Effects of External and Fiscal Policy Shocks in Japan:
Evidence from an Open Economy DSGE Model
with Partial Exchange Rate Pass-through

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Abstract

This paper develops a small open economy New Keynesian model in which the exchange rate pass-through is neither 100% nor zero, and estimates the model using Japanese data by a Bayesian approach. Our goal is to evaluate importance of external shocks (such as changes in export demand and import prices) and domestic fiscal and monetary policies in Japanese business cycles. We find that external shocks are important for GDP, while domestic policies are not. In particular, despite that we incorporate several features into the model that could potentially make fiscal policy quite effective, our estimates show that its effects are quite limited.
1 Introduction

This paper proposes a way to evaluate macroeconomic importance of external shocks and domestic fiscal as well as monetary policy shocks in business cycles. The distinguishing characteristic of our approach is that we build a relatively small scale open economy New Keynesian model in which nominal exchange rate pass-through is allowed to be “partial”: that is, the degree of pass-through does not have to be either 100% or zero but can potentially take an intermediate value, on both export and import sides. The pass-through rates are determined by a set of parameters. By estimating this structural model directly from data using a Bayesian approach, we obtain estimates for those parameters. By doing so, we gain insights on how pass-through is affecting responses of macroeconomic variables to not only external disturbances such as changes in import prices, but also to internal shocks such as policy changes and productivity increases in the exporting sector.

We apply our approach to the Japanese data. Despite the wide variety of trade partners, use of the US dollars is prevalent in the country’s trade. On the other hand, the Japanese yen also plays a non-negligible role. In Table 1, the shares of major currencies in trade contracting on both the export and the import sides of Japan’s trade as of December 2008 are reported. The numbers are directly taken from the Bank of Japan’s “Component Ratio by Contract Currency in the EPI and IPI”. The shares of the US dollars are about 55% and 70%, respectively, for exports from and imports into Japan. The corresponding numbers for the Japanese yen are about 30% and 25%.

Table 1: Shares of major currencies used in trade contracts in Japan (December 2008)

<table>
<thead>
<tr>
<th></th>
<th>US dollars</th>
<th>Euro</th>
<th>Yen</th>
</tr>
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<tbody>
<tr>
<td>Exports from Japan</td>
<td>54.7</td>
<td>12.5</td>
<td>30.3</td>
</tr>
<tr>
<td>Imports into Japan</td>
<td>70.4</td>
<td>3.0</td>
<td>24.6</td>
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Data source: “Component Ratio by Contract Currency in the EPI and IPI”, Bank of Japan. All numbers are in percentages.

If we can assume that the actual pricing patterns in international trade are correlated with the above patterns of contracting currencies, we expect the exchange rate
pass-through on both the export and the import sides to be fairly incomplete, but less than negligible. Our methodology seems to be most suitable for analyzing such a situation. An additional reason for choosing Japan is that data is available for reasonably long periods, and there has not been any drastic change in the country’s exchange rate regime since the mid 1970s. It should however be noted that there is nothing country-specific with our methodology, and analyses similar to the one conducted here for Japan can be carried out for other countries as well, provided that sufficient amount of data exists.

Our estimation is parsimonious for a study of this kind and involves just eight variables: the exchange rate, export prices, import prices, exports, government expenditure, domestic inflation, the interest rate and GDP. Eight types of structural disturbances are recovered: shocks to risk premium in the foreign exchange market, foreign price shocks, productivity shocks that are common to the overall production sector, shocks to the relative productivity between tradable and non-tradable goods sectors, external demand shocks to the country’s exports, preference shocks, fiscal policy shocks, and monetary policy shocks. We find that, in response to a risk premium shock (which can be considered as something close to an “autonomous exchange rate shock” in a VAR analysis), the yen depreciates by 3.6% and, at the same time, export prices and import prices increase by about 2.5% and 2.0%, respectively. Under complete pass-through, the corresponding numbers would be 0% and 3.6%. Our analysis thus confirms incompleteness of pass-through on both sides of trade for Japan. A major advantage of estimating the degrees of pass-through as a part of a bigger exercise of estimating a fully specified DSGE model is that it allows us to draw meaningful conclusions about the implications of the pass-through rates on the effects of other types of economic disturbances, most notably policy shocks.

Among existing work, a paper that is most closely related to ours is Adolfson, Laséen, Lindé, and Villani (2007). Their approach is similar to ours in that they estimate a small open economy DSGE model which features incomplete exchange rate pass-through. They apply their methodology to the Euro area. Our model differs from theirs in that we introduce non-tradable goods producing sector into the model. It is our belief that, in any advanced economy, presence of a large non-tradables sector cannot be ignored when discussing the effects of exchange rate fluctuations and external shocks. In
Adolfson, Laséen, Lindé, and Villani (2007), there is a single domestic production sector whose products are sold both domestically and abroad. There are “exporters” who buy domestically produced goods and sell them to foreigners: their pricing behaviors are subject to Calvo type restriction. They also introduce “importers” who buy goods from abroad (they are imperfect substitutes with domestically produced goods) who also exhibit Calvo type pricing behaviors. As will be clear later, our formulation of the import sector is close to theirs but that of pricing of tradable goods by domestic firms is more elaborate, and allows a mixture of producer currency pricing and local currency pricing behaviors. On the other hand, those authors build a medium scale model which includes investment and their estimation involves as many as fifteen variables. Our model is far more parsimonious and the goal of the analysis is a more modest one.

The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 summarizes our model. Section 4 briefly introduces our empirical methodology, and section 5 explains our data set. We present our empirical results in section 6, and, in section 7, perform some counterfactual experiments to further investigate the implications of our estimates. Section 8 concludes.

2 Overview of Literature

In the recent literature on New Keynesian macroeconomic models, nominal price stickiness plays a crucial role. In a closed economy model, it is fairly clear what is meant by this phrase: it is stickiness in prices denominated in that country’s currency unit. When extending this framework to an open economy setting, however, a researcher must face a question: in which country’s currency unit are prices sticky? Obstfeld and Rogoff (1995, 1996), which are widely considered to be the first attempt to build a so-called New Open Economy Macroeconomics model, it was assumed that prices are preset in the units of the currency of the exporter’s country: an assumption now known as Producer Currency Pricing (PCP). Using a two country model with this setting, they show that a monetary expansion of one country is always beneficial (in the sense of welfare) to the other country. Betts and Devereux (2000) utilize a similar framework but make a very different assumption about price setting: in their model, prices are preset in
the units of the currency of the importer’s country. This assumption is known as \textit{Local Currency Pricing (LCP)}. They show that the different assumptions about price setting leads to very different welfare conclusions. Expansionary monetary policy is a beggar-thy-neighbor policy in the Betts-Devereux model, while it raises welfare in both the home and foreign countries in the Obstfeld-Rogoff model. There is an increasing attention on the third type of price setting specification: \textit{Vehicle Currency Pricing} (refer to Goldberg and Tille (2008)). It is known that, in many instances, trade between two non-US countries involves use of U.S. dollars as invoicing currencies. It is our belief that, in a serious empirical attempt to estimate an open economy model with price stickiness, we have to allow for a possibility of an intermediate case. As we have already discussed in the introduction, in Japan, for example, contracting currencies are neither completely domestic nor foreign. In this paper, we construct a small open economy model which is flexible enough to allow for the possibility that prices of exports are partially sticky in the units of the home currency and partially sticky in the units of the foreign currency\textsuperscript{5}.

