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Dynamic Demand Adjustment and Exchange Rate Volatility*

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Abstract

A common finding in the international-economics literature is that the elasticity of substitution between domestically produced and imported goods is smaller in the short than in the long run. Despite this, most of today's commonly used macroeconomic models assume this elasticity to be constant. This paper studies the implications of relaxing the assumption that the elasticity is constant over time horizons, through the modeling of habit formation. Compared to the standard model without habits, the proposed dynamic demand model exhibits substantially more volatile exchange rates and can generate higher real exchange rate persistence in the presence of interest rate smoothing. A high volatility of the exchange rate turns out to be optimal in this model and is hence not an artefact of the assumed monetary policy rule. Moreover, the dynamic demand model outperforms the standard model in terms of matching moments in data for a number of other variables.

Keywords: Elasticities, Exchange Rates, Habit Formation, Optimal Monetary Policy

JEL classification: E21, E52, F31, F41, F44

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1 Introduction

There is ample empirical evidence that shows that the elasticity of substitution between domestically produced and imported goods is smaller in the short than in the long run – see McDaniel and Balistreri (2003) for a summary. Studies such as McDaniel and Balistreri (2003) and Ruhl (2008) have further shown that the elasticity of substitution is of fundamental importance for policy analysis. However, in international business cycle models, this elasticity is generally assumed to be the same for all time horizons.[1] There may thus exist non-negligible flaws in policy analysis models and the recommendations based on those, indicating a need to improve the models along the international dimension. This paper presents an intuitive and convenient way of separating the elasticity of substitution in the short and the long run, and studies the implications of this for monetary policy. Compared to the standard model, the proposed model is more in line with data and delivers some interesting policy implications.

This paper starts from two observations. One is the above mentioned common finding in the international economics literature that the elasticity of substitution between imported and domestically produced goods is smaller in the short than in the long run. The other starting point is the exchange rate disconnect puzzle, listed by Obstfeld and Rogoff (2000) as one of the six major puzzles in international macroeconomics. As pointed out in their paper, *"exchange rates are remarkably volatile relative to any model we have of underlying fundamentals"* (p. 380). These two observations may well be interrelated. Reducing the elasticity of substitution in the short run, as observed in data, should force international goods markets to clear to a higher extent through fluctuations in relative prices. When prices are sticky and central banks try to stabilize inflation, these relative price adjustments will take the form of changes in exchange rates.

I provide a simple micro-founded way of reducing the short-run elasticity of substitution in a standard international business cycle setting without altering the long-run properties of the model. This is done by introducing country-specific habit formation. Here, *country-specific* refers to habits being introduced separately for domestically produced and imported goods. More specifically, what affects the household's choices is the last period's aggregate consumption of domestically produced goods and the last period's aggregate consumption of imports. With different elasticities of substitution in the short and the long run, demand adjustment is not constant over time; thus I refer to this model as the *dynamic demand* model. The standard modeling of demand, which is a special case of the more general demand specification presented in this paper, is referred to as the standard DSGE model.

The country-specific habits setup introduced in this paper resembles the deep-habits setting by Ravn, Schmitt-Grohé, and Uribe (2006) in that the habits are formed separately for different goods. This can be motivated by the presence of consumer switching costs affecting

[1] For examples of business cycle studies, where the constant-elasticity-of-substitution specification is the standard way of modeling consumers' demand, see Galí and Monacelli (2005), Benigno and Benigno (2006), or Chari, Kehoe, and McGrattan (2002).

the agents choices, as in for example Klemperer (1987, 1995). However, while intuitively plausible, the latter setting severely complicates the model derivations. The semi-disaggregated habit formation imposed in the present model should be viewed as a convenient middle course, enabling the study of the international dimensions of habit formation without loosing much of the analytical tractability of the standard New-Keynesian model setup. It renders the supply side of the model unchanged, making it easy to include in a model featuring nominal rigidities. The modeling feature presented in this paper is thus demonstrated in a framework well suited for studying monetary policy. I study the implications for monetary policy assuming first that it follows a Taylor rule, and second that it is conducted optimally.

The main results can be summarized as follows. With the benchmark calibration, the responses of both real and nominal exchange rates are approximately twice as large on impact in the proposed model compared to the standard. Hence, allowing for elasticities of substitution to be varying over time horizons, we do not only obtain a more flexible and accurate description of consumer demand, but also take a step towards an explanation of the observed exchange rate volatility. A comparison between the dynamic demand and the standard DSGE models indicates that the inclusion of country-specific habits improves the model's performance in important ways. In addition to increasing the volatility of the exchange rates, it also brings the volatilities of some other variables and the correlations between variables overall closer to data. Assuming that monetary policy follows the classical Taylor rule, the volatility of exchange rates increases compared to the standard DSGE model, reconfirming the importance of the elasticity of international substitution for the workings of open-economy models. It should be pointed out that in the present model a high volatility of the exchange rate also turns out to be optimal. It is hence not an artefact of the assumed monetary policy rule. In fact, under the model-implied welfare-maximizing monetary policy we obtain even stronger responses in exchange rates to shocks than under the classical Taylor rule. Finally, assuming that the monetary policy authorities have a preference for interest-rate smoothing, the dynamic demand model generates more persistent real exchange rates than the standard DSGE model, matching the persistence found in data.

The rest of the paper is organized as follows. Section 2 provides a short overview of related literature. In Section 3, the model is introduced and developed. Section 4 contains a description of how monetary policy is conducted, and Section 5 a discussion of the calibration choices. In Section 6 simulation results are presented, starting with the outcomes under the rule-based monetary policy. These are followed by the results under optimal policy, as well as comparisons of the simulated second moments of the model with the corresponding ones in data. In Section 7, the sensitivity of the results to changes in calibration and an alternative modeling specification are discussed. Finally, Section 8 concludes.

2 Related literature

The topic of concern in this paper relates to at least three different branches of the macroeconomic literature. Some of the relevant contributions to each of these are discussed below.

The first one is the literature dealing with the elasticities of international substitution. The amount of available estimates is vast, especially so for the US, but many of these are plagued by biases and problems of identification.[2] In their survey of the literature over the last thirty years, McDaniel and Balistreri (2003) summarize the robust findings that emerge. Generally, long-run estimates are found to be higher than short-run ones, sometimes considerably so. Furthermore, cross-sectional studies generally arrive at higher estimates than time series studies, which has been attributed to the former capturing the long-term differences in trade flow levels that the latter cannot. While time series estimates of short-term elasticities are often found to be around unity or even lower, long-term estimates can be as high as 10 or even 20.[3] Of course, methodological differences between studies are bound to affect the estimates. Though most studies focus on one time horizon or the other, some specifications allow for estimation of both, thus offering a sense of the difference in magnitude that cannot be attributed to methodology. One such study is Gottfries (2002), who estimates the long-run elasticity to be more than ten times the short run one. Specifically, applying instrumental-variable methods, Gottfries (2002) finds that the within-quarter elasticity of Swedish exports is 0.27, while the long-run elasticity equals 3. Gallaway, McDaniel, and Rivera (2003) estimate short- and long-term elasticities on US data and find the long-term elasticity to be up to five times the short-term one.[4] The findings from these studies can and will be used to infer the appropriate calibration of the habit parameter in our model, as there exist no direct estimates of this parameter in earlier studies.

A second body of literature raises the issue of how monetary policy optimally should be conducted in open economies. Galí and Monacelli (2005) study monetary policy in a small open economy setting, finding that, in the special case of log utility and a unit elasticity

[2] As pointed out already by Orcutt (1950), a standard regression of quantities on prices yields an estimate that is some weighted average of the price elasticities of supply and demand. Simultaneous shifts in both the demand and the supply schedules are likely to occur, which makes it impossible to clearly distinguish the response of demand to price changes in the standard reduced-form setting. As emphasized further by Leamer (1981), a negative estimate should be treated as an estimate of a demand curve and a positive as an estimate of a supply curve, but in either case the obtained elasticity estimates are biased toward zero.

[3] An elasticity of substitution below unity is often considered theoretically unappealing, as it implies that all goods or, as in our case, both the basket of domestically produced goods and the basket of imported goods are essential to obtain utility. This, in turn, would imply that even with an infinitely high price, one would still demand some amount of both types of goods. While this may seem implausible in the long run, it may not be unreasonable to assume that both types of goods are indispensable in the short run, as adjustment is not likely to be immediate. In the rest of this paper, hence, I will restrict the long-run elasticity of substitution to be higher than unity, but place no such restriction on the magnitude of this elasticity in the short run.

[4] As theirs is a simple single-equation time-series analysis, however, their estimates may suffer from endogeneity problems. Moreover, a non-negligible fraction of their estimated elasticities turn out to be insignificant. For other estimates of short-term elasticities, see for example Hooper, Johnson, and Marquez (2000) who estimate trade elasticities for the G7 countries. For further examples of long-term elasticities, see Feenstra (1994) and Broda and Weinstein (2006), among others.

of substitution, the optimal policy requires that the domestic price level is fully stabilized. Furthermore, comparing three simple monetary policy rules, the authors find that they can be welfare ranked in terms of their implied volatility for the nominal exchange rate and the terms of trade, so that the policy that implies the highest exchange rate volatility is the highest ranked.[5] Benigno and Benigno (2006) study optimal monetary policy in a two-country setting finding that, generally, there are gains from policy cooperation.

Finally, related to this exercise and worth briefly discussing is the literature on non-standard preferences, specifically habit formation in consumption. Habits imposed on the aggregate consumption level are frequently seen in the literature; in fact, practically any DSGE model that is taken to the data incorporates habits on the aggregate level in order to match the empirically observed consumption persistence.[6] Although this type of habit specification is the by far most predominant one, other types exist in the literature. Ravn et al. (2006) allow for consumers to form habits over specific goods. They thereby manage to successfully match important features of firms' pricing, as the deep-habit-formation assumption generates countercyclical movements in markups. Ravn et al. argue that their model can be viewed as a natural vehicle for incorporating switching-cost/customer-market models into a dynamic general equilibrium framework. However, habit formation on the level of individual goods severely complicates the supply side derivations, and Ravn et al. (2006) do not include any nominal rigidities in their model.[7]

Preceding the study by Ravn et al. (2006), there is a body of literature dealing with the issue of consumer switching costs.[8] It presents convincing evidence that consumers perceive it as costly to switch to consuming new brands due to information costs, which affects consumption choices. As discussed by Klemperer (1987, 1995), there are also physical costs involved in brand switching, such as transactions costs or contractual costs. The *brand loyalty* that this results in certainly resembles the phenomenon we model as habit formation, at least on the disaggregated level. In a macroeconomic setting the degree of aggregation in any macro model is then chosen facing a tradeoff between realism and analytical simplicity. In the present paper, I impose habits on a semi-disaggregated level. The advantage of the type

[5]Excess smoothness in the nominal exchange rate, when combined with sluggish nominal prices, slows down the adjustment in relative prices following shocks. Consequently, the lower the exchange rate volatility implied by a policy, the lower is that policy ranked in welfare terms. It is a general finding that there are either no or small performance improvements from including the real exchange rate into the policy rule – see Taylor (2001) for a review of the literature.

