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# Oil Price Shocks and Exchange Rate Management: The Implications of Consumer Durables for the Small Open Economy\*

Michael Plante<sup>†</sup>

April 17, 2008

## Abstract

This paper examines exchange rate management issues when a small open economy is hit by an exogenous oil price shock. In this model consumer durables play an important role in the demand for oil and oil based products as opposed to the traditional role of oil as a factor of production. When prices are sticky, oil price shocks lead to reduced output, lower inflation, and real exchange rate depreciation. Output losses occur whether or not oil is in the production function because of volatile spending on durables. Tentative results suggest that flexible exchange rates produce smaller output losses and less volatile inflation in the non-tradables sector than fixed exchange rates but at the cost of front-loading real exchange rate movements.

JEL Codes: E31, F41, E52

Keywords: Oil, durables, exchange rates

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# 1 Introduction

There is a growing literature that examines how monetary policy should respond to oil price shocks. One common characteristic of many models in use is that they are closed in the sense that exchange rate movements and trade deficits are abstracted from. A host of empirical papers, however, suggest that oil prices have strong effects on both these variables. In addition, for the central banks of many small open economies current account and exchange rate movements are of great interest. Unfortunately, the previously developed theoretical models are silent on how oil price shocks will affect either of them.

The first contribution of this paper is relax the closed economy assumption by constructing a fully articulated small open economy model. The model features both traded and non-traded goods, complete integration into world capital markets, and price stickiness in the non-tradables sector. The model is rich enough to ask the question of whether or not specific exchange rate management policies might be more or less useful in dealing with exogenous oil price shocks.

The second contribution of this paper is to explicitly model the demand side channel of oil prices in a small open economy model. Many of the models in use emphasize what I call the supply side channel of oil prices while ignoring the demand side channel. That is, they assume that oil directly affects the economy in its role as a factor of production. For many economies, however, consumer durables such as automobiles are an important source of demand for oil and oil based products.<sup>1</sup> This provides a direct link between oil prices and consumer demand not found when oil is a factor of production.

Results from this paper suggest that consumer durables are an important channel for oil prices to affect the small open economy. Unlike non-durables consumption, which has a weak relationship to oil and is constrained by the intertemporal elasticity of substitution, spending on durables can be much more volatile in response to an oil price shock. This allows consumer demand to have strong effects on real output, the real exchange rate, and

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<sup>1</sup>In what follows I will refer to oil and oil based products generically as oil.

the rate of inflation.

The paper also suggests that tradeoffs exist when choosing between the polar extremes of fully flexible exchange rates and a crawling peg. For the calibrations considered, when there is a positive oil price shock flexible exchange rates appear to better buffer the economy from real output losses and also produce smaller deviations of inflation from its steady state level. This comes at the cost of larger and more rapid movements in real exchange rates than found under a crawling peg.<sup>2</sup>

The outline of the paper is as follows. In the second section I review the literature and point out more specifically how this paper differs from previous work. Section three provides some empirical motivation for incorporating open economy features and consumer durables. This section also presents some stylized facts about oil price shocks. Sections four and five deal with setting up the model and the solution procedure. Section six presents results and then the paper concludes.

## 2 Related Literature

There is a very large literature that investigates the impacts that oil prices have on the macroeconomy. It has been shown that oil price shocks are associated with, amongst other things, lower economic growth, reduced consumer demand, and in some cases with higher inflation.<sup>3</sup> For some time it was assumed that oil price shocks were the cause of these effects. An important paper by Bernanke, Gertler, and Watson (1997), however, presented evidence for the United States that suggested monetary policy responses to oil prices could be responsible for many of the apparent negative effects of oil price shocks. While some of the results of that paper have been questioned by later work such as Hamilton and Herrera (2004) and Carlstrom and Fuerst (2006), it did raise the important issue that interactions between monetary policy and oil prices should not be overlooked.

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<sup>2</sup>An extension of the current work that I hope to pursue in the near future is to look at other specifications of monetary policy.

<sup>3</sup>Those interested in further readings can find a number of references in Brown and Yucel (2002).

In light of this debate some recent papers have taken the issue up by developing optimizing models which incorporate a demand for oil and allow for real effects of monetary policy. This approach allows one to examine the implications of different specifications of monetary policy on macroeconomic variables without having to worry about a host of issues that have plagued the empirical literature. Most closely related to the work in this paper are Leduc and Sill (2004), Dhawan and Jeske (2007), Montoro (2007), and Kormilitsina (2008).<sup>4</sup>

Leduc and Sill (2004) develop a model with sticky prices and wages where oil is a factor of production. They investigate how different specifications of systematic monetary policy, such as various forms of Taylor Rules, affect inflation and output. Dhawan and Jeske (2007) extend the work in Leduc and Sill (2004) by incorporating durable goods as an additional channel by which oil affects the economy. The results from both papers suggest that an emphasis on fighting inflation, as opposed to responding to output deviations seems to produce the best results. The papers by Montoro (2007) and Kormilitsina (2008) derive optimal policy responses as opposed to examining systematic monetary policy. A key assumption found in all of these papers is that they work in the closed economy framework. All of them assume that trade must be balanced each period and ignore exchange rate movements. My paper extends the literature by removing these assumptions.

### 3 Empirical Motivation

The model incorporates open economy features and consumer durables, both of which have been relatively unexplored. This section provides motivation for including these features. It also summarizes some key facts that appear in the empirical literature.

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<sup>4</sup>Other papers in this line of work include Carlstrom and Fuerst (2006) and Leduc and Sill (2006).

### **3.1 Oil Prices and the Small Open Economy**

As mentioned earlier, empirical evidence suggests that oil prices have a variety of effects on macroeconomic variables. The earliest works in this literature, such as Hamilton (1983), produced results specific to the United States. These papers have found that for the United States oil price shocks have effects on economic growth, real exchange rates, and consumer demand, among many other variables.

One might wonder, of course, whether or not these results are specific to the United States. Other papers have shown that this is not the case. Results have been produced for Japan (Lee, Lee, and Ratti, (2001)), a number of European countries (Jimenez-Rodriguez and Sanchez,(2004), and Cunado and de Gracia, (2003)), a number of Asian countries besides Japan (Cunado and Perez de Gracia, (2005), and Abeysinghe, (2001)), and New Zealand (Gounder and Bartleet, (2007)). These papers all provide evidence that most of the effects found in the United States can also be found in these other economies, many of which could be characterized as small and open.

### **3.2 Oil Prices and the Current Account**

According to Higgins, Klitgaard, and Lerman (2006), from 2002 to 2006 the oil exporting countries have seen their revenues from oil exports rise by about 670 billion dollars to about 970 billion US dollars. While the numbers are not precise, work in the same article and in Rebucci and Spatafora (2006) suggests that at most only about half of this extra income has been used to purchase goods from abroad. As shown in Kilian, Rebucci, and Spatafora (2007) this has resulted in a worsening of the current accounts of most oil importing countries as they borrow from abroad to deal with the rise in oil prices.

### 3.3 Oil Prices and Real Exchange Rate Movements

A fair amount of empirical work has documented what appears to be a rather strong relationship between real oil prices and the real exchange rates of a number of countries. Work in Issa, Lafrance, and Murray (2006), Korhonen and Juurikkala (2007), Jahan-Parvar (2006), and many others have shown that rising oil prices produce real exchange rate appreciation in oil producing countries. This result is not surprising since many of these countries earn significant revenues from oil exports.<sup>5</sup>

A strong relationship between real oil prices and the real exchange rates also exists for oil importing countries. In general, oil importing countries tend to experience real exchange rate depreciation when oil prices rise.<sup>6</sup> Evidence has been produced for Spain (Camarero and Tamarit (2002)), New Zealand (Gounder and Bartleet (2007)), Germany and Japan (Amano and van Norden (1998)), and a number of European countries (Jimenez-Rodriguez and Sanchez (2004)). A recent paper by Chen and Chen (2006) uses panel data and also finds that real exchange rates and real oil prices are co-integrated and that higher oil prices lead to real exchange rate depreciation. Beyond this, Chaudhuri and Daniel (1998) finds evidence that the non-stationarity of real exchange rates is due to the non-stationarity of real oil prices.

### 3.4 Oil Prices and Consumer Durables

This section deals with the relationship between oil and consumer durables. I provide an argument for why the two should be modeled together, some empirical evidence regarding the response of consumer demand for durables to oil price shocks, and finally some data about how important oil use that occurs from consumer durables is with respect to other uses of oil.

Consumers purchase oil products in conjunction with consumer durables. Fuels produced

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<sup>5</sup>These countries effectively are special cases of the currency commodity countries.

<sup>6</sup>One important exception is the United States, which experiences real exchange rate appreciation.

from crude oil are often used for home heating, as an energy source for cars and trucks, and in some countries as a source of electricity. In this regard there is a tight relationship between the two which necessitates modeling them together because not doing so misses an important aspect of how oil can affect the economy.<sup>7</sup>

There is also a fair amount of empirical evidence suggesting that oil prices have strong effects on consumer demand for durables. Edelstien and Kilian (2007) presents evidence that consumer demand for durables is much more sensitive to energy price shocks than non-durables demand.<sup>8</sup> Using disaggregated data Lee and Ni (2002) finds that oil price shocks tend to have a depressing effect on the demand for durable goods while having more classic supply side effects for industries heavily reliant on oil, such as the petroleum industry. While not exactly of the same nature, impulse responses found in Bernanke, Gertler, and Watson (1997) show demand for residential housing and producer durables declining in response to oil price shocks. Further evidence is provided by Davis and Haltiwanger (2001) which shows that increasing product durability leads to stronger effects from oil price shocks. While the previously mentioned papers deal with data from the United States, I believe the results should carry over to other countries because the fundamental economic forces at play are the same in all countries.