There have been a few studies which have introduced local currency pricing type features into fully fledged dynamic open economy models. Most of them follow Monacelli (2005) and introduce Calvo (1983) type importers. They buy goods that are produced domestically and sell them to foreign countries, but face Calvo type pricing frictions: they can reset their prices optimally only occasionally. For example, Smets and Wouters (2002) incorporate the monopolistically competitive importers into a relatively large scale open economy model. Lubik and Schorfheide (2005) is one of earlier attempts to estimate an open economy New Keynesian model via a Bayesian method: they incorporate monopolistically competitive importers in their otherwise relatively small scale DSGE model. Adolfson, Laséen, Lindé, and Villani (2007) extend the large scale closed economy model of Christiano, Eichenbaum and Evans (2005) into a small open economy setting and estimate the model via a Bayesian estimation method. Erceg, Guerrieri, and Gust (2006) explains the Federal Reserve’s open economy model called SIGMA: in this model, firms are supposed to price their exports in foreign

\textsuperscript{5} Note that, in a small open economy model, as well as in a two country model, it is not possible to distinguish local currency pricing from vehicle currency pricing, as there is only a single foreign entity called the “rest of the world”.

currency units, and face different Calvo-probability of resetting prices between the home market and the foreign market.

Our concern is that, except for Erceg, Guerrieri, and Gust (2006), studies listed above introduce, inadvertently, dual stickiness into export prices. That is, when producers sell their goods in the home market, they can change prices only infrequently: this is price stickiness in home currency units. On top of that, in the case of exports, they are subject to additional price stickiness when importers buy those goods and sell them in their own countries: this is price stickiness in foreign (from the viewpoint of producers) currency units. On the other hand, our model is flexible enough to allow for the possibility that prices of goods that are exported are actually less sticky.

Exchange rate pass-through has also been an important research subject in empirical studies. Campa and Goldberg (2005) study a data set consisting of twenty three OECD countries extensively and find evidence in favor of partial pass-through. That is, neither complete producer currency pricing nor local currency pricing is the whole story. Parsons and Sato (2006, 2008) study pass-through on Japanese exports at highly disaggregated levels of products. Ito and Sato (2008) employ a VAR methodology to study pass-through in East and Southeast Asia in the post Asian crisis period. This paper complements this literature by proposing a model based estimation approach to the issue of pass-through.

This paper is also a part of our ongoing project that is aimed at uncovering the effects of monetary and fiscal policies in the environment of partial pass-through. Shioji, Vu and Takeuchi (2007a) develop a simple model of partial pass-through. They also perform VAR analyses of pass-through using Japanese aggregate data. Shioji, Vu and Takeuchi (2007b, 2008) utilize the framework developed in the above paper to study the effects of fiscal policy by calibration. In a related study, Shioji (2006) develops a three country model in which prices of traded goods are preset in units of certain weighted averages of the currencies of those three countries. He assumes that one of the countries employs a basket currency peg, and searches for the currency weights in the basket that most stabilize that country’s current account.

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6 In their model, prices of goods that are exported are sticky in local currency units only.
3 Model

We consider a small open economy called “home” country, denoted by H. Prices and the interest rate set in “foreign” country, as well as the demand of “foreign” country for “home” tradable goods are given to the home country.

3-1 Basics

Goods types

There are three types of goods in the model: Home tradable goods (H goods), Foreign tradable goods (F goods), and Non-tradable goods (that are produced at home, N goods). Households (as well as the government) buy all three types of goods. On the producer side, there are two types of firms: H firms, that produce H goods, and N firms, that are specialized in the production of N goods.

Household types

There are two types of households, called “optimizing households” and “rule-of-thumb households”. The former type solves an intertemporal optimization problem and determines its consumption in each period optimally. The latter type simply spends all of its income on consumption in each period, though the goods composition of total consumption expenditure is chosen optimally. The presence of rule-of-thumb households is necessary for a New Keynesian type model to have any hope of obtaining large effects of fiscal policy on output (Gali, Lopez-Salido and Valles (2007)). Total number of households is 1, and the number of each type of households is fixed. We denote the population ratio of the rule-of-thumb households by $\text{pop}_K$.

Nominal price stickiness and pass-through

In this model, nominal prices are sticky because firms have to pay quadratic adjustment costs when changing prices. It is assumed that, when H firms export their goods abroad, they face a linear combination of two types of adjustment costs: the first type of costs arise when they change prices of their products quoted in their own currency units, and the second type is a function of changes in prices denominated in foreign customers’
currency units. It is also assumed that, when foreign exporters sell their goods in the home market, they also face the cost of changing prices denominated in the home currency unit.

3-2 Optimizing Households

The optimizing household maximizes its expected discounted sum of utility:

$$U_t = E \sum_{\tau=t}^{\infty} \left( \prod_{k=1}^{t-\tau} \beta_{t+k} \right) u_t,$$

where

$$u_t = \ln \left( C_t^{opt} - q_h \cdot \bar{C}_{t-1}^{opt} \right).$$

Here $C_t^{opt}$ is this household’s consumption, or more accurately, its “composite consumption index” that consists of utilities from various types of goods. Its details will be specified later. We introduce an external habit formation in consumption: $\bar{C}_{t-1}^{opt}$ is consumption per capita of optimizing households in the previous period. The habit parameter, $q_h$, is assumed to be between zero and one. The time-varying discount factor, $\beta_t$, is assumed to follow an exogenous stochastic process and will be specified in detail below.

For the specification of the labor market, we follow Gali, Lopez-Salido and Valles (2007): rather than assuming a market-based determination of wages, we assume that wages are set by a social norm which is represented by a wage function, and that the amount of labor is determined by the labor demand side. Again, this rather strong assumption is needed for fiscal policy to have any chance of having large effects on output. Moreover, it is assumed that labor is freely mobile between firms and between the two sectors of production, H and N. As a consequence, the wage rate will be equalized across firms and across sectors. We denote nominal wage per hour by $W_t$ and labor per household by $L_t$.

In the financial market, the household can allocate its wealth between three types of assets. The first type is bond. Bond holding per optimizing household is denoted as $B_t^{opt}$, which is denominated in home currency units with an interest rate equal to the nominal interest rate of home country, $i_t$, and can be traded internationally. The other two types of assets are the ownership or the shares of H firms and N firms in home country, which are traded only domestically between optimizing households. Denote the
overall value of H firms by $V_{H,t}$, and the household’s share in those firms by $s_{H,t}$, then the total amount of share holding for this sector is $V_{H,t} \cdot s_{H,t}$. Holding this fraction of the shares, the household will be entitled to the same proportion of overall profit of sector H in the next period, denoted by $\Pi_{H,t+1}$. Likewise, for sector N, denoting the overall value of the firms by $V_{N,t}$ and the household’s share by $s_{N,t}$, the overall share holding for this sector is $V_{N,t} \cdot s_{N,t}$, and the household is entitled to the same fraction of the overall profit, $\Pi_{N,t+1}$.

Then the household’s budget constraint at period $t$ can be written as follows

$$W_t \cdot L_t + (V_{H,t} + \Pi_{H,t}) \cdot s_{H,t-1} + (V_{N,t} + \Pi_{N,t}) \cdot s_{N,t-1} + (1 + i_{t-1})B_{t-1}^{opt} - P_t \cdot T_t = P_t \cdot C_t^{opt} + B_{t+1}^{opt} + V_{H,t+1} \cdot s_{H,t} + V_{N,t+1} \cdot s_{N,t},$$

where $T_t$ denotes the real value of lump sum tax payment, whose amount is the same across all the households.

### 3-3 Rule-of-thumb Households

Again, this type of household simply consumes all of its income in each period. It is assumed that their wages are the same as those of optimizing households. As work hours are demand-determined in this model, they are assumed to work for the same hours as optimizing households. As for shares of firms, we assume that, in the beginning of the world, the same number of shares was distributed to each optimizing as well as rule-of-thumb households, and, since then, the latter types of households were shut out of the stock market transaction\(^7\). This means that, in each period, number of shares held by each optimizing and rule-of-thumb households are equal. Taking all the assumptions together, income of each rule-of-thumb household will be equal to average GDP per household in each period. This minus lump sum taxes in turn will be equal to consumption per rule-of-thumb household, denoted as $c^{rt}_t$.