[6]See Smets and Wouters (2003, 2007) and Christiano, Eichenbaum, and Evans (2005), among others. It is worth noting that estimated values of the habit parameter, normally restricted to pertain to the unit interval, are usually found to be quite high – see Fuhrer (2000), Guerrón-Quintana (2010), and Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez (2008), among others.

[7]Following the work of Ravn et al. (2006), Moore and Roche (2008) model habit formation on the good level in a two-good two-country model. While the idea is related to the one underlying this study, the framework is very different from the one used here and not suited for the study of monetary policy, nor is the simpler model setup easily generalized. Nevertheless, Moore and Roche (2008) find that exchange rate volatility is significantly increased in their model, indicating that the inclusion of habit formation on the international level is a promising approach.

[8]See, for example, Gottfries (1986), von Weizsäcker (1984), Klemperer (1987, 1989, 1995), Beggs and Klemperer (1992), and Stango (2002).

of habit formation modeled here is that it considerably simplifies the analysis relative to the deep-habits model, while still having substantial effects on the dynamics of the international relative prices.

3 The model economy

The implications of the dynamic demand assumption are studied in a two-country dynamic stochastic general equilibrium model, featuring imperfectly competitive firms and staggered price setting as in Calvo (1983). We keep the model as simple as possible, to make the implications of this assumption clear and intuitive. Habits are external or, in other words, of the *keeping-up-with-the-Joneses* type, and can thus be seen as a consumption externality. The world consists of two countries, *Home* and *Foreign*. Each of the two economies is populated by a number of households defined over a continuum of unit mass, and assumed to be immobile between countries. The firms in the two economies each produce a differentiated good using the same production technology, with labor as the only input. Firms are indexed by i, while households are indexed by j. The subscripts H and F denote consumption and prices of *Home* and *Foreign* goods respectively, while an asterisk denotes allocations and prices in the *Foreign* country. In other words, the subscripts H and F refer to the origin of the good, while the asterisk refers to where it is consumed, so that C_F denotes the *Home* agents' consumption of *Foreign* goods, C_H^* denotes the *Foreign* agent's consumption of *Home* goods, etc. The economy is assumed to be a cashless limiting economy, following Woodford (2003). Finally, asset markets are assumed to be complete both internationally and domestically.

3.1 Preferences

The expected lifetime utility of the *Home* household j is given by

$$U_t^j = \mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \left\{ u\left(C_t^j;\xi_t\right) - v\left(L_t^j\right)\right\}, \tag{1}$$

where C_t^j and L_t^j denote household j's time-t consumption and labor supply, and β is the household's discount factor. The utility function u is given by

$$u(C_t^j;\xi_t) = \xi_t \frac{1}{1-\theta}(C_t^j)^{1-\theta}, \tag{2}$$

where ξ_t denotes a preference shock at time t, the process of which will be further specified below. The disutility of labor v, in turn, is given by

$$v(L_t^j) = \frac{1}{1+\varphi}(L_t^j)^{1+\varphi}. \tag{3}$$

In each of the two countries a continuum of differentiated goods, defined on the unit interval, is produced. The consumption indices of *Home* and *Foreign* goods, C_H and C_F, respectively, are then defined as follows

$$C_H^j \equiv \left[\int_0^1 c^j(i)^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}} \qquad C_F^j \equiv \left[\int_0^1 c^j(i)^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

where $\sigma > 1$ is the elasticity of substitution between the individual differentiated goods. Each individual household's consumption consists of aggregates of differentiated *Home* and *Foreign* goods, so that the total consumption basket is defined as an aggregate of the two types. Specifically, I define

$$C_t^j = \left[(1-\omega_t)^{\frac{1}{\gamma}} C_{H,t}^{j\,\frac{\gamma-1}{\gamma}} + \omega_t^{\frac{1}{\gamma}} C_{F,t}^{j\,\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}, \tag{5}$$

where $C_{H,t}^j$ is household j's consumption of the *Home*-produced goods, $C_{F,t}^j$ is the corresponding consumption of *Foreign*-produced goods, and the time-varying import share ω_t is defined as

$$\omega_t \equiv \frac{\nu^{1-h}\left(\frac{C_{F,t-1}}{C_{t-1}}\right)^h}{(1-\nu)^{1-h}\left(\frac{C_{H,t-1}}{C_{t-1}}\right)^h + \nu^{1-h}\left(\frac{C_{F,t-1}}{C_{t-1}}\right)^h}. \tag{6}$$

Note that the denominator in ω_t is included only for normalization purposes, so that the weights of the consumption index at all times sum to one. We thus focus on the numerator. The parameter h determines the strength of habit persistence. Consumers form habits in the shares of *Home* and *Foreign* goods consumed; the current period's consumption level of a particular basket of goods is multiplied by a function of last period's consumption share of that same basket. The parameter ν denotes the steady-state consumption share of imports.[9] When ν is set to one half, consumption is split equally between domestic and imported goods, while a value of ν in the interval $[0, \frac{1}{2})$ implies that there is home bias in consumption. If $\nu = 0$, we end up in the extreme of no trade in goods taking place between the two countries.

In the above specification, γ is the short-run elasticity of substitution between *Home* and *Foreign* goods, while the long-run elasticity is given by $\frac{\gamma}{1-h}$ (see Appendix A.4 for derivations). Hence, the habit formation introduced here can be thought of as adding a rigidity in the short run affecting the international dimension of the model. The strength of the persistence of habit formation can be varied with the parametrization of h. In the extreme case of $h = 0$, equation (5) reduces to the standard specification where utility is affected by current consumption only, in which case γ becomes the only elasticity of substitution between *Home* and *Foreign* goods. As $h \to 1$, the long-run elasticity of substitution goes to infinity independently of what value the short-run elasticity takes. Hence, the larger the value of h, the more pronounced is the short-term rigidity and the larger is the difference between the

[9]That ν equals the steady-state import share is clear from the steady-state result that $\bar{\omega} = \nu$. See Appendix A.3 for details and derivations.

elasticities in the long and the short run.

As shown in Appendix A.1, with the above specification, the implied price index is

$$P_t = \left[(1-\omega_t)P_{H,t}^{1-\gamma} + \omega_t P_{F,t}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \ , \tag{7}$$

where

$$P_{H,t} = \left[\int_0^1 p(i)^{1-\sigma}\,\mathrm{d}i\right]^{\frac{1}{1-\sigma}} \qquad P_{F,t} = \left[\int_0^1 p(i)^{1-\sigma}\,\mathrm{d}i\right]^{\frac{1}{1-\sigma}} . \tag{8}$$

The demand for *Home* and *Foreign* goods coming from *Home* consumers is given by

$$C_{H,t}^j = (1-\omega_t)\frac{P_{H,t}}{P_t}^{-\gamma} C_t^j \tag{9}$$

$$C_{F,t}^j = \omega_t \frac{P_{F,t}}{P_t}^{-\gamma} C_t^j \tag{10}$$

The price index and the demand functions are of the same form as in the Dixit-Stiglitz framework, with the only difference that ω_t is now a function of last period's consumption shares instead of being a constant. Further details on the comparison with the standard setup are included in Appendix A.2.

Finally, given that the consumers in the *Foreign* economy have identical preferences as the consumers in *Home*, the demand for a particular *Home* good i, i.e. the demand that the *Home* firm i faces, is given by

$$Y_t(i) = \left(\frac{p_t(i)}{P_{H,t}}\right)^{-\sigma}\left[C_{H,t} + C_{H,t}^*\right] \ , \quad i \in [0,1] \, . \tag{11}$$

The preferences of the *Foreign* households equal those of the *Home* households with the weight on the *Home* consumption aggregate now given by ω_t^*, defined as

$$\omega_t^* \equiv \frac{(\nu^*)^{1-h^*}\left(\frac{C_{H,t-1}^*}{C_{t-1}^*}\right)^{h^*}}{(1-\nu^*)^{1-h^*}\left(\frac{C_{F,t-1}^*}{C_{t-1}^*}\right)^{h^*} + (\nu^*)^{1-h^*}\left(\frac{C_{F,t-1}^*}{C_{t-1}^*}\right)^{h^*}} \, . \tag{12}$$

3.2 Technology and resource constraints

Each firm produces one single differentiated good, which is sold both in *Home* and *Foreign*, acting under monopolistic competition. To keep the derivation simple, we assume producer currency pricing, i.e. the firms set one single price in the currency of the country where the firm is located.[10] This assumption implies that there is full exchange rate pass-through into import prices. All firms within a country use the same linear production technology, which,

[10]This assumption does not work in favor of increasing the volatility of the exchange rate. If anything, assuming producer currency pricing may have a restraining effect on volatility – see discussion in Section 8.

for *Home* goods, is given by

$$Y_t(i) = X_t L_t(i)\,, \tag{13}$$

Here, X_t is the level of technology in the *Home* economy at time t.

The resource constraint in the *Home* economy is given by[11]

$$Y_t = C_{H,t} + C^*_{H,t}\,, \tag{14}$$

where Y_t denotes aggregate production in the *Home* country at time t.

3.3 Budget constraints and the household's optimization

The *Home* households maximize the utility function given by (1), with $u(C_t^j;\xi_t)$ and $v(L_t^j)$ defined as in (2) and (3), subject to the sequence of budget constraints

$$P_t C_t^j + \sum_{s^{t+1}} q(s_{t+1}|s^t) B^j(s_{t+1}|s^t) \leq B^j(s_t|s^{t-1}) + W_t L_t^j + \int_0^1 \Pi_t^j(i)\mathrm{d}i\,. \tag{15}$$

Agents consume *Home* and *Foreign* goods, and buy state-contingent bonds $B(s_{t+1}|s^t)$ at the price $q(s_{t+1}|s^t)$ denoted in *Home* currency where s_{t+1} denotes a possible state at time $t+1$, and $s^t = (s_t, s_{t-1}, ..., s_0)$ denotes the history of events that have occurred up through time period t.[12] The income comes from previous period's bond savings, wages W_t and profits Π_t. It is assumed that every agent in the economy owns an equally large fraction of each firm in the economy. The ownership of *Home* (*Foreign*) firms is restricted to the *Home* (*Foreign*) population.

