Explaining the Effects of Government Spending Shocks ☆

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Abstract

Using panel structural VAR analysis and quarterly data from four industrialized countries, we document that an increase in government purchases raises output and private consumption, deteriorates the trade balance, and depreciates the real exchange rate. This pattern of comovement poses a puzzle for both neoclassical and Keynesian models. An explanation based on the deep-habit mechanism is proposed. An estimated two-country model with deep-habits is shown to replicate well the observed responses of output, consumption, and the trade balance, and the initial response of the real exchange rate to an estimated government spending shock.

Keywords: Government spending shocks, deep habits, real exchange rate. *JEL* Classification: F4, E3, E6.

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1. Introduction

Government spending is one of the main tools of macroeconomic stabilization policy. The vast fiscal stimulus packages enacted in response to the 2008 global recession exemplify the importance that policy makers place on this policy instrument. Therefore it is important to understand the macroeconomic consequences of variations in government spending and the mechanism through which they propagate. This paper presents an empirical and theoretical investigation into the effects of government spending shocks on output, consumption, the trade balance, and the real exchange rate. Our empirical analysis uses quarterly data from a panel of four industrialized countries, the United States, the United Kingdom, Canada, and Australia, over the post-Bretton Woods period and employs a structural vector autoregressive (SVAR) representation of the data. Following Blanchard and Perotti (2002), we identify government spending shocks by assuming that no innovation other than government spending shocks themselves can affect government spending within the quarter. A positive innovation in government spending is found to cause an expansion in output, an expansion in consumption, a deterioration of the trade balance, and a depreciation of the real exchange rate (that is, a decline in domestic prices relative to exchange-rate-adjusted foreign prices).

The effects of government spending shocks on domestic aggregate activity and private absorption have been extensively studied in the related empirical literature. Our finding that government spending shocks raise output and consumption is consistent with previous studies that have used identification assumptions and estimation techniques similar to those we employ in the present paper.[3]

By contrast, the effects of government spending shocks on the external sector of the economy, and in particular on the real exchange rate, have received considerably less attention.[4] The empirical finding of a depreciation of the real exchange rate in response to a positive government spending shock is striking for it goes against the conventional wisdom. The standard view is that an increase in domestic absorption drives up domestic prices rendering the domestic economy relatively more expensive than the rest of the world. Contrary to this view, the data show that conditional on an unanticipated increase in government spending, the economy in which this innovation originates becomes relatively cheaper than its trading partners.

The observed responses of the real exchange rate and private consumption to innovations in government spending are hard to reconcile with the predictions of existing theoretical models of the transmission of government spending shocks. For instance, it is well known that the standard neoclassical model faces serious difficulties explaining the observed expansion in private consumption in response to a positive innovation in government spending. In this model an increase in government spending generates a negative wealth effect that causes an increase in labor supply, a decline in real wages, and a contraction in household spending.

The observed real depreciation of the exchange rate following a positive government spending shock is equally challenging for the neoclassical paradigm. In the absence of home bias, an increase in public consumption generates no changes in international relative prices. As a result the real exchange rate is unperturbed by the fiscal shock. In the presence of home bias, the relative price of domestically produced goods in terms of foreign produced goods increases, causing the neoclassical model to predict a counterfactual appreciation of the real exchange rate.

Our empirical findings pose a significant problem not only for the neoclassical model but also for models situated on the other end of the theoretical spectrum. For example, the Mundell-Flemming extension of the IS-LM model, while capturing the increase in consumption, fails to account for the observed real depreciation of the exchange rate triggered by an increase in public consumption. Within this framework, an increase in government purchases produces an expansion in aggregate demand that drives interest rates up. In turn, the elevated level of interest rates attracts foreign capital inflows, which increase the demand for domestic currency resulting in a nominal appreciation of the exchange rate. With product prices rigid in the short run, the nominal appreciation translates into a real appreciation.

Furthermore, more modern versions of the Mundell-Flemming IS-LM model with optimizing households and firms and sluggish nominal price adjustment can be shown to fail to predict a real exchange rate depreciation in response to a government spending increase. For instance, Monacelli and Perotti (2006) study the effects of government spending shocks in the context of a neo-Keynesian open-economy model with sticky

[3] See, for example, Rotemberg and Woodford, 1992; Blanchard and Perotti, 2002; Fatás and Mihov, 2001; Perotti, 2004, 2008; and Galí, López-Salido, and Vallés, 2007.

[4] Notable exceptions are Monacelli and Perotti (2006), Corsetti and Müller (2006), and Kim and Roubini (2008).

prices. These authors show that the neo-Keynesian framework is unable to generate the observed initial real depreciation in response to a positive innovation in government spending. Extensions of the neo-Keynesian open economy model that allow for rule-of-thumb consumers, while being able to explain qualitatively the rise in consumption, have also been shown to face difficulties explaining the observed initial real depreciation (see, for example, Erceg et al., 2005).

A central contribution of our investigation is to advance and test a theoretical explanation for the observed effects of government spending shocks based on the deep-habit mechanism developed by Ravn, Schmitt-Grohé, and Uribe (2006). To this end, we introduce deep habits into a two-country model. Under deep habits, an increase in domestic aggregate demand provides an incentive for firms selling in the domestic market to lower markups. Thus, an increase in government spending in the domestic economy leads to a decline in domestic markups relative to foreign markups. In this way, the domestic economy becomes less expensive relative to the foreign economy, or, equivalently, the real exchange rate depreciates. At the same time, a decline in domestic markups shifts the labor demand curve outward, giving rise to an increase in domestic real wages. In turn, the rise in wages induces households to substitute consumption for leisure. This substitution effect may be strong enough to offset the negative wealth effect stemming from the increase in public absorption, resulting in an equilibrium increase in private consumption.

The structural parameters defining the deep-habit mechanism are estimated using a limited information approach. The estimation of the model yields substantial support for the presence of deep habits in private and public consumption. The impulse responses of consumption, output, and the trade balance predicted by the deep-habit model is found to match well in size and shape their empirical counterparts. The model also matches the initial response of the real exchange rate. In particular, not only does our theoretical model predict an increase in output and a deterioration in the trade balance in response to a positive innovation in public spending, but also — and more importantly — an expansion in private consumption and an initial depreciation in the real exchange rate. While the model captures well the initial real depreciation of the exchange rate, it cannot explain its considerable persistence.

Section 2 estimates econometrically the effects of government spending shocks on output, consumption, the trade balance, and the real exchange rate using a panel SVAR model. The main difference between our empirical strategy and that adopted in the related literature, e.g., Monacelli and Perotti (2006), Corsetti and Müller (2006), and Kim and Roubini (2008), is our pooling of data across countries. We justify a panel analysis by observing that the identified effects of government spending shocks, particularly on consumption and the real exchange rate, whose behavior is the focus of our study, are similar across the individual countries considered.[5] The purpose of our panel approach is to obtain an efficient estimate of a single benchmark against which to evaluate our proposed theoretical explanation of the transmission of government spending shocks. Section 3 presents a two-country model with deep habits. Section 4 explains at an intuitive level how the deep-habit mechanism affects the transmission of aggregate demand shocks. Section 5 describes the calibration of the nonestimated structural parameters of the model. Section 6 presents the estimation of the structural parameters defining the deep-habit mechanism. Section 7 compares the predicted and estimated impulse response functions. Section 8 explores the robustness of our findings to changes in key structural parameters, detrending technique, the introduction of endogenous investment, and computing predicted impulse responses by estimating SVARs on artificial data generated by the deep habit model. Section 9 concludes.

2. The Observed Effects of Government Spending Shocks

The effects of government spending shocks on key macroeconomic variables are estimated using a structural vector autoregression model of the form

[5] Country-by-country estimates are available in the supplementary material collected in Ravn, Schmitt-Grohé, and Uribe (2011) and posted on the website of the JME.

$$A \begin{bmatrix} \hat{g}_t \\ \hat{y}_t \\ \hat{c}_t \\ \widehat{nxy}_t \\ \hat{e}_t \end{bmatrix} = B(L) \begin{bmatrix} \hat{g}_{t-1} \\ \hat{y}_{t-1} \\ \hat{c}_{t-1} \\ \widehat{nxy}_{t-1} \\ \hat{e}_{t-1} \end{bmatrix} + \epsilon_t, \tag{1}$$

where g_t denotes real per capita government consumption spending deflated by the GDP deflator, y_t denotes real per capita GDP, c_t denotes real per capita private consumption of nondurables and services, nxy_t denotes the net export-to-GDP ratio, and e_t denotes the real exchange rate defined as the ratio of a trade-weighted average of exchange-rate-adjusted foreign CPIs to the domestic CPI.[6] According to this definition, an increase in e_t means that the real exchange rate of the domestic country depreciates, or that the domestic country becomes cheaper relative to its trading partners. A hat over a variable denotes the log deviation from trend, except for nxy_t, for which it indicates the level deviation from trend. All variables are seasonally adjusted, and detrended with a linear and quadratic trend. The variable ϵ_t is a mean-zero, serially uncorrelated vector of disturbances with diagonal variance-covariance matrix Σ_ϵ. The factor $B(L) \equiv B_0 + B_1 L + B_2 L^2 + \ldots$ denotes a lag polynomial, with L denoting the lag operator. The matrices of coefficients B_i and A are of size 5 by 5.

2.1. Identification

Following Blanchard and Perotti (2002), innovations to government spending are identified by assuming that government spending responds with at least a one-quarter lag to structural innovations other than innovations to government spending itself. Formally, the identification restriction requires that the first row of the matrix A contain unity in its first element and zeros in all other elements.

We estimate the structural VAR pooling quarterly data from Australia, Canada, the United Kingdom, and the United States. Our sample begins in the first quarter of 1975 and ends in the fourth quarter of 2005. Our choice of countries is guided by our desire to limit attention to industrialized countries, and by the availability of reliable quarterly data on aggregate private consumption of nondurable goods and services and public consumption. The empirical strategy places emphasis on the availability of quarterly data, because, in our view, the validity of the Blanchard and Perotti (2002) identification strategy for government spending shocks depends crucially on the frequency at which the data are observed. With lower-than-quarterly frequency data, such as annual data, it is much less compelling to assume that within a period government spending cannot respond discretionarily to contemporaneous innovations in aggregate activity. That is, at a lower-than-quarterly frequency, one cannot be sure that the innovation to the $\hat{g}_t$ equation is not a linear combination of all of the structural innovations of the SVAR model.

The rationale for pooling data is to gain efficiency and to obtain a single benchmark against which to evaluate the performance of our theoretical model to be presented in section 3. We estimate the VAR system by OLS including country dummies. A potential concern with the panel VAR is the inconsistency of the least squares parameter estimates due to the combination of fixed effects and lagged dependent variables (e.g., Nickell, 1981). However, because the time series dimension of our data is large (124 observations), the inconsistency problem is likely not to be a major concern. Monte Carlo analysis confirms that the size of the Nickell bias is small.[7] A different potential problem is the possibility of correlated residuals across countries. To gauge the importance of this problem, impulse response functions were also computed from a feasible GLS estimation designed to correct for contemporaneous cross-country correlations in the error terms. The resulting impulse response functions (not shown) are fairly close to their OLS counterparts. Guided by the

[6] The data source for government consumption, GDP, and net exports is the OECD national accounts section. The source for the real exchange rate is the OECD Main Economic Indicators data base. And the sources for consumption of nondurables and services are the national statistical offices of each particular country. Government consumption is the sum of federal, state, and local public consumption spending.