### 3-4 Firm Optimization

**Individual Firms**

\(^7\) An alternative way of modeling those households would be to assume that they just do not own stocks, and that they only earn wage income. However, Eguchi (2009) shows that this assumption could weaken the effects of fiscal policy considerably, when combined with the assumption of wage rigidity.
Each of the production sectors, H and N, consists of a continuum of firms, whose number is normalized to be one for each sector. The goods markets are monopolistically competitive, as each firm in either sector specializes in production of a single “brand” or a differentiated variety of products. When changing prices, they have to incur adjustment costs. Consider firm \( j \) of sector \( J (J=H \text{ or } N) \). Its objective is to maximize the shareholder value of the firm, or the discounted sum of profit flows (discounted at the rate at which the shareholders discount future) as follows

\[
V_{J,t}(j) = E_t \sum_{\tau=t+1}^{\infty} \left( \prod_{k=0}^{\tau-1} \beta_{t,k} \right) \cdot d\lambda_{t,\tau} \cdot \Pi_{J,t}(j),
\]

where \( d\lambda_{t,\tau} \) is equal to \( \lambda_{J,t,\tau} / \lambda_{J,t,\tau} \), where \( \lambda_{J,t,\tau} \) is the Lagrange multiplier associated with the budget constraint in the household’s optimization problem. Profit for this firm in period \( t \), \( \Pi_{J,t}(j) \), is given by

\[
\Pi_{J,t}(j) = P_{J,t}(j) \cdot D_{J,t}(j) - W_t \cdot L_{J,t}(j) - P_t \cdot ACP_{J,t}(j),
\]

where \( P_{J,t}(j) \) is the price set by this firm, \( D_{J,t}(j) \) is the demand curve this firm faces, \( L_{J,t}(j) \) is the amount of labor employed by the firm, and \( ACP_{J,t}(j) \) is the firm’s price adjustment cost, and is measured by units of the aggregate consumption index.

The firm faces the following constraints. First, the demand for the firm must equal its supply, which is given by a production function linear in labor input

\[
D_{J,t}(j) = Y_{J,t}(j) = A_{J,t} \cdot \Gamma_t \cdot L_{J,t}(j),
\]

where \( \Gamma_t \) corresponds to the deterministic trend in the aggregate level of technology, and it increases at the rate \( \gamma \) each period. \( A_{J,t} (J=H, N) \) are exogenous processes to be specified in Sub-section 4-9. Next, the demand curve has a constant elasticity form

\[
D_{J,t}(j) = \left( P_{J,t}(j) \right)^{\theta} \cdot Z_{J,t},
\]

where \( \theta > 0 \) is the price elasticity of demand, and \( Z_{J,t} \) is a variable that is beyond the control of this firm.

The last constraint is the adjustment cost of prices, whose specification is crucial to the analysis. We will discuss this issue in detail below.

**Adjustment cost of changing prices, N Firms**

The adjustment cost is modeled as a quadratic function of price changes a la Rotemberg (1982). For N firms, which produce and sell goods exclusively at home, it seems
reasonable to assume that the cost arises when changing prices denoted in home currency units

\[ ACP_{N,t}(j) = acp_{N,t}(j) \cdot D_{N,t}(j), \]

\[ acp_{N,t}(j) = \frac{\psi_{P}^{N}}{2} \cdot \left[ \frac{P_{N,t}(j) - \mu P_{N,t-1}(j) - (1 - \mu) P_{N,t-2}(j)}{P_{t} \cdot P_{N,t-1}(j)} \right]^{2}, \quad (8) \]

where \( acp_{N,t}(j) \) denotes the per-unit adjustment cost, and \( \psi_{P}^{N} > 0 \) and \( 0 < \mu < 1 \) are parameters. Here the price change is specified as the weighted average of price changes in the last two periods. This is somewhat different from the conventional specification of the Rotemberg quadratic adjustment function in that the price set in two periods earlier, \( P_{N,t-2} \), enters the cost function. The purpose for this is to incorporate a backward-looking feature into behaviors of inflation as a consequence of an optimal price setting behavior of firms. It is known that such a feature could improve the empirical performance of an optimization based dynamic model. A similar backward looking feature has been introduced in a price setting model a la Calvo by incorporating rule-of-thumb price setters (see, for example, Smets and Wouters 2003). As shown in (8), \( 1 - \mu \) expresses the degree of “backward-looking-ness” of inflation. When \( 1 - \mu = 0 \), (13) reduces to the conventional Rotemberg quadratic adjustment function, and in this case inflation is purely forward-looking.

**Adjustment cost of changing prices, H Firms**

The case of firms producing tradable goods is a more subtle one. They sell some part of their products in the home market. For those goods, it seems reasonable to assume that the adjustment cost is related to changes in prices quoted in home currency units. However, for those goods sold abroad, it is not clear if we should model the adjustment cost in relation to prices denoted in home currency units or those quoted in foreign currency units. If we assume the former, prices quoted in home currency units will become sticky, and fluctuations in the nominal exchange rate will be passed on to their prices in the foreign market (especially if the adjustment cost coefficient is large). This case is similar to what is known as “producer currency pricing” situation in the literature. On the other hand, the latter assumption will imply that the prices will become sticky in the foreign market, and most of the impact of exchange rate fluctuations will be
absorbed by changes in profits of H firms. This case is akin to what is generally termed as “local currency pricing” situation. In this paper, we assume that the adjustment cost of changing prices of exported goods is a weighted average of the adjustment cost associated with prices quoted in home currency unit and the cost related to changing prices denominated in foreign currency units. Thus, our specification allows us to study both “producer currency pricing” and “local currency pricing” as special cases. We believe that this way of modeling exchange rate pass-through gives us an important degree of flexibility compared with previous studies that model export price stickiness by the Calvo style staggered pricing.

More concretely, denote the price of a good sold by an H firm (indexed as $j$) in the foreign market as $P_{H,t}^*(j)$, and its value converted in home currency units as $H_{t,P}^*(j)$. Obviously, we have

$$Q_{t,j}(j) \cdot e = P_{H,t}^*(j).$$

Then the adjustment cost of price changes for this firm takes the following form:

$$ACP_{H,t}(j) = acp_{H,t}(j) \cdot D_{H,t}^s(j) + \left(c_{pcp} \cdot acp_{H,t}^*(j) + (1 - c_{pcp}) \cdot acq_{H,t}(j)\right) \cdot D_{H,t}^p(j).$$

In the above, $D_{H,t}^s(j)$ denotes the amount of goods sold by this firm in the home market, while $D_{H,t}^p(j)$ is the amount sold in the foreign market. There are three types of per-unit adjustment cost involved: $acp_{H,t}(j)$ is associated with goods sold in the home market, $acp_{H,t}^*(j)$ to prices of goods sold in the foreign market that are quoted in units of home currency, and $acq_{H,t}$ to changing prices of those goods denominated in units of foreign currency. The parameter $c_{pcp}$ takes a value between 0 and 1, and represents the relative importance of those two types of adjustment costs of changing export prices. The per-unit costs are specified as follows:

$$acp_{H,t}(j) = \frac{\mu}{2} \left[P_{H,t}(j) - \mu P_{H,t-1}(j) - \left(1 - \mu\right) P_{H,t-2}(j)\right]^2 \cdot P_{t,H} P_{H,t-1}(j),$$

$$acp_{H,t}^*(j) = \frac{\mu^*}{2} \left[P_{H,t}^*(j) - \mu P_{H,t-1}^*(j) - \left(1 - \mu\right) P_{H,t-2}^*(j)\right]^2 \cdot P_{t,H} P_{H,t-1}(j).$$
and

\[
acq_{H,t} = \frac{\psi_P^*}{2} \frac{[Q_{H,t} - \mu Q_{H,t-1} - (1-\mu)Q_{H,t-2}]^2}{(P_t/e_t)Q_{H,t-1}}.
\]  \hspace{1cm} (11-3)