With complete financial markets, the expected marginal utility of income is equal across agents. Having assumed a utility function that is separable in consumption and labor supply, we in addition have that the marginal utility of consumption depends on the level of consumption only, implying that the consumption levels are equalized across agents within a country. Hence, consumption is equalized across *Home* agents, why I henceforth omit the household index j. The first-order conditions with respect to C_t and $B^j(s_{t+1}|s^t)$ combined, after summing over all possible states at $t+1$, yield the familiar Euler equation

$$u_C(C_t, \xi_t) \quad = \quad R_t \beta\, \mathrm{E}_t \left\{ u_C(C_{t+1}, \xi_{t+1}) \frac{P_t}{P_{t+1}} \right\}, \tag{16}$$

where R_t denotes the gross nominal interest rate. Combining the first order conditions with

[11] I implicitly assume that there is a wholesale sector in the economy, packaging the continuum of differentiated goods into the *Home* and *Foreign* aggregate goods according to consumers' preferences. Remembering that the total demand for *Home* good i coming from *Home* and *Foreign* is given by $c_t(i)$ and $c_t^*(i)$, respectively, and that for each individual good we must have that production equals demand, the final aggregator can be written as $Y_t = \left[\int_0^1 y_t(i)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}} + \left[\int_0^1 y_t^*(i)^{\frac{\sigma-1}{\sigma}}\mathrm{d}i\right]^{\frac{\sigma}{\sigma-1}}$.

[12] It is understood that all other variables are state dependent as well. However, to simplify notation, I have let C_t denote $C(s^t)$, L_t denote $L(s^t)$, etc.

respect to C_t and L_t, next, we have

$$\frac{v_L(L_t)}{u_C(C_t,\xi_t)} = \frac{W_t}{P_t}\,, \tag{17}$$

which tells us that the marginal rate of substitution between consumption and labor must be equal to the real wage.

3.4 The firm's optimization and price setting

Taking wages as given, firms minimize their expenditures, which yields the following expression for the firm's nominal marginal costs:

$$MC_t(i) = MC_t = \frac{W_t}{X_t}\,. \tag{18}$$

Note that, since the firms all face the same wage and the same technology, the marginal costs are equal for all firms.

Prices are set in a staggered fashion as in Calvo (1983). A fraction $(1-\alpha)$ of randomly chosen firms are allowed to reset their price in each period. When allowed to change its price, a firm maximizes the expected discounted value of its profits in the current period and every future period during which it does not get the opportunity to reoptimize. Letting α^z denote the probability of the chosen price still remaining effective z periods ahead, the firm maximizes

$$E_t \sum_{z=0}^{\infty} (\alpha\beta)^z \Lambda_{t,t+z} \left((1-\tau_{t+z})\, p_t(i)\, Y_{t+z}(i) - W_{t+z} L_{t+z}(i)\right)\,, \tag{19}$$

subject to the sequence of demand functions

$$Y_{t+z}(i) = \left(\frac{p_t(i)}{P_{H,t+z}}\right)^{-\sigma} Y_{t+z}\,. \tag{20}$$

Here, I have defined

$$\Lambda_{t,t+z} \equiv E_t \frac{u_C(C_{t+z})}{P_{t+z}} \frac{P_t}{u_C(C_t)}\,, \tag{21}$$

and let τ_t denote a tax on the firm's profits. Using equation (17) along with the production function (13), we can derive the following optimal price:

$$p^o_{H,t} = \left[\frac{E_t\left\{\sum_{z=0}^{\infty} (\alpha\beta)^z (1+\varphi)\, \mu_{t+z} P_{t,t+z}^{-\sigma(1+\varphi)} Y_{t+z}^{1+\varphi} X_{t+z}^{-(1+\varphi)}\right\}}{E_t\left\{\sum_{z=0}^{\infty} (\alpha\beta)^z P_{t,t+z}^{1-\sigma} \xi_{t+z} C_{t+z}^{-\theta} Y_{t+z} T_{H,t+z}\right\}}\right]^{\frac{1}{1+\sigma\varphi}}\,. \tag{22}$$

Note that I have defined $p^o_{H,t} \equiv p_t(i)/P_{H,t}$ and $P_{t,t+z} \equiv P_{H,t}/P_{H,t+z}$, and that μ_t denotes the price markup defined by

$$\frac{1}{\mu_t} \equiv \frac{\sigma-1}{\sigma}(1-\tau_t)\,, \tag{23}$$

and hence allowed to vary over time with τ_t. Given that there is a continuum of firms in the economy, and thus the law of large numbers applies, the Calvo price-setting assumption implies that the evolution of the *Home* price sub-index is given by

$$1 = \alpha \pi_{H,t}^{\sigma-1} + (1-\alpha)\left(p_{H,t}^{o}\right)^{1-\sigma} . \tag{24}$$

3.5 Optimal risk sharing

Combining the *Home* bond price equation with its *Foreign* equivalent, we have

$$\frac{u_C(C_{t+1})}{u_C(C_t)} \frac{P_t}{P_{t+1}} = \frac{u_C(C_{t+1}^*)}{u_C(C_t^*)} \frac{S_t P_t^*}{S_{t+1} P_{t+1}^*} . \tag{25}$$

Iterating, we obtain the optimal risk-sharing condition

$$\frac{u_C(C_t)}{u_C(C_0)} \frac{P_0}{P_t} = \frac{u_C(C_t^*)}{u_C(C_0^*)} \frac{S_0}{S_t} \frac{P_0^*}{P_t^*} . \tag{26}$$

Defining the real exchange rate as $Q_t \equiv \frac{S_t P_t^*}{P_t}$, we have that

$$Q_t = \psi \, \frac{u_C(C_t^*)}{u_C(C_t)} , \tag{27}$$

where $\psi \equiv \frac{u_C(C_0)}{u_C(C_0^*)} \frac{S_0 P_0^*}{P_0}$ is a constant depending on the two countries' initial conditions. Using the assumed utility function (2), we can write the optimal risk-sharing condition as

$$C_t = \psi^{\frac{1}{\theta}} \left(\frac{\xi_t}{\xi_t^*}\right)^{\frac{1}{\theta}} Q_t^{\frac{1}{\theta}} C_t^* . \tag{28}$$

4 Monetary Policy

For the above model to be complete, we need to specify how monetary policy is conducted. We model monetary policy in two ways: it is either assumed that the monetary authority follows a Taylor rule, or, it is assumed that the monetary authority minimizes a loss function derived from consumer welfare. In the second setting, the resulting monetary policy is the optimal one.

4.1 Rule-based monetary policy

In the first part of the analysis, monetary policy is modeled as an interest-rate feedback rule, given by

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left[\left(\frac{\pi_{H,t}}{\bar{\pi}_H}\right)^{\mu_\pi} \cdot \left(\frac{Y_t}{Y_t^n}\right)^{\mu_Y} \right]^{1-\rho_R} \varepsilon_t , \tag{29}$$

where ε_t is a shock to monetary policy at time t and Y_t^n denotes the natural level of output. In the case of $\rho_R = 0$, we obtain the classical Taylor rule as a special case. A positive value of ρ_R implies that the monetary authority has a preference for interest-rate smoothing.

4.2 Optimal monetary policy

In the second part of the analysis, we instead turn our focus to the optimal policy implied by the model. To do this, we need to derive and optimize the model-specific objective function of the monetary policy authority.

The welfare of each country is simply the expected utility of its representative consumer, for *Home* given by

$$\mathbb{W} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[u\left(C_t; \xi_t\right) - \int_0^1 v\left(Y_t\left(i\right); X_t\right) di \right] \right\} . \tag{30}$$

World welfare is then defined as the sum of the two countries' utilities, so that

$$\mathbb{W}^W = \frac{1}{2}\mathbb{W} + \frac{1}{2}\mathbb{W}^* . \tag{31}$$

Following the methodology laid out in Benigno and Woodford (2008), I use the linear-quadratic approach to the optimal policy problem. Hence, while the model equations are kept linear, I derive a quadratic approximation to the welfare function. This is done by first taking a second-order Taylor expansion of the utility function around the efficient steady state, and then eliminating the linear terms in the obtained expression using second-order approximations of the model equations. In practice, I form a system of equations using the model's conditions and find the linear combination of the equations of the system that exactly offsets the linear terms in the welfare function thus leaving us with quadratic terms only, as in Benigno and Benigno (2006). The details of these derivations are presented in Appendix B.

When choosing the optimal monetary policy, I assume that the monetary authorities of the two countries cooperate to maximize world welfare. As Benigno and Benigno (2006) show that there are, in general, gains from policy cooperation, the analysis in this paper is restricted to cooperative policy outcomes.

5 Calibration

The time period is one quarter. We focus on the case of two completely symmetrical countries, i.e. all parameters are set equal for *Home* and *Foreign*. The openness parameter ν is set to 0.25; in other words, a quarter of all goods produced within one of the countries is exported to the other. Following Chari et al. (2002) and Benigno (2004) among others, the preference parameters are chosen so that $\sigma = 10$, yielding a steady-state markup of approximately 11 %, and $\varphi = 2$, yielding a Frisch elasticity of labor supply of one half. Furthermore, the risk aversion parameter θ is set to 2, a value representative of the range of values commonly used in the literature.[13] The calibration of γ and h deserves special attention, since a combination of these governs the difference between the elasticities of substitution in the short and long runs. I set the within-quarter price elasticity γ to 0.3, based on the findings in Gottfries (2002). In order to make the long-run elasticity of substitution, given by $\frac{\gamma}{(1-h)}$, plausibly large, I then set h to 0.9. This makes the long-run elasticity ten times the short-run one. The discount factor β is set to 0.99, which approximately corresponds to a yearly interest rate of 4 % in steady state. The Calvo parameter α is set to 0.75, yielding an expected price duration of one year. Monetary policy is conducted according to the classical Taylor rule, with the policy parameters $\mu_\pi = 1.5$ and $\mu_Y = 0.5$ as in the original Taylor (1993) study. To calibrate the shock processes, I use the estimates obtained in Adolfson, Laséen, Lindé, and Villani (2007).[14] I set the persistence of the technology shock, ρ_X, to 0.909 and the persistence of the shock to consumption preferences, ρ_ξ, to 0.935. The monetary policy shock and the shock to the price markup are assumed to have no autoregressive component, following Adolfson et al. (2007), Christiano, Trabandt, and Walentin (2011), and others. For the simulation of the second moments of model variables we need to calibrate the standard deviations of the shocks as well. These are set to 0.452, 0.151, 0.133 and 0.130 for the technology, consumption, monetary policy and price markup shocks, respectively, based on the estimates in Adolfson et al. (2007).

