambda_{w,t}^j \tag{C.8}$$

The budget constraint is

$$\sum_{i=1}^{N} p_i^j m_i^j + b_{w,t+1} = (1-\tau_{L,t})\omega_t^j L_t^j + (1+r_{b,t}^j)(b_{w,t}) + T_t^H \tag{C.9}$$

2. Two (2) auxiliary variables; namely, $\{M, X_w\}$.

$$M_t^j = \left[\sum_{i=1}^{N}\left(m_i^j\right)^{\varepsilon}\right]^{1/\varepsilon} \tag{C.10}$$

$$X_{w,t}^j = (1-\tau_L^H)\omega_t^j L_t^j + (1+r_{b,t}^j)b_t^j - b_{t+1}^j + T_t^H \tag{C.11}$$

C.1.2. For Capitalists

Utility:

$$\mathbb{E}\sum_{t=1}^{\infty}\beta^t\left[C_t^j\right] \tag{C.12}$$

such that

$$\sum_{i=1}^{C} p_{i,t}^j c_{i,t}^j + b_{t+1} + \sum_{i=1}^{C} I_{j,t}^i = \sum_{i=1}^{C} s_{j,t}^i (1-\tau_t^i)\pi_t^i + (1+r_{b,t}^j)b_t \tag{C.13}$$

$$s_j^i = \frac{k_{j,t}^i}{K_t^j} \qquad \forall i \neq j \tag{C.14}$$

$$K_t^j = \sum_{i=1}^{C} k_{i,t}^j \tag{C.15}$$

$$C_t^j = \left[\sum_{i=1}^{C}\left(c_i^j\right)^{\varepsilon}\right]^{1/\varepsilon} \tag{C.16}$$

Since cross-border capital investment requires additional costs, the capital evolution process can be written as follows:

$$\frac{1}{\eta_i^j} I_{i,t}^j = k_{i,t+1}^j - (1-\delta)k_{i,t}^j \tag{C.17}$$

Where the financial costs of holding capital overseas $\eta_j^i > 1$ if $i \neq j$ and identical to one when $i = j$. The set of variables for the capitalists include:

1. Six (6) choice variables; namely, $\{n_H, n_F, \lambda_c, k^H, k^F, b_c,\}$. It is helpful to note that since the conditions for workers imply the aggregate price index (which does not need to be in the system of equation), only one of the two first order conditions for capitalists and the CES aggregator for

capitalist consumption are sufficient.

$$\lambda^j_{c,t} p^j_{i,t} = \left[\sum_{i=1}^{C}\left(c^j_{i,t}\right)^{\varepsilon}\right]^{1/\varepsilon-1}\left(c^j_{i,t}\right)^{\varepsilon-1} \qquad \forall i=j \tag{C.18}$$

$$\lambda^j_{c,t} p^j_{i,t} = \left[\sum_{i=1}^{C}\left(c^j_{i,t}\right)^{\varepsilon}\right]^{1/\varepsilon-1}\left(c^j_{i,t}\right)^{\varepsilon-1} \qquad \forall i\neq j \tag{C.19}$$

$$\lambda^j_{c,t} = \beta\mathbb{E}\left[\lambda^j_{c,t+1}(1+r^j_{b,t+1})\right] \tag{C.20}$$

$$\forall i=H \quad 1 = \beta\mathbb{E}\left\{\frac{\lambda^j_{c,t+1}}{\lambda^j_{c,t}}\left[\frac{(1-s^i_{j,t+1})}{\eta^i_j K^i_{t+1}}(1-\tau^i_t)\pi^i_t+(1-\delta)\right]\right\} \tag{C.21}$$

$$\forall i=F \quad 1 = \beta\mathbb{E}\left\{\frac{\lambda^j_{c,t+1}}{\lambda^j_{c,t}}\left[\frac{(1-s^i_{j,t+1})}{\eta^i_j K^i_{t+1}}(1-\tau^i_t)\pi^i_t+(1-\delta)\right]\right\} \tag{C.22}$$

$$\sum_{i=1}^{C} p^j_{i,t}c^j_{i,t} + b_t + \sum_{i=1}^{C} I^i_{j,t} = \sum_{i=1}^{C} s^i_{j,t-1}(1-\tau^i_{t-1})\pi^i_{t-1} + (1+r^j_{b,t})b_{t-1} \tag{C.23}$$