[7] Specifically, the following experiment is carried out. Given the OLS estimates of A, the lag polynomial $B(L)$, and the country fixed effects, 10,000 artificial data series are generated by bootstrapping the estimated errors. Then the pooled fixed effects VAR is estimated by OLS on each of the artificial data series and the point estimates of the empirical impulse responses are compared with the median estimates over the 10,000 Monte Carlo experiments. The two estimates are found to be very similar.

likelihood ratio test proposed by Sims (1980), the SVAR specification allows for four lags.[8]

Our estimation procedure imposes that the matrices A and $B(L)$ are the same across the four countries from which we pool information. This simplifying assumption seems appropriate in light of the fact that estimations using individual country data yield similar results for the dynamic effects of government spending shocks on consumption and the real exchange rate. Our SVAR specification is similar to the one estimated in Monacelli and Perotti (2006). Like theirs, our specification comprises data from the US, the UK, Canada, and Australia, and applies the Blanchard and Perotti (2002) identification strategy. The main differences between our empirical approach and that of Monacelli and Perotti is that ours pools data, does not include taxes or the nominal interest rate in the SVAR specification, and that the sample considered is 16 quarters longer per country.

[Figure 1 about here.]

2.2. Estimation Results

Figure 1 displays with solid lines the empirical impulse response function of government spending, output, consumption, the net export-to-GDP ratio, and the real exchange rate to a unit innovation in government spending. The figure depicts with broken lines a two-standard error band on each side of the point estimate of the impulse response function computed using the delta method.[9]

The response of government spending is highly persistent, with a half life of about 5 quarters. A one-percent increase in government spending raises output by 0.1 percent. Assuming a government share of 19 percent (the average of government spending over the sample period for the four countries in our sample), the government-spending multiplier, $\Delta y_t/\Delta g_t$, is 0.52 on impact, indicating that for each unit increase in public spending output increases by 0.52 units on impact.

Private consumption of nondurables and services experiences a persistent expansion following the increase in public spending. This finding is in line with many other SVAR studies on the effects of government spending. See, for example, Fatás and Mihov (2001) and Blanchard and Perotti (2002).[10]

The bottom left panel of figure 1 shows that the real exchange rate depreciates by one third of one percent when the economy is hit by a one-percent increase in government spending. That is, an expansion in public consumption causes the domestic country to become cheaper relative to its trading partners. This result is at odds with the conventional wisdom, according to which an expansion in government consumption is associated with an increase in domestic prices, that is, with an appreciation of the real exchange rate. The empirical evidence typically drawn upon to support the conventional view is based on raw correlations between government consumption and the real exchange rate. The difficulty with this type of evidence is that, in principle, movements in the real exchange rate and government spending may be driven by a multitude of shocks. By contrast, the impulse responses shown in figure 1, isolate movements in all variables driven exclusively by an innovation in government purchases. That is, the figure states that conditional on a positive innovation in government spending the real exchange rate depreciates. It follows that the evidence reported here and that emanating from the analysis of raw correlations are not necessarily contradictory. We note further that other empirical studies have also found that the real exchange rate depreciates in response to a positive government spending shock. For example, Monacelli and Perotti (2006) document this fact for each of the individual countries included in our panel. The reaction of the real exchange rate is quite

[8] The test rejects the hypothesis of one or two lags in favor of a longer lag structure. To maintain comparability with the related literature, a lag length of four quarters was adopted. The three-lag and four-lag specifications yield virtually identical impulse response functions and error bands.

[9] The results are robust to using parametric or nonparametric bootstrap methods for computing error bands.

[10] The finding that private consumption expands with government purchases is, however, not uncontroversial. A strand of the literature identifies innovations in government spending using the narrative approach. These studies find that in response to news about upcoming military buildups consumption fails to increase. In Ravn, Schmitt-Grohé and Uribe (2007), it is argued that the effects of government spending shocks estimated using the SVAR and narrative approaches are not at odds with each other. There the case is made that the SVAR methodology, followed here, identifies unanticipated changes in government spending, while the narrative approach identifies news (or anticipated innovations) in future expansion in public spending. Moreover, that study argues that in general these two types of shock trigger quite different impulse responses in a theoretical model of the transmission of public spending shocks. And in particular, that paper shows that in the context of the deep-habits model developed here, the theoretical impulse responses to these two types of shock are in line with their empirical counterparts.

persistent. The peak depreciation occurs only 10 quarters after the innovation in government spending takes place.

The expansion in public spending results in a protracted albeit small deterioration in the trade balance. Corsetti and Müller (2006) and Monacelli and Perotti, consistent with our results, also report a worsening of the trade balance in response to a positive innovation in public spending.

Summarizing, our empirical results deliver four regularities that serve as the basis for evaluating the theory presented in the next section. Namely, in response to an increase in government spending output and consumption increase, the trade balance deteriorates, and the real exchange rate depreciates. These empirical regularities are quite robust. They also emerge in country-by-country estimations, under specifications including additional fiscal variables, such as taxes, and monetary policy variables, such as the nominal interest rate (see Monacelli and Perotti, 2006), and under alternative detrending schemes (see section 8 below).

3. A Two-Country Model of Pricing to Habits

The model economy consists of two countries, the home country and the foreign country. Each country specializes in the production of a set of differentiated goods. We denote by a the set of goods produced by the home country and by b the set of goods produced by the foreign country. All goods are internationally traded.

3.1. Households

Only the household's problem in the domestic economy is described. The foreign counterpart is a mirror image. The domestic economy is populated by a large number of identical households with preferences described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(x_t^c, h_t). \tag{2}$$

The variable x_t^c is a composite defined as

$$x_t^c = \chi(x_{a,t}^c, x_{b,t}^c), \tag{3}$$

where the aggregator function χ is assumed to be increasing and homogeneous of degree one in both arguments. The variable $x_{a,t}^c$ is a habit-adjusted composite consumption good of varieties of goods of type a.

3.1.1. Deep Habits

Following Ravn, Schmitt-Grohé, and Uribe (2006), it is assumed that habits form at the level of each individual variety of goods instead of at the level of the aggregate consumption good. Further, deep habits are assumed to be external to the individual household (i.e., habits are modeled as catching up with the Joneses good by good). Formally, $x_{a,t}^c$ is given by

$$x_{a,t}^c = \left[\int_0^1 (c_{i,a,t} - \theta_a^c s_{i,a,t-1}^c)^{1-1/\eta} di \right]^{1/(1-1/\eta)}. \tag{4}$$

Here $c_{i,a,t}$ denotes consumption of variety i of goods belonging to the set a in period t. The parameter $\theta_a^c \in [0,1)$ measures the intensity of deep external habits for consumption goods of type a. When θ_a^c is equal to zero, preferences for goods of type a display no deep habit formation. The parameter $\eta > 1$ represents the intratemporal elasticity of substitution across varieties. The variable $s_{i,a,t}^c$ denotes the stock of external habit in consumption of variety i of good a. This habit stock is assumed to evolve according to the following law of motion:

$$s_{i,a,t}^c = \rho s_{i,a,t-1}^c + (1-\rho)\tilde{c}_{i,a,t}, \tag{5}$$

where $\tilde{c}_{i,a,t}$ denotes the average per capita consumption of variety i of good a in the domestic country; that is, $\tilde{c}_{i,a,t}$ is the integral of $c_{i,a,t}$ over all domestic households. The parameter $1-\rho \in (0,1]$ denotes the rate at which the stock of external habits decays over time.

Similarly, $x^c_{b,t}$ is given by

$$x^c_{b,t} = \left[\int_0^1 (c_{i,b,t} - \theta^c_b s^c_{i,b,t-1})^{1-1/\eta} di\right]^{1/(1-1/\eta)}, \tag{6}$$

with

$$s^c_{i,b,t} = \rho s^c_{i,b,t-1} + (1-\rho)\tilde{c}_{i,b,t}. \tag{7}$$

To characterize the household's demands for varieties of type-a and type-b goods, consider a two-step problem. Suppose the household has determined its desired consumption of the aggregate goods a and b, that is, $x^c_{a,t}$ and $x^c_{b,t}$. Then it is optimal for the household to distribute its purchases of individual varieties to minimize costs, that is,

$$\min_{c_{i,a,t}} \int_0^1 P_{i,a,t} c_{i,a,t} di \tag{8}$$

subject to (4). This minimization problem yields the following demand function for variety i of good a:

$$c_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}}\right)^{-\eta} x^c_{a,t} + \theta^c_a s^c_{i,a,t-1}, \tag{9}$$

where $P_{a,t}$ denotes a price index for goods of type a given by

$$P_{a,t} = \left[\int_0^1 (P_{j,a,t})^{1-\eta} dj\right]^{1/(1-\eta)}. \tag{10}$$

Similarly, one can express the demand for variety i of good b as

$$c_{i,b,t} = \left(\frac{P_{i,b,t}}{P_{b,t}}\right)^{-\eta} x^c_{b,t} + \theta^c_b s^c_{i,b,t-1}, \tag{11}$$

where $P_{b,t}$ is a price index of goods of type b defined as

$$P_{b,t} = \left[\int_0^1 (P_{j,b,t})^{1-\eta} dj\right]^{1/(1-\eta)}. \tag{12}$$

Note that the demand for each variety of good a, say, is decreasing in its relative price, $P_{i,a,t}/P_{a,t}$, increasing in the level of habit-adjusted consumption of the composite good of type a, $x^c_{a,t}$, and increasing in the stock of habit of the variety in question $s^c_{i,a,t-1}$.

Total expenditure on goods of type a in period t is given by

$$\int_0^1 P_{i,a,t} c_{i,a,t} di = P_{a,t} x^c_{a,t} + \theta^c_a \int_0^1 P_{i,a,t} s^c_{i,a,t-1} di. \tag{13}$$

Let $\omega_{a,t}$ and $\omega_{b,t}$ be defined, respectively, as $\omega_{a,t} \equiv \theta^c_a \int_0^1 P_{i,a,t} s^c_{i,a,t-1} di$ and $\omega_{b,t} \equiv \theta^c_b \int_0^1 P_{i,b,t} s^c_{i,b,t-1} di$. Note that because habits are assumed to be external, the household takes both $\omega_{a,t}$ and $\omega_{b,t}$ as exogenously given. It follows that total expenditure on goods of type a and b, respectively, can be written as $\int_0^1 P_{i,a,t} c_{i,a,t} di = P_{a,t} x^c_{a,t} + \omega_{a,t}$ and $\int_0^1 P_{i,b,t} c_{i,b,t} di = P_{b,t} x^c_{b,t} + \omega_{b,t}$.