The calibration of the comparison model, i.e. the standard DSGE model (see Appendix A.2), differs from the dynamic demand model only by the calibration of the elasticity of substitution between *Home* and *Foreign* goods. Since this elasticity is constant over time horizons under standard demand, it is chosen so that it equals the long-run elasticity in the dynamic demand model, rendering the steady states of the two models equal.

6 Results

We study the impulse response functions following the shocks, assuming first that monetary policy follows a Taylor rule, and, second, that monetary policy is conducted optimally. Then, the second moments of the main variables of interest are presented and compared to data. Finally, the present model is compared to a model that includes import-adjustment costs instead of habit formation.

[13] Restricting ourselves to the studies using open-economy models similar to the present one, on one hand we can find a number of papers that restrict the elasticities of the model to equal unity, as this simplifies the workings of the model (see Galí and Monacelli (2005) among others). On the other hand, Chari et al. (2002) and other papers following them, set the risk aversion parameter to values as high as 6, as this is the value needed to generate a high enough volatility in the real exchange rate. As the exchange rate dynamics in my model differ from the dynamics in a model with standard preferences, I choose a value of θ that falls in between these low and high extremes.

[14] Adolfson et al. (2007) has the advantage of containing all of the relevant shocks, and providing estimates of standard deviations that can be easily used for calibration purposes. As we will eventually look at the volatility of some variable relative to the volatility of GDP, what matters in the end is not the absolute size of the shocks but only their relative sizes.

6.1 Impulse response functions under rule-based monetary policy

The impulse responses to unit shocks to productivity and consumption preferences are presented in Figures 1 and 2. The solid lines are the responses from the benchmark dynamic demand model, and the dotted lines are the responses from the standard DSGE model with $h = 0$, plotted for comparison.

The impulse responses in Figure 1, generated by the technology shock X_t, display a number of interesting features. Focusing first on the real side of the economy, we note that the increase in total production is smaller with habits, compared to the standard model. With less substitution towards *Home* goods taking place in the short run and, due to habit formation being present also in the *Foreign* economy, exports respond less compared to the standard DSGE model. The response of imports is not only smaller, but initially even turns positive in the dynamic demand model. This is explained by the immediate increase in *Home* households' income, and hence total consumption, after the shock occurs, in combination with a delayed response in the fraction of income allocated to each basket of goods. Eventually, households substitute away from the more expensive *Foreign* good, but this substitution is slower when habits are present.

In both models, a real depreciation is required because of the rise in domestic supply. However, from the impulse responses in the third row of Figure 1, we see that the response of both the real and the nominal exchange rate is substantially stronger in the model with dynamic demand. The intuition behind this is simple. When the shock hits the technology of the *Home* economy, *Home* goods can be produced and sold cheaper on the world market. The relative price of *Foreign* goods thus increases, and substitution away from the *Foreign* to the cheaper *Home* goods occurs. Compared to the standard model, however, the habit formation present in the dynamic model mitigates this substitution effect in the short run. As prices are sticky, the short-run change in goods' prices is limited and, hence, practically all of the adjustment needed to clear the international goods market following the shock occurs through the exchange rate. With the benchmark calibration shown here, the responses of the exchange rates, both real and nominal, are approximately twice as large on impact in the dynamic demand compared to the standard DSGE model.

Looking next at the implications of the assumed type of habit formation for monetary policy, we see that the dynamic demand model calls for a stronger response in the interest rate than does the model with standard preferences. At the same time, the *Foreign* interest rate needs not respond as strongly, as the demand is now directed to a lesser extent towards the cheaper goods produced by *Home*. In the figure, this demonstrates itself through the greater interest rate differential that we observe in the second-from-above right panel.[15]

The impulse responses following the consumption preference shock ξ_t are presented in Figure 2. The shock increases the households' willingness to consume in the present period

[15] As the model is kept simple for clarity, we have abstracted from for example non-tradable goods. This then implies that the impulse responses of the terms of trade move together with the ones of the real exchange rate, differing only in magnitudes. The former are therefore not shown here.

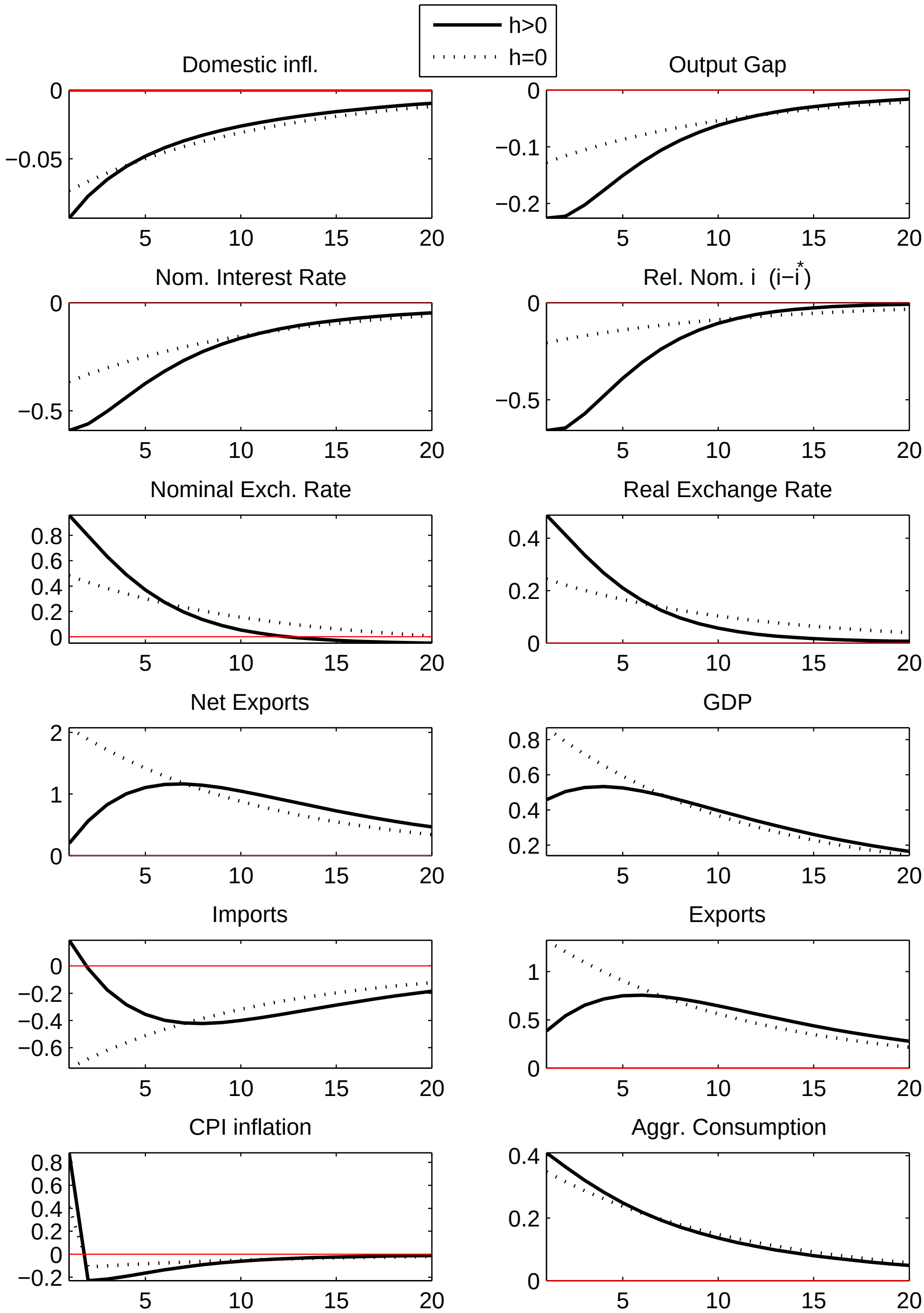

Figure 1: Impulse responses to a unit shock to Home technology under the classical Taylor rule

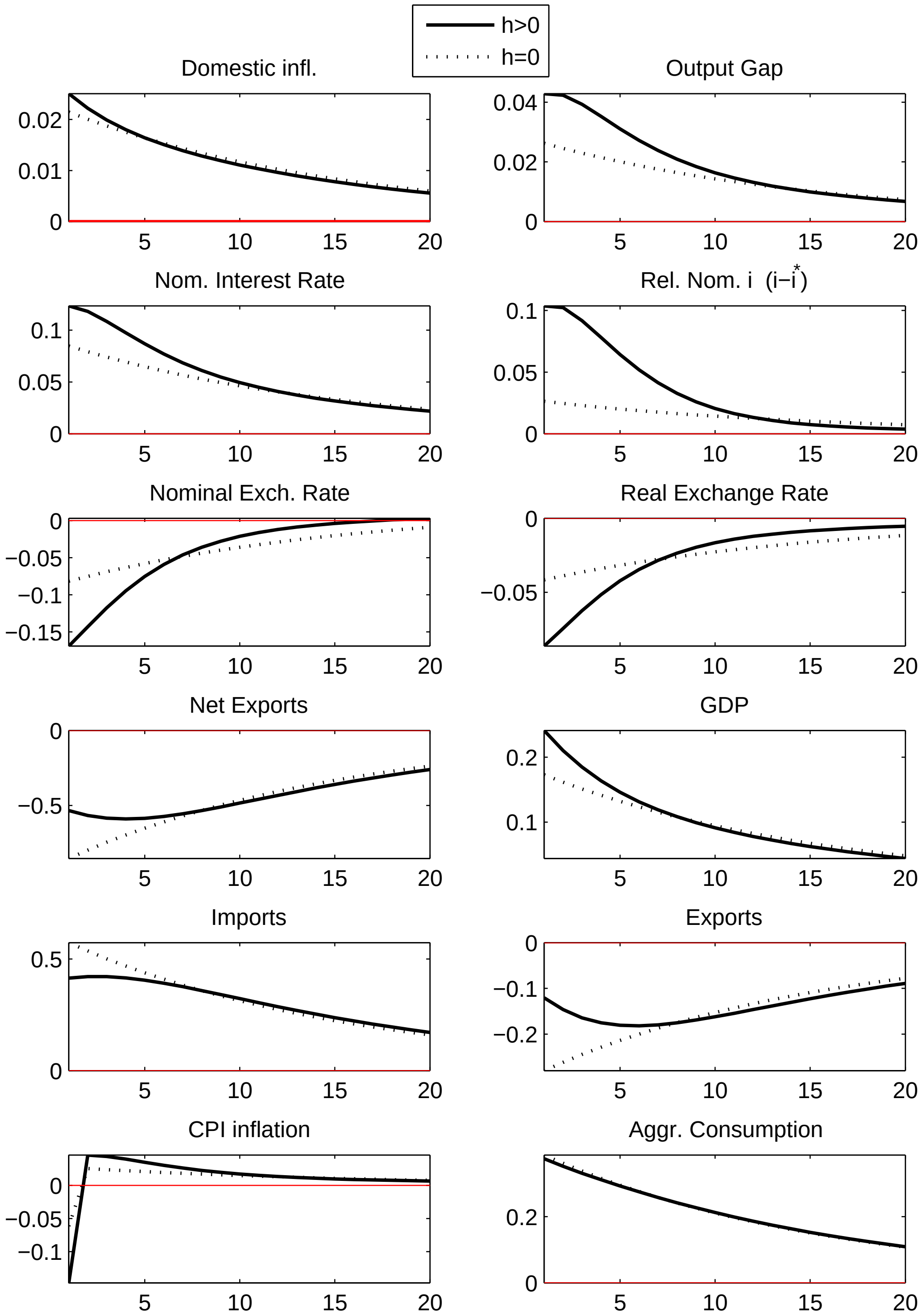

Figure 2: Impulse responses to a unit shock to Home consumption preferences under the classical Taylor rule