2. Six (6) auxiliary variables; namely, $\{X_c, s^H, s^F, I_H, I_F, C\}$.

$$X_{c,t} = \sum_{i=1}^{C} p^j_{i,t} n^j_{i,t} \tag{C.24}$$

$$s^i_j = \frac{k^i_{j,t}}{K^i_t} \qquad \forall i\neq j \tag{C.25}$$

$$s^i_j = \frac{k^i_{j,t}}{K^i_t} \qquad \forall i=j \tag{C.26}$$

$$k^i_{j,t+1} = \frac{1}{\eta^i_j} I^i_{j,t} + (1-\delta)k^i_{j,t} \qquad \forall i\neq j \tag{C.27}$$

$$k^i_{j,t+1} = \frac{1}{\eta^i_j} I^i_{j,t} + (1-\delta)k^i_{j,t} \qquad \forall i=j \tag{C.28}$$

$$C^j_t = \left[\sum_{i=1}^{C}\left(n^j_i\right)^{\varepsilon}\right]^{1/\varepsilon} \tag{C.29}$$

$$\tag{C.30}$$

C.1.3. For Firms

The set of variables for firms include:

1. Three (3) choice variables; namely, $\{p_t^H, K_t^j, \omega_t^j\}$.

$$
\begin{aligned}
p_t^j &= \frac{1}{\varepsilon}\Omega_t^j && \text{(C.31)}\\
w_t^j &= \Omega_t^j A_t^j (1-\alpha)\left[\frac{K_t^j}{L_t^j}\right]^{\alpha} && \text{(C.32)}\\
r_t^j &= \Omega_t^j A_t^j \alpha \left[\frac{L_t^j}{K_t^j}\right]^{1-\alpha} && \text{(C.33)}
\end{aligned}
$$

2. Four (4) auxiliary variables; namely, $\{p_j^i, \Omega^j, \pi^j, Y^j\}$.

$$Y_t^j = A_t^j (K^H)^{\alpha}(L^H)^{1-\alpha} \tag{C.34}$$

$$p_{j,t}^i = \theta_{j,t}^i p_{j,t}^j \tag{C.35}$$

$$\pi_t^j = \frac{1}{\sigma-1}\Omega_t^j A_t^j \left(\frac{w_t^j}{r_t^j}\frac{\alpha}{1-\alpha}\right)^{\alpha} L_t^j \tag{C.36}$$

C.1.4. National Variables

The set of national variables include (5) variables; namely $\{P^j, B^j, w^j, r^j, r_b^j\}$.

$$B_t^j = b_{w,t}^j + b_{c,t}^j \tag{C.37}$$

$$K_t^j = \sum_{i=1}^{N} k_{i,t}^j \tag{C.38}$$

$$P_t^j = \left[\sum_{i=1}^{N}\left(p_i^j\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{C.39}$$

C.1.5. Government and Productivity Variables

Four (05) exogenous/government variables; that is, $\{A, T, G, \Delta G, \tau\}$

$$T_t^j = \tau_t^j \pi_t^j - p_j^j G_t^j \tag{C.40}$$

$$b_{w,t}^j + b_{c,t}^j = 0 \tag{C.41}$$

$$\log A_t^j = \rho_A \log A_{t-1}^j + u_t^j \tag{C.42}$$

$$\Delta \log G_t^j = \log G_t^j - \log G_{t-1}^j \tag{C.43}$$

$$\Delta \log G_t^j = \rho_g \Delta \log G_t^j + v_t^j \tag{C.44}$$

$$\tau_t^j = (1-\rho_\tau)\bar{\tau} + \rho_\tau \tau_t^j + v_t^j \tag{C.45}$$

C.2. Solutions to the Steady States

From the budget constraint for capitalists, it follows that:

$$s_H^H = \frac{\eta_F^H}{1+\eta_F^H} \qquad s_F^H = \frac{1}{1+\eta_F^H} \tag{C.46}$$

$$s_F^F = \frac{\eta_H^F}{1+\eta_H^F} \qquad s_H^F = \frac{1}{1+\eta_H^F} \tag{C.47}$$