The International Energy Agency (IEA) has a number of statistics available about energy usage. In order to gauge how important the demand side channel might be I have used IEA data to compile two useful quantities for a set of countries that can be categorized as small open economies, all of which produce little or no oil. The first quantity is the share of Total Primary Energy Supply (TPES) derived from oil for each country. TPES is defined as domestic production of energy plus net imports of energy minus uses for international bunkers plus changes in stocks. The data comes from International Energy Agency (IEA) Energy Statistics for the year 2004. Table 1 reports the percentage of TPES that each country derives from oil use. The results show that while there are exceptions to the rule

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<sup>7</sup>In some cases aggregate energy prices appear to be fairly correlated with oil prices and this would tighten the relationship between household durables and oil.

<sup>8</sup>The focus of that paper is on aggregate energy prices but the most important component of this is purchases of fuel.



many countries still produce a significant fraction of their energy from oil.

I then use IEA statistics on sectoral use of oil products to derive the percentage of oil use that could reasonably be attributed to household use. There is, unfortunately, some uncertainty about this quantity. This occurs because use associated with the transportation sector contains demand from both firms and households. To deal with this I report in table two a high and low value for consumer demand. The high value considers oil use for the transportation sector and residential use while the low value considers only oil use reported for residential use.

Given that most household demand for oil is probably due to automobiles, I believe that the low number significantly understates actual consumer demand. I instead choose to focus on the high end results while keeping in mind that these numbers probably overstate the importance of the demand side channel.

Table 2 suggests that the countries can roughly be broken into three groups. The first group consists of countries where industry is the major consumer of oil, such as South Korea, Taiwan, Singapore, and Iceland. For these countries, it would probably be more relevant to consider oil as an input to production if we wanted to see how an oil price shock drives macroeconomic variables. The second group consists of countries where the producer and consumer channel seem roughly equal, such as Holland and Finland. Finally there are those countries where household demand seems to play the major role, such as in New Zealand and Luxembourg.

### **3.5 Monetary Policy and Consumer Durables**

In addition to the relationship between oil prices and consumer durables there is also an important connection between monetary policy/exchange rate management and consumer demand for durable goods which I feel should be emphasized if we are discussing monetary responses to oil price shocks.

As shown in many papers, including Erceg and Levin (2006), Buffie and Atolia (2007),

and Buﬃe and Atolia (2005), spending on consumer durables can be highly sensitive to movements in interest rates and exchange rates. This occurs because durables are a form of investment from which a significant proportion of the utility derived occurs in the future. Therefore, any reduction in the cost of them leads to big swings in purchases.

In a model where prices are sticky and output varies in response to consumer demand, oil prices alone would tend to depress output because consumers will spend less on both durables and non-durables. Sub optimal responses of monetary policy, however, could also lead to reductions in output. This loss in output will be magnified when consumer durables are included in the model.

## 4 The Model

The model is a continuous time, perfect foresight model with a representative agent. The economy is a small open economy completely integrated into world financial markets with access to a tradable real bond,  $b$ .

The economy in question produces a fixed amount of a composite traded good,  $Q_t$  and a non-traded good  $Q_n$ . In this paper production is assumed to be completely exogenous. This is done to focus on the role of consumer demand in driving macroeconomic variables. An important extension I hope to pursue in the near future will be make production endogenous so as to allow oil to have two channels to affect the economy.

The agent derives utility from a consumption good,  $C$ , which is a composite of consumption of both the traded good and nontraded good,  $C_t$  and  $C_n$  respectively. In addition, the agent also derives utility from the service flow of a durable good,  $S$ , which is produced using a stock of durables,  $D$ , and oil,  $O$ .<sup>9</sup> Money is motivated by assuming that the agent derives utility from holding real money balances, which are denoted by  $m$ .

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<sup>9</sup>More generally, I have in mind all products that are close substitutes for oil products and whose price tracks the price of oil.

## 4.1 Prices

There are seven prices in the model: the nominal exchange rate,  $e$ ; the nominal price of the non-traded good,  $\tilde{P}_n$ ; the real price of oil in dollars,  $P^o$ ; the dollar price of the traded good,  $P^*$ ; the relative price of the non-traded good,  $P_n = \frac{\tilde{P}_n}{e}$ ; the price of the durable good,  $P_d$ ; and a measure of aggregate prices,  $P$ . I assume that the traded good is the numeraire so prices and wealth are measured in dollars.

The country in question is neither a large producer nor consumer of oil products on the world market. As such the price of oil is taken as completely exogenous.<sup>10</sup> Because the economy is small, the price of the traded good is also exogenous and is set to 1 for convenience, so the nominal exchange rate sets the domestic price of the traded good.

There are several ways to model durable goods. For example, Erceg and Levin (2006) work with a two-sector economy with a durable and non-durable sector. Given the emphasis here on open economy matters I assume instead that the durable good is a composite good composed of 1 unit of a traded durable and  $a_1$  units of the non-tradable good. Given this assumption the price of the durable is therefore

$$P_d = 1 + a_1 P_n. \tag{1}$$

This assumption captures the notion, discussed at some length in Burstein, Neves, and Rebelo (2003), that distribution and retail costs are an important component of the prices of many tradable goods (here limited to durables).

Prices in the nontradables sector are assumed to be sticky as in Calvo and Vegh (1993). Firms change their prices only when they receive a random signal. Sticky prices imply that output in the nontradables sector is demand determined. It can be shown that the differential equations governing  $P_n$  and  $\pi_n$  are

$$\dot{P}_n = (\pi_n - \chi) P_n, \tag{2}$$

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<sup>10</sup>I have in mind countries such as New Zealand, Switzerland, and Iceland.

$$\dot{\pi}_n = -\alpha (C_n + a_1 I_d - Q_{n,o}), \alpha > 0, \quad (3)$$

where  $Q_{n,o}$  is notional output, in this case the steady state level of non-tradables output.<sup>11</sup>

In this model the domestic price level,  $P$ , is a measure of core prices, that is it excludes oil prices.  $P$  is a geometric weighted average of the price of the traded good and the non-traded good,

$$P = e P_n^\gamma. \quad (4)$$

so that the core inflation rate is

$$\pi = (1 - \gamma)\chi + \gamma\pi_n, \quad (5)$$

where  $\pi_n$  is the rate of inflation of in the non-tradables sector and  $\gamma$  is the expenditure share of the nontradable good in overall spending. That is,  $\gamma \equiv \gamma_{nd}\gamma_{xd} + \gamma_{ne}\gamma_{xe}$ , where  $\gamma_{xe}$  and  $\gamma_{xd}$  are the expenditure shares of non-durables and durables and  $\gamma_{ne}$  and  $\gamma_{nd}$  is the share of the non-tradable good in the relevant expenditure share.

## 4.2 Financial Markets

The agent can buy and sell bonds,  $b$ , in a perfect world capital market. Interest parity holds so that the nominal interest rate is

$$i = r + \chi. \quad (6)$$

## 4.3 The Agent's Optimization Problem

The agents instantaneous utility function is of the form

$$U [C (C_t, C_n), S (D, O)] - R \left( \frac{I}{D} - \delta \right) D + \phi \left( \frac{M}{P} \right). \quad (7)$$

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<sup>11</sup>To derive (2) take the time derivative of  $P_n = \frac{\tilde{P}_n}{e}$ . For a derivation of  $\pi_n$  see Calvo (1983)

The function  $C(C_t, C_n)$  aggregates consumption of the nontradable and tradable good.  $U[C(C_t, C_n), S]$  is utility derived from the service flow and the aggregated consumption good. Utility from holdings of currency is represented by the function  $\phi\left(\frac{M}{P}\right)$ . Note that while utility is possibly non-separable in  $C$  and  $S$  it is separable in real money balances.

The function  $S(D, O)$  is a production function for the service flow. In many models the service flow is proportional to the stock of durables. In this model, however, generation of the service flow requires oil as an input. Loosely speaking, one can view  $O$  as representing not only oil but also products which are derived directly from oil, such as gasoline, diesel, and heating oil.

As with capital goods, investment in durable goods is ridiculously volatile in models without some form of adjustment costs. The function  $R$  represents a form of adjustment costs known as deliberation costs first introduced in Bernanke (1985). As discussed in Bernanke's paper, purchasing a durable good is a much more complicated and time consuming affair than purchasing a consumption good. Generally, the decision to do so requires a good deal of time and effort on the part of a consumer. The function  $R$  reflects, in some sense, utility lost from possibly worrying about the decision and/or lost leisure from the time spent in preparation for the purchase.

Before setting up the agent's optimization problem I perform two preliminary algebraic steps on the utility function. First, I replace  $C$  with its indirect utility function. This is done by solving for the Marshallian demand functions for  $C_t$  and  $C_n$ , given the constraint  $C_t + P_n C_n = E$ , where  $E$  is real non-durables expenditure measured in dollars, and substituting these solutions into  $C$ . I denote the solution to this problem as  $H(E, P_n)$  and using this re-write  $U$  as  $V[H(E, P_n), S(D, O)]$ .

Second, as originally written  $\phi$  is a function of  $\frac{M}{P}$ . It is helpful to re-write this in terms of  $m = \frac{M}{e}$  using the aggregate price index. Doing this  $\phi$  can be re-written as

$$\phi\left(P_n^{-\gamma} m\right). \tag{8}$$

With these preliminary steps done the agent's problem is to maximize

$$\int_0^{\infty} \{V[H(E, P_n), S(D, O)] - R\left(\frac{I}{D} - \delta\right)D + \phi(P_n^{-\gamma}m)\}e^{-\rho t} dt, \quad (9)$$

subject to a wealth constraint

$$a = m + b, \quad (10)$$

a flow constraint on the accumulation of the durable good,

$$\dot{D} = I - \delta D, \quad (11)$$

and the budget constraint

$$\dot{a} = Q_t + P_n Q_n + P_n^\gamma g + rb - E - P_d I - P^O O - \chi m. \quad (12)$$

In the budget constraint  $g$  is lump sum transfers from the government. This term is multiplied by  $P_n^\gamma$  because they are indexed to aggregate prices but the numeraire is the traded good.