and for some periods ahead as the shock is assumed to be persistent, creating an increase in demand. Since there is home bias in the model, the increase in demand from the *Home* households will to a larger extent affect the domestically produced goods, increasing their relative price. As very little substitution takes place immediately after the shock, the increase in the demand for *Home* goods is even more pronounced than in the standard model, causing production to increase more. By the same argument, i.e. due to the lack of on-impact substitution away from the more expensive good, the responses of imports and exports are both muted in the short run.

With the demand for *Home* goods increasing, a real appreciation is required to take place in both models. As with the technology shock, the exchange rate responds more strongly in the model with dynamic demand. Qualitatively, the responses of the real and nominal exchange rates are again similar between the two models, but quantitatively, we observe a clear difference in the short-run responses. As expected then, given the dynamics of the exchange rates, the interest rate differential is larger in the dynamic demand model than in the standard DSGE model, almost entirely due to a weaker response in the *Foreign* country during the periods immediately after the shock.

In the interest of brevity, the impulse responses to shocks to monetary policy and the price markup are presented and discussed in Appendix C. The main conclusions from the analysis of these shocks are largely the same as for the two shocks discussed above: we again see that the responses of production and net exports are somewhat less pronounced in the dynamic demand than in the standard DSGE model, while the responses of exchange rates are magnified.

6.2 Impulse response functions under optimal monetary policy

The solution to the optimal policy problem yields the impulse response functions in Figures 3 and 4. As in Figures 1 and 2, the solid lines denote the responses of the dynamic demand model and the dotted lines the responses of the comparison model with standard preferences. We focus here on the technology and consumption preference shocks. The responses to the remaining shocks are again discussed in the appendix. In the model with standard preferences, optimal monetary policy implies complete stabilization of domestic inflation and the output gap. This is not true in the dynamic demand model. Still, the fluctuations of these variables are strongly reduced compared to the case of the classical Taylor rule. With optimal monetary policy, the response in the interest rate becomes more aggressive and there is a much stronger response in the exchange rates – real as well as nominal – compared to the Taylor rule. The on-impact responses of the nominal exchange rate are up to four times stronger with habit formation present compared to when the elasticity of substitution is restricted to be constant over all time horizons. Moreover, the exchange rate responses have doubled compared to the case where monetary policy is assumed to follow a Taylor rule. The increase in exchange rate volatility when monetary policy is conducted optimally is in line with the studies by Taylor

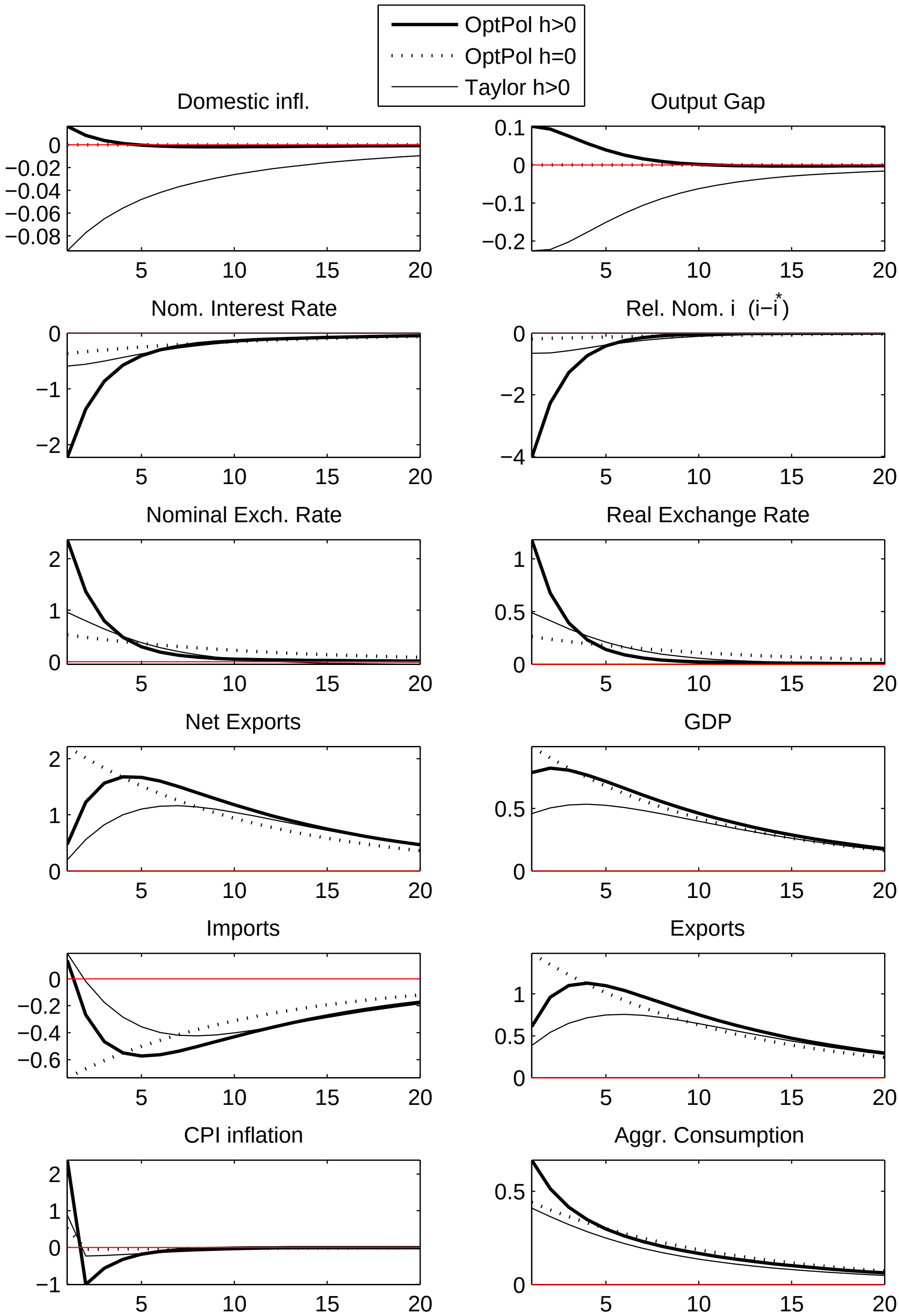

Figure 3: Impulse responses to a unit shock to Home technology under optimal monetary policy

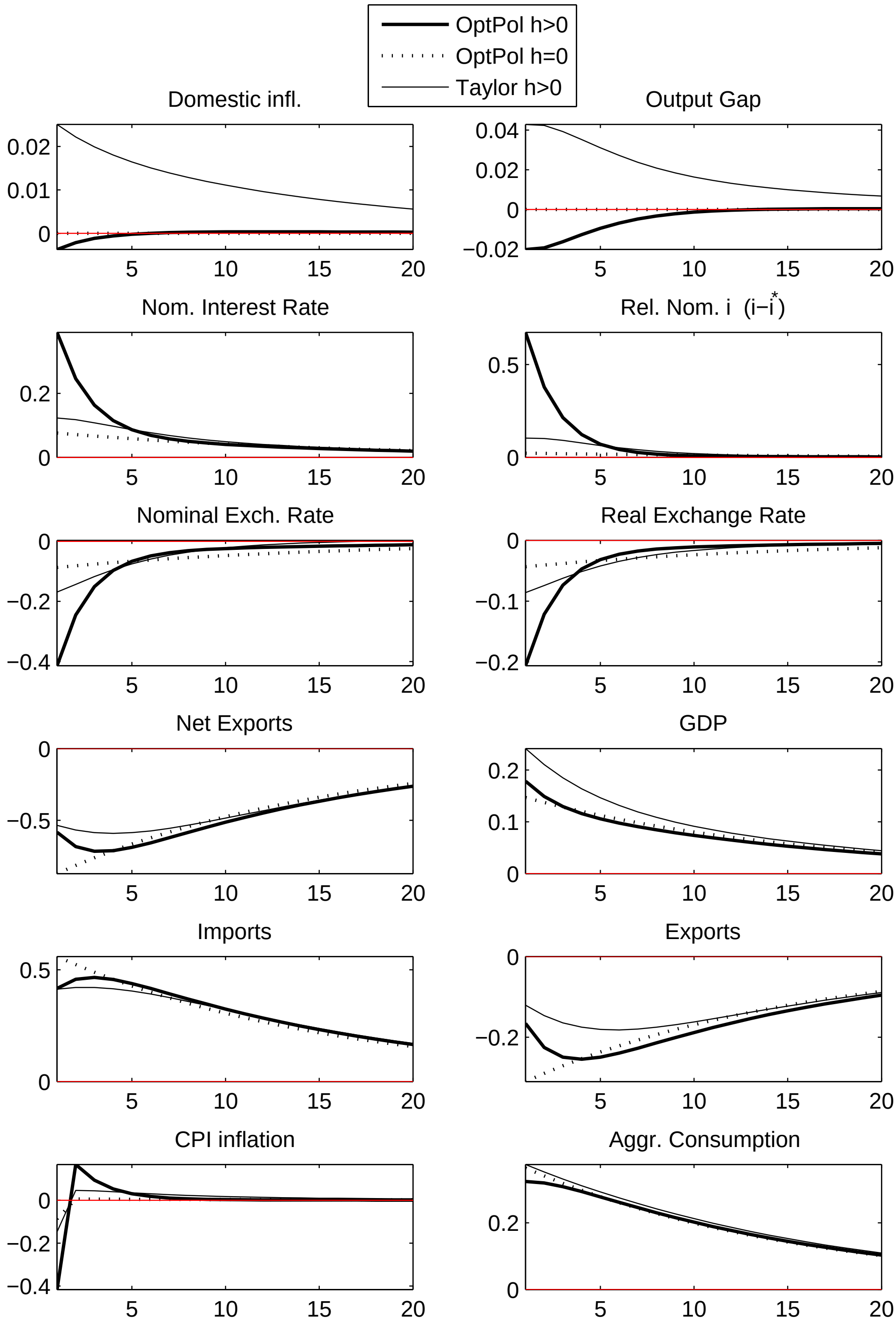

Figure 4: Impulse responses to a unit shock to Home consumption preferences under optimal monetary policy

(2001) and Adolfson (2007), arguing that exchange rate should not be targeted by monetary policy, as this would in fact reduce welfare.