3.1.2. Budget constraint and optimality conditions

In each period $t \geq 0$, households are assumed to have access to complete contingent claims markets. Let $r_{t,t+j}$ denote the stochastic discount factor such that $E_t r_{t,t+j} d_{t+j}$ is the period-t price of a random payment d_{t+j} of the (numeraire good) in period $t+j$. In addition, households are assumed to be entitled to the receipt of pure profits from the ownership of firms, Φ_t. Households pay lump-sum taxes in the amount T_t. Then, the domestic representative household's period-by-period budget constraint can be written as

$$P_{a,t}x^c_{a,t} + \omega_{a,t} + P_{b,t}x^c_{b,t} + \omega_{b,t} + E_t r_{t,t+1} d_{t+1} + T_t = d_t + W_t h_t + \Phi_t. \tag{14}$$

The variable W_t denotes the wage rate. In addition, households are assumed to be subject to a borrowing constraint of the form $\lim_{j\to\infty} E_t r_{t,t+j} d_{t+j} \geq 0$, which prevents them from engaging in Ponzi games. The representative household's optimization problem consists in choosing processes $x^c_{a,t}$, $x^c_{b,t}$, h_t, and d_{t+1} to maximize the lifetime utility function (2) subject to (3), (14), and the no-Ponzi-game constraint, taking as given the processes for $\omega_{a,t}$, $\omega_{b,t}$, W_t, T_t, and Φ_t and initial asset holdings d_0.

The first-order conditions of the household's optimization problem are the constraints (3) and (14), the no-Ponzi-game constraint holding with equality, and

$$\frac{\chi_a(x^c_{a,t}, x^c_{b,t})}{\chi_b(x^c_{a,t}, x^c_{b,t})} = \frac{P_{a,t}}{P_{b,t}}, \tag{15}$$

$$-\frac{U_h(x^c_t, h_t)}{U_x(x^c_t, h_t)\chi_a(x^c_{a,t}, x^c_{b,t})} = \frac{W_t}{P_{a,t}}, \tag{16}$$

and

$$\frac{U_x(x^c_t, h_t)\chi_a(x^c_{a,t}, x^c_{b,t})}{P_{a,t}} r_{t,t+1} = \beta \frac{U_x(x^c_{t+1}, h_{t+1})\chi_a(x^c_{a,t+1}, x^c_{b,t+1})}{P_{a,t+1}}. \tag{17}$$

The first equation states that the marginal rate of substitution between the composite goods a and b must equal their relative price. The second equation implicitly defines the supply of labor. It equates the real domestic product wage to the marginal rate of substitution between leisure and consumption of composite good a. The last equation is a standard asset pricing relation equating the price of contingent claims to the intertemporal marginal rate of substitution.

3.2. The Government

Like households, the government is assumed to form habits on consumption of individual varieties of goods. This assumption is important for understanding the transmission of government purchases shocks in the context of our model. The deep-habit formulation in public spending can be interpreted as private households valuing public goods in a way that is separable from private consumption and leisure and households deriving external habits from consumption of government-provided goods. By good-specific external habit formation in the consumption of public goods we mean situations in which the provision of public services in one community—such as street lighting, traffic signals, yard-waste collection— creates the desire in other communities to have access to the same type of service. Alternatively, one can assume that the government forms procurement relationships that create a tendency for it to favor transactions with sellers that supplied public goods in the past.

Government habits are assumed to be external. Conceivably, government habits could be treated as internal to the government even if they are external to their beneficiaries, namely households. This alternative is, however, less tractable, and is therefore not pursued here. In the econometric estimation of the model, presented later in the paper, we let the data tell how much habit formation there is in public spending.

The government is assumed to aggregate individual varieties of domestic and foreign goods to produce two intermediate composite goods denoted $x^g_{a,t}$ and $x^g_{b,t}$, using the same aggregator function as the private sector:[11]

$$x^g_{a,t} = \left[\int_0^1 (g_{i,a,t} - \theta^g_a s^g_{i,a,t-1})^{1-1/\eta} di\right]^{1/(1-1/\eta)} \tag{18}$$

and

[11] A more general formulation would allow for the government and consumers to absorb different subsets of goods.

$$x_{b,t}^g = \left[\int_0^1 (g_{i,b,t} - \theta_b^g s_{i,b,t-1}^g)^{1-1/\eta} di \right]^{1/(1-1/\eta)}. \tag{19}$$

The parameters $\theta_a^g, \theta_b^g \in [0, 1)$ measure the degree of habit formation in government consumption of domestic and foreign goods, respectively. The variables $s_{i,a,t}^g$ and $s_{i,b,t}^g$ denote the government's stocks of habit in variety i of goods a and b, respectively, and are assumed to evolve over time as

$$s_{i,a,t}^g = \rho s_{i,a,t-1}^g + (1-\rho) g_{i,a,t} \tag{20}$$

and

$$s_{i,b,t}^g = \rho s_{i,b,t-1}^g + (1-\rho) g_{i,b,t}, \tag{21}$$

where $1 - \rho \in (0, 1]$ denotes the rate of depreciation of the stocks of habit. The government combines the intermediate goods $x_{a,t}^g$ and $x_{b,t}^g$ to produce a final, public good x_t^g according to the relationship

$$x_t^g = \chi(x_{a,t}^g, x_{b,t}^g). \tag{22}$$

Note that the aggregator function χ is the same as the one used by private consumers.

As in the empirical SVAR model of section 2, let g_t denote total real government spending expressed in units of domestic GDP (i.e., nominal government spending divided by the GDP deflator). Then, letting P_t^y denote the GDP deflator, to be defined later, one obtains

$$g_t \equiv \frac{\int_0^1 (P_{i,a,t} g_{i,a,t} + P_{i,b,t} g_{i,b,t}) di}{P_t^y}. \tag{23}$$

3.2.1. Government spending process

To allow for the empirical and the theoretical models to feature the same feedback mechanism and driving process for total government purchases, we assume that fiscal policy takes the form of a feedback rule given by the first equation of the SVAR system given in equation (1). Formally, g_t satisfies

$$\hat{g}_t = B^1(L) \begin{bmatrix} \hat{g}_{t-1} \\ \hat{y}_{t-1} \\ \hat{c}_{t-1} \\ \widehat{nxy}_{t-1} \\ \hat{e}_{t-1} \end{bmatrix} + \epsilon_t^1, \tag{24}$$

where $B^1(L)$ denotes the first row of $B(L)$ and ϵ_t^1 denotes the first element of the vector of innovations ϵ_t. Here, hatted variables denote log-deviations from deterministic steady-state values, except for the variable $\widehat{nxy}_t$, for which a hat indicates the level deviation of nxy_t from its deterministic steady state. Note that the values assigned to $B^1(L)$ are those estimated in section 2. However, the behavior of the endogenous variables appearing in the above law of motion for g_t is dictated by the dynamics of the theoretical model. For this reason, the theoretical and empirical impulse responses of g_t to an innovation in ϵ_t^1 will in general not coincide. Government spending is assumed to be financed by lump-sum taxes.

The government's problem consists in choosing $g_{i,a,t}$ and $g_{i,b,t}$, $i \in [0, 1]$, to maximize x_t^g subject to (18)-(23), taking as given g_t, P_t^y, $P_{i,a,t}$, $P_{i,b,t}$, $s_{i,a,t-1}^g$, and $s_{i,b,t-1}^g$ for all $i \in [0, 1]$ and $t \geq 0$.

The government's problem implies demand functions for individual varieties of goods a and b of the form

$$g_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}} \right)^{-\eta} x_{a,t}^g + \theta_a^g s_{i,a,t-1}^g \tag{25}$$

and

$$g_{i,b,t} = \left(\frac{P_{i,b,t}}{P_{b,t}} \right)^{-\eta} x_{b,t}^g + \theta_b^g s_{i,b,t-1}^g. \tag{26}$$

3.3. Firms

Goods of type a are produced exclusively in the domestic country, and goods of type b are produced exclusively abroad. Each individual variety of good of type a or b is assumed to be produced by a monopolist. Each good $i \in [0,1]$ is manufactured using labor as the sole input with a linear production technology. Specifically domestic output of variety i of type a, denoted $y_{i,a,t}$, is produced according to the relationship

$$y_{i,a,t} = h_{i,a,t}, \tag{27}$$

where $h_{i,a,t}$ denotes labor input in producing variety i of good a.

The producer of variety i of good a faces demands from the private and public sectors in the domestic and foreign countries. The private and public domestic demand functions are given by

$$c_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}}\right)^{-\eta} x^c_{a,t} + \theta^c_a s^c_{i,a,t-1} \tag{28}$$

and

$$g_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}}\right)^{-\eta} x^g_{a,t} + \theta^g_a s^g_{i,a,t-1}. \tag{29}$$

Letting an asterisk denote a foreign variable or parameter, the foreign private and public components of demand for variety i of type a goods are given by

$$c^*_{i,a,t} = \left(\frac{P^*_{i,a,t}}{P^*_{a,t}}\right)^{-\eta} x^{c*}_{a,t} + \theta^{c*}_a s^{c*}_{i,a,t-1} \tag{30}$$

and

$$g^*_{i,a,t} = \left(\frac{P^*_{i,a,t}}{P^*_{a,t}}\right)^{-\eta} x^{g*}_{a,t} + \theta^{g*}_a s^{g*}_{i,a,t-1}. \tag{31}$$

Implicit in the above demand functions are the assumptions that firms can price discriminate between the domestic and foreign markets but not between the government and households residing in the same country.

A number of important implications for the model's predictions regarding deviations from the law of one price, and hence movements in the real exchange rate, are evident from inspection of the above demand functions. First, each demand function for an individual variety of goods is of the form $d_t = p_t^{-\eta} x_t + \theta s_{t-1}$. That is, each demand function is the sum of a price-elastic component, $p_t^{-\eta} x_t$, and a price inelastic component, θs_{t-1}. The price elastic component has price elasticity η and is proportional to a measure of current aggregate demand, x_t. The price inelastic term is purely habitual in nature. It follows that the price elasticity of each demand function is a weighted average of η and 0, with the weight on η given by the relative importance of the price-elastic, nonhabitual demand component in total demand. An increase in aggregate demand enlarges the importance of the price elastic component of demand increasing the price elasticity. In other words, the price elasticity of each demand function is procyclical. Second, the fact that the price elasticity is procyclical opens the possibility for markups to move countercyclically in equilibrium. Third, in spite of the fact that the elasticity of the price elastic component of demand, η, is assumed to be identical across countries, the price elasticity of demand can in principle be different across countries. This is because the aggregate demand, x_t, or the stocks of habit, s_{t-1}, themselves can vary across countries. This implies that firms have an incentive to charge different markups domestically and abroad. We refer to this incentive for price discrimination as 'pricing to habits' as it originates from the presence of a habitual demand for individual varieties of goods. More importantly, pricing to habits gives rise to deviations from the law of one price over the business cycle at the level of individual goods traded across borders. Finally, because firms understand that the stock of habit is a weighted average of all past sales, their profit-maximization problem is dynamic in nature. Thus, customer-market and brand-switching cost considerations in the spirit of Phelps and Winter (1970) and Froot and Klemperer (1989) will endogenously emerge in the pricing behavior of firms, affecting the size and persistence of deviations from the law of one price and movements in the real exchange rate.