**Adjustment cost of changing prices, F goods**

We also model incomplete pass-through on the import price side. For that purpose, we introduce monopolistically competitive exporters in “foreign” country: each exporter sells only one type of F goods and is subject to adjustment cost of changing prices in units of home currency. Consider an exporter who sells brand \(j\) of F goods. It faces a marginal cost of obtaining a unit of this brand of goods, \(MC_{F,j}\), which is equal to the foreign-currency denominated price of the F good, \(Q_{F,t}(j)\), times the exchange rate, and is the same across all \(j\)'s. Due to the small open economy nature of the model, \(Q_{F,t}(j)\) is supposed to follow an exogenous process which will be mentioned in more detail in sub-section 4-9. The exporter maximizes the following objective function of profit

\[
V_{F,t}(j) = E \sum_{\tau=1}^{\infty} \left( \prod_{\nu=1}^{\tau} \frac{1}{1+i_{H,t}} \right) \left[ P_{F,t}(j) \cdot D_{F,t}(j) - MC_{F,j} \cdot D_{F,t}(j) - P_t \cdot \text{acp}_{F,t}(j) \cdot D_{F,t}(j) \right],
\]

subject to the demand function of the form (7), and the following per-unit adjustment cost of changing prices:

\[
\text{acp}_{F,t}(j) = \frac{\psi_P^F}{2} \frac{[P_{F,t}(j) - \mu P_{F,t-1}(j) - (1-\mu)P_{F,t-2}(j)]^2}{P_t \cdot P_{F,t-1}(j)}.
\]  \hspace{1cm} (13)

The case of complete exchange rate pass-through to import prices is obtained when \(\psi_P^F = 0\).

**3-5 Composite goods indices and average price indices**

For both optimizing households and rule-of-thumb households, “total consumption”, denoted as \(C_{t}^{\text{opt}}\) and \(C_{t}^{r}\), respectively, is in fact a composite of three types of consumption goods. As the two types of composite consumption indices have the identical structure, for the ease of exposition, let us drop the superscripts and simply denote it (and all the sub-indices included) as \(C_{t}\). It consists of consumption of H
goods, $C_{H,t}$, N goods, $C_{N,t}$, and F goods, $C_{F,t}$, each of which is aggregated according to a CES function as follows

$$C_t = \left[ \omega^{\eta/(\eta-1)} C_{T,t}^{(\eta-1)/\eta} + (1-\omega)^{\eta/\eta} C_{N,t}^{(\eta-1)/\eta} \right]^{\eta/(\eta-1)} \quad (14-1)$$

$$C_{T,t} = \left[ \phi^{\rho/(\rho-1)} C_{H,t}^{(\rho-1)/\rho} + (1-\phi)^{\rho/\rho} C_{F,t}^{(\rho-1)/\rho} \right]^{\rho/(\rho-1)} \quad (14-2)$$

and

$$C_{J,t} = \left[ \int C_{J,t}(j)^{(\theta-1)/\theta} \, dj \right]^{\theta/(\theta-1)} \quad (J=H, N, or F). \quad (14-3)$$

The elasticities, $\eta, \rho$ and $\theta$, are all positive. The share parameters, $\omega$ and $\phi$, are between 0 and 1. The letter “T” stands for tradable goods, which consist of H and F goods. The corresponding price indices are suitably defined as follows

$$P_t = \left[ \omega P_{T,t}^{1-\eta} + (1-\omega) P_{N,t}^{1-\eta} \right]^{1/(1-\eta)}, \quad (15-1)$$

$$P_{T,t} = \left[ \phi P_{H,t}^{1-\rho} + (1-\phi) P_{F,t}^{1-\rho} \right]^{1/(1-\rho)}, \quad (15-2)$$

and

$$P_{J,t} = \left[ \int P_{J,t}(j)^{1-\theta} \, dj \right]^{1/(1-\theta)} \quad (J=H, N, or F). \quad (15-3)$$

Individual demand functions are given by

$$C_{T,t} = \omega \cdot \left[ \frac{P_{T,t}}{P_t} \right]^{-\eta} \cdot C_t, \quad C_{N,t} = (1-\omega) \cdot \left[ \frac{P_{N,t}}{P_t} \right]^{-\eta} \cdot C_t, \quad (16-1)$$

$$C_{H,t} = \phi \cdot \left[ \frac{P_{H,t}}{P_{T,t}} \right]^{-\rho} \cdot C_{T,t}, \quad C_{F,t} = (1-\phi) \cdot \left[ \frac{P_{F,t}}{P_{T,t}} \right]^{-\rho} \cdot C_{T,t}, \quad (16-2)$$

and

$$C_{J,t}(j) = \left[ \frac{P_{J,t}(j)}{P_{J,t}} \right]^{-\theta} \cdot C_{J,t} \quad (J=H, N, or F). \quad (16-3)$$

3-6 Monetary Authority

We assume that monetary policy follows a version of the Taylor rule specified as follows
\[
\log(1+i_t) - \log(1+i_{ss}) = (1-q) \left[ q \cdot (\pi_t - \pi_{ss}) + q \cdot (Y_t - Y_{ss}) \right] + q \cdot \left[ \log(1+i_{t-1}) - \log(1+i_{ss}) \right] + (1-q)u_{M, t}.
\]

(17)

In equation (17), \( i_t, \pi_t, \text{ and } Y_t \) are, respectively, the interest rate, inflation rate, and real GDP of “home” country, while the terms with a subscript SS denote the steady-state values of the corresponding variables. \( q_\pi \) and \( q_y \) are the weights on inflation gap and output gaps, respectively. It is assumed that \( q_\pi > 1 \) to achieve uniqueness of the equilibrium path. \( q_i \) is the parameter for interest rate smoothing, and \( u_{M, t} \) is an exogenous term associated with the monetary shock to be specified in Sub-section 4-9.

3-7 Fiscal Authority

Evolution of government expenditure is governed by the index \( G_t \) which follows an AR(1) process (see subsection 3-11). Total expenditure is allocated to each type of goods according to the following rule:

\[
G_{H,t} = \omega_0 \cdot \phi_G \cdot G_t, \quad G_{F,t} = \omega_0 \cdot (1-\phi_G) \cdot G_t, \quad G_{N,t} = (1-\omega_0) \cdot G_t
\]

(18)

where \( G_{H,t}, G_{F,t}, \) and \( G_{N,t} \) denote units of H, F, and N goods purchased by the government, respectively, \( 0 < \omega_0 < 1 \), and \( 0 < \phi_G < 1 \). Real government expenditure is defined as

\[
RG_t = \left( P_{H,t}G_{H,t} + P_{F,t}G_{F,t} + P_{N,t}G_{N,t} \right) / P_t,
\]

(19)

which may differ from the index \( G_t \) in each period (later, we make suitable assumptions to ensure that they will be equal in the steady state).