Looking closer at the responses to the technology shock, we see that optimal policy calls for a slightly positive inflation and a positive output gap following the positive shock. The differences in the loss function derived from the dynamic demand model compared to the one based on the assumption of the standard model, is the occurrence of quadratic terms related to the time-varying import share. This introduces a tradeoff between stabilizing inflation and stabilizing the output gap following any of the shocks.[16] These fluctuations of inflation and the output gap are minor, however, compared to the responses under the Taylor rule. Roughly speaking, the optimal policy is still to stabilize domestic inflation, and thus the output gap.

The implications of optimal policy following a consumption preference shock display a similar pattern: the sign of the, now weaker, output gap response is reversed compared to the case of the Taylor rule, and the response in the interest rate is notably stronger. The on-impact response in the exchange rate is increased compared to the model with the Taylor rule, with the response in the dynamic demand model being three times as large as the response in the standard DSGE model.

In summary, when the elasticity of international substitution is allowed to take on different values in the short and in the long run, optimal policy calls for a stronger interest rate reaction. This results in much larger fluctuations in real and nominal exchange rates than when the elasticity is assumed constant over time horizons. Moreover, there exists a tradeoff between stabilizing inflation and stabilizing the output gap, implying that neither is fully stabilized, although their fluctuations are small in magnitude.

6.3 Simulated second moments

Complementing the analysis of the impulse response functions, this section presents second moments based on simulations of the dynamic demand model, as well as the standard DSGE model used for comparison.

Table 1 presents the standard deviations of the main variables of interest in our model, namely the international prices, as well as the interest rate, all as a fraction of the standard deviation of output.[17] In the rightmost column, the same measures based on data for Sweden, United Kingdom and United States are presented as a reference point. These countries have been chosen as examples of a small, a medium-sized and a large economy, respectively.

[16] In the standard DSGE setting, no such tradeoff exists following a technology nor a preference shock, as can be seen in Figures 3 and 4, where both of these variables are fully stabilized. Following a markup shock, however, such a tradeoff is present even in the standard model.

[17] The numbers for the nominal depreciation rate, the real exchange rate, the terms of trade and the interest rate are computed as $\frac{\mathrm{std}\widehat{\Delta S}}{\mathrm{std}\hat{Y}}$, $\frac{\mathrm{std}\hat{Q}}{\mathrm{std}\hat{Y}}$, $\frac{\mathrm{std}\widehat{TT}}{\mathrm{std}\hat{Y}}$, and $\frac{\mathrm{std}\hat{R}}{\mathrm{std}\hat{Y}}$, respectively, where $TT \equiv P_F/P_H$ denotes the terms of trade. The nominal exchange rate is here presented in differences rather than levels, since its level is indeterminate in the model. This is true for any nominal price in the models of the sort we are dealing with here.

Table 1: Standard deviations of international prices and the interest rate relative to output in models and data

	Taylor rule		**Optimal policy**		**Data**		
	$h = 0.9$	$h = 0$	$h = 0.9$	$h = 0$	*Sweden*	*UK*	*US*
All shocks							
Nominal depr.	1.85	0.62	3.06	0.56	1.41	1.81	1.83
Terms of trade	2.18	0.75	2.87	0.72	1.19	2.21	2.28
Real exch. rate	1.09	0.38	1.44	0.36	2.14	3.37	2.37
Interest rate	0.39	0.19	0.60	0.10	0.54	0.67	0.87
Tech. shocks only							
Nominal depr.	1.79	0.59	3.07	0.56			
Terms of trade	2.18	0.75	2.89	0.72			
Real exch. rate	1.09	0.38	1.44	0.36			
Interest rate	0.26	0.11	0.60	0.10			

Note: The numbers in the three rightmost columns are obtained using quarterly data from *OECD Economic Outlook No. 90* covering the period 1993q1-2010q4. The depreciation rate is computed from the nominal effective exchange rate; the real exchange rate is measured as the competitiveness indicator based on relative consumer prices; the terms of trade are computed as the ratio between the imports deflator and a the total domestic expenditures deflator; and the interest rate is the gross short term rate. Output is measured as real GDP per capita; to transform the data into per capita terms, I have used total population data from *OECD Employment and Labour Market Statistics*. As population data is not reported at quarterly frequency, I use the highest frequency available (for Sweden and US, mid-year and end-year; for UK, mid-year estimates) and assume growth to be constant between each pair of consecutive observations.

The numbers are averages of 100 repeated simulations of the economy over 2100 quarters, discarding the first 100, using the same sequence of simulated shock processes for all models. The first panel displays second moments for the *Home* economy where all of the modeled shock processes are included, and the second where the shock process consists of technology shocks only. Parametrization is unchanged compared to the impulse response function analysis, except for the magnitudes of the shocks, as discussed in Section 5 above.

The second moments confirm what was indicated by the impulse responses above: allowing for dynamic demand increases the volatility of the exchange rate substantially. Independent of whether all shock processes or only technology shocks are used, all of the relative standard deviations more than double when habit formation is introduced. In fact, the model with habits and the Taylor rule matches the relative standard deviations of the depreciation rate and the terms of trade that we observe in the US data remarkably well. The real exchange rate, however, is still much less volatile than we observe in data. Nevertheless, the dynamic demand model displays a far more volatile real exchange rate than does the standard DSGE model, both under the Taylor rule and under optimal monetary policy. The same is true for the interest rate, the volatility of which is markedly increased when habit formation is included in the model, bringing it much closer to the volatilities observed in data.

Table 2: Persistence, correlations and volatility of selected variables in models and data

	Baseline calibration		**Interest-rate smoothing**		**Data**		
	$h = 0.9$	$h = 0$	$h = 0.9$	$h = 0$	*Sweden*	*UK*	*US*
Autocorrelations							
$autocorr(Y)$	0.80	0.67	0.81	0.63	0.86	0.89	0.88
$autocorr(C)$	0.68	0.68	0.68	0.68	0.77	0.84	0.91
$autocorr(Q)$	0.63	0.66	0.68	0.62	0.75	0.85	0.72
$autocorr(\Delta S)$	-0.12	-0.14	-0.08	-0.15	0.23	0.31	0.18
$autocorr(TT)$	0.63	0.66	0.68	0.61	0.63	0.85	0.75
$autocorr(R)$	0.26	0.18	0.60	0.52	0.87	0.86	0.91
$autocorr(IM)$	0.88	0.66	0.89	0.62	0.84	0.76	0.87
$autocorr(EX)$	0.88	0.66	0.89	0.62	0.97	0.70	0.85
Correlations							
$corr(Y, NX)$	0.67	0.88	0.69	0.90	-0.26	-0.26	-0.20
$corr(Y, EX)$	0.90	0.97	0.91	0.98	0.90	0.58	0.81
$corr(Y, IM)$	-0.29	-0.73	-0.32	-0.76	0.85	0.68	0.92
$corr(IM, EX)$	-0.57	-0.86	-0.59	-0.87	0.94	0.88	0.83
$corr(C, Q)$	0.35	0.19	0.36	0.20	-0.12	0.53	-0.20
Correlations							
$corr(Y, Y^*)$	-0.12	-0.60	-0.14	-0.64	0.86^{US}	0.81^{SE}	0.87^{UK}
$corr(C, C^*)$	0.61	0.79	0.63	0.80	0.82^{US}	0.82^{SE}	0.74^{UK}
Volatility							
$std(C)/std(Y)$	0.74	0.47	0.73	0.45	0.65	0.86	0.80
$std(Q)/std(Y)$	1.10	0.38	1.08	0.38	2.14	3.37	2.37
$std(\Delta S)/std(Y)$	1.86	0.62	1.73	0.67	1.41	1.81	1.83
$std(TT)/std(Y)$	2.20	0.76	2.16	0.76	1.19	2.21	2.28
$std(R)/std(Y)$	0.39	0.19	0.36	0.18	0.54	0.67	0.87
$std(IM)/std(Y)$	1.44	1.68	1.45	1.69	2.66	3.04	3.59
$std(EX)/std(Y)$	1.43	1.68	1.44	1.68	2.25	3.07	3.43

Note: The numbers in the three rightmost columns are obtained using quarterly data from *OECD Economic Outlook No. 90* along with population data from *OECD Employment and Labour Market Statistics*, covering the period 1993q1-2010q4 (see also note under Table 1). The last three rows display cross country correlations; the superscript together with the respective column title indicate for which pair of countries the correlation has been measured.

To further assess the workings of the dynamic demand model, Table 2 presents the correlations and the autocorrelations of some other variables of interest. As we have kept the model simple, it should not be expected that it be able to match the moments perfectly. Rather, the exercise is meant to compare the dynamic demand setting to the standard DSGE setting, in terms of accordance with the moments observed in data. Starting with the autocorrelations under the baseline calibration discussed in Section 5, we see that the dynamic demand model does somewhat better for most variables. The dynamic model matches the autocorrelation of output, imports and exports well, while the standard DSGE model does worse. It also performs slightly better in terms of matching the interest rate. The autocorrelations of the relative prices do not change much between the models. If anything, the dynamic demand model performs slightly worse here, matching only the autocorrelation of the nominal exchange rate slightly better and the autocorrelation of the real exchange rate (and that of the terms of trade, which is the same in a model with no non-tradables) slightly worse. The autocorrelation of the nominal exchange rate has the wrong sign in both models.