Define  $\omega_1$  and  $\omega_2$  as the multipliers on the flow constraints. The first order conditions for the problem are

$$V_E = \omega_1 \quad (13)$$

$$V_s S_o = P^o \omega_1 \quad (14)$$

$$\omega_2 = R' + P_d \omega_1 \quad (15)$$

$$\frac{\kappa_3 \phi_m}{\omega_1 P_n^\gamma} = r + \chi \quad (16)$$

$$\dot{\omega}_1 = \omega_1 (\rho - r) \quad (17)$$

$$\dot{\omega}_2 = -V_s S_d - R' \frac{I}{D} + (\rho + \delta) \omega_2 + R. \quad (18)$$

The first four of these equations are simply the first order conditions equating the marginal benefits of  $E$ ,  $O$ ,  $I$ , and  $m$  with their respective marginal costs. The latter two equations

are the co-state equations for  $b$  and  $D$ .

#### 4.4 The Public Sector

The consolidated government budget constraint is

$$\dot{m} = P_n^\gamma g + \dot{k} - rk - \chi m. \quad (19)$$

The variable  $k$  represents the holdings of the bond by the government. I assume that the government has access to the tradable bond and invests all foreign exchange holdings into this asset.

#### 4.5 Market Clearing

Total consumption of the non-traded good is given by non-durables consumption as well as the non-traded component of the durable good. The market clearing condition in the non-tradable sector is therefore

$$C_n + a_1 I = Q_n. \quad (20)$$

#### 4.6 Net Foreign Asset Accumulation

Combining the consolidated government budget constraint and the agent's budget constraint gives an equation linking the current account and net foreign asset accumulation,

$$\dot{Z} = P_n Q_n + Q_t + rZ - E - P_d I - P^o O, \quad (21)$$

where  $Z = k + b$ . Note that if one imposes the market clearing condition for the non-tradables sector this reduces to

$$\dot{Z} = Q_t + rZ - C_t - I - P^o O.$$

## 5 Calibration and Solution Method

### 5.1 Functional Forms

Solving the model requires specifying functional forms for  $U$ ,  $S$ ,  $C$ ,  $R$ ,  $\phi$ , and  $H$ . In this paper I work with the following functional forms:

$$\begin{aligned}
 U [C, S (D, O)] &= \frac{[C^a + \kappa_1 S^a]^{\frac{w}{a}}}{w}, \\
 S (D, O) &= \left[ D^b + \kappa_2 O^b \right]^{\frac{1}{b}} \\
 C (C_t, C_n) &= \left[ C_t^x + \kappa_4 C_n^x \right]^{\frac{1}{x}} \\
 \phi (m) &= \kappa_3 \frac{(P_n^{-\gamma} m)^w}{w}, \\
 R \left( \frac{I}{D} - \delta \right) &= \frac{v}{2} \left( \frac{I}{D} - \delta \right)^2, \\
 H (E, P_n) &= E \left( 1 + \kappa_4^\nu P_n^{1-\nu} \right)^{\frac{1}{\nu-1}},
 \end{aligned}$$

with

$$\begin{aligned}
 a &= \frac{\sigma-1}{\sigma}, \\
 b &= \frac{\beta-1}{\beta}, \\
 x &= \frac{\nu-1}{\nu} \\
 w &= 1 - \frac{1}{\tau}.
 \end{aligned}$$

The parameters have the following interpretations:

- $\sigma$ : Elasticity of substitution between the consumption good and the service flow
- $\tau$ : Intertemporal elasticity of substitution.
- $\beta$ : Elasticity of substitution between the durable good and oil.
- $\nu$ : Elasticity of substitution between non-durables consumption of the traded and non-traded good.
- $\kappa_1, \kappa_2, \kappa_3, \kappa_4$ : Distribution parameters.
- $v$ : Distribution parameter for deliberation costs which controls the volatility of  $I$ .



## 5.2 The Real Price of Oil

It is necessary to specify how oil prices behave in the model. The standard way of doing so in the theoretical literature has been to work with a Wold representation of the price process. The parameters for this process are either calibrated or estimated and impulse response functions are then analyzed for temporary price shocks.

While this is a useful approach a few caveats should be mentioned. First, some of the more famous oil price shocks, such as the big shocks in the 1970s and 80s appear as permanent one time jumps in the price level. In addition, the results from estimating the price process are sensitive to the sample period used. Full sample studies which use data from the late 1940s to the present typically find that the real price series is non-stationary. Akarca and Andrianacos (1997), however, find a break in the oil price series such that pre-86 prices appear non-stationary whereas post-86 prices appear to be stationary. One last caveat is given by recent work in Kilian (2007) which suggests that oil prices are driven by three types of shocks: supply shocks, shocks to global economic activity, and oil specific demand shocks. Each type of shock appears to lead to different behavior on the part of oil prices.

Reflecting on all of this uncertainty I have decided to examine the implications of two types of oil price shocks. In the first case, I work under the assumption that shocks to the price of oil are persistent, but temporary, in nature. Following a surprise shock the price declines monotonically to its steady state level according to

$$\dot{P}^o = \theta (P_o^o - P^o), \theta > 0 \quad (22)$$

where  $P_o^o$  is the initial steady state level of the real price of oil. In the second case I posit that the price of oil permanently jumps to a new steady state level.<sup>12</sup>

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<sup>12</sup>A possibly more interesting case, not analyzed here, is the situation where agents mistakenly believe that a permanent price shock is actually temporary for some length of time.

### 5.3 Initial Values and Deep Parameters

The model is calibrated to an initial steady state with parameter and starting values chosen to represent a typical oil importing small open economy. Table 3 at the end of the text contains the starting values for the variables in the model as well the values of the deep parameters. An appendix provides a more detailed description of the calibration procedure itself while the following paragraph gives a discussion about some of the choices.

- **Intertemporal elasticity of substitution ( $\tau$ ).** A number of papers have provided estimates for this parameter in developed countries. The main problem with using previous results is that papers such as Ogaki and Reinhart (1998a), Ogaki and Reinhart (1998b), and Pakos (2006) show that estimates of this parameter are sensitive to whether or not durables are included in the model and how  $S$  is modeled. The formulation of  $S$  in this paper has not, to my knowledge, been estimated before so an educated guess must be made. The previous works suggest that a value somewhere between 0 and 1 is most likely so I calibrate  $\tau$  to .50.
- **Elasticity of substitution between the consumption good and the service flow ( $\sigma$ ).** Whether or not  $C$  and  $S$  are compliments, substitutes, or separable depends upon both the magnitude of  $\tau$  and  $\sigma$ .<sup>13</sup> Unfortunately, estimates of this parameter are sparse and imprecise, even for developed countries. Also, as with  $\tau$ , the estimates that have been found appear to be sensitive to different specifications of  $S$ . Given this uncertainty I use the separable case as the baseline model.
- **Time preference rate ( $\rho$ ).** The time preference rate is set to equal the world real interest rate. How one chooses the exact level of this depends on what assets one looks at. I consider an interest rate of .05 which is in between the return on US Treasuries and stocks.
- **Elasticity of substitution between durables and oil ( $\beta$ ).** Estimates of this parameter were impossible to find even if one considers energy in general as opposed to

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<sup>13</sup>More specifically,  $C$  and  $S$  are compliments, separable, or substitutes as  $\tau - \sigma$  is greater than, equal to, or less than zero.

oil products. Previous papers, such as Dhawan and Jeske (2006), have relied on educated guesses. Estimates for this elasticity do exist for capital goods but the results are all across the board. Common sense suggests, however, that in the short run this parameter should be relatively small as it is very difficult to substitute towards more fuel efficient durables in the short run. Another justification for a small value is that large values of this parameter will lead to large swings in the use of oil in the model and this has not been seen in the data. With this in mind, I calibrate it at a low value of .25.

- **The q-elasticity of durables spending ( $\Omega$ ).** The parameter  $v$  in the function  $R$  can be calibrated by choosing a value of the q-elasticity of durables spending, which I label as  $\Omega$ .<sup>14</sup> This parameter controls the volatility of spending on consumer durables. More specifically, up to a first order it controls the size of the initial jump in spending on durables when there is an oil price shock, with larger values allowing for a large jump. Unfortunately, the literature has generally resorted to guessing its value, with guesses ranging from 5 (Buffie and Atolia, (2007)) to 200 (Baxter, (1996)). My baseline calibration works with a value of 10.
- **Elasticity of Substitution between non-traded and traded, non-durables consumption ( $\nu$ ):** As discussed in Buffie and Atolia (2005) studies generally find low elasticities of substitution at high levels of aggregation. Working on this assumption I set  $\nu$  to .50.
- **Speed of Price Adjustment in the Nontradables Sector ( $\alpha$ ).** I choose a value of 3 which suggests that prices adjust fairly rapidly but not instantaneously.
- **Speed of Adjustment of Oil Prices ( $\theta$ )** Estimates for this parameter exist for monthly and quarterly data but are subject to the caveats mentioned earlier. Pre-86 data suggest a value between .95 and 1 for the corresponding AR(1) coefficient while post-86 data suggest a value around .90. This corresponds to a range for  $\theta$  between .10 and 0. I choose the conservative value of .10 for the case of a temporary shock. My

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<sup>14</sup>More specifically, it can be shown that in a steady state  $v = \frac{P_d V_E}{\Omega \delta}$ .

analysis of a permanent price shock captures the case when  $\theta$  is 0.