From the market clearing condition for capital, it follows that

$$c = \frac{r^F}{r^H} \tag{C.48}$$

$$r^F = \frac{\left[1-\beta(1-\delta)\right]\left[1+\eta_H^F\right](\sigma-1)\alpha}{\beta(1-\tau^F)} \tag{C.49}$$

$$r^H = \frac{\left[1-\beta(1-\delta)\right]\left[1+\eta_F^H\right](\sigma-1)\alpha}{\beta(1-\tau^H)} \tag{C.50}$$

$$\frac{K^F}{K^H} = \left(\frac{1-\tau^F}{1-\tau^H}\right)\left(\frac{1+\eta_F^H}{1+\eta_H^F}\right)\left(\frac{\omega^F L^F}{\omega^H L^H}\right) \tag{C.51}$$

$$\pi^i = \left(\frac{1}{\sigma-1}\right)\left(\frac{\omega^i L^i}{1-\alpha}\right) \tag{C.52}$$

$$K^H = \left(\frac{1-\tau^H}{1+\eta_F^H}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{\omega^H L^H}{(\sigma-1)(1-\alpha)}\right) \tag{C.53}$$

$$K^F = \left(\frac{1-\tau^F}{1+\eta_H^F}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{\omega^F L^F}{(\sigma-1)(1-\alpha)}\right) \tag{C.54}$$

$$k_H^H = \left(\frac{1-\tau^H}{(1+\eta_F^H)^2}\right)\left(\frac{\beta\eta_F^H}{1-\beta(1-\delta)}\right)\left(\frac{\omega^H L^H}{(\sigma-1)(1-\alpha)}\right) \tag{C.55}$$

$$k_F^H = \left(\frac{1-\tau^H}{(1+\eta_F^H)^2}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{\omega^H L^H}{(\sigma-1)(1-\alpha)}\right) \tag{C.56}$$

$$k_F^F = \left(\frac{1-\tau^F}{(1+\eta_H^F)^2}\right)\left(\frac{\beta\eta_H^F}{1-\beta(1-\delta)}\right)\left(\frac{\omega^F L^F}{(\sigma-1)(1-\alpha)}\right) \tag{C.57}$$

$$k_H^F = \left(\frac{1-\tau^F}{(1+\eta_H^F)^2}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{\omega^F L^F}{(\sigma-1)(1-\alpha)}\right) \tag{C.58}$$

Given the formula for the price indices, it follows that

$$p_F^F = p_H^H\left(\frac{(\theta_H^F)^{1-\sigma}-Q^{1-\sigma}}{(Q\theta_F^H)^{1-\sigma}-1}\right)^{1/(1-\sigma)} \tag{C.59}$$

$$\frac{P^H}{p_H^H} = \left[\frac{\left(\theta_F^H\theta_H^F\right)^{1-\sigma}-1}{\left(Q\theta_F^H\right)^{1-\sigma}-1}\right]^{1/(1-\sigma)} \tag{C.60}$$

$$\frac{p_F^F}{P^F} = \frac{1}{Q}\left[\frac{\left(\theta_H^F\right)^{1-\sigma}-Q^{1-\sigma}}{\left(\theta_F^H\theta_H^F\right)^{1-\sigma}-1}\right]^{1/(1-\sigma)} \tag{C.61}$$

$$P^F = QP^H \tag{C.62}$$

Steady states capitalist consumption income, outputs and total consumption are:

$$X_c^H = a_1\omega^H L^H + a_2\omega^F L^F + r_b^H b_c^H \tag{C.63}$$

$$X_c^F = b_1\omega^F L^F + b_2\omega^H L^H + r_b^F b_c^F \tag{C.64}$$

$$Y^H = \left(\frac{L^H}{1-L^H}\right)\left(\frac{1}{\varepsilon(1-\alpha)}\right)\left[\frac{\left(\theta_F^H\theta_H^F\right)^{1-\sigma}-1}{\left(Q\theta_F^H\right)^{1-\sigma}-1}\right]^{1/(1-\sigma)} \tag{C.65}$$

$$Y^F = \left(\frac{L^F}{1-L^F}\right)\left(\frac{Q}{\varepsilon(1-\alpha)}\right)\left[\frac{\left(\theta_F^H\theta_H^F\right)^{1-\sigma}-1}{\left(\theta_H^F\right)^{1-\sigma}-Q^{1-\sigma}}\right]^{1/(1-\sigma)} \tag{C.66}$$

$$Y^H = \left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{P^H}{(1-L^H)(\sigma-1)(1-\alpha)}\right)\right]^\alpha A^H L^H \tag{C.67}$$

$$Y^F = \left[\left(\frac{1-\tau^F}{1+\eta_H^F}\right)\left(\frac{\beta}{1-\beta(1-\delta)}\right)\left(\frac{P^F}{(1-L^F)(\sigma-1)(1-\alpha)}\right)\right]^\alpha A^F L^F \tag{C.68}$$