With respect to the contemporaneous correlations between variables, the dynamic demand model generally does better than the standard DSGE model. Note that there is a problem in both models with the predictions for the dynamics of imports: in data, the imports are positively and strongly correlated with output and with exports, while the models predict a negative correlation. From the analysis of the impulse response functions in the two preceding sections, we know that the imports in the dynamic demand model are positively correlated with output and exports immediately after a shock, but that the correlation turns negative as substitution takes place. The dynamic demand setting hence takes the model in the right direction, although not all the way. The inability of the models to match the correlation of net exports with output mainly stems from the poor matching of the imports dynamics, as the correlation between exports and output is well matched, in particular by the dynamic demand model. A potentially related problem is that the cross-country correlations of output have the wrong sign in both models, although the dynamic demand model is again closer to the data.[18] This issue is, of course, more complicated, as the models abstract from investments and government spending, and the measures of output in the models and in data are hence very different. Moreover, in this simple exercise we have assumed in the model that the shocks are uncorrelated, which in reality is not likely to be the case. We finally note that, with the baseline calibration, the standard DSGE model does somewhat better in terms of matching the correlations of consumption across countries. The conclusions regarding the correlation of consumption and the real exchange rate are less clear, as the dynamic model is more in line with the positive correlation in the UK data, but further from the negative Swedish and US correlations.

We next focus on the results in the two middle columns, obtained using a somewhat more realistic calibration where we introduce interest-rate smoothing in the Taylor rule. There is wide support in the empirical literature for slow adjustment of the policy interest rate, and the estimated degree of smoothing is often found to be around 0.8 or higher. In line with the recent estimates in Christiano et al. (2011), we set the interest-rate smoothing parameter, ρ_R, to 0.8. To maintain a symmetric calibration, the value is chosen to be the same in both countries. Under this calibration, the performance of the dynamic model is significantly improved. Most notably, the dynamic demand model now matches the autocorrelation in the real exchange rate and the terms of trade better, generating more persistent real exchange rate

[18] Increasing the degree of habits somewhat compared to our benchmark calibration, the dynamic demand model actually generates a positive cross-country correlation of output, as well as consumption. See Section 7 and Appendix D for details.

than the standard DSGE model. In the absence of interest rate smoothing, we observe larger interest rate shifts in the model with dynamic demand than in the standard DSGE model. When the interest rate movements are constrained by the monetary authorities preference for smoothing, these large deviations instead transfer into less pronounced, but more persistent interest rate differentials following a technology shock. These, in turn, generate somewhat less volatile, but more persistent exchange rates. However, the shocks that generate the largest differences between the dynamic demand and the standard DSGE model are not the persistent shocks, but the non-persistent ones, i.e. the monetary policy and the markup shocks. Without the possibility of quickly bringing back the interest rate to steady state, and with a constraint on the international flows of goods imposed by the habit formation in the dynamic demand model, the response following these one period shocks are quite long-lived. In the standard DSGE model, we instead observe rather large fluctuations in the flows of imports and exports when the adjustments in the interest rate are not immediate, which more rapidly bring the economy back to steady state. Under interest rate smoothing, the autocorrelations of the interest rate and the nominal exchange rate in the dynamic demand model are also brought closer to those in data. The increase in persistence happens at some expense of exchange rate volatility; the volatility is however only marginally decreased, and still much higher in the dynamic demand than in the standard DSGE model.

While both models have been kept simple and lack some relevant features for a comprehensive comparison of the models with data, the above analysis suggests that allowing for dynamic demand considerably improves the performance of the model along several important dimensions.

6.4 Spillover effects

We next analyze the effects of *Foreign* shocks on the *Home* economy. The impulse responses for the technology and consumption preference shocks are shown in Figures 5 and 6. As the countries are assumed symmetric, the responses of the international relative prices are just the negative of the responses following the corresponding shock occurring at *Home*, and have hence been discussed in Sections 6.1 and 6.2 above. The same holds for imports and exports, as the two-country setting implies that the imports of one country are simply the exports of the other. Therefore, only the responses of domestic variables are shown in the figures. The thinner lines show responses generated with the calibrated Taylor rule, while the thicker ones show the responses generated under optimal monetary policy. Just as before, the solid lines correspond to the model with dynamic demand and the dotted ones to the standard DSGE model.

Focusing first on the calibrated Taylor rule, we see that a *Foreign* technology shock initially raises *Home* production and creates a positive output gap. This response differs from the standard DSGE model; this is, as previously argued, due to less substitution taking place towards the now cheaper *Foreign* good. There is even an increase in demand for *Home*

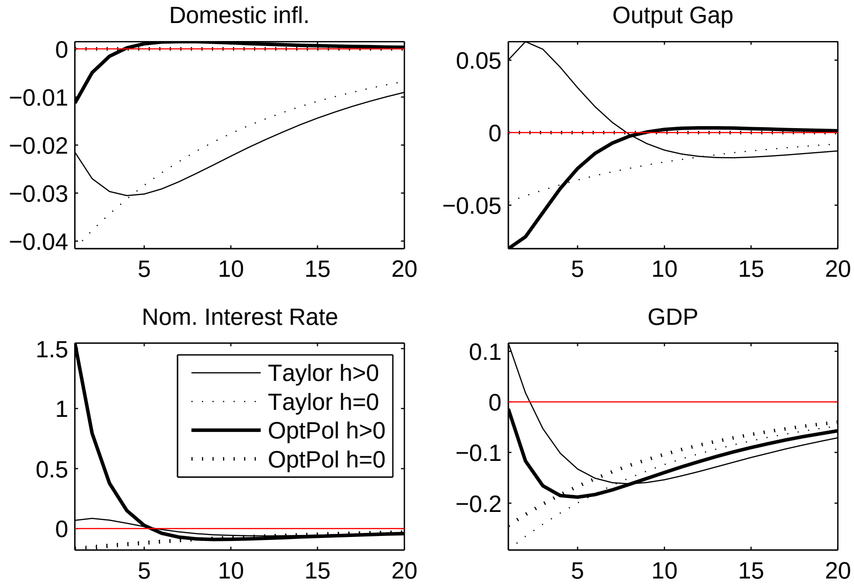

Figure 5: Impulse responses to a unit shock to *Foreign* technology

goods since the world as a whole has become richer, explaining the rise in *Home* production. The interest rate response is now small but positive at first, before turning slightly negative six quarters after the shock. Moving on to the responses under optimal monetary policy, interestingly, the optimal interest rate response is reversed compared to the standard DSGE model. Following the technology shock, optimal monetary policy calls not only for a rise instead of a decrease in the *Home* interest rate, but for a rather large one as well, in order for the inflation to be near-stabilized. As the *Foreign* technology shock has made the world as a whole able to consume more than prior to the shock occurring, but demand is only redirected towards *Foreign* goods to a small extent, the *Home* economy is in fact overheated, causing the interest rate to rise.

A consumption preference shock affecting the *Foreign* consumers results, under the classical Taylor rule, in somewhat smaller deviations in all of the presented variables compared to the standard DSGE model, as the *Foreign* consumers are demanding relatively less of the now cheaper *Home* goods in the dynamic demand than in the standard DSGE model. Even here, the sign of the output gap is initially reversed, by the same reasoning as for the technology shock. Under optimal monetary policy, the interest rate response is reverted just as in the case of the *Foreign* technology shock, although it is now initially negative instead of positive as in the standard DSGE model. In other words, demand for the cheaper *Home* good is now relatively low, compared to the standard DSGE setting, causing a fall in the interest rate instead.

The responses to the monetary-policy and markup shocks are shown in Figures C.4 and C.5 in the appendix, and discussed in relation to those.

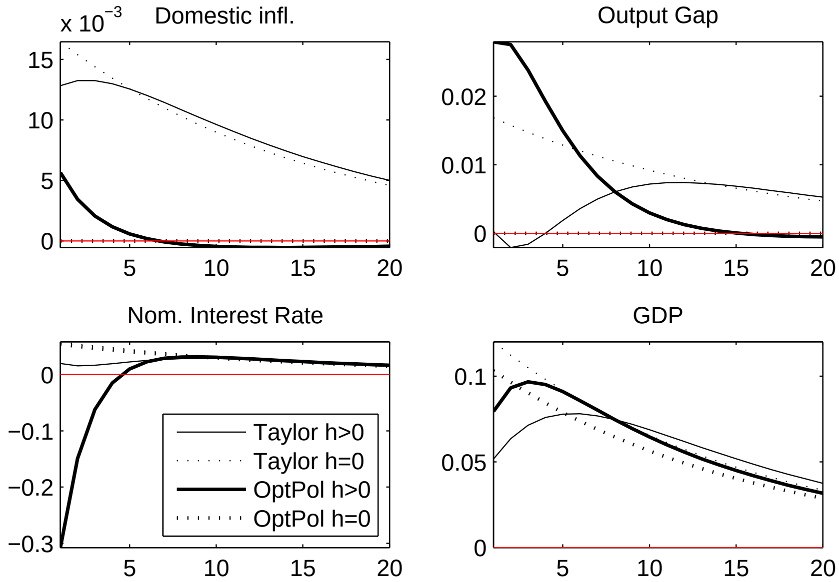

Figure 6: Impulse responses to a unit shock to *Foreign* consumption preferences

7 Sensitivity analysis

In this section, I briefly discuss the effects of changes in the calibration of some individual parameters, one at a time, while keeping the rest of the calibration fixed. Specifically, I comment on the sensitivity to changes in the habits parameter h, and thereby the elasticities of substitution, the risk aversion parameter θ, and the openness parameter ν. Finally, the baseline model is compared to a model including import adjustment costs. In the interest of brevity, the tables pertaining to the sensitivity analysis are placed in Appendix D.

The baseline calibration of the elasticities of substitution was based on the findings in Gottfries (1986). Basing the calibration instead on the estimates in Gallaway et al. (2003), while keeping the long-run elasticity unchanged, would instead imply that $\gamma = 0.6$ and $h = 0.8$. This reduction in the degree of habit formation has no implications for the qualitative results, but it does have some implications on magnitudes. The volatility of the exchange rates is still considerably increased compared to the standard DSGE model. However, the volatility increase and the other improvements brought about by the dynamic demand assumption are now mitigated. Furthermore, the persistence of the exchange rates is now lowered, which is at odds with the data. Increasing h to 0.95 instead further strengthens the advantages of the dynamic demand model: the exchange rates are now more volatile and more persistent, and the correlations of imports with output and of output across countries are both positive, in line with the correlations in data.

Varying the risk aversion parameter has notable effects on the volatility of the exchange rates, as has already been pointed out in earlier literature. Just as in Chari et al. (2002), an increase in the risk aversion parameter increases exchange rate volatility, leaving the persistence nearly unchanged. However, the correlations between the remaining variables are markedly worsened compared to data. This is the case in both the dynamic demand and the standard DSGE models. Decreasing the risk aversion instead improves the model's performance, in all aspects but the magnitude of the exchange rate volatility. As we have seen above, however, in the dynamic demand setting there are other ways of increasing the volatility of exchange rates. Thus, a low risk aversion parameter together with dynamic demand seems like a promising venue.