We assume that the government does not necessarily balance its budget each period. Lump sum taxes respond to accumulation of public debt in the following manner:

\[
T_t = G_0 + \xi \cdot B_{G,t}
\]

(20)

where \( G_0 \) is the steady state value of government expenditure, \( B_{G,t} \) is the real public debt outstanding, and \( \xi \) is a positive constant that has to be greater than the steady state real interest rate. In our estimation, we set the value of \( \xi \) to a very low number, which permits the possibility that rule-of-thumb households would respond strongly to an expansionary fiscal policy. Lastly, the government budget constraint is

\[
T_t + B_{G,t} = RG_t + \frac{1+i_t}{1+\pi_t} \cdot B_{G,t-1}.
\]

(21)
3-8 International environment

**Foreign demand for H goods**

“Foreign” country buys H goods from “home” country. It is assumed that the price elasticity of the overall foreign demand for H goods is equal to a positive constant, \( \rho_X \).

It is also assumed that the price elasticity of the foreign demand for individual H firms is equal to that for the home demand, \( \theta \). Specifically,

\[
X_t = \left( \frac{P^*_{H,t}}{e_t} \right)^{-\rho_X} \cdot Y^\text{FOR}_t, \tag{22}
\]

where \( X_t \) is the foreign demand for H goods, or home exports, and \( Y^\text{FOR}_t \) is an exogenous process that represents shifts in foreign demand. For simplicity, we assume that \( Y^\text{FOR}_t \) is fixed. Also,

\[
X_t(j) = \left[ \frac{P^*_{H,t}(j)}{P^*_{H,t}} \right]^{-\theta} \cdot X_t, \tag{23}
\]

where \( X_t(j) \) is the foreign demand for firm \( j \) in the H-goods producing sector.

**International financial market**

Home and world interest rates are linked through the uncovered interest rate parity condition in which we assumed that there exists a risk premium on the home interest rate, which in turn depends on the overall position of the country in the international market.

\[
i_t = (i_t^w + \%\Delta E_{t+1} e_{t+1}) + \kappa_t, \tag{24}
\]

\[
\kappa_t = \varphi \left[ \exp \left( -B_t / NY_t \right) - 1 \right] + u_{\kappa,t}. \tag{25}
\]

Here \( i_t^w \) denotes world interest rate which is assumed to be fixed, \( \%\Delta E_{t+1} e_{t+1} \) the expected percentage change of exchange rate, \( \kappa_t \) the risk premium, and \( NY_t \) is the aggregate nominal output defined as:

\[
NY_t = P_{H,t} Y_{H,t} + P_{N,t} Y_{N,t}. \tag{26}
\]

\( u_{\kappa,t} \) is an exogenous process associated with the risk-premium risk, which will be
described in detail in Sub-section 4-9. The parameter $\varphi$ is positive. This is a modified version of the idea of “debt elastic interest rate” in Uribe and Schmitt-Grohé (2003). As they emphasize, we need this (or an alternative assumption) to achieve stability of the whole system. Without this, the model would not satisfy the Blanchard and Kahn (1980) condition.

3-9 Labor Market
We follow Gali, Lopez-Salido and Valles (2007) to assume that wages are set by some “wage function”, which presumably reflects some type of social norm, rather than determined competitively. Again, this assumption gives a chance for fiscal policy to have large effects on output. The function takes the following form:

$$
\frac{W_t}{P_t} = c_L \cdot C_t \cdot L_t^{1/e_L}
$$

where $c_L$ is a positive constant and $e_L$ is also a positive constant that measures the degree of real wage rigidity. Also, $C_t$ is the aggregate consumption between optimizing and rule-of-thumb households.

3-10 Goods market equilibrium
The goods market clearing conditions are:

$$
Y_{H,t} = (1 - pop_K) \cdot C_{H,t}^{opt} + pop_K \cdot C_{H,t}^{opt} + G_{H,t} + X_t,
$$

and

$$
Y_{N,t} = (1 - pop_K) \cdot C_{N,t}^{opt} + pop_K \cdot C_{N,t}^{opt} + G_{N,t},
$$

where, again, $pop_K$ denotes the population share of the rule-of-thumb (or the “Keynes type”) households. We take advantage of the Walras’ law and drop the condition for F goods sector. In addition, the money and the bond markets have to clear.

3-11 Exogenous variables and shocks
Each of the exogenous variables $\beta_t$, $A_{H,t}$, $A_{N,t}$, $Q_{F,t}$, $u_{M,t}$, $u_{k,t}$, $G_t$ and $Y_t^{POE}$ is assumed to follow an AR(1) process as follows

$$
\log(\beta_t / \beta) = r_{\beta} \cdot \log(\beta_{t-1} / \beta) + (1 - r_{\beta}) \cdot e_{\beta,t},
$$

$$
\log(A_{H,t} / A_{H}) = r_{AH} \cdot \log(A_{H,t-1} / A_{H}) + (1 - r_{AH}) \cdot (e_{AH,t} + e_{H-N,t}),
$$

$$
\log(A_{N,t} / A_{N}) = r_{AN} \cdot \log(A_{N,t-1} / A_{N}) + (1 - r_{AN}) \cdot (e_{AN,t} - e_{H-N,t}),
$$

8 The only difference is that we normalize by $NY_t$. 

18
\[
\log(\frac{Q_{F,t}}{Q_{F,t-1}}) = r_p \cdot \log(\frac{Q_{F,t-1}}{Q_{F,t-2}}) + (1 - r_p) \cdot e_{p,t}, \\
u_{M,t} = r_M \cdot u_{M,t-1} + (1 - r_M) \cdot e_{uM,t}, \\
u_{x,t} = r_x \cdot u_{x,t-1} + (1 - r_x) \cdot e_{uX,t}, \\
\ln(\frac{G_t}{\overline{G}}) = r_G \cdot \ln(\frac{G_{t-1}}{\overline{G}}) + (1 - r_G) \cdot e_{G,t}, \\
\ln(\frac{Y_{t}^{\text{FOR}}}{\overline{Y}^{\text{FOR}}}) = r_X \cdot \ln(\frac{Y_{t-1}^{\text{FOR}}}{\overline{Y}^{\text{FOR}}}) + (1 - r_X) \cdot e_{G,t},
\]

where \( e_B, e_p, e_M, e_I, e_G, \) and \( e_X \) are the discount factor shock, shock to foreign goods prices, monetary shock, international risk-premium shock, fiscal policy shock, and external demand shock (for the country’s exports), respectively. In equations (30) and (31), two types of technology shocks appear: the first one is \( e_A \), “overall” productivity shock, that affects the two production sectors equally, and the second one, \( e_{H-N} \), is the relative productivity shock that raises the productivity of sector H while reducing that of sector N. These shocks are assumed to be \textit{i.i.d.} normal and orthogonal to one another. In addition, \( r \)'s are parameters expressing the persistence of shocks (whose absolute values are assumed to be smaller than one), and the terms with a bar denote the steady state levels of the corresponding variables.

4 Empirical methodology

This paper employs a Bayesian methodology to estimate the above structural model. This methodology has recently been used extensively in estimating complex stochastic models involving very large numbers of parameters. In such cases, it is typical to use the Bayesian estimation via Markov-chain Monte-Carlo (MCMC) simulation rather than the straightforward maximum likelihood estimation: this is because in most of such cases it is not possible to specify the joint distribution of parameters in an explicit manner. This paper employs the Metropolis-Hastings (MH) algorithm, which is one of the oldest among the existing MCMC sampling methods.

The basic idea of the Bayesian estimation can be summarized as follows.

\textbf{Bayesian estimation}

\textit{Let} \( \Theta \) \textit{denote the set of the unknown parameters.}

1. \textit{Specify the prior distribution,} \( f(\Theta) \).
2. Using the Bayes theorem, write the posterior distribution $\textit{f} (\theta | \text{data})$ as follows:

$$
f (\theta | \text{data}) = \frac{\textit{f} (\text{data} | \theta) \textit{f} (\theta)}{\int \textit{f} (\text{data} | \theta) \textit{f} (\theta) d\theta},
$$

where $\textit{f} (\text{data} | \theta)$ is the likelihood function.