in which,

$$a_1 = s_H^H\left(\frac{(1-\tau^H)}{(\sigma-1)(1-\alpha)}\right)\left(1-\frac{\delta\beta}{(1+\eta_F^H)(1-\beta(1-\delta))}\right) \tag{C.69}$$

$$a_2 = s_H^F\left(\frac{(1-\tau^F)}{(\sigma-1)(1-\alpha)}\right)\left(1-\frac{\eta_H^F\delta\beta}{(1+\eta_H^F)(1-\beta(1-\delta))}\right) \tag{C.70}$$

$$b_1 = s_F^F\left(\frac{(1-\tau^F)}{(\sigma-1)(1-\alpha)}\right)\left(1-\frac{\delta\beta}{(1+\eta_H^F)(1-\beta(1-\delta))}\right) \tag{C.71}$$

$$b_2 = s_F^H\left(\frac{(1-\tau^H)}{(\sigma-1)(1-\alpha)}\right)\left(1-\frac{\eta_F^H\delta\beta}{(1+\eta_F^H)(1-\beta(1-\delta))}\right) \tag{C.72}$$

Alternative equations for Y Use $Y = C + I + G + N_x$ and the first two equation for Y from above. Also define: $\tilde{\beta} = \frac{\beta}{1-\beta(1-\delta)}$ and $\tilde{\sigma} = (\sigma-1)(1-\alpha)$.

$$\left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\frac{\tilde{\beta}\omega^H}{\tilde{\sigma}}\right]^\alpha L^H = G^H + \delta k_H^H + \eta_H^F k_H^F + \frac{(p_H^H)^{-\sigma}}{(P^H)^{1-\sigma}}\left\{\omega^H L^H\left(1+\frac{\tau^H}{\tilde{\sigma}}+a_1\right) - p_H^H G^H \ldots\right.$$
$$\left. + a_2\omega^F L^F + \left(\frac{\theta_H^F}{Q}\right)^{1-\sigma}\left[\omega^F L^F\left(1+\frac{\tau^F}{\tilde{\sigma}}+b_1\right) - p_F^F G^F + b_2\omega^H L^H\right]\right\}$$

$$\left[\left(\frac{1-\tau^F}{1+\eta_H^F}\right)\frac{\tilde{\beta}\omega^F}{\tilde{\sigma}}\right]^\alpha L^F = G^F + \delta k_F^F + \eta_F^H k_F^H + \frac{(p_F^F)^{-\sigma}}{(P^F)^{1-\sigma}}\left\{\omega^F L^F\left(1+\frac{\tau^F}{\tilde{\sigma}}+b_1\right) - p_F^F G^F \ldots\right.$$
$$\left. + b_2\omega^H L^H + \left(\theta_F^H Q\right)^{1-\sigma}\left[\omega^H L^H\left(1+\frac{\tau^H}{\tilde{\sigma}}+a_1\right) - p_H^H G^H + a_2\omega^F L^F\right]\right\}$$

To find Q we employ two more equations. First we fix ω^H to be unity, which allows us to express the equilibrium labor of both countries by the following formulas:

$$1-L^H = \left(\frac{1}{\varepsilon(1-\alpha)}\right)\left[\frac{(\theta_F^H\theta_H^F)^{1-\sigma}-1}{(Q\theta_F^H)^{1-\sigma}-1}\right]^{\frac{1}{1-\sigma}}\left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\frac{\tilde{\beta}\omega^H}{(\sigma-1)(1-\alpha)}\right]^{-\alpha} \quad (C.73)$$

$$1-L^F = \left(\frac{Q}{\varepsilon(1-\alpha)}\right)\left[\frac{(\theta_F^H\theta_H^F)^{1-\sigma}-1}{(\theta_H^F)^{1-\sigma}-Q^{1-\sigma}}\right]^{\frac{1}{1-\sigma}}\left[\left(\frac{1-\tau^F}{1+\eta_H^F}\right)\frac{\tilde{\beta}\omega^F}{(\sigma-1)(1-\alpha)}\right]^{-\alpha} \quad (C.74)$$

The ratio of the previous two equations paired with the labor supply conditions yield the following relation between the foreign wage and the real exchange rate:

$$\left(\frac{\omega^F}{\omega^H}\right)^{1-\alpha} = \left[\frac{(1-\tau^F)(1+\eta_F^H)}{(1-\tau^H)(1+\eta_H^F)}\right]^{\alpha}\left[\frac{(Q\theta_F^H)^{1-\sigma}-1}{(\theta_H^F)^{1-\sigma}-Q^{1-\sigma}}\right]^{1/(\sigma-1)} \quad (C.75)$$