3.3.1. The price setting problem

The firm's problem consists in choosing processes $\{P_{i,a,t}, P^*_{i,a,t}, c_{i,a,t}, g_{i,a,t}, c^*_{i,a,t}, g^*_{i,a,t}, s^c_{i,a,t}, s^g_{i,a,t}, s^{c*}_{i,a,t}, s^{g*}_{i,a,t}, h_{i,a,t}\}_{t=0}^{\infty}$ to maximize

$$E_0 \sum_{t=0}^{\infty} r_{0,t} \left[P_{i,a,t}(c_{i,a,t} + g_{i,a,t}) + P^*_{i,a,t}(c^*_{i,a,t} + g^*_{i,a,t}) - W_t h_{i,a,t}\right] \tag{32}$$

subject to

$$c_{i,a,t} + g_{i,a,t} + c^*_{i,a,t} + g^*_{i,a,t} = h_{i,a,t}, \tag{33}$$

$$c_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}}\right)^{-\eta} x^c_{a,t} + \theta^c_a s^c_{i,a,t-1}, \tag{34}$$

$$g_{i,a,t} = \left(\frac{P_{i,a,t}}{P_{a,t}}\right)^{-\eta} x^g_{a,t} + \theta^g_a s^g_{i,a,t-1}, \tag{35}$$

$$c^*_{i,a,t} = \left(\frac{P^*_{i,a,t}}{P^*_{a,t}}\right)^{-\eta} x^{c*}_{a,t} + \theta^{c*}_a s^{c*}_{i,a,t-1}, \tag{36}$$

$$g^*_{i,a,t} = \left(\frac{P^*_{i,a,t}}{P^*_{a,t}}\right)^{-\eta} x^{g*}_{a,t} + \theta^{g*}_a s^{g*}_{i,a,t-1}, \tag{37}$$

$$s^c_{i,a,t} = \rho s^c_{i,a,t-1} + (1-\rho)c_{i,a,t}, \tag{38}$$

$$s^g_{i,a,t} = \rho s^g_{i,a,t-1} + (1-\rho)g_{i,a,t}, \tag{39}$$

$$s^{c*}_{i,a,t} = \rho s^{c*}_{i,a,t-1} + (1-\rho)c^*_{i,a,t}, \tag{40}$$

and

$$s^{g*}_{i,a,t} = \rho s^{g*}_{i,a,t-1} + (1-\rho)g^*_{i,a,t}, \tag{41}$$

taking as given the processes $r_{0,t}$, W_t, $P_{a,t}$, $P^*_{a,t}$, $x^c_{a,t}$, $x^g_{a,t}$, $x^{c*}_{a,t}$, $x^{g*}_{a,t}$, and the initial conditions $s^c_{i,a,-1}$, $s^g_{i,a,-1}$, $s^{c*}_{i,a,-1}$, and $s^{g*}_{i,a,-1}$. The associated optimality conditions are presented in Ravn, Schmitt-Grohé, and Uribe (2011). Foreign firms face a similar optimization problem.

3.4. Symmetric Equilibrium

We assume that given the type of good (a or b), the type of consumer (private or public), and the location of the consumer (domestic market or foreign market), initial habit stocks are identical across different varieties. Then, in a symmetric equilibrium, all firms producing varieties of good a for the domestic market will charge the same price. That is, $P_{i,a,t} = P_{a,t}$ for all i. Similarly, all firms producing varieties of good a for the foreign market will charge the same price, or $P^*_{i,a,t} = P^*_{a,t}$ for all i. The same symmetry applies to the foreign produced goods (type b), that is, $P_{i,b,t} = P_{b,t}$ and $P^*_{i,b,t} = P^*_{b,t}$ for all i. It follows from these assumptions that equilibrium consumption will be the same across varieties as well, that is, $c_{i,a,t} = c_{a,t}$, $g_{i,a,t} = g_{a,t}$, $c_{i,b,t} = c_{b,t}$, $g_{i,b,t} = g_{b,t}$, $c^*_{i,a,t} = c^*_{a,t}$, $g^*_{i,a,t} = g^*_{a,t}$, $c^*_{i,b,t} = c^*_{b,t}$, and $g^*_{i,b,t} = g^*_{b,t}$, for all i.

3.5. Asset Market Structure

We close the model by assuming that financial markets are complete and that financial capital can flow freely across countries. This means that domestic and foreign households face the same contingent-claim prices $r_{t,t+1}$. Combining the domestic Euler equation (17) with its foreign counterpart to eliminate $r_{t,t+1}$ yields $\left[U_x(x^c_{t+1}, h_{t+1})\chi_a(x^c_{a,t+1}, x^c_{b,t+1})P_{a,t}\right] / \left[U_x(x^c_t, h_t)\chi_a(x^c_{a,t}, x^c_{b,t})P_{a,t+1}\right] = \left[U_{x^*}(x^{c*}_{t+1}, h^*_{t+1})\chi^*_a(x^{c*}_{a,t+1}, x^{c*}_{b,t+1})P^*_{a,t}\right] / \left[U_{x^*}(x^{c*}_t, h^*_t)\chi^*_a(x^{c*}_{a,t}, x^{c*}_{b,t})P^*_{a,t+1}\right]$. Because this expression holds in every date and every state, it follows that $\frac{U_x(x^c_t,h_t)\chi_a(x^c_{a,t},x^c_{b,t})}{P_{a,t}}$ must be proportional to $\frac{U_{x^*}(x^{c*}_t,h^*_t)\chi^*_a(x^{c*}_{a,t},x^{c*}_{b,t})}{P^*_{a,t}}$. The factor of proportionality is determined by the relative wealth of the two countries. We consider a case in which both countries are equally wealthy so that the factor of proportionality is unity. It follows that

$$\frac{P^*_{a,t}}{P_{a,t}} = \frac{U_{x^*}(x^{c*}_t, h^*_t)\chi^*_a(x^{c*}_{a,t}, x^{c*}_{b,t})}{U_x(x^c_t, h_t)\chi_a(x^c_{a,t}, x^c_{b,t})}. \tag{42}$$

The complete set of equilibrium conditions is given in Ravn, Schmitt-Grohé, and Uribe (2011).

3.6. Theoretical Counterparts of Variables Included in the SVAR

Two good-specific real exchange rates are defined. One is the relative price of good a abroad in terms of units of good a at home, which is denoted by $e_{a,t}$. The second is the relative price of good b abroad in terms of units of good b in the home market, denoted $e_{b,t}$. Formally, the real exchange rates for goods a and b, respectively, are given by $e_{a,t} = \frac{P^*_{a,t}}{P_{a,t}}$ and $e_{b,t} = \frac{P^*_{b,t}}{P_{b,t}}$. Because firms can price discriminate across domestic and foreign markets, good-specific real exchange rates need not be unity. When the real exchange rate for a particular good is different from one, we say that the law of one price for that good is violated.

At a more aggregate level, the real exchange rate, denoted e_t, is defined as the relative price of foreign consumption in terms of domestic consumption, or

$$e_t \equiv \frac{P^*_t}{P_t}, \tag{43}$$

where P_t and P^*_t denote, respectively, the domestic and foreign consumer price indices. In the model economy under study, however, the presence of habit formation at a good-by-good level implies that there is no natural concept of either an aggregate consumption price index or even aggregate consumption. We therefore define the consumption price index as an expenditure weighted average of the price of final goods: $P_t = \gamma P_{a,t} + (1-\gamma)P_{b,t}$, where γ is a fixed weight defined as $\gamma = (P_a(c_a+g_a))/(P_a(c_a+g_a)+P_b(c_b+g_b))$, where variables without a time subscript represent the deterministic steady state value of their time-subscripted counterparts.

We adopt a fixed-weight price index to mimic a common practice in developed countries, whereby consumer price indices take the Laspeyres form. This definition of the consumer price index takes an arithmetic mean of prices in the broad categories a and b. Within each of these two categories, price indices are constructed as geometric means of individual prices. This convention is in line with the construction of the consumer price index in the United States where, since January 1999, a geometric mean formula has been used to average prices within item categories, while an arithmetic mean formula has been used to average prices across item categories. The consumer price index in the foreign country is defined in a similar fashion: $P^*_t = \gamma^* P^*_{a,t} + (1-\gamma^*)P^*_{b,t}$, with $\gamma^* = \frac{P^*_a(c^*_a+g^*_a)}{P^*_a(c^*_a+g^*_a)+P^*_b(c^*_b+g^*_b)}$.

Let τ_t denote the domestic relative price of imported goods in terms of domestically produced goods. That is, $\tau_t \equiv \frac{P_{b,t}}{P_{a,t}}$. One can then express the real exchange rate in terms of this relative price and the good-specific real exchange rates:

$$e_t = \frac{\gamma^* e_{a,t} + (1-\gamma^*)e_{b,t}\tau_t}{\gamma + (1-\gamma)\tau_t}. \tag{44}$$

Define aggregate domestic consumption as $c_t = (P_{a,t}c_{a,t} + P_{b,t}c_{b,t})/P_t$, or $c_t = \frac{c_{a,t}+\tau_t c_{b,t}}{\gamma+(1-\gamma)\tau_t}$. Similarly, define foreign aggregate consumption as $c^*_t = (P^*_{a,t}c^*_{a,t} + P^*_{b,t}c^*_{b,t})/P^*_t$, or $c^*_t = \frac{e_{a,t}c^*_{a,t}+e_{b,t}\tau_t c^*_{b,t}}{\gamma^* e_{a,t}+(1-\gamma^*)e_{b,t}\tau_t}$.

Define real GDP as follows. Pick steady-state prices as the base-year prices. Recalling that in the steady state all varieties of goods of type a are sold at the same price domestically and abroad (i.e., $P_{i,a} = P^*_{i,a} = P_a$ for all i), normalizing the steady-state price of the domestic good at unity ($P_a = 1$), and taking into account the linearity of the production technology, real GDP at base-year prices, denoted y_t, is given by $y_t = h_t$.

Market clearing for domestically produced goods requires that $y_t = c_{a,t} + g_{a,t} + c^*_{a,t} + g^*_{a,t}$. The GDP deflator P^y_t is defined as the ratio of nominal GDP to real GDP. Nominal GDP is given by $P_{a,t}(c_{a,t}+g_{a,t}) + P^*_{a,t}(c^*_{a,t}+g^*_{a,t})$. Then, the GDP deflator is given by $P^y_t = [P_{a,t}(c_{a,t}+g_{a,t}) + P^*_{a,t}(c^*_{a,t}+g^*_{a,t}]/h_t$.

The nominal trade balance is the difference between nominal exports, given by $P^*_{a,t}(c^*_{a,t}+g^*_{a,t})$, and nominal imports, given by $P_{b,t}(c_{b,t}+g_{b,t})$. The trade balance-to-GDP ratio, nxy_t, can then be written as

$nxy_t =$
$\left[e_{a,t}(c^*_{a,t}+g^*_{a,t})-\tau_t(c_{b,t}+g_{b,t})\right] / \left[(c_{a,t}+g_{a,t})+e_{a,t}(c^*_{a,t}+g^*_{a,t})\right].$

The variables g_t, y_t, c_t, nxy_t, and e_t are conceptually consistent with the homonymous variables used in the empirical analysis of section 2.