3. Compute various statistics such as the mean, the mode, and the credibility intervals for each of the parameters. Note that derivation of the intervals involves computation of the marginal posterior distribution for each of the parameters, i.e., integrating out the other parameters from the joint posterior distribution.

In practice, it is often difficult to write down the joint posterior distribution in an explicit form, and it is even more difficult to derive the marginal posterior distribution analytically. Recent studies overcome this difficulty by resorting to MCMC simulations. The main idea behind the Metropolis-Hastings algorithm can be summarized as follows.

The Metropolis-Hastings (MH) algorithm is one of the oldest among the existing MCMC sampling methods. Another well known MCMC sampling method, Gibbs sampler, is a special case of this method. If the form of the posterior distribution for each parameter, conditional on the other parameters, is known, the Gibbs sampler method can be employed. This, however, is not the case in many practices. In such a case, the MH algorithm, summarized below, can be useful.

**Metropolis Hastings Algorithm**

1. Start from a certain initial value vector for the parameters, which will be denoted as $\theta^{(0)}$.

2. Generate $\theta'$ from a "proposal density" with $\theta^{(i-1)}$ given $(i = 1, \ldots, T)$:

$$
g (\theta' | \theta^{(i-1)}). \text{ In theory, the proposal density can take any form.}
$$

3. Compute the following "acceptance rate":

20
\[ q = \min \left[ \frac{f(\theta')g(\theta^{(i-1)}|\theta')}{f(\theta^{(i-1)})g(\theta|\theta^{(i-1)})}, 1 \right]. \]

4. Set \( \theta^{(i)} = \theta' \) with probability \( q \), and \( \theta^{(i)} = \theta^{(i-1)} \) with probability \( 1-q \).

5. Repeat Step 1, 2, and 3 \( N \) times to get enough samples of parameters. After discarding initial samples that belong to the “burn-in” period, to remove influences of the initial values, save the rest of the samples. Report the means, the credibility intervals, etc.

5 Data

Eight variables are involved in our estimation: GDP, inflation, the interest rate, the exchange rate, import prices, export prices, exports, and government expenditure. All the data used here is quarterly. Sample period is 1975Q2-2009Q4. Data for Japanese GDP, government expenditure and exports are taken from the System of National Accounts from the Economic and Social Research Institute of Japan. Series from the 1968SNA (base year = 1990) and the 1993SNA (chained) are connected in the first quarter of the year 1980 using growth rates. For all three variables, we take deviations of their logarithms from their respective trends estimated by the Hodrick Prescott Filter with the smoothing parameter of 1,600. In estimating trends in this paper, we always utilize the longest available sample, without sticking to the sample period of the estimation mentioned above.

Inflation is the log first difference in CPI (total excluding imputed rents) from the Ministry of Internal Affairs and Communication. The interest rate is the call rate (with collateral, annualized) from the Bank of Japan, divided by 400 to make it a quarterly rate. We estimate trend in inflation by the Hodrick Prescott Filter with a large smoothing parameter (100,000). Then we subtract this trend from both inflation and the interest rate.

The exchange rate is the nominal effective exchange rate from the Bank of Japan. As this variable is defined in such a way that an increase in its value means an appreciation, we multiply its log by -1 to make it consistent with the specification in the model.
Import prices are the Import Price Index and export prices are the Export Price Index, both from the Bank of Japan. Following the specification of the model, we divide the exchange rate, import prices and export prices by the Japanese CPI (total) and then take their logarithms. Then we eliminate trends in each of those series, individually, by the Hodrick-Prescott filter with a smoothing parameter of 1,600. Prior to the estimation, we demean all the eight series, as the model variables are all expressed as deviations from the steady state. Figure 2 presents the eight series thus constructed for the period 1975Q1-2009Q4.

Figure 1: Data series, detrended and demeaned, 1975Q1-2009Q4

6 Estimation details and results

6.1 Prior distributions and parameter restrictions
This sub-section explains details of our estimation, especially the prior distributions employed. Values of certain parameters are fixed, rather than estimated, to generate certain characteristics of the steady state. Some of those characteristics are purely
normalization, while some others are meant to reproduce realistic long run features of
the Japanese data. Most importantly, the spending share parameters for households and
the government are chosen to match actual patterns of spending of the private sector and
the government as of year 2005\(^9\). Table 2 reports names of such parameters as well as
their targets. We note the fact that the government expenditure is more biased toward
non-tradable goods than private expenditure.

<table>
<thead>
<tr>
<th>Steady state targets</th>
<th>parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP=1, C=0.8, G=0.2, L=1/3</td>
<td>Average of ( \bar{A}_H ) and ( \bar{A}_N ), ( \bar{G} ), ( c_L )</td>
</tr>
<tr>
<td>( C_f=0.29<em>0.55C, C_N=(1-0.29)C ), ( C_f=0.29</em>(1-0.55)C )</td>
<td>( \omega=0.29, \phi=0.55 )</td>
</tr>
<tr>
<td>( G_f=0.15<em>0.53G, G_N=(1-0.15)G ), ( G_f=0.15</em>(1-0.53)G )</td>
<td>( \omega_G=0.15, \phi_G=0.53 )</td>
</tr>
<tr>
<td>( P_f/P=P_N/P=P_e/P=e/P=1 )</td>
<td>( \bar{A}_H/\bar{A}_N, \bar{Y}_F, \bar{Q}_F )</td>
</tr>
<tr>
<td>Inflation rate = 0, Real interest rate=0.37%</td>
<td>( \pi_{SS}=0, \bar{\beta}=0.9963, i_{SS}=0.0037 )</td>
</tr>
<tr>
<td>Fixed mainly for ease of estimation.</td>
<td>( \alpha=0.5, \theta=10, \varphi=0.01, \xi=0.05, \mu_F=1, q_y=0 )</td>
</tr>
</tbody>
</table>

In Table 3, we summarize the prior distributions used for the estimated parameters.

<table>
<thead>
<tr>
<th>Name</th>
<th>Prior Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{eI}, \sigma_{eP}, \sigma_{eA}, \sigma_{eH-N} )</td>
<td>Inverse Gamma (0.1, Inf)</td>
</tr>
<tr>
<td>( \sigma_{eM}, \sigma_{eB} )</td>
<td>Inverse Gamma (0.01, Inf)</td>
</tr>
</tbody>
</table>

\(^9\) The expenditure shares on imported goods are determined based on the input output table of 2005.
We derive the import inducement coefficients for both private spending and government spending,
and set the shares of F goods equal to those values. As for domestically produced goods, we think of
the tradable goods sector as all of the primary and secondary industries other than construction. The
non-tradable goods sector is the tertiary industry plus construction. Again using the I-O table, we
take sums of the value added inducement coefficients for the “tradable” sector as well as the
“non-tradable” sector for both private and government spending, and set the shares of H and N
goods equal to them.
We use the conventional Inverse Gamma distribution for the standard deviations of the shocks. The choices of the distribution parameters reflect our initial guess that $e_M$ and $e_B$, which are likely to be closely linked to the domestic interest rate and inflation, would tend to have lower standard deviations, while some others are more likely to have larger standard deviation. For shocks to government expenditure and exports, we take their respective standard deviations we observe in the data. Note that many of the parameters in the model are restricted to be between zero and one (such as $\mu$), while others are only restricted to be between -1 and 1 but are reasonably expected to be positive (such as the AR(1) coefficients of the shock series). For those parameters, we use Beta (0.5, 0.2). As will be shown in Figure 2 below, its density function is centered at 0.5 and decreases smoothly as we move away from the center toward either 0 or 1. This distribution is convenient to summarize a belief that “we are sure that this parameter is between 0 and 1, and we think it is probably somewhere in the middle (i.e., not too close to either 0 or 1)”. For the Taylor rule coefficient on inflation, we apply a transformation which ensures that its value cannot go below 1.01, so that the Taylor principle would always be satisfied. The same transformation also implies that it would not exceed 3.01, which is likely to be an innocuous restriction. For the AR(1) parameters for shocks to government expenditure and exports, we estimate AR(1)
models for actual government expenditure and export series, and set the prior means equal to the point estimates. The price adjustment cost parameters for domestic firms, $\psi^N_p$, $\psi^H_p$, and $\psi^{H*}_p$, are restricted to be the same, and to be positive. The prior variance is set to be quite large, reflecting the uncertainty surrounding this parameter. The adjustment cost parameter for converting foreign currency prices of imported goods into yen, namely $\psi^F_p$, is expected to be smaller. As for the elasticity of substitution, $\eta$ and $\rho$, we expect them to be reasonably small. Their prior means are around 1.5. We had trouble estimating $\rho$, the elasticity of substitution between home tradables and foreign tradables. If the estimation procedure wanders into a region with small values of $\rho$, we encountered various error messages, and we think this is because a small $\rho$ would violate the stability condition for a reason similar to the Marshall-Lerner condition in basic international economics. We thus apply a transformation to this parameter so that it would never go below 0.7. Also, its prior is tightly distributed around 1.5.