- **Expenditure Shares** Total expenditure in the model is given by  $E + P_d I + P^o O$ . The expenditure shares are denoted as

$$\begin{aligned}\gamma_{xe} &= \frac{E}{E + P_d I + P^o O}, \\ \gamma_{xd} &= \frac{P_d I}{E + P_d I + P^o O}, \\ \gamma_{xo} &= \frac{P^o O}{E + P_d I + P^o O}.\end{aligned}$$

Finding exact, model equivalent shares in the data is complicated. For example, different countries use oil for different purposes. In some cases, like Iceland, oil's primary purpose is as a fuel for automobiles. In others, like Ireland, it is used not only for automobiles, but for generating electricity and providing heat in homes. This means that the relevant measure of durables spending might also vary across countries. Instead of trying to be dogmatic about these shares I instead investigate several data sources and several different definitions of spending for a number of OECD countries to get a feel for the range of possible values.

The first source of data is the National Income Accounts (NIA) tables recorded by the OECD for the years of 2000-2005. The NIA tables provide data on consumer expenditures broken down into a number of different components. With this data it is possible to decompose spending into non-durables spending (spending on goods and services), durables spending, and spending on oil and oil related products.

As far as spending on oil products is concerned, the NIA tables contain two possibly relevant measures, "Electricity, gas, and other fuels" and "Operation of personal transport equipment". Expenditure shares that focus on just "Operation of personal transport equipment" range from about five to ten percent of spending while adding "Electricity, gas, and other fuels" pushes the range from about ten percent to fifteen percent.

The second source of data used is the International Energy Association's publication Oil Information. This work provides detailed input-output style tables for petroleum

products. Using these tables it is possible to calculate the total amount of petroleum products imported (recorded in metric tonnes oil equivalent). Conversion formulas then allow for a measure of the number of barrels of oil imported. Fixing a dollar price for a barrel of oil would allow an approximation to be made of the total amount spent on importing oil products.<sup>15</sup> For a price of \$ 30 a barrel, roughly the average price for the latter half of the 90s and the first part of the 2000s, the expenditure shares range from 2 to 4 percent. A price of \$ 50 a barrel pushes this up from about 3 to 6 percent.

Given the wide range of potential estimates I have decided to calibrate  $\gamma_{xo}$  to .05. This seems to be a reasonable compromise between the high end estimates of .15, which are based on the NIA tables, and the low end estimates of .02 based on my own calculations using the IEA tables.

To calculate the expenditure share on durables I rely solely on the NIA tables. These tables are detailed enough to allow for broader or narrower definitions of durables spending if necessary. A broad measure of durables that includes some spending on housing, purchases of automobiles, and purchases of household appliances puts the expenditure share between about 15 to 23 percent depending on the country. A smaller measure of durables which focuses on purchases of automobiles and durables such as lawnmowers reduces this range from about 8 to 15 percent. I choose to calibrate  $\gamma_{xd}$  at .15 as this seems neither too high nor too low, and also reflects uncertainty regarding the country specific measure of durables.

Given the uncertainty regarding some of the parameter values I undertake some sensitivity analysis. This is discussed at the end of section 6.

## 5.4 Solution Method

As is well known, the small open economy model is saddled with a unit root problem. In response to a shock the steady state of the model changes but by how much depends on the

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<sup>15</sup>Note, this value understates true spending because it does not take into account the fact that finished products will cost more to import than crude oil itself.

transition paths of the variables. These transition paths, of course, in turn depend on the new steady state of the model so that the transition paths and the new steady state need to be computed simultaneously in order to get the correct solution.

The model is solved using a method discussed in Schmitt-Grohe and Uribe (2003). The real interest rate is posited to be a function of the debt-gdp ratio of the economy,

$$r = \rho + h \left( \frac{Z}{P_n Q_n + Q_t} - \frac{Z_o}{P_{n,o} Q_{n,o} + Q_{t,o}} \right), \quad h < 0. \quad (23)$$

The parameter  $h$  is assigned a tiny value which implies that even very large changes in the debt-gdp ratio of the economy lead to tiny changes in the world real interest rate. This keeps the interest rate nearly constant and replaces the 0 eigenvalue in the model with a very small negative number. It should be noted, however, that this method introduces some error into the solutions. The hope is, however, that for the time horizon of interest the transition paths given by this method are close to the non-linear solution.

## 6 Results

The model is complicated but it is not impossible to understand the results. Good intuition can be had by thinking about five specific forces at work when there is an oil price shock.

- **Income Effect of an Oil Price Shock** Perhaps one of the most important effects in the model is the income effect. Increases in the price of oil directly reduce the real income of the consumer which leads to reductions in  $C$ ,  $I$ , and  $O$  along the transition path.
- **Substitution Effect of an Oil Price Shock** Increases in the price of oil raise the cost of producing  $S$  for the agent. As  $S$  varies along the transition path so will  $C$ . The exact direction of this effect depends upon on whether  $C$  and  $S$  are compliments or substitutes.
- **Current Account Effects** The open economy aspect of the model allows the agent

to smooth away shocks by running trade deficits (surpluses) when the price of oil is temporarily higher (lower).

- **Market Clearing in the Non-tradables Sector** A positive oil price shock reduces consumer demand for the non-tradable good. As the non-tradables market must clear at any point in time this requires adjustment of either the price level or the quantity produced. Fully flexible prices insure that the price level adjusts so that output remains at its steady state level. When prices are sticky, however, there is a combination of falling prices and output.
- **Consuming the Stock of Durables** At any instant in time the agent holds a stock of durables. This stock plays a form of savings because the agent can temporarily consume more by allowing the stock to depreciate over time.

The rest of the section is devoted to discussing the transition paths of the variables of the model. I first examine the case of a temporary oil price shock and then look at the case of a permanent change in the price of oil.

The variables reported are real non-durables expenditure, real durables expenditure, debt, real output in the non-tradable sector, the relative price of the non-tradable good, the rate of crawl, core inflation, and inflation in the non-tradable sector. The variables not related to prices are measured in percentage terms from their original steady state values. Note that the non-stationarity of the model implies that many of these variables do NOT return to their original steady state value, so that the percentage terms do not decline to 0.<sup>16</sup>

## 6.1 Temporary Shocks to the Price of Oil

### Case 1: Flexible Exchange Rates

When exchange rates are fully flexible the government never intervenes in the foreign ex-

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<sup>16</sup>Under the approximation method these variables return to their steady state values after many many years.

change market so  $\dot{k}$  is always 0 and equations (19) and (21) read

$$\dot{m} = P_n^\gamma g + rk_o - \chi m, \quad (24)$$

$$\dot{b} = P_n Q_n + Q_t + rb - E - P_d I - P^o O. \quad (25)$$

The core dynamic system consists of equations (17), (18), (24), (25), (11), (22), (2) and (3). The jump variables in the system are  $\omega_1$ ,  $\omega_2$ ,  $P_n$ , and  $\pi_n$  while the pre-determined state variables are  $b$ ,  $D$ ,  $P^o$ , and  $\tilde{m} = \frac{M}{\tilde{P}_n}$ .<sup>17</sup> The model is linearized around the initial steady state and solved using standard techniques. The solution to the linearized model exists and is unique.

At time 0 there is an unexpected 25 percent increase in the price of oil. Although the price shock is fairly persistent ( $\theta = 0.10$ ) most of the action happens in the first five years so I only report the transition paths up 15 years.

The rise in the price oil reduces the real income of the consumer and also raises the price of  $S$ . This produces a small negative drop in real non-durables expenditure on the order of less than a percent. Investment spending on durables, however, drops significantly more, by about six percentage points. The economy makes good use of the tradable bond and accumulates a fair amount of debt, on the order of 4 percent of GDP, as it borrows to smooth consumption over time.

Sticky prices in the non-tradables sector implies that some combination of price and output adjustment has to occur to clear this market. In the case of fully flexible prices the price would do all of the adjusting and output would remain at its initial steady state level. There is still some adjustment of the relative price which occurs because there is an instantaneous exchange rate depreciation but this depreciation is not enough to fully offset the reduction in consumer demand. Hence there is a short lived but very noticeable drop in output in the non-traded sector.

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<sup>17</sup>One could replace  $\omega_1$  and  $\omega_2$  with equations for  $E$  and  $I$ .



Another interesting result of the model is that the rate of inflation (both in the non-traded sector and core) is reduced by the oil price shock. Usual thinking about oil price shocks, focused on its role as a factor of production, assumes that an oil price shock should increase inflation. That is not the case here because oil price shocks act as a demand shock by reducing consumer demand. An interesting question that needs to be addressed in future research is how robust this result would be if oil affected production directly. There would then be two competing forces pulling inflation in opposite directions.

### **Case 2: A Crawling Peg**

On the opposite side of the exchange rate policy spectrum is the crawling peg. The government fixes the rate of depreciation at some level  $\chi$  and trades in the foreign exchange market to protect the rate of crawl. At any instant in time the nominal exchange rate is fixed and the public can effectively trade domestic currency for the tradable bond at that rate.

The equations in the core system are now (17), (18), (21), (11), (22), (2) and (3). When the exchange rate is fixed the variables in the core system are  $\omega_1$ ,  $\omega_2$ ,  $D$ ,  $Z$ ,  $P^o$ ,  $P_n$  and  $\pi_n$ . Real money balances are now endogenously determined in the model and do not enter the core system. The jump variables in the core system are  $\omega_1$ ,  $\omega_2$ , and  $\pi_n$ . In this case,  $P_n$  is a predetermined state variable as both the nominal exchange rate and the nominal price of the non-traded good are fixed at any point in time.<sup>18</sup> The model is linearized around the initial steady state and solved using standard techniques. The solution exists and is unique.