4. How the Pricing-To-Habits Mechanism Works

We now discuss at an intuitive level the potential of the pricing-to-habits mechanism to predict a depreciation of the real exchange rate and an expansion in private consumption in response to an increase in domestic government spending. To simplify the exposition, in this section, we consider the special case in which all stocks of habit depreciate completely after one period ($\rho = 0$) and the degrees of habit formation in private and public consumption are the same domestically and abroad ($\theta^c_a = \theta^g_a = \theta^{c*}_a = \theta^{g*}_a = \theta$). In this case, one can show that the equilibrium markup of price over marginal cost charged on varieties of good a in the domestic market, denoted $\mu_{a,t} \equiv P_{a,t}/W_t$, must satisfy

$$\mu_{a,t} = \left[1 - \frac{1}{\eta\left(1-\theta d_{a,t-1}/d_{a,t}\right)} + \theta\Omega_{a,t}\right]^{-1}, \tag{45}$$

where $d_{a,t} \equiv c_{a,t}+g_{a,t}$ denotes aggregate domestic demand for good a and $\Omega_{a,t}$ denotes the present discounted value of a sale in the domestic market in period $t+1$. Note that in the absence of deep habits ($\theta = 0$), the markup is constant and equal to $1/(1-1/\eta)$. The above expression shows that under deep habits, the markup falls in response to expansions in domestic aggregate demand for good a, that is, when $d_{a,t}$ increases. We refer to this effect as the price elasticity effect of deep habits. It originates from the fact that when demand increases, the relative importance of the price-inelastic (or habitual) component of demand falls. In addition, the markup is decreasing in the present discounted value of a future sale, $\Omega_{a,t}$. We refer to this effect as the intertemporal effect of deep habits. This effect arises because when the present value of a future sale increases, it pays for the firm to invest in market share today by lowering current markups.

In the foreign market for good a, domestic firms charge a markup $\mu^*_{a,t}$ given by

$$\mu^*_{a,t} = \left[1 - \frac{1}{\eta\left(1-\theta d^*_{a,t-1}/d^*_{a,t}\right)} + \theta\Omega^*_{a,t}\right]^{-1}. \tag{46}$$

Suppose now that domestic government expenditure increases. This shock increases domestic aggregate demand relative to foreign aggregate demand. By the price elasticity effect of deep habits, firms will lower domestic markups relative to foreign markups. That is, good a will become relatively cheaper in the domestic country than in the foreign country. Similarly, the increase in government spending leads to an increase in domestic demand for good b, inducing foreign firms to lower domestic markups relative to foreign markups. That is, the price of good b falls domestically relative to the rest of the world. The fact that all goods in the domestic economy (a and b) become cheaper relative to the foreign economy implies that the real exchange rate of the country experiencing the increase in government purchases depreciates.

The decline in markups brought about by the expansion in government spending, is key for the deep-habit model to predict an increase in private consumption. To see this, note first that the increase in government spending produces a negative wealth effect on households, which, all other things equal, induces households to reduce consumption and increase labor effort. In turn, the expansion in the labor supply schedule tends to depress real wages. This is the basic mechanism at work in the standard neoclassical model. Under deep habits, however, the decline in markups that takes place following the government spending shock acts as a positive productivity shock that shifts the labor demand upward. This expansion in the demand for labor can be strong enough to cause the real wage to increase. In turn, higher real wages produce a substitution effect whereby households increase consumption and reduce the demand for leisure. This substitution effect may be strong enough to offset the negative wealth effect on consumption. In this case, private consumption increases in response to an expansion in government spending.

5. Calibration and Functional Forms

The period utility function and the aggregator functions are assumed to be of the forms:

$$U(x,h) = \frac{\left[x_t^{\phi}(1-h_t)^{1-\phi}\right]^{1-\sigma} - 1}{1-\sigma}, \tag{47}$$

$$\chi(x_a, x_b) = \left[\omega x_a^{1-1/\xi} + (1-\omega) x_b^{1-1/\xi}\right]^{1/(1-1/\xi)}, \tag{48}$$

and

$$\chi^*(x_a^*, x_b^*) = \left[(1-\omega) x_a^{*\,1-1/\xi} + \omega x_b^{*\,1-1/\xi}\right]^{1/(1-1/\xi)}. \tag{49}$$

[Table 1 about here.]

Table 1 displays the values assigned to the structural parameters in the baseline calibration of the model. The time unit is meant to be one quarter. The discount factor β is set at a value consistent with an interest rate of 4 percent per year. The curvature of the period utility function, σ, is set at 1, which implies that preferences are separable in leisure and consumption. The case of separable preferences in consumption and leisure is of particular interest because it highlights the fact that the pricing-to-habits mechanism does not depend on the assumption of nonseparabilities between leisure and consumption to deliver empirically realistic dynamics for consumption and the real exchange rate in response to public consumption shocks. The parameter ϕ of the utility function is chosen so that households devote about one fourth of their time to paid work in the deterministic steady state. The parameter ω of the aggregator function of domestic and foreign goods is set to 0.5. This value allows us to abstract from home-bias effects in the transmission of government spending shocks. It implies a relatively high share of imports in GDP of 50 percent. In our sample, the average share of imports in GDP is 22 percent, which would correspond to a value of ω of 0.7. Later in section 8 the robustness of our findings to increasing the value of ω is discussed. The elasticity of substitution between home and foreign goods, ξ, is set to 1.5, a value commonly used in business-cycle analysis. The elasticity of substitution across habit-adjusted consumption of individual varieties, η, is set to 5. The steady-state level of government consumption is assumed to represent 20 percent of value added, which is the mean value of the observed government share in our sample. The implied steady-state level of government spending, $g = g^*$, is 0.0487. The feedback rule for government spending given in equation (24) is calibrated using the econometric estimates obtained in section 2. Specifically, the following values are assigned

$$\begin{bmatrix} B_0^1 \\ B_1^1 \\ B_2^1 \\ B_3^1 \end{bmatrix} = \begin{bmatrix} 0.656 & -0.234 & 0.0878 & 0.0198 & 0.0138 \\ 0.156 & 0.263 & -0.18 & -0.144 & -0.0632 \\ 0.134 & -0.0348 & 0.0671 & 0.189 & 0.0421 \\ -0.0385 & 0.0349 & 0.0494 & -0.0632 & -0.0451 \end{bmatrix}. \tag{50}$$

6. Estimation of the Deep-Habit Parameters

There exists no readily available evidence on the parameters defining the deep-habit mechanism. For this reason, we proceed to estimate them. The parameter structure is simplified by assuming that the degree of habit formation is common across types of goods and countries. That is, it is imposed that $\theta_a^c = \theta_b^c = \theta_a^{c*} = \theta_b^{c*} = \theta^c$ and $\theta_a^g = \theta_b^g = \theta_a^{g*} = \theta_b^{g*} = \theta^g$. The parameter θ^c is not constrained to be equal to θ^g. In this way, the data determines the degrees of private and public deep-habit formation separately. In addition, the parameter ρ measuring the persistence in the stock of habits is also econometrically estimated.

Our estimation procedure consists in assigning values for θ^c, θ^g, and ρ to minimize the distance between the empirical impulse response functions shown with solid lines in figure 1 and the corresponding theoretical impulse response functions implied by the deep-habit model. The theoretical impulse response functions up to first order are computed using the log-linearization procedure described in Schmitt-Grohé and Uribe (2004). The first 9 quarters of the impulse response functions of 5 variables (government spending, output, consumption, the trade balance-to-GDP ratio, and the real exchange rate) to a unit innovation in government spending are considered. Specifically, let $\Theta \equiv [\theta^c \; \theta^g \; \rho]'$ denote the 3×1 vector of parameters to be estimated, IR^e the 44×1 vector of empirical impulse response functions, and $IR^m(\Theta)$ the corresponding vector of impulse responses implied by the theoretical model, which is a function of the three parameters that we wish to estimate. Then, the estimate of Θ, denoted $\hat{\Theta}$, is given by

$$\hat{\Theta} = \underset{\Theta}{\operatorname{argmin}}[IR^e - IR^m(\Theta)]' \Sigma_{IR^e}^{-1} [IR^e - IR^m(\Theta)], \tag{51}$$

where Σ_{IR^e} is the 44×44 variance covariance matrix of IR^e computed using the delta method. This matrix penalizes those elements of the estimated impulse response functions associated with large confidence intervals.[12]

An estimate of the variance-covariance matrix of $\hat{\Theta}$, denoted $\Sigma_{\hat{\Theta}}$, is given by

$$\Sigma_{\hat{\Theta}} = \left[J_{IR^m}(\hat{\Theta})' \Sigma_{IR^e}^{-1} J_{IR^m}(\hat{\Theta}) \right]^{-1}, \tag{52}$$

where $J_{IR^m}(\Theta) \equiv \partial IR^m(\Theta)/\partial\Theta$ denotes the 44×3 Jacobian matrix of the theoretical impulse response function with respect to the vector Θ.

The estimation results are shown in table 2.

[Table 2 about here.]

The estimated degree of deep habit formation in private consumption is 0.52, which lies well within the range of values estimated on the basis of models featuring superficial habit formation. The estimated degree of deep habit persistence in public consumption is slightly higher than its private counterpart at 0.57. The estimated value of ρ is 0.9876, which implies that the stock of habits depreciates rather slowly over time. This finding is not uncommon in the related literature on superficial habits. For example, consumption-based models of stock returns typically require a high degree of persistence in the habit stock to fit the data (Campbell and Cochrane, 1999). Section 8 studies the sensitivity of our results to lowering the value of ρ. All parameters are estimated to be significantly different from zero. Of particular interest is the fact that the data identifies a nonnegligible amount of deep-habit persistence in public consumption.

7. Comparing Predicted and Observed Impulse Responses

Figure 1 plots with crossed lines the impulse responses to a one-percent increase in government spending predicted by the deep-habit model. The deep-habit model predicts an expansion in output and private consumption, a deterioration in the trade balance, and a depreciation of the real exchange rate. The model does a relatively good job at explaining the observed transmission of government spending shocks. All predicted responses fall within the estimated error bands, except for the late transition dynamics of the real exchange rate. As is well known, real exchange rate movements are highly persistent, a fact that in our regressions is reflected in a peak response occurring only 10 quarters after the innovation. Explaining such a high level of persistence in the real exchange rate is a challenge for many macroeconomic models including ours.

7.1. Markups

An important prediction of the deep habit model is that markups move countercyclically in equilibrium. An increase in domestic government spending induces a decline in markups in all domestically sold goods, regardless of whether they are imported or domestically produced.