6.2 Estimation results

We run 100,000 Metropolis-Hastings runs and discard the first 25% of them as “burn-ins”. The acceptance rate was 30.7%. The resulting posterior distributions are shown in thick lines in Figure 2, along with the prior distributions (thin lines). Most of parameters are reasonably tightly estimated. The only exception is $e_L$, the degree of wage stickiness. This could be because we are not directly using the data on wages. Note that the posterior mean of the share of exporting firms with producer currency pricing, the parameter $c_{PCP}$, estimated to be low (the posterior mean is 0.11). This implies a low pass-through of exchange rate fluctuations on export prices in the short run. Also, the share of the rule-of-thumb households, $pop_K$, is estimated to be only 0.09. We will see later that this leads to a small estimated effect of fiscal policy on GDP.
Figure 2: Priors (thin lines) and Posteriors (thick lines)

Note: “SE” refers to standard deviations of structural shocks.
Next, in Figure 3, we present median Bayesian impulse responses, along with their 90 percentile bands. In Table 4, we present variance decomposition results for the 1, 4 and 8 quarters ahead forecast error variance. Here, we start with the results on the two most important domestic variables, GDP and inflation. We note that, for GDP, the most important driving force is the overall productivity shock. Table 4(1) shows that, even at the impact, its contribution to the variance of GDP is close to 50%. In two years, the relative contribution climbs up to 70%. Three types of external shocks, namely risk premium shock, foreign price shock, and external demand shock, when combined, make sizable contribution to GDP. In Table 4(1), their combined contribution at the impact is about 30% of the variance of GDP.

\[\text{Contribution of each type of shock is simply measured by the square of the median Bayesian impulse responses that appear in Figure 3.}\]
GDP. But their contributions quickly dwindle. Monetary and fiscal policies are not so important. For inflation, monetary policy and private demand shocks are the most important: in Table 4(2), their relative contributions to the variance of inflation are about 39% and 23%, respectively, at the impact. But risk premium and foreign price shocks are also important in the short run, each contributing to a little over 10% of the variations in inflation.

Now we consider effects of each type of shock to the other variables in turn. Risk premium shocks, which can roughly be considered as the “exchange rate shock” at least in the short run, are an important driving force behind fluctuations in both import and export prices. From Figure 3(1), a shock that causes a 3.6% depreciation of the Japanese yen at the impact causes approximately 2.5% increase in import prices and 2.0% increase in export prices during the same quarter. This implies that the short run exchange rate pass-through is neither perfect nor zero. Let us define the “pass-through rate” on the import side as the ratio between the rate of import price increase and the rate of depreciation. Also, define the corresponding notion on the export side as one minus the rate of increase in export prices divided by the rate of depreciation. Then the “impact pass-through rate” is 69% on the import side and 44% on the export side. It is notable that those ratios are not too far from the shares of US dollars in currency invoicing that we observed in Table 1. After four quarters, the response of import prices converges to that of the exchange rate: that is, pass-through becomes nearly perfect in one year. The response of export prices becomes basically zero after 4-7 quarters. That is, on the export side, pass-through becomes almost perfect in a little over a year.

In Figure 3(2), monetary policy does not have much of an impact on any variable other than inflation. This could reflect the fact that, in our estimation results, monetary policy is strongly anti-inflation. A monetary tightening, which lowers inflation, is likely to be followed by a quick undoing of the initial policy action.

In Figure 3(3), a positive foreign price shock induces monetary tightening, which causes the exchange rate to appreciate. As this effect is not fully offset by lower export prices, exports decrease, though only marginally.

In Figure 3(4), a contraction of private demand induces the central bank to cut the interest rate, and this induces a currency depreciation, which increases exports (though by a little).
In Figure 3(5), as a productivity increase lowers inflation rate, this again induces a rate cut, and then a currency depreciation and an export boom. Table 4 (4) and (8) show that these effects are sizable and persistent.

In Figure 3(6), an improvement in H goods production technology (relative to N goods) means that firms can produce export goods at lower prices, which leads to lower export prices and more exports.

In Figure 3(7), fiscal policy has little effects on any variable other than government expenditure itself. We will come back to this result in the next section.

Finally, in Figure 3(8), a larger demand for exports leads to expansions in exports and thus output. The interest rate increases to partially offset these effects, and this cause the yen to appreciate.

Figure 3 Estimated impulse responses, median and 90 percentile bands
(1) Responses to a risk premium shock
(2) Responses to a monetary policy shock

(3) Responses to a foreign price shock
(4) Responses to a private demand shock

![Graphs showing responses to a private demand shock for different economic indicators.]

(5) Responses to an overall productivity shock

![Graphs showing responses to an overall productivity shock for different economic indicators.]

31
(6) Responses to a relative productivity shock

![Graphs showing the response of different economic variables to a relative productivity shock.](image)

(7) Responses to a fiscal policy shock

![Graphs showing the response of different economic variables to a fiscal policy shock.](image)
(8) Responses to an external demand shock

Table 4: Decomposition of T periods ahead forecast error variance
(note: T=1 means “at the impact”)

(1) GDP

<table>
<thead>
<tr>
<th>Shock to:</th>
<th>risk premium</th>
<th>monetary policy</th>
<th>foreign prices</th>
<th>private demand</th>
<th>overall productivity</th>
<th>relative productivity</th>
<th>fiscal policy</th>
<th>external demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=1</td>
<td>7.2%</td>
<td>2.1%</td>
<td>15.1%</td>
<td>5.5%</td>
<td>48.3%</td>
<td>11.8%</td>
<td>1.6%</td>
<td>8.5%</td>
</tr>
<tr>
<td>T=4</td>
<td>3.5%</td>
<td>0.0%</td>
<td>12.7%</td>
<td>0.4%</td>
<td>64.1%</td>
<td>15.8%</td>
<td>0.3%</td>
<td>3.2%</td>
</tr>
<tr>
<td>T=8</td>
<td>1.5%</td>
<td>0.0%</td>
<td>9.4%</td>
<td>0.1%</td>
<td>70.0%</td>
<td>17.3%</td>
<td>0.1%</td>
<td>1.7%</td>
</tr>
</tbody>
</table>