The fact that the relative price of the non-traded good is a pre-determined variable leads to some important differences between the crawling peg and flexible rates. When exchange rates are flexible the jump in oil prices leads to an instantaneous nominal exchange rate depreciation at time 0. This brings about an initial drop in the relative price of the non-traded good which helps ease the reduction in output that would be needed to clear the market. When the exchange rate is fixed this effect disappears and the adjustment must take place elsewhere, namely in the initial drop in output and in the inflation rate.

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<sup>18</sup>Remember that  $P_n = \frac{\bar{P}_n}{e}$ .

The transition paths for the variables are shown in figure 2. The shapes of the transition paths are generally similar and as before most of the action takes place in the first five years. Quantitatively the results reflect the intuition presented in the previous paragraph. In particular, the drop in consumer spending, and consequently output in the non-traded sector and the inflation rate, is larger than the case of flexible exchange rates. Fixed rates, however, avoid the sudden jump in the real exchange rate.

### **Summary**

Overall, exogenous shocks to the real price of oil have a number of effects on the small open economy. First, they reduce non-durables and durables expenditure because of their effect on real income. Second, they lead to trade deficits and accumulation of debt as the economy attempts to smooth away the shock. Third, whether or not prices are flexible or sticky, oil price shocks lead to real exchange rate depreciations.

When exchange rates are flexible, nominal exchange rate depreciation and drops in the price of the non-traded good lead to real exchange rate depreciation. When exchange rates are fixed, the real depreciation still occurs except that the effect is fully from adjustment to the nominal price of the non-traded good. When prices are sticky these shocks cause reductions in the rate of inflation and in output because they reduce consumer demand across the board.

As far as policy recommendations are concerned the preliminary results suggest that when prices are sticky flexible exchange rates are the better option unless there is particular emphasis on the real exchange rate. This is true for the simple reason that depressed consumer demand leads to a slow down in the non-tradables sector. The nominal exchange rate depreciation that occurs when rates are flexible aids in the adjustment process and leads to less output loss and less deviations from the steady state rate of inflation, both core and non-tradables inflation.

## 6.2 Permanent Shocks to the Price of Oil

In this section I consider the case where there is a one time 25 percent increase to the steady state level of oil prices. The fact that the shock is permanent may have important implications for the previous results because when a shock is permanent there is little incentive to smooth it away. Instead, it is very possible that the agent will adjust to the shock fairly rapidly. It turns out, however, that the inclusion of a stock of durables and the non-traded sector prevent such instantaneous adjustments so that permanent shocks still can have interesting dynamics. The results for the permanent shock are summarized as in the case of a temporary shock, with flexible rates examined before the crawling peg.

### Case 1: Flexible Exchange Rates

If prices were fully flexible the results would be fairly straightforward (and boring). Most of the variables would instantaneously jump to their new steady state levels and dynamics would be almost non-existent. With sticky prices in the non-tradable sector, however, this kind of instantaneous adjustment is impossible. The results of the permanent shock are shown in figure three. The results are quite similar to the case of the temporary shock. There are large drops in spending at  $t = 0$ , losses in output, and reductions in inflation.

One result at odds with the temporary shock is that the agent accumulates a small amount of the tradable bond. While this seems odd a logical explanation exists. Essentially, the rise in the price of oil reduces the steady state level of the durable that the agent would like to hold. In order to reach this new steady state level the agent runs down his stock of durables. Some of this goes towards non-durables consumption and some of this is saved in the form of the tradable bond.

It should be noted that the accumulation of assets is at odds with the experiences of most countries and the problem here appears to be that the consumer adjusts his spending too quickly which is not what appears to happen in reality. This deserves more attention and I hope to resolve this issue in the future.

### Case 2: A Crawling Peg

Suppose now the exchange rate policy is a crawling peg. In this case, the permanent rise in the price of oil causes a permanently higher steady state rate of crawl. I assume that the government adjusts its rate of crawl at the time of the shock so that the policy is sustainable.

Once again the important result comes from the fact that the fixed exchange rate hampers adjustment in the non-tradables sector. As in the case of a temporary shock, flexible exchange rates provided for some adjustment in the relative price of the non-traded good. This adjustment no longer takes place so that the full brunt of the price shock falls on output and inflation.

The results for the crawling peg are shown in figure four. As was hypothesized, because  $P_n$  is predetermined the permanent shock affects consumer demand, output, and inflation more so than it does in the flexible exchange rate. As in the previous case the agent once again accumulates a small amount of the traded bond.

### **Summary**

When the oil price shock is permanent incentives to smooth away the shock are much less important so that without some kind of friction most variables should jump very close to their new steady state levels. Durables and sticky prices in the non-tradable sector creates just such a friction. Permanent shocks lead to reduced consumer demand and output just as in the case of temporary shocks.

One counterintuitive result that shows up in both cases is that the agent accumulates assets in the form of the tradable bond. This occurs because permanently higher oil prices reduce the steady state level of durables and on the transition path the agent eats some of the stock by allowing it to depreciate. This result goes against what has usually occurred for oil importing countries and suggests that further work needs to be done on the model for permanent price shocks.

The policy recommendations offered earlier for temporary shocks seem to apply to this case as well. When prices are sticky fixed exchange rates hinder the adjustment of the relative price of the non-traded good which leads to reductions in output that go beyond that which

occurs when exchange rates are flexible.

### 6.3 Sensitivity Analysis

Given the uncertainty surrounding some of the calibrated parameter values it is of interest to check how sensitive the results are to other calibrations. For the sake of brevity I do not present the results and instead focus on a summary and intuitive explanations for why they occur.<sup>19</sup>

- **The q-elasticity of durables spending ( $\Omega$ )**

This parameter essentially controls how large of an initial drop will occur in durables spending when there is an oil price shock. The baseline calibration is 10 but I experimented with values ranging from  $\frac{1}{2}$  to 200. Higher (lower) values of this parameter lead to larger (smaller) jumps in investment spending, which leads to larger (smaller) output losses and larger (smaller) reductions in inflation.

- **Adjustment of oil prices ( $\theta$ )** I chose a conservative estimate of  $z = \frac{1}{10}$ . Making the shock more (less) persistent makes the outcomes (worse) for the economy in question, with larger output losses the more persistent the shock.

- **The non-traded component of the durable good ( $a_1$ )** Higher (lower) values of this number worsen (improve) the impacts on the non-traded sector for obvious reasons. When this number is higher (lower) the drop in durables spending hits the non-traded sector more (less).

### 6.4 Habit Formation

One qualitative aspect of most the responses is that they all have large drops at  $t = 0$  followed by (generally) monotonic rises over time. The limited empirical evidence available suggests that in response to an oil price shock there is typically little movement in variables such as

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<sup>19</sup>Results are available upon request.

durables spending and output in the first few quarters. Instead, the responses appear to be hump shaped with the strongest effects showing up within a year or two and then rapidly reversing themselves thereafter.

At this point, it is not clear whether correcting this would overturn any of the results found earlier. For example, is it still the case that the flexible rate offers lower output losses? In the interest of exploring this issue I modify the model by including a special type of habit formation. This type of habit formation, unlike the usual specification, does not assume that people form habits in the stock of durables. Instead, it assumes that people form habits over the level of spending on consumer durables.

Incorporating this type of habit formation requires changing the functional form of the deliberation costs. To this end I specify that

$$R(I, H) = \frac{v}{2} \left( \frac{I}{H} - 1 \right)^2 H, \quad (26)$$

$$\dot{H} = q(I - H), \quad q > 0. \quad (27)$$

This specification requires calibrating  $\Omega$ , as before, but also the parameter  $q$ . I calibrate these parameters in order to roughly match two features that appear in the data. The first is the small initial response in durables spending. The second is the fact that durables spending and output tend to reach a trough rather rapidly, within a year or at most two, and then rapidly rise again following this. Sensitivity analysis on my part led me to calibrate the two parameters to  $\Omega = \frac{1}{2}$  and  $q = 30$ . Given this calibration the initial drop in real spending on durables is less than a percent, reaches a trough in roughly a year or so, and then recovers and overshoots by year three.

The results for the model with temporary shocks with habit formation are contained in figures 5 - 6. The transition path of real durables spending displays the small initial jump, the rapid drop in spending, and the rapid recovery and overshooting that was just discussed. This new result tends to produce similar shaped responses in most of the other variables such as real output and real non-durables consumption.

The most important result, however, is that the inclusion of habit formation and the qualitative changes in the shape of the responses do not change the previous result regarding flexible versus fixed exchange rates. More specifically, fixed rates still lead to less volatile real exchange rate movements but produce larger drops in output and inflation.

## 7 Conclusion

Previous research on the interactions between monetary policy and oil prices have worked with closed economy models. Empirical research, however, has shown that oil prices have strong impacts on variables such as the real exchange rate and the current account. These variables are of great importance to central bankers from small open economies but are abstracted from in the previous models developed.

This paper contributes to the literature by constructing a small open economy model which can provide guidance as to the likely effects of oil price shocks and help answer the question of whether exchange rate policy matters for the evolution of macroeconomic variables. The model incorporates a non-traded sector so that real exchange rate movements are possible. Consumer durables are the main channel by which oil affects the economy. I examine the implications of flexible exchange rates versus crawling pegs and temporary versus permanent oil price shocks. I also explore the implications of a specific type of habit formation in the model.