The above equation uses the relationship

$$\frac{1-L^F}{1-L^H} = Q\frac{\omega^H}{\omega^F} \quad (C.76)$$

We notice that

$$\frac{P^F}{P^H} = Q = \left[\frac{(\Omega^H)^{1-\sigma}+(\theta_F^H\Omega^F)^{1-\sigma}}{(\Omega^F)^{1-\sigma}+(\theta_H^F\Omega^H)^{1-\sigma}}\right]^{1/(1-\sigma)} \quad (C.77)$$

noting that the marginal cost can be written as a function of wages, labor, and Q.

Pinning down the unique steady state There are five equations that help us pin down the unique steady state. The ***first*** equation is the feasibility condition for home country; that is,

$$\left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\frac{\tilde{\beta}\omega^H}{\tilde{\sigma}}\right]^{\alpha} L^H = G^H + \delta k_H^H + \eta_H^F k_H^F + \frac{(p_H^H)^{-\sigma}}{(P^H)^{1-\sigma}}\left\{\omega^H L^H\left(1+\frac{\tau^H}{\tilde{\sigma}}+a_1\right) - p_H^H G^H \dots\right.$$
$$\left. + a_2\omega^F L^F + \left(\frac{\theta_H^F}{Q}\right)^{1-\sigma}\left[\omega^F L^F\left(1+\frac{\tau^F}{\tilde{\sigma}}+b_1\right) - p_F^F G^F + b_2\omega^H L^H\right]\right\}$$

The ***second*** equation governs the relative sizes of the two economies, in which case the feasibility condition for the foreign economy is implicitly implied. This equation writes

$$\frac{\left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\frac{\tilde{\beta}\omega^H}{\tilde{\sigma}}\right]^{\alpha} L^H}{\left[\left(\frac{1-\tau^F}{1+\eta_H^F}\right)\frac{\tilde{\beta}\omega^F}{\tilde{\sigma}}\right]^{\alpha} L^F} = \Xi$$

in which Ξ denotes the relative size of the home economy w.r.t. the foreign economy. The ***third*** and ***fourth*** equations use the conditions that labor market must be clear at each of the country because labor is immobile by assumption.

$$
\begin{aligned}
1 - L^H &= \left(\frac{1}{\varepsilon(1-\alpha)}\right)\left[\frac{(\theta_F^H \theta_H^F)^{1-\sigma} - 1}{(Q\theta_F^H)^{1-\sigma} - 1}\right]^{\frac{1}{1-\sigma}} \left[\left(\frac{1-\tau^H}{1+\eta_F^H}\right)\frac{\tilde{\beta}\omega^H}{(\sigma-1)(1-\alpha)}\right]^{-\alpha} \\
1 - L^F &= \left(\frac{Q}{\varepsilon(1-\alpha)}\right)\left[\frac{(\theta_F^H \theta_H^F)^{1-\sigma} - 1}{(\theta_H^F)^{1-\sigma} - Q^{1-\sigma}}\right]^{\frac{1}{1-\sigma}} \left[\left(\frac{1-\tau^F}{1+\eta_H^F}\right)\frac{\tilde{\beta}\omega^F}{(\sigma-1)(1-\alpha)}\right]^{-\alpha}
\end{aligned}
$$

The ***fifth*** equation comes from the definition of Q itself; that is, An alternative to the balance trade condition, we notice that

$$
\frac{P^F}{P^H} = Q = \left[\frac{(\Omega^H)^{1-\sigma} + (\theta_F^H \Omega^F)^{1-\sigma}}{(\Omega^F)^{1-\sigma} + (\theta_H^F \Omega^H)^{1-\sigma}}\right]^{1/(1-\sigma)} \tag{C.78}
$$

noting that the marginal cost can be written as a function of wages, labor, and Q. All in all, this system of ***five*** equations solves for the steady state values of $\{\omega^H, \omega^F, L^H, L^F, Q\}$.