(2) Inflation

<table>
<thead>
<tr>
<th>Shock to:</th>
<th>risk premium</th>
<th>monetary policy</th>
<th>foreign prices</th>
<th>private demand</th>
<th>overall productivity</th>
<th>relative productivity</th>
<th>fiscal policy</th>
<th>external demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.7%</td>
<td>38.9%</td>
<td>10.7%</td>
<td>23.0%</td>
<td>12.0%</td>
<td>2.8%</td>
<td>0.6%</td>
<td>0.5%</td>
</tr>
<tr>
<td>4</td>
<td>2.0%</td>
<td>12.8%</td>
<td>0.3%</td>
<td>25.2%</td>
<td>40.4%</td>
<td>19.3%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>8</td>
<td>11.0%</td>
<td>0.1%</td>
<td>3.6%</td>
<td>8.4%</td>
<td>55.1%</td>
<td>21.3%</td>
<td>0.2%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>
### (3) interest rate

<table>
<thead>
<tr>
<th>shock to:</th>
<th>premium</th>
<th>policy</th>
<th>prices</th>
<th>demand</th>
<th>productivity</th>
<th>productivity</th>
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<td>0.1%</td>
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### (4) exchange rate

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<th>prices</th>
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<td>24.3%</td>
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<td>8.9%</td>
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### (5) import prices

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<th>prices</th>
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### (6) export prices

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<th>prices</th>
<th>demand</th>
<th>productivity</th>
<th>productivity</th>
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### (7) government expenditure

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<tr>
<td>8</td>
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<td>16.7%</td>
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<td>4.7%</td>
<td>36.4%</td>
<td>26.4%</td>
<td>1.0%</td>
</tr>
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</table>
7 Counterfactual impulse response analyses

A major advantage of the structural estimation approach, like the one employed in this paper, is that it allows us to conduct “what if...?” type analyses. In this section, we study how the impulse responses would look like if one of the parameter values was different from the one we have estimated. This counter-“factual” exercise would help us understand roles played by each of the parameters, not only qualitatively but also quantitatively. Given the theme of the paper, we shall focus mostly on the two key parameters that govern the degrees of exchange rate pass-through, namely $\psi_p^I$ on the import side and $c_{PCP}$ on the export side. We will also investigate reasons behind the very weak effects of fiscal policy that we saw in the previous section, by studying the roles of $pop_K$ and $e_L$. In this section, we call the impulse responses derived by setting all the parameter values at their posterior means as the “baseline” impulse responses, and they are compared to the responses derived under alternative assumptions.

7.1 Roles of exchange rate pass-through, import side

In this sub-section, we investigate the role played by $\psi_p^I$, the adjustment cost parameter for changing imported goods prices. In our estimation, its posterior mean was 4.68. In Figure 4, we try three alternative values: 0.01, 20, and 100. Note that a higher value means a lower pass-through. In the figure, we report responses of import prices, inflation rate, the interest rate and GDP in the baseline as well as the alternative cases. Note that the responses reported in this section are always responses to a one unit shock, and thus their sizes are not directly comparable to those of Figure 3. As expected, as the pass-through rate is lowered, import prices become less responsive to a currency depreciation, and so does inflation rate. This means that the central bank would increase
the interest rate by less, and thus output would contract by less.

Figure 4 Impulse responses under different values of $\psi_F$

7.2 Roles of exchange rate pass-through, export side

Next, we study the role played by the parameter $c_{PCP}$, the importance of producer currency pricing in the exporting sector. In our estimation, its posterior mean was 0.114. In Figure 5(1)-(3), we try three alternative values: 0.01, 0.5, and 0.9. Note that a higher value means a higher pass-through. In Figure 5(1), we compare responses of export prices as well as exports to a risk premium shock under different assumptions about $c_{PCP}$. As expected, a lower pass-through means that export prices become less responsive, and exports tend to react more. Note that our estimation results are close to the case of almost zero pass-through. That is, pass-through on the export side is quite limited in Japan, and this prevents export volumes from reacting strongly to exchange rate fluctuations. In Figure 5(2), we report responses of the same two variables to an external demand shock. In this case, the fact that pass-through is low in Japan means that export volumes react strongly to external demand. Figure 5(3) shows responses of the same two variables to a fiscal policy shock. A fiscal expansion crowds out exports. When the pass-through rate is high, a currency appreciation has a larger negative effect on export volumes (and, as a consequence, the yen prices of those exports do not have to decrease so much).
Figure 5 Impulse responses under different values of $c_{PCP}$

(1) Responses to a risk premium shock

(2) Responses to an external demand shock

(3) Responses to a fiscal policy shock
7.3 Roles of rule-of-thumb households

Next, we study the role played by the parameter $pop_K$, the population share of rule-of-thumb households. In our estimation, its posterior mean was 0.093. In Figure 6, we try two alternative values, 0.5, and 0.9. It is clear that the value of this parameter is a crucial determinant of the effects of fiscal policy.

Figure 6 Impulse responses to a fiscal policy shock under different values of $pop_K$

In the last panel of Figure 6, we compute the familiar “fiscal multipliers”. They are computed as follows. Note that both GDP and government expenditure are in logarithms. Thus,

$$\text{Fiscal multiplier} = \frac{\text{IRF of GDP}}{\text{IRF of Gov. Exp.}} \cdot \frac{Y^*}{G^*}$$

Where $Y^*$ and $G^*$ are the steady state levels of GDP and government expenditure, respectively. We compute two types of multipliers. An “impact” multiplier uses impulse responses for the first period in the above computation. An “eight quarters cumulative” multiplier uses the sums of impulse responses for the first eight quarters. The panel shows that the share parameter is an important determinant of the multiplier but, on the other hand, even if this share was 50%, the multiplier would still be below one.
7.4 Roles of wage rigidity

Finally, we study the role played by the parameter $e_L$, the degree of real wage rigidity. In our estimation, its posterior mean was 6.66. In Figure 7, we try two alternative values, 0.01, and 100. Two things are noteworthy. First, the effects of fiscal policy depend crucially on the value of this parameter. Second, our estimation results are almost identical to the case of extreme wage rigidity. Thus, if any parameter was driving the result of weak fiscal policy effects, this is not the one.

Figure 7 Impulse responses to a fiscal policy shock under different values of $e_L$

8 Conclusions

In this paper, we have constructed a relatively simple small open economy DSGE model which allows for the possibility of partial exchange rate pass-through on both export and import sides. This model was estimated by a Bayesian method using Japanese data. Estimation results support the idea that pass-through is partial on both export and import sides. This implies that, compared to the case of complete pass-through, exchange rate
fluctuations tend to have smaller effects on import prices (in Japanese yen) and smaller expenditure switching effects on the export side: that is, quantity of exports tends to be less sensitive to the exchange rate, though profits of exporter firms tend to vary more. We also find that policy effects are limited. In particular, fiscal policy turns out to be quite ineffective despite many modeling strategies employed in this paper that would give the policy a chance to be quite effective. In future research, we plan to study causes of this ineffectiveness further.

Appendix: convergence diagnostics

In studies using an MCMC simulation method, it is important to make sure that the simulation has converged to a stationary distribution. In this work, we check for convergence in the following way. Let T be the total number of simulations, and S be the length of the “burn-in” period. Then, starting from the “T-S+1”th run, we compute cumulative means of each simulated parameter. The results are shown in Figure A-1: in this figure, for graphical purposes, we divide those cumulative means by the average of the cumulative means between the “T+S+1”th and the Tth runs. If the process is convergent, we expect all the plots to converge smoothly to 1. Panel (1) shows results for the standard deviations of the shock terms, panel (2) is for the model parameters such as various elasticities, and panel (3) is for the AR(1) parameters of the shock processes. It is fairly clear from panels (2) and (3) that the model parameters and the AR(1) coefficients converge. Panel (1) shows that we could probably work a little more on the shock standard deviations.
Figure A-1 Convergence diagnostics

(1) Standard deviations of the shock terms.

(2) Model parameters

(3) AR(1) parameters of the shocks
Reference