There are several key results. First, it is possible to generate recessionary effects from an oil price shock even if oil does not directly affect production. Volatile spending on consumer durables can lead to sharp reductions in consumer demand. If prices are sticky in the non-tradables sector this leads to reductions in output. Second, contrary to the popular belief that oil prices cause inflation, the model predicts that reduced inflation is a possible consequence of an oil price shock when oil does not directly affect production. This occurs, once again, because of the combination of sticky prices and reductions in consumer demand. Third, when exchange rates are flexible oil price shocks bring about real exchange rate depreciation

due to both nominal exchange rate depreciation and a drop in the price of the non-traded good. When exchange rates are fixed real exchange rate depreciation still occurs but the adjustment takes place fully in the price of the non-traded good. Finally, when prices are sticky flexible rates seem to provide better outcomes. When the rate is flexible, adjustment is more rapid in the relative price level of the non-traded good and this reduces the loss of output and the impact on inflation in the non-traded sector. This occurs even when habit formation over spending on consumer durables is included in the model.

While the model provides tantalizing results it perhaps too early to make a complete assessment on the best exchange rate policy. This is because the model does not allow oil to directly affect production and it is not known how robust some of the results in this paper will be to this extension. I hope to address both of these issues in the near future.



Figure 1: Sticky Prices, Flex Rate, IRF,  $\tau = .5, \sigma = .5$

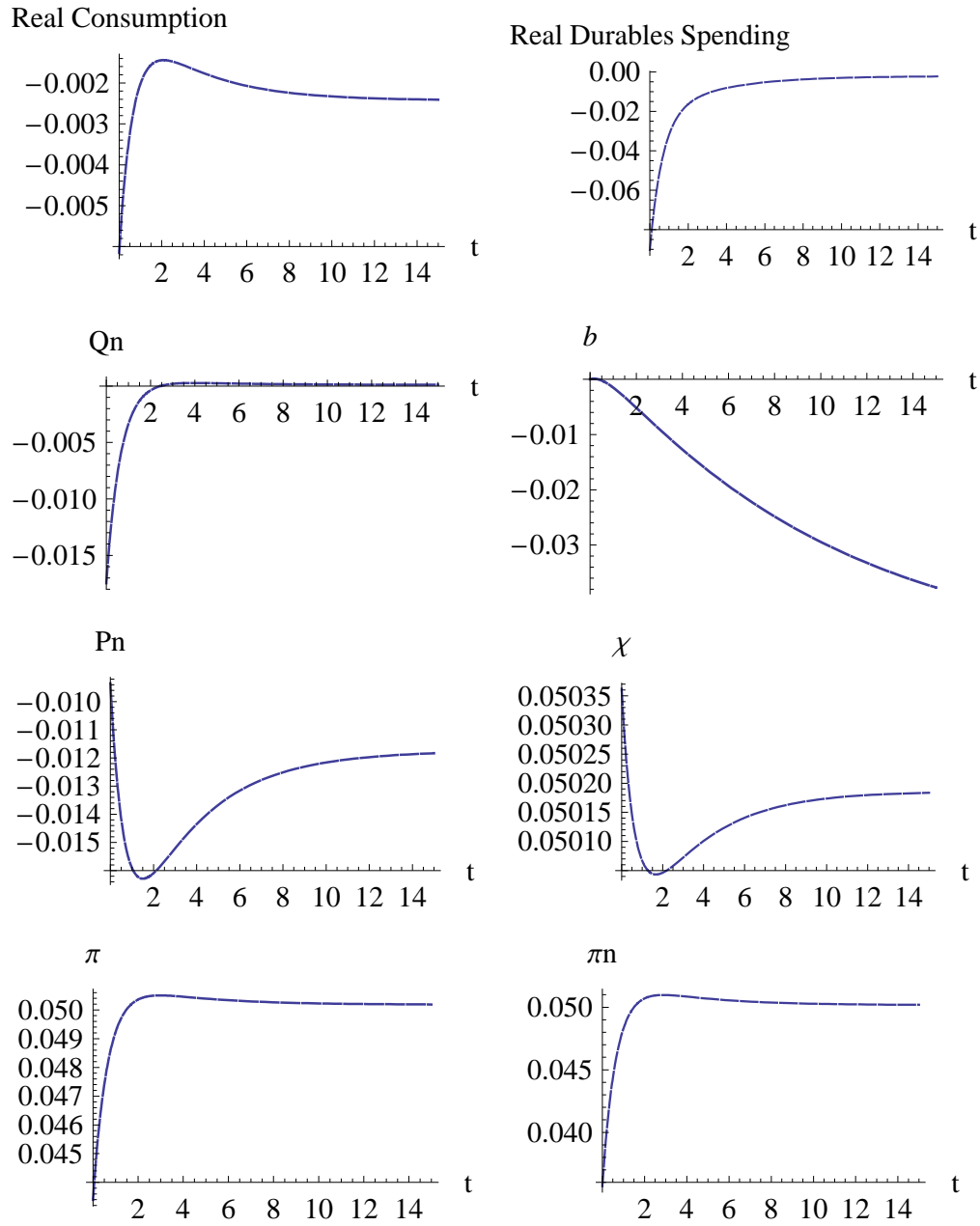


Figure 2: Sticky Prices, Fix Rate, IRF,  $\tau = .5$ ,  $\sigma = .5$

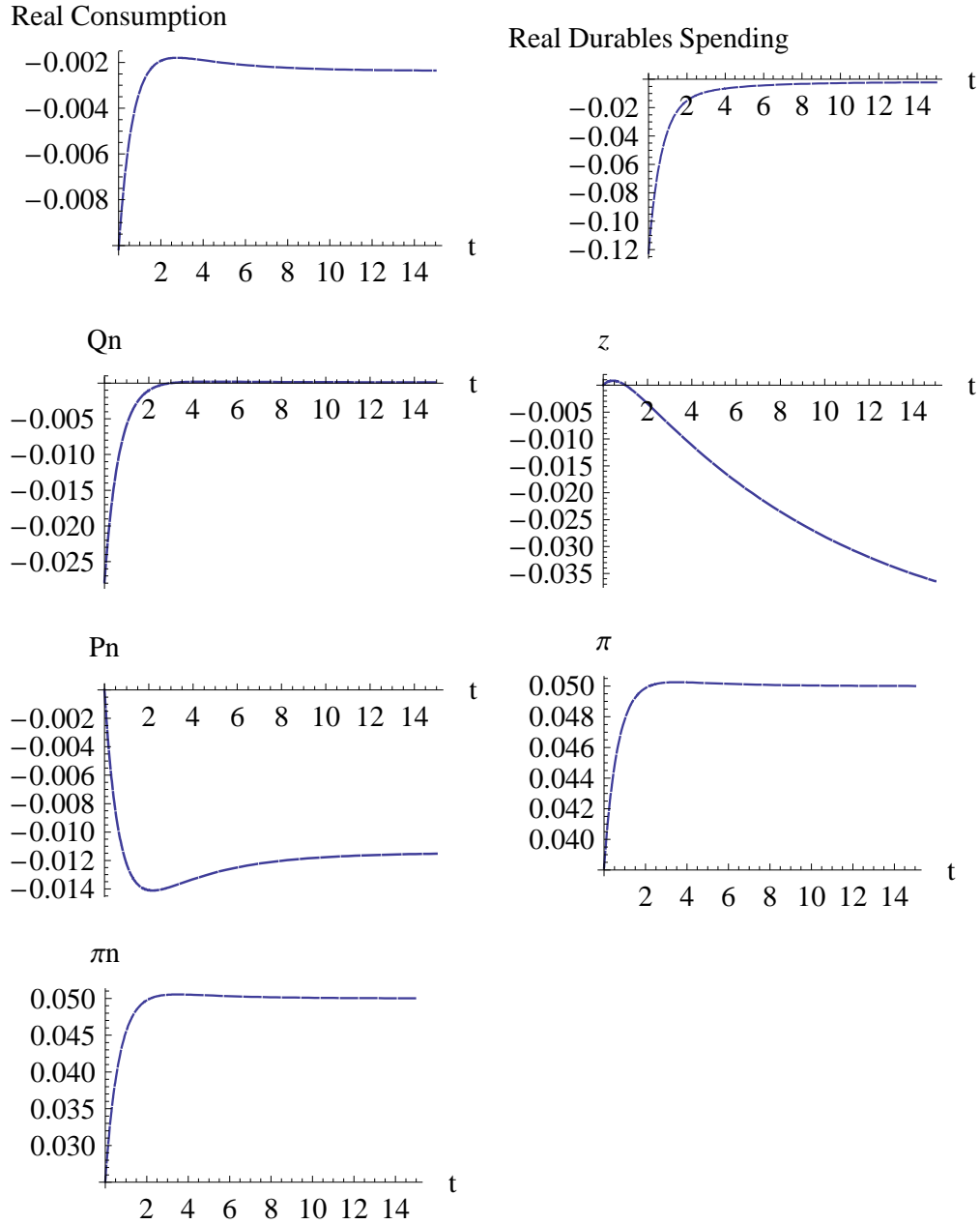


Figure 3: Sticky Prices, Flex Rate, Permanent,  $\tau = .5$ ,  $\sigma = .5$