At the same time, in the foreign economy markups increase as a consequence of a contraction in foreign aggregate demand brought about by the negative wealth effect associated with the increase in domestic government spending (and transmitted via complete international asset markets). The impulse responses of the domestic and foreign markups are shown in figure 2(a.).[13] In response to a one-percent increase in

[12] The impulse response functions implied by the estimated theoretical model shown below are little changed when the weighing matrix is defined as the diagonal of Σ_{IR^e} rather than as Σ_{IR^e} itself.

[13] Because of our maintained assumption of no home bias ($\omega = 1/2$), the impulse response functions of the domestic markups on imported and domestically produced goods are identical. For the same reason, the impulse response functions of foreign markups on goods produced in the domestic and the foreign countries are also identical.

domestic government spending, markups in domestic markets fall by 26 basis points on impact and markups in foreign markets rise by 7 basis points.

[Figure 2 about here.]

Firms selling in domestic markets find it optimal to reduce markups because the increase in aggregate demand stemming from the local public sector renders the demand for individual goods more price elastic. Recall that in the deep habit model, the price elasticity is an increasing function of the importance of current demand relative to habitual demand. The increase in government spending increases the importance of current demand causing a rise in the price elasticity and a corresponding decline in markups. At the same time, the decline in aggregate demand in the foreign country causes a decline in the price elasticity of demand across all markets inducing sellers to increase their margins.

The generalized fall in markups that takes place in the domestic economy following a positive innovation in government spending acts much like a positive technology shock, shifting the demand for labor out and to the right. This increase in the demand for labor tends to push real wages upward. Figure 2(b.) shows that the real wage increases by 0.26 percent in response to a one-percent government spending shock. This prediction of the deep-habit model is consistent with SVAR evidence employing the Blanchard and Perotti (2002) identification assumption. See, for example, Perotti (2008) for evidence from the United States, the United Kingdom, and Canada, three of the four countries included in our panel.

A natural question is whether in the data markups of prices over marginal cost indeed fall in response to a positive innovation in government spending, as required for our theoretical model to capture the observed increase in consumption and real depreciation of the exchange rate. Monacelli and Perotti (2008) provide empirical evidence for the United States supporting the countercyclicality of markups in response to government spending shocks. These authors identify movements in markups with movements in the inverse of the labor share. We note that this identification approach is valid in the context of our theoretical framework. For in our model, the domestic markup equals the inverse of the domestic real product wage, which, in turn, given our assumption of a linear production technology, equals the inverse of the labor share.

The implied countercyclicality of markups is crucial in allowing the deep-habit model to capture the observed expansion in private consumption and the observed initial depreciation of the real exchange rate. In effect, the combination of lower domestic markups and higher foreign markups makes the domestic economy cheaper relative to the foreign economy. That is, the domestic real exchange rate depreciates. In fact, the real depreciation of about one third of one percent on impact predicted by the model is equal to the sum of the decline in markups in domestic markets (26 basis points) and the increase in markups in foreign markets (7 basis points).

7.2. The real exchange rate

As discussed in the introduction, accounting for the observed depreciation of the domestic real exchange rate in response to a positive innovation in government spending poses a major challenge for the neoclassical growth model. Figure 2 (c.) substantiates this claim. It displays the response of the real exchange rate under deep and superficial habits. In the economy with superficial habits, habits form at the level of each composite good (domestic and imported), as opposed to at the level of each individual variety. The figure shows that the deep habit model captures well the observed initial real exchange rate depreciation. By contrast, the superficial habits model counterfactually predicts that the real exchange rate is completely unaffected by the government spending shock. The same mute response in the real exchange rate would obtain under the assumption of no habits at all.

To understand why the real exchange rate is unresponsive in the absence of deep habits, note that in the economy with superficial or no habits, the monopolists producing individual varieties of goods face a static demand function with a constant price elasticity. Therefore, equilibrium markups are constant over time and across countries. Furthermore, because the marginal costs of producing a given variety is independent of destination market, the monopolistic producer will charge the same price in the domestic and the foreign markets. Thus, in the absence of deep habits we have that $P_{i,a,t} = P^*_{i,a,t}$ and $P_{i,b,t} = P^*_{i,b,t}$ for all $i \in [0, 1]$. So that, under the maintained assumption of no home bias ($\omega = 0.5$), the domestic and foreign consumer price indices are identical, or, equivalently, the real exchange rate is constant over time. We note that if in the economies with superficial or no habits one were to allow for home bias, by setting $\omega > 0.5$, then an increase in government purchases would increase the price of good a relative to good b causing a counterfactual appreciation of the real exchange rate.

7.3. Consumption

A second major difficulty of the neoclassical growth model is its inability to explain the observed expansion in private consumption following an increase in public spending. Figure 2(d.) illustrates this problem by depicting the impulse response function of consumption to an innovation in government spending in the economy with superficial habits. The counterfactual predicted decline in consumption is driven by a negative wealth effect brought about by the elevated absorption of resources in the public sector.[14] A central contribution of the deep-habit mechanism is to enable an otherwise standard model to overcome this difficulty. In effect, figure 2(d.) shows that the deep-habit model predicts not only an expansion in consumption but also one that is similar in magnitude and persistence to the one estimated using actual data. As in the model with superficial habits, in the model with deep habits an increase in government spending creates a negative wealth effect, which tends to depress private consumption spending. However, the deep-habit mechanism generates, at the same time, an increase in wages, driven by a generalized decline in markups, which induces households to substitute away from leisure and into consumption. This substitution effect more than offsets the negative wealth effect, resulting in an equilibrium increase in consumption.

8. Sensitivity Analysis

This section reports results of a number of robustness checks regarding the ability of the deep-habit model to explain the response of consumption, the real exchange rate, and net exports to government spending shocks. These tests include allowing for home bias, reducing the persistence of the stock of habit, considering an alternative method—the HP filter—for extracting the cyclical component of time series in the empirical analysis, introducing capital accumulation into the theoretical model, and estimating the SVAR system using artificial time series generated by the theoretical model.

8.1. Home Bias

In our baseline model, no home bias in consumption is assumed. That is, the parameter ω in the aggregator function of domestic and foreign goods (equation (3)) takes the value 0.5. As indicated earlier, this value of ω implies an import share of 50 percent of GDP, which is large relative to the average import share of 22 percent observed in our panel. When ω is exactly 0.5, an increase in domestic aggregate demand does not lead to an increase in the relative price of domestically produced goods. That is, the relative price of imported goods in terms of domestically produced goods, $P_{b,t}/P_{a,t}$, is unchanged. It follows that movements in the real exchange rate are entirely due to variations in the deviations from the law of one price, via the deep-habit mechanism, and not due to variations in the relative price of imported goods.

When ω is set to 0.7, the implied steady-state import share is more in line with its empirical counterpart observed in our panel. For this value of ω, agents in both countries have a bias toward goods produced in their own country. In the presence of home bias, an increase in domestic government spending causes an increase in the domestic price of domestically produced goods relative to the domestic price of foreign-produced goods. That is $P_{a,t}/P_{b,t}$ goes up. Because goods of type a have a larger share in the domestic CPI index than in the foreign CPI index, the increase in the relative price of domestically produced goods tends, all other things equal, to appreciate the real exchange rate. The response of the real exchange rate to an increase in aggregate demand is then determined by two (opposing) effects, the domestic-relative-price effect, which tends to appreciate the real exchange rate and the pricing-to-habits effect, which tends to depreciate it. Figure 2(e.) compares the response of the real exchange rate to a positive government spending shock in economies with and without home bias. In the economy with home bias, all parameters other than ω take the values shown in tables 1 and 2. Overall, the two theoretical impulse responses for the real exchange rate are fairly similar. In line with the intuition developed above, when home bias is present, the impulse response function of the real exchange rate lies below the one corresponding to the baseline case without home bias.

[14] Government spending shocks also have contractionary effects on consumption in the case of no habits at all.

Figure 2(f.) compares the impulse response of consumption in an economy with and without home bias. The deep-habit model with home bias continues to predict a persistent rise in consumption that tracks the actual response fairly well.

8.2. Persistence of Habit Stocks

Our second robustness check concerns the persistence of the habit stocks. Our estimation of the pricing-to-habits model yields a value of ρ of 0.9876, which induces highly persistent stocks of habit in equilibrium. To gauge the sensitivity of our results to a less persistent stock of habits, consider the case that $\rho = 0.85$. This value is more than four standard deviations below its point estimate. All other parameters take the values shown in tables 1 and 2. Figures 2(e.) and (f.) display with diamonds the impulse responses of the real exchange rate and consumption for this value of ρ. As one would expect, the impulse responses of the real exchange rate and consumption are less persistent when the stock of habits itself is less persistent.

8.3. HP Filtering

Our third sensitivity experiment focuses on the detrending method used to compute empirical impulse responses to a government spending shock. In the baseline case all variables are detrended using a quadratic trend. Here this detrending method is replaced with the Hodrick-Prescott filter.

[Figure 3 about here.]

Figure 3 shows the empirical impulse response functions obtained after HP filtering the data with a smoothing parameter of 1,600. Comparing this figure with figure 1, one can see that the empirical impulse responses obtained from HP filtered data are quite similar to those obtained after removing a quadratic trend from the raw data. In particular, a positive innovation in government spending causes an increase in output and consumption, a depreciation of the real exchange rate, and a deterioration of the trade-balance-to-output ratio. Figure 3 also depicts the impulse responses predicted by the theoretical model, where the structural parameters of the deep-habit mechanism were reestimated to match the impulse responses associated with the HP-filtered data.[15] Inspection of the figure suggests, that the fit of the theoretical model does not appear to be sensitive to whether the empirical impulse responses are estimated from HP filtered or from quadratically detrended data.

8.4. Capital Accumulation

A further sensitivity experiment consists in allowing for capital accumulation in the domestic and foreign economies. To this end, assume that domestic output of variety i of type a, $y_{i,a,t}$, is produced according to the technological relationship

$$y_{i,a,t} = k_{i,a,t}^{\alpha} h_{i,a,t}^{1-\alpha}, \tag{53}$$

where $k_{i,a,t}$ and $h_{i,a,t}$ denote, respectively, capital and labor services used in the production of variety i of goods of type a. Set the parameter α to 0.25. Capital is accumulated by households and evolves according to the law of motion

$$k_{t+1} = (1-\delta)k_t + x_t^I \left[1 - \frac{\kappa}{2}\left(\frac{x_t^I}{x_{t-1}^I} - 1\right)^2\right], \tag{54}$$

where k_t denotes the aggregate level of physical capital and x_t^I denotes gross investment. Set the parameters δ and κ governing the rate of depreciation and the degree of investment adjustment costs at 0.025 and 15, respectively. The investment good is a composite of domestic and foreign goods of the type

$$x_t^I = \left[\omega (x_{a,t}^I)^{1-1/\xi} + (1-\omega)(x_{b,t}^I)^{1-1/\xi}\right]^{1/(1-1/\xi)}, \tag{55}$$

[15] The resulting point estimates of θ^c, θ^g, and ρ are, respectively, 0.56, 0.48, and 0.99.

where $x^I_{a,t}$ and $x^I_{b,t}$ denote investment goods of type a and b, respectively. In turn, these investment goods are composites of a continuum of intermediate varieties produced as follows

$$x^I_{a,t} = \left[\int_0^1 I_{i,a,t}^{1-1/\eta} di\right]^{1/(1-1/\eta)} \tag{56}$$

and

$$x^I_{b,t} = \left[\int_0^1 I_{i,b,t}^{1-1/\eta} di\right]^{1/(1-1/\eta)}, \tag{57}$$

where $I_{i,a,t}$ ($I_{i,b,t}$) denotes inputs of variety i and type a (b) in the production of investment good a (b). The resource constraint for capital requires that $k_t = \int_0^1 k_{i,a,t} di$. The production and accumulation of physical capital in the foreign economy is symmetric.