C.3. Proof of Steady State Properties

Proof of 4.4.1

Proof. Let $j \neq i$. Taking the derivatives of the capital rental rate for home and foreign with respect to foreign corporate taxes yields

$$
\begin{aligned}
\frac{\partial r^j}{\partial \tau^j} &= \frac{\left[1-\beta(1-\delta)\right]\left[1+\eta_i^j\right](\sigma-1)\alpha}{\beta\left(1-\tau^j\right)^2} > 0 \\
\frac{\partial r^j}{\partial \eta_i^j} &= \frac{\left[1-\beta(1-\delta)\right](\sigma-1)\alpha}{\beta\left(1-\tau^j\right)} > 0
\end{aligned}
$$

The strict inequalities hold since we assume that $0 \leq \tau^j < 1$ for $j = H, F$ and η_j^i is strictly greater than one. The above equations prove the first two bullet points of the proposition. Given that both values are strictly greater than zero we take their ratio and get $(1+\eta_i^j)/(1+\tau^j)$ which is always greater than one. $\square$

Proof of 4.4.2

Proof.

$$\frac{\partial s_j^j}{\partial \eta_i^j} = -\frac{\partial s_i^j}{\partial \eta_i^j} = \frac{1}{(1+\eta_i^j)^2} > 0$$

□

Proof of proposition 4.4.3

Proof. The steady state solution appendix shows that the formula for foreign wage is

$$\left(\frac{\omega^F}{\omega^H}\right)^{1-\alpha} = \left[\frac{(1-\tau^F)(1+\eta_F^H)}{(1-\tau^H)(1+\eta_H^F)}\right]^{\alpha} \left[\frac{(Q\theta_F^H)^{1-\sigma}-1}{(\theta_H^F)^{1-\sigma}-Q^{1-\sigma}}\right]^{1/(\sigma-1)} \tag{C.79}$$

To ensure that $\omega^F \in \mathbb{R}^+$ we must restrict the second bracket of the above equation to be strictly positive. Such restriction is fulfill with two different cases:

- **Case 1:** $Q < \theta_H^F$ and $Q > 1/\theta_F^H$
- **Case 2:** $Q > \theta_H^F$ and $Q < 1/\theta_F^H$

However case 2 is not possible in our model. Given that $\theta \geq 1$, case 2 implies that Q is greater than one and also strictly less than one, a contradiction. Therefore, wages are positive real numbers only when $Q \in (1/\theta_F^H\,;\,\theta_H^F)$ □

Proof of proposition 4.4.4

Proof. Assume countries are symmetric in θ, η, τ then the ratio of marginal costs is:

$$\frac{\Omega^F}{\Omega^H} = \left(\frac{\omega^F}{\omega^H}\right)^{1-\alpha} = \left[\frac{(Q\theta)^{1-\sigma}-1}{(\theta)^{1-\sigma}-Q^{1-\sigma}}\right]^{1/(\sigma-1)}$$

Multiply and divide equation C.78 by Ω^H and use the above ratio to obtain:

$$Q = \frac{1}{Q^{1-\sigma}}$$

Thus, if $\sigma \neq 1$ then $Q = 1$ is the steady state solution to the ration of prices indexes. □

Proof of proposition 4.4.6

Proof. Take the ratio of home and foreign outputs combined with the formulas for profit to obtain:

$$\frac{Y^H}{Y^F} = \frac{\pi^H}{\pi^F}\left[\frac{\left(\theta_H^F\right)^{1-\sigma} - Q^{1-\sigma}}{\left(Q\theta_F^H\right)^{1-\sigma} - 1}\right]^{\frac{1}{1-\sigma}}$$

Since the ratio of outputs is constant then the total derivative of the expression above is given by:

$$0 = \frac{\partial\left(\pi^H/\pi^F\right)}{\partial Q}\left[\frac{\left(\theta_H^F\right)^{1-\sigma} - Q^{1-\sigma}}{\left(Q\theta_F^H\right)^{1-\sigma} - 1}\right]^{\frac{1}{1-\sigma}} dQ + \frac{(1-\sigma)\left(1-\left(\theta_H^F\theta_F^H\right)^{1-\sigma}\right)}{\left(\left(Q\theta_F^H\right)^{1-\sigma} - 1\right)^2}\frac{\pi^H}{\pi^F}\, dQ$$

Using the bounds of Q as well as $\theta \geq 1$ it can be easily shown that $\frac{(1-\sigma)\left(1-\left(\theta_H^F\theta_F^H\right)^{1-\sigma}\right)}{\left(\left(Q\theta_F^H\right)^{1-\sigma} - 1\right)^2} < 0$. Thus, if dQ is positive, i.e the prices in the foreign country become more expensive relative to those of the home country, then $\frac{\partial\left(\pi^H/\pi^F\right)}{\partial Q}$ must be positive in order to balance the equation; that is, the profit of the home country firm must increase relative to that of the foreign firm.

□