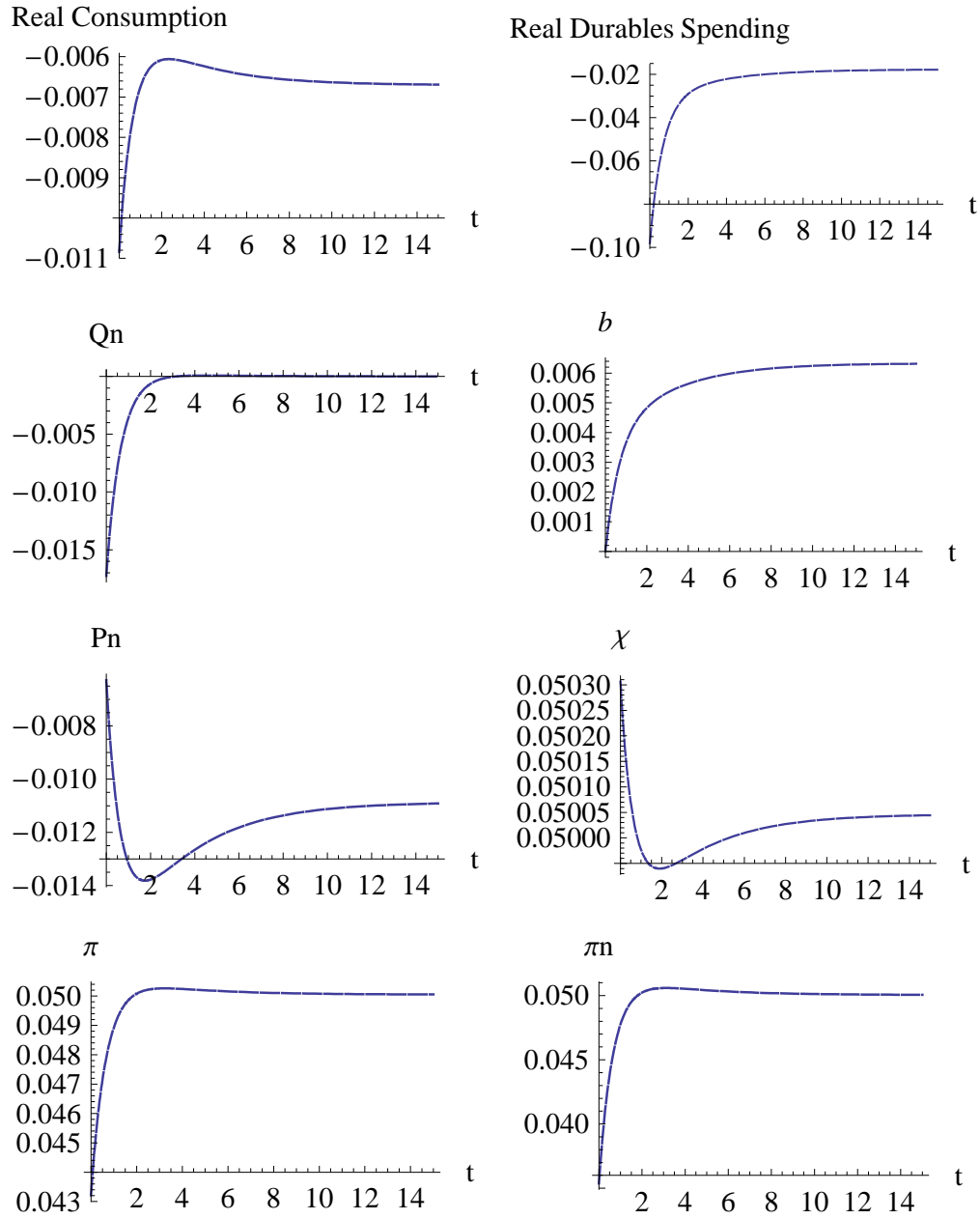


Figure 4: Sticky Prices, Fix Rate, Perm,  $\tau = .5$ ,  $\sigma = .5$

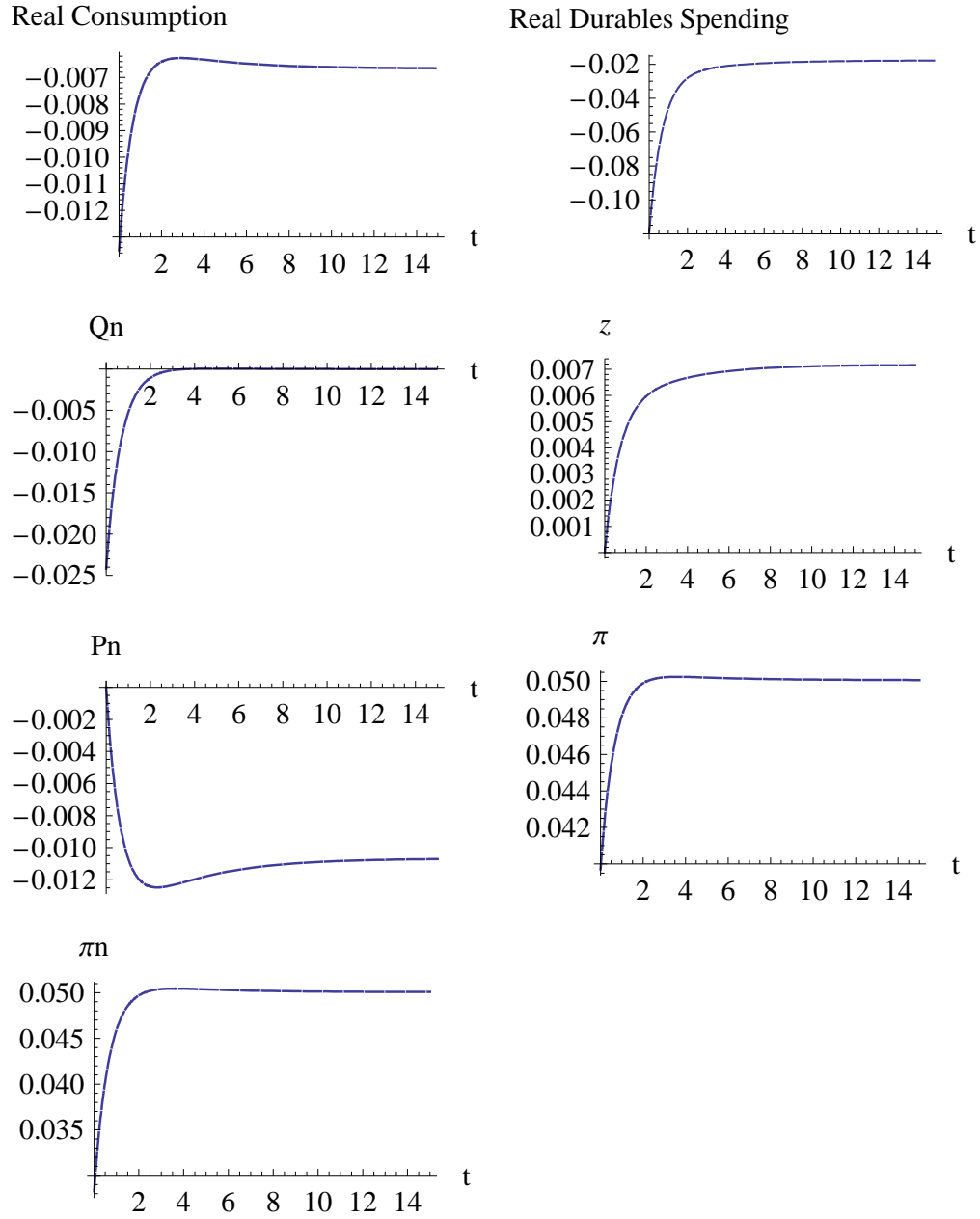


Figure 5: Habit Formation, Flex Rate, IRF,  $\tau = .5, \sigma = .5$

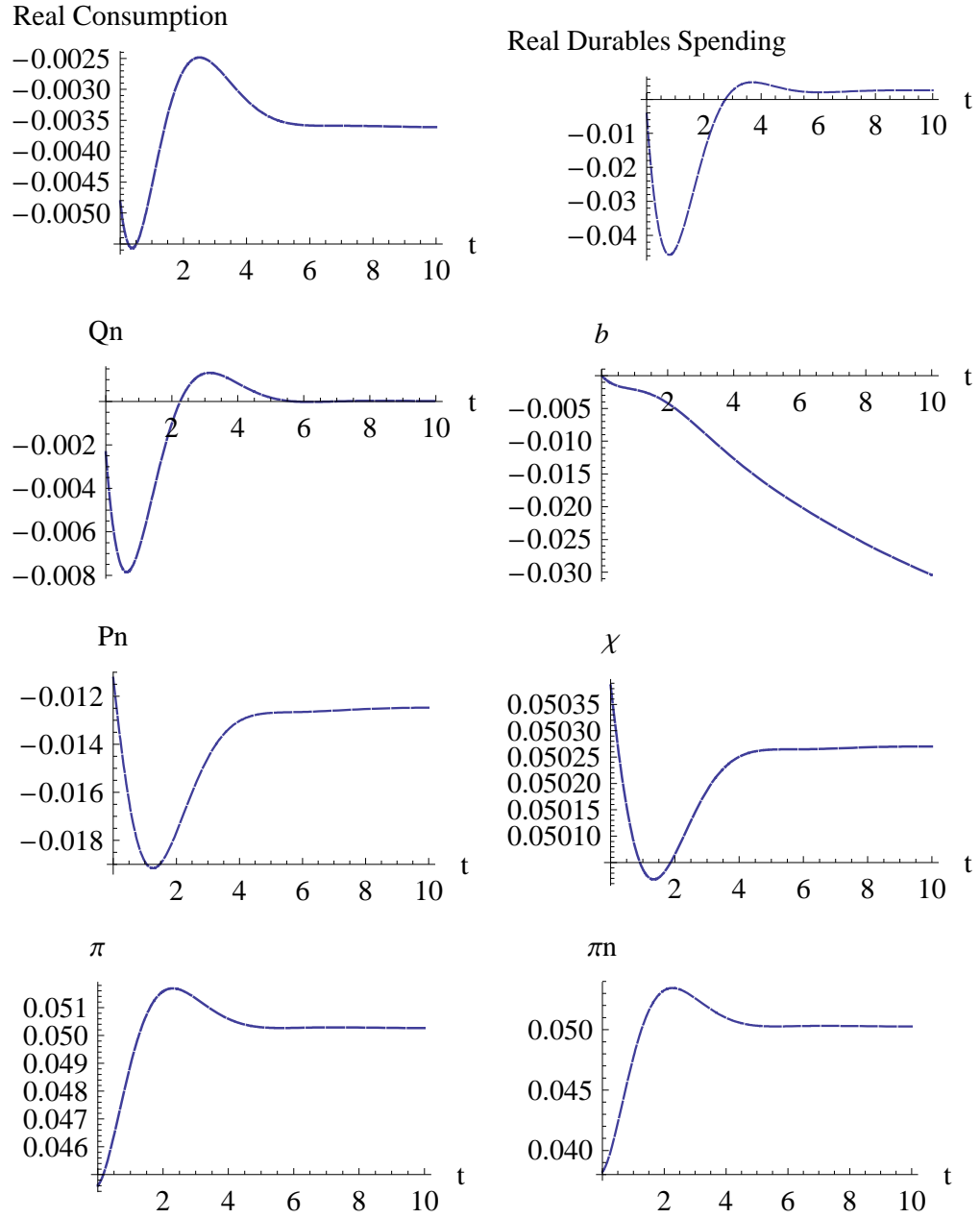


Figure 6: Habit Formation, Fix Rate, IRF,  $\tau = .5$ ,  $\sigma = .5$

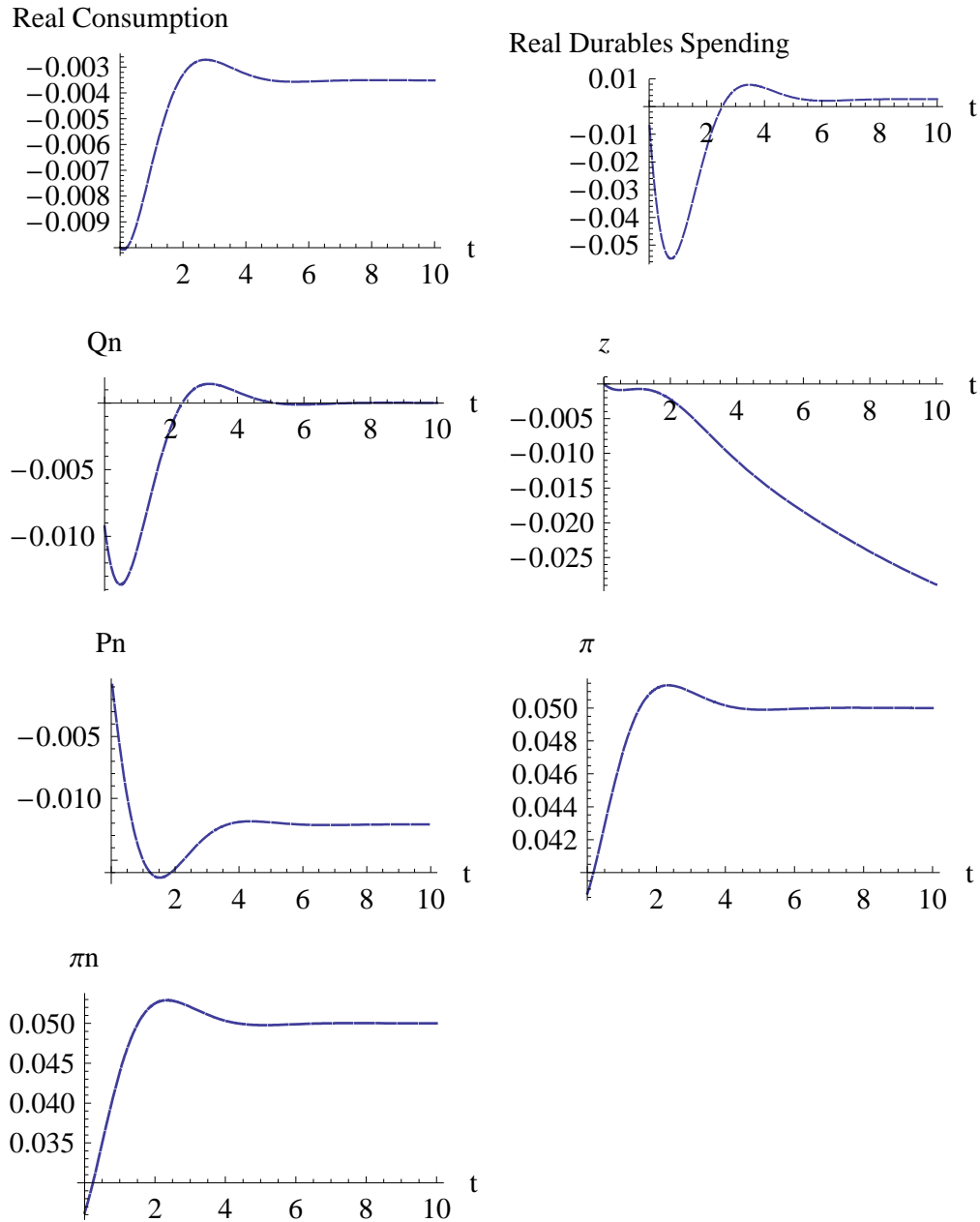


Table 1: Oil Share of Total Primary Energy Supply in Million Tons of Oil Equivalent (mtoe)

Country	TPES in mtoe	Percent From Oil
Belgium	58	40.4
Finland	38	29.8
France	275	32.8
Iceland	3	25
Ireland	15	58.5
Israel	20	53.2
Italy	184	46.2
Korea	213	47.6
Luxembourg	5	69.4
Netherlands	82	41
New Zealand	18	39.9
Portugal	27	59.3
Singapore	25	79.3
Spain	142	49.7
Sweden	54	28.6
Switzerland	27	46.1
Taiwan	104	44

Source: International Energy Agency (IEA) Energy Statistics

Table 2: Percent of Oil Used for Residential (Low End) and Residential Plus Transportation (High End).

Country	Percent of TPES From Oil	Low End	High End
Belgium	40.4	15.79	59.7
Finland	29.8	7.99	49.9
France	8	11.42	67.4
Iceland	25	0.8	48
Ireland	58.5	12.54	66.2
Israel	53.2	8.90	45.4
Italy	46.2	7.22	58.4
Korea	47.6	3.36	36.7
Luxembourg	69.4	8.96	86.7
Netherlands	41	2.26	47.8
New Zealand	39.9	6.49	86.9
Portugal	59.3	4.91	51.2
Singapore	79.3	0	25.9
Spain	49.7	6.33	60.8
Sweden	28.6	3.26	55.9
Switzerland	46.1	25.06	80
Taiwan	44	2.67	34.5

Source: International Energy Agency (IEA) Energy Statistics



Table 3: Calibrated Parameter Values

Parameter	Value
Intertemporal elasticity of substitution( $\tau$ )	.50
Elasticity of substitution between $C$ and $S(\sigma)$	.50
q-elasticity of durables spending( $\Omega$ )	10
Elasticity of substitution between $C_t$ and $C_n(\nu)$	.50
Time preference rate( $\rho$ )	.05
Speed of adjustment of $P_n(\alpha)$	3
Speed of adjustment of $P^o(\theta)$	.10
Depreciation rate of the durable good( $\delta$ )	.10
Ratio of domestic currency to GDP	0.1
Share of nontradables in nondurables and durable expenditure( $\gamma_{ne}, \gamma_{nd}$ )	.50