In the empirical SVAR, investment is measured as the sum of residential and nonresidential investment. Following Monacelli and Perotti (2006), the investment equation is estimated by replacing consumption with investment in the panel VAR system.

[Figure 4 about here.]

Figure 4 shows that the estimated response of investment to a one-percent increase in government spending is negative but insignificant. The two-standard-deviation confidence band includes zero at all horizons. This weak response of investment is in line with the findings of existing empirical studies. See, for instance, Perotti (2008), figure 3.14.[16] As in previous sections, the structural parameters θ^c, θ^g, and ρ defining the degree of deep habit formation are estimated by minimizing a weighted difference between the theoretical and empirical impulse responses. The point estimates are $\theta^c = 0.53$, $\theta^g = 0.68$, and $\rho = 0.95$. These values are similar in magnitude to those estimated under the assumption of no capital accumulation. The model predictions regarding the responses of consumption and the real exchange rate to a government spending shock, which are the focus of our study, continue to be as successful in matching the observed responses as in the model without capital. The same is true for output and the trade-balance-to-output ratio. The predicted impulse response for investment lies within the two-standard-error band. These findings indicate that the ability of the deep-habit model to explain the response of consumption, the real exchange rate, and the trade balance to government spending shocks is robust to the introduction of capital accumulation.

8.5. Estimating the SVAR on Simulated Data

Our final sensitivity test sheds light on whether the theoretical impulse responses are comparable to the ones implied by the empirical VAR system. The reason why this question is of interest is that the theoretical model, driven by a single government spending shock, does not have a VAR representation of the type proposed in the empirical analysis. Even after adding structural shocks to equalize the number of disturbances and observables, a VAR representation may not exist. Furthermore, if a VAR representation did exist, the theoretical VAR system will in general contain an infinite lag structure, while its empirical counterpart must necessarily feature a finite lag length. To address this issue, exogenous structural disturbances are added to the deep habit model with capital accumulation and then impulse response functions are derived from SVARs estimated on artificial time series generated by the deep habit model. Specifically, a foreign government spending shock, domestic and foreign productivity shocks, and domestic and foreign preference shocks are added. All of these additional disturbances are assumed to follow AR(1) processes. The persistence and contemporaneous correlation of productivity shocks are set as in Backus et al. (1992), the persistence of the foreign government spending shock is set at 0.87, which is the observed serial correlation of public consumption in the postwar United States, and the persistence of the preference shocks is set at 0.9. Finally, the volatilities of the exogenous driving forces are calibrated to ensure that government spending shocks, preference shocks, and productivity shocks explain, respectively, 20 percent, 20 percent, and 60 percent of the unconditional variance of domestic output. It is assumed that shock volatilities are of equal size across

[16] Perotti uses a 68 percent confidence interval based on 500 Monte Carlo simulations.

countries. Then 10,000 time series for government spending, output, consumption, the trade-balance-to-output ratio, the real exchange rate, and investment are simulated from the theoretical model. The size of each of the 10,000 artificial samples is set at 512 observations, which matches the length of our panel data set (4 countries and 128 quarters per country). Finally, for each of the 10,000 samples a SVAR system is estimated using the same lag structure and identification assumptions as in the empirical analysis. Figure 4 displays with circled lines the mean of the 10,000 impulse responses. The impulse responses obtained by this Monte Carlo experiment are almost identical to the true theoretical impulse responses. The main insight of this exercise is that in the context of our model and under our identification assumptions, an SVAR model uncovers the true impulse response functions to government spending shocks.

9. Conclusion

Using quarterly data from a panel of four industrialized countries from 1975 to 2005, we identify the effects of government spending shocks on output, consumption, the real exchange rate, and the trade balance. An increase in government spending produces an expansion in output, an expansion in consumption, a depreciation of the real exchange rate, and a deterioration of the trade balance.

A central contribution is to propose and test the hypothesis that deep habits generates a transmission mechanism for government purchases shocks that is consistent with this empirical evidence. The key feature of the transmission channel invoked by deep habits is countercyclical movements in equilibrium markups of prices over marginal costs. In our model, an increase in government spending generates a generalized decline in markups in domestic markets and an increase in markups in foreign markets. Thus, the domestic economy becomes inexpensive relative to the foreign economy, or the real exchange rate depreciates. At the same time, the decline in domestic markups shifts the demand for labor outward pushing real wages up. In turn, the increase in labor remunerations induces households to sacrifice leisure in favor of consumption. In the estimated deep-habit model, this substitution effect dominates the negative wealth effect stemming from the increase in public absorption of resources. As a result private consumption increases in equilibrium.

Estimation of the structural parameters defining the deep-habit mechanism provide strong evidence in favor of habit formation at a good-by-good level both in private and public consumption. The predictions of the deep-habit model replicate well the estimated impulse responses of output, consumption, and the trade balance, and the initial response of the real exchange rate. These results represent, in our opinion, a step forward in the understanding of the effects of fiscal policy.

This paper focuses on explaining the effects of unanticipated changes in government spending identified using the SVAR methodology proposed in Blanchard and Perotti (2002). A natural next step in this research agenda is to understand the observed effects of anticipated increases in government spending, such as news about future expected military build-ups triggered by war, as identified by the narrative approach. In the working-paper version of this paper (Ravn, Schmitt-Grohé and Uribe, 2007, section 8), it is shown that in the context of a deep habit model, consumption and wages fail to increase upon the release of news about future expansions in public spending. This prediction of the deep habit model is consistent with the empirical evidence emerging from the narrative approach to identifying government spending shocks.

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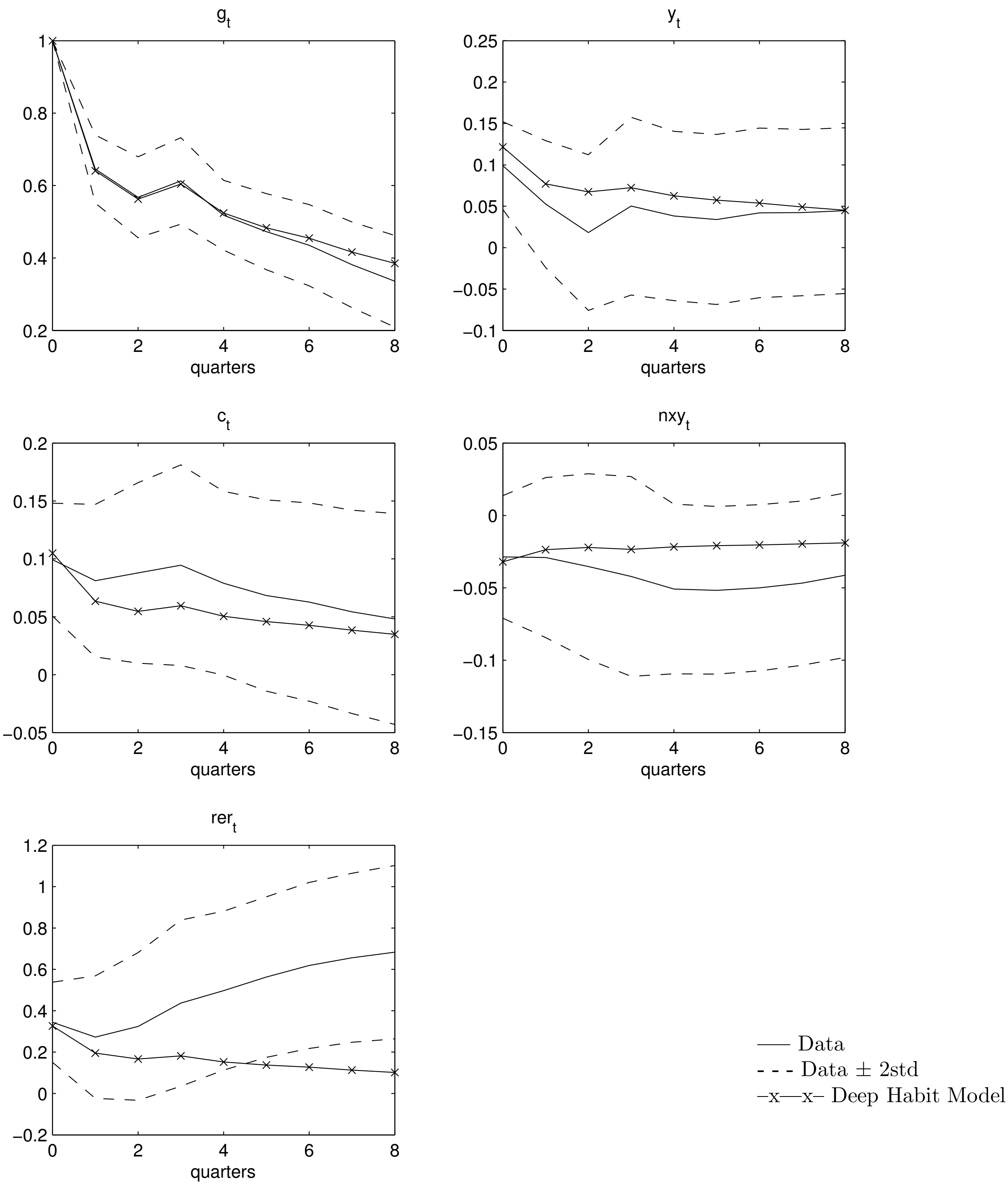
Figure 1: Estimated and Predicted Impulse Responses To A One-Percent Innovation in Government Spending



Note. All responses are expressed in percent deviations from trend with the exception of the net exports-to-GDP ratio, which is in level deviations from trend and expressed in percentage points of GDP.

Figure 2: Robustness

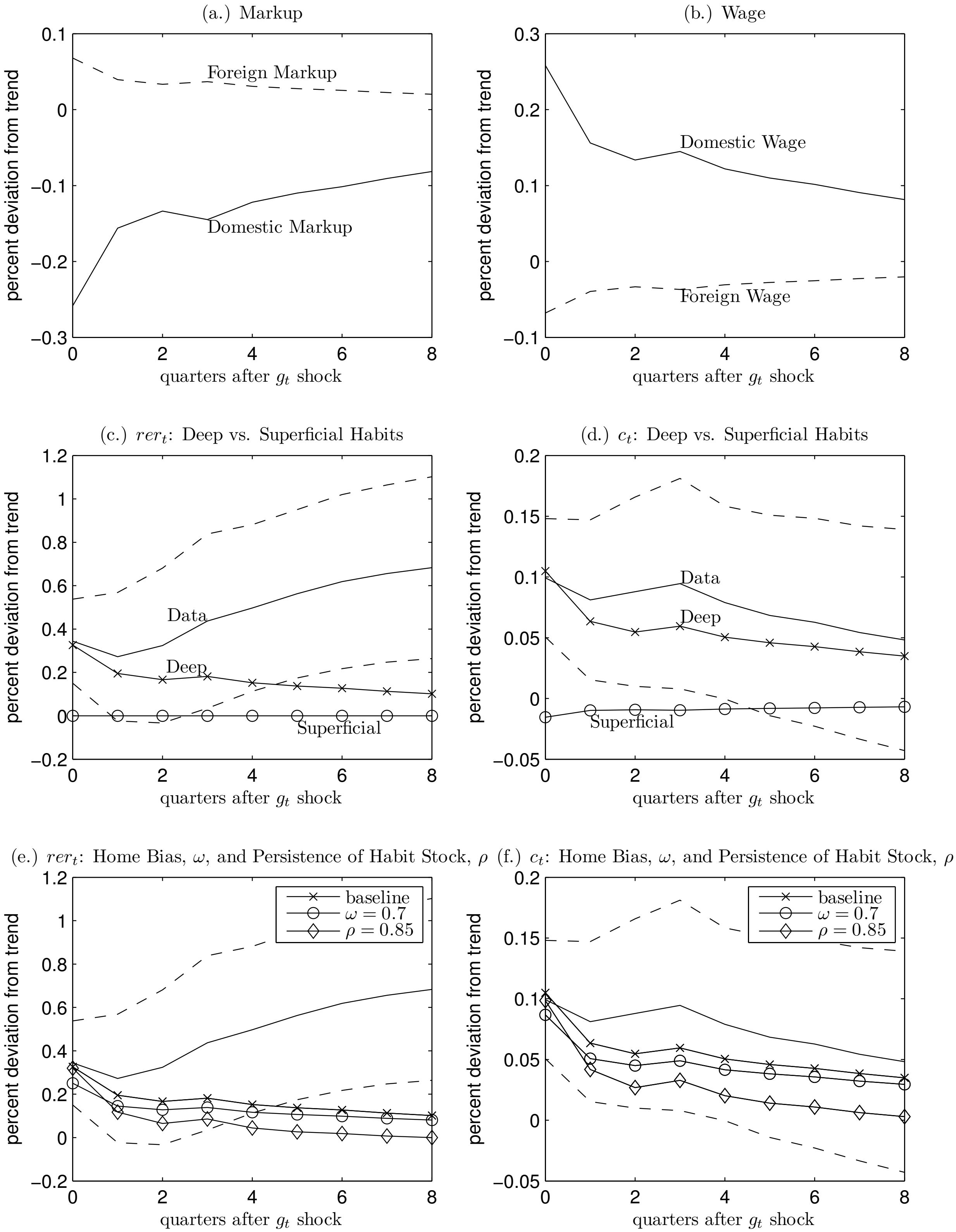
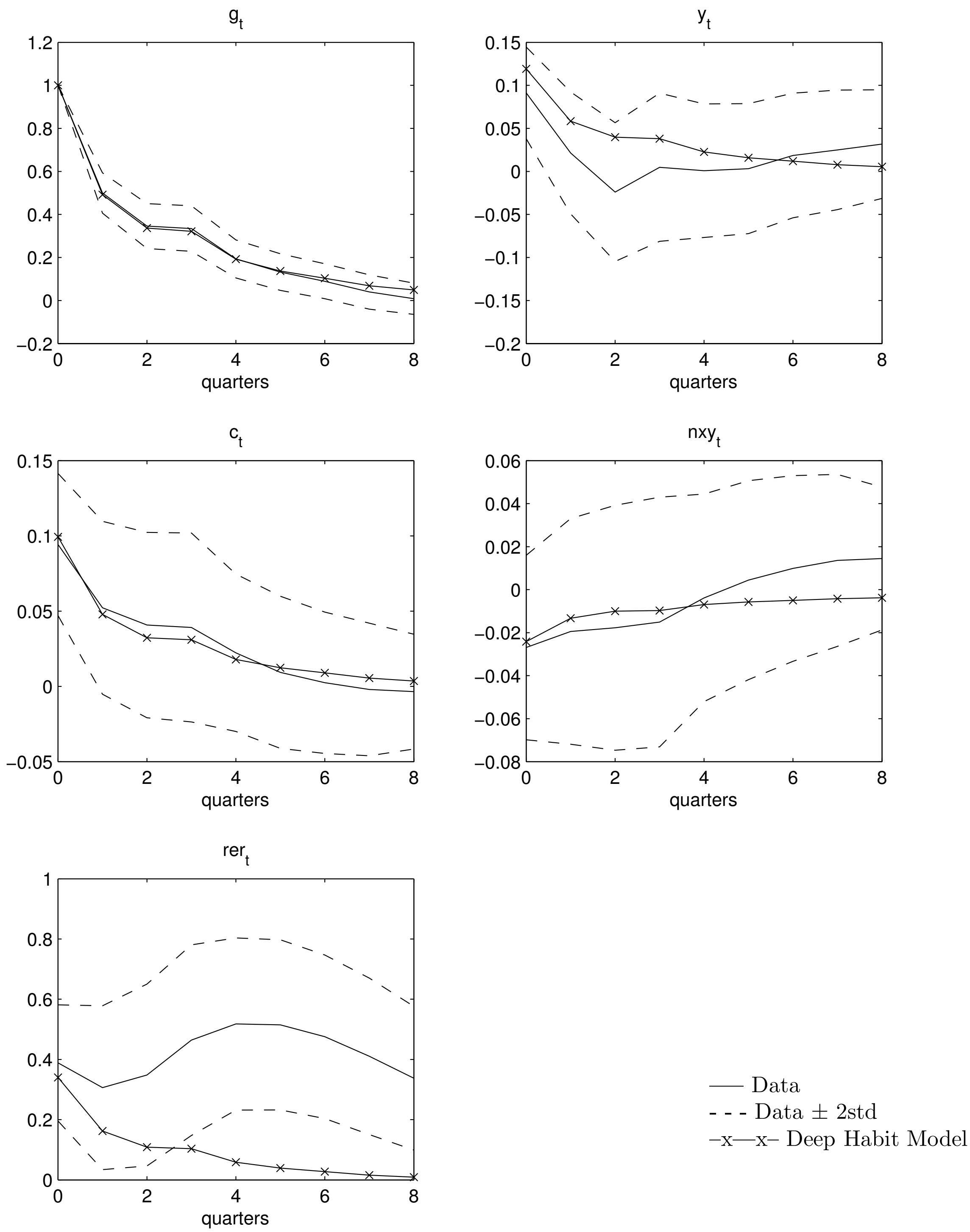
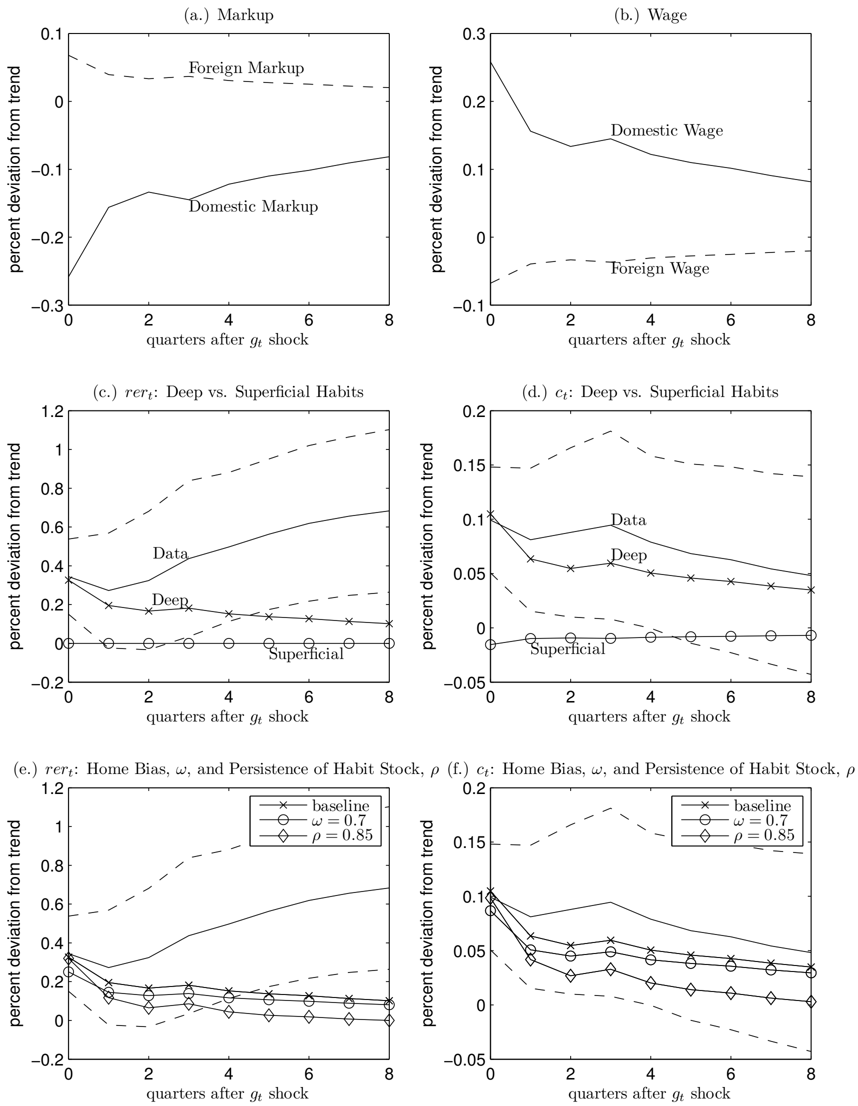


Figure 3: Sensitivity Analysis: HP Filtering



Note. All responses are expressed in percent deviations from trend with the exception of the net exports-to-GDP ratio, which is expressed in level deviations from trend.

Figure 4: The Model With Capital Accumulation: Predicted and Estimated Impulse Responses To A One-Percent Innovation in Government Spending



—— Data   - - - Data ± 2std   –x– Model (population)   –o– Model (SVAR)

Note. All responses are expressed in percent deviations from trend with the exception of the net exports-to-GDP ratio, which is in level deviations from trend and expressed in percentage points of GDP.

Table 1: Calibrated Parameters

Parameter	Value	Description
β	0.99	Subjective discount factor (quarterly)
σ	1	Intertemporal elasticity of substitution
ϕ	0.15	Preference parameter
ω	0.5	Preference parameter
ξ	1.5	Elasticity of substitution between home and foreign goods
η	5	Elasticity of substitution among varieties of habit-adjusted consumption
s_g, s_g^*	0.2	Steady-state share of government consumption in GDP

Table 2: Estimated Parameters

Parameter	Point Estimate	Standard Deviation	Description
θ^c	0.52	0.08	Degree of deep-habit formation in private consumption
θ^g	0.57	0.15	Degree of deep-habit formation in public consumption
ρ	0.9876	0.03	Persistence of deep-habit stock