Expenditure share of oil( $\gamma_{xo}$ )	.05
Expenditure share of durables spending( $\gamma_{xd}$ )	.15
Steady state rate of currency depreciation( $\chi = \pi_n$ )	.05

## A. The Calibration Procedure

The model is calibrated to an initial steady state and in what follows all variables are evaluated at this initial steady state. An explanation of how the deep parameters of the model are calibrated is given in the body of the paper. The following gives a sketch of the procedure used when calibrating the model.

1. Choose units so that  $P_t = P_n = P^o = 1$ .
2. Choose units so that  $P_n Q_n + Q_T = 1$ .
3. Calibrate  $\chi$ ,  $m$ ,  $k$ , and  $\pi_n$  using data.
4. Calculate  $g$  using the government budget constraint.
5. Use (13) and (14) to calculate  $\kappa_1$ .
6. Use (18) and (14) to calculate  $\kappa_2$ .
7. Use (16) to calculate  $\kappa_3$ .
8. From (17)  $r = \rho$ .
9. From (21)  $E + P^o O + P_d I = Q_t + P_n Q_n$  or  $\gamma_e + \gamma_o + \gamma_i = 1$ . These parameters can be calibrated using data.
10. From  $E = C_t + P_n C_n$  one can calibrate  $\gamma_{et} = \frac{C_t}{E}$  and  $\gamma_{en} = \frac{P_n C_n}{E}$  from data.
11. From  $P_d I = I + a_1 P_n I$  define  $\gamma_{it} = \frac{I}{P_d I}$  and  $\gamma_{in} = \frac{a_1 P_n I}{P_d I}$ , which can be calibrated from data.
12. Given  $\gamma_{it}$  calibrate  $P_d = \frac{1}{\gamma_{it}}$ .
13. Given  $P_n$  and  $P_d$  calibrate  $a_1 = \gamma_{in} P_d$ .
14. Use the flow constraint for the durable good to derive  $D = \frac{\gamma_i}{P_d \delta}$ .
15. The distribution parameter  $\kappa_4$  can be calibrated using the Marshallian demand function for non-durables consumption of the non-traded good.
16. To calculate  $v$  in the deliberation costs function, use (15) to derive an equation for  $\Omega$ . Then note that  $v = \frac{\omega_1}{\Omega \delta}$ . Calibrating  $\Omega$  provides a number for  $v$ .

## B. The Dynamic Systems of the Models

Work soon to be here.

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