The effects of varying the openness parameter ν manifest themselves mainly through a change in the volatility of the exchange rates. More open economies exhibit somewhat less volatile exchange rates than more closed ones – due to the composition of consumption in the two countries being more similar the more open is the economy, the relative prices need not change as much to clear the international goods market following a shock in one of the economies. Changing the steady-state share of imports to 0.20 or 0.30 has, however, only minor implications for the volatility of the exchange rates, and renders all other moments nearly unchanged compared to the baseline scenario.

Earlier studies in the literature have used the modeling of import adjustment costs to dampen the responsiveness of quantities to changes in prices on the international level – see, for example, Laxton and Pesenti (2003). There, it is assumed that it is costly to change the share of imported goods in the aggregate in response to relative price changes.[19] Table D.2 in the appendix presents a comparison between the two models in terms of simulated second moments. We compare first the results based on simulations with the parameter ϕ_M set to 2 with our benchmark calibration. While replicating the autocorrelation of the nominal exchange rate somewhat better, the import adjustment cost model does worse than the dynamic demand model when it comes to the autocorrelations of the real exchange rate, the terms of trade, the interest rate, and consumption. The import adjustment cost model also does worse in replicating most of the cross-correlations between variables. Exports and imports are too highly correlated with output and with each other. The correlation of imports with output and exports has the wrong sign in both models, but the problem is more pronounced in the import adjustment cost model. The model with import adjustment costs is better at replicating in particular the volatility of the real exchange rate, while the dynamic demand model does somewhat better in replicating the volatilities of the terms of trade and the nominal exchange rate. Both models generate too low volatilities of imports and exports, the dynamic demand model slightly more so than the import adjustment cost

[19] For the model comparison, I assume that the consumption aggregate is given by the following function:

$$C_t^j = \left[(1-\nu)^{\frac{1}{\gamma}} \left(C_{H,t}^j \right)^{\frac{\gamma-1}{\gamma}} + \nu^{\frac{1}{\gamma}} \left[C_{F,t}^j \left(1 - \Gamma_t^j \right) \right]^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}},$$

where

$$\Gamma_t^j \equiv \frac{\phi_M}{2} \left(\frac{C_{F,t}^j}{C_t^j} / \frac{C_{F,t-1}}{C_{t-1}} - 1 \right)^2 .$$

model. However, comparing with the standard DSGE model with $h = 0$, we see that these volatilities are only marginally decreased when these additional mechanisms are introduced.

Scaling up the import adjustment costs and comparing to a high degree of habits (see columns 3 and 5 in Table D.2), we can see that the volatility of relative prices is further increased in both models while the volatility of imports and exports is somewhat lowered. However, increasing the importance of the import adjustment costs worsens the correlation between output and imports, and the cross-country correlations generated by the import adjustment cost model. On the contrary, the dynamic demand model now generates positive correlations of both output and imports, and output across countries when the degree of habits is scaled up. This speaks in favor of the mechanism in the dynamic demand model, as it appears to move the model in the right direction. In summary, comparing the benchmark model to the import adjustment cost model, we can conclude that both generate considerably more volatile exchange rates than does the standard DSGE model – the import adjustment cost model even more so than our benchmark when it comes to the real exchange rate. However, the benchmark model performs better in several other dimensions, generating cross-correlations and autocorrelations of other variables that are more in line with those observed in data.

8 Conclusions

Using a two-country general equilibrium model with separate habit formation in the consumption of imports and domestically produced goods, and otherwise standard features, I am able to separate the short-run elasticity of substitution from the long-run one as observed in data. Contrasting the results of the model with habits to results obtained from the model with standard preferences, I find much larger effects of shocks on international relative prices, as well as on interest rates. In particular, the volatility of exchange rates is considerably increased when the short-term substitution effect is reduced, bringing the model closer to the data. Furthermore, a high volatility of the exchange rate turns out to be optimal in this model and is hence not an artefact of the assumed monetary policy rule. In fact, the model-implied optimal monetary policy results in even stronger responses in exchange rates to shocks than does the classical Taylor rule. Allowing for interest-rate smoothing, the dynamic demand model also generates more persistent real exchange rates than does the standard DSGE model, yielding a persistence more in line with that found in data.

While relaxing the assumption that the elasticity of substitution is constant over all time horizons brings us much closer to explaining the volatility of exchange rates, the real exchange rate in the present model is still not quite as volatile as in data. One possible reason for this is the producer-currency pricing assumption, which implies that all movements in exchange rates are directly passed on to consumer prices. Other papers, such as Chari et al. (2002) and Devereux and Engel (2002), have used local-currency pricing in combination with specific parameter values or a list of other model elements to eliminate the pass-through of exchange rate changes to the rest of the economy, thus "disconnecting" the movements of the exchange rate. It would be interesting to investigate what the implications of local-currency pricing would be in our model setting. It would also be interesting to study the model's performance when estimated, especially so when allowing for a more developed and realistic economic setting. While such an exercise would offer a natural way to further assess the model and the mechanism at hand, it is beyond the scope of the theoretical exercise in this paper.

There are other ways of introducing slow adjustment of demand into macroeconomic models, such as information frictions or various types of adjustment costs. Söderberg (2011) presents a model of customer markets where households only occasionally reoptimize their allocation, slowing down demand adjustment without altering household preferences. Mankiw (1985) shows that small menu costs can have large effects on demand adjustment. While appealing and tangible in a closed-economy setting, the mechanisms in these papers are not easily extended to open economies. The advantage of the mechanism for slow adjustment presented in the present paper is its tractability. It captures the elasticity findings and generates moments closer to those in data, while being simple enough to be easily incorporated in larger and more realistic models. Finally, as shown in the sensitivity analysis, the present model outperforms the import adjustment costs model in terms of matching data moments for most of the modeled variables.

References

Adolfson, M. (2007): "Incomplete exchange rate pass-through and simple monetary policy rules," *Journal of International Money and Finance*, 26, 468–494.

Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2007): "Bayesian estimation of an open economy DSGE model with incomplete pass-through," *Journal of International Economics*, 72, 481–511.

Beggs, A. and P. Klemperer (1992): "Multi-period competition with switching costs," *Econometrica: Journal of the Econometric Society*, 60, 651–666.

Benigno, G. (2004): "Real exchange rate persistence and monetary policy rules," *Journal of Monetary Economics*, 51, 473–502.

Benigno, G. and P. Benigno (2006): "Designing targeting rules for international monetary policy cooperation," *Journal of Monetary Economics*, 53, 473–506.

Benigno, P. and M. Woodford (2008): "Linear-Quadratic Approximation of Optimal Policy Problems," *Discussion Papers*.

Broda, C. and D. Weinstein (2006): "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, 121, 541–585.

Calvo, G. (1983): "Staggered prices in a utility-maximizing framework," *Journal of Monetary Economics*, 12, 383–98.

Chari, V., P. Kehoe, and E. McGrattan (2002): "Can sticky price models generate volatile and persistent real exchange rates?" *Review of Economic Studies*, 533–563.

Christiano, L., M. Eichenbaum, and C. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113.

Christiano, L., M. Trabandt, and K. Walentin (2011): "Introducing financial frictions and unemployment into a small open economy model," *Journal of Economic Dynamics and Control*.

Devereux, M. and C. Engel (2002): "Exchange rate pass-through, exchange rate volatility, and exchange rate disconnect," *Journal of Monetary economics*, 49, 913–940.

Feenstra, R. (1994): "New product varieties and the measurement of international prices," *The American Economic Review*, 84, 157–177.

Fernández-Villaverde, J., P. Guerrón-Quintana, and J. Rubio-Ramírez (2008): "The new macroeconometrics: a Bayesian approach," *Handbook of Applied Bayesian Analysis*.

Fuhrer, J. (2000): "Habit formation in consumption and its implications for monetary-policy models," *American Economic Review*, 367–390.

Galí, J. and T. Monacelli (2005): "Monetary policy and exchange rate volatility in a small open economy," *Review of Economic Studies*, 72, 707–734.

Gallaway, M., C. McDaniel, and S. Rivera (2003): "Short-run and long-run industry-level estimates of US Armington elasticities," *North American Journal of Economics and Finance*, 14, 49–68.

Gottfries, N. (1986): "Price dynamics of exporting and import-competing firms," *The Scandinavian Journal of Economics*, 417–436.

——— (2002): "Market shares, financial constraints and pricing behaviour in the export market," *Economica*, 69, 583–607.

Guerrón-Quintana, P. (2010): "What you match does matter: the effects of data on DSGE estimation," *Journal of Applied Econometrics*, 25, 774–804.

Hooper, P., K. Johnson, and J. Marquez (2000): "Trade Elasticities for the G-7 Countries, N 87," *Princeton Studies in International Economics.*

Klemperer, P. (1987): "Markets with consumer switching costs," *The Quarterly Journal of Economics*, 102, 375–394.

——— (1989): "Price wars caused by switching costs," *The Review of Economic Studies*, 56, 405–420.

——— (1995): "Competition when consumers have switching costs: An overview with applications to industrial organization, macroeconomics, and international trade," *The Review of Economic Studies*, 515–539.

Laxton, D. and P. Pesenti (2003): "Monetary rules for small, open, emerging economies," *Journal of Monetary Economics*, 50, 1109–1146.

Leamer, E. (1981): "Is it a demand curve, or is it a supply curve? Partial identification through inequality constraints," *The Review of Economics and Statistics*, 63, 319–327.

Mankiw, N. (1985): "Small menu costs and large business cycles: A macroeconomic model of monopoly," *The Quarterly Journal of Economics*, 100, 529–537.

McDaniel, C. and E. Balistreri (2003): "A review of Armington trade substitution elasticities," *Economie internationale*, 301–313.

Moore, M. and M. Roche (2008): "Volatile and persistent real exchange rates with or without sticky prices," *Journal of Monetary Economics*, 55, 423–433.

Obstfeld, M. and K. Rogoff (2000): "The six major puzzles in international macroeconomics: is there a common cause?" *NBER macroeconomics annual*, 15, 339–390.

Orcutt, G. (1950): "Measurement of price elasticities in international trade," *The Review of Economics and Statistics*, 32, 117–132.

Ravn, M., S. Schmitt-Grohé, and M. Uribe (2006): "Deep Habits," *Review of Economic Studies*, 73, 195–218.

Ruhl, K. (2008): "The international elasticity puzzle," *University of Texas-Austin unpublished manuscript.*

Smets, F. and R. Wouters (2003): "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European Economic Association*, 1, 1123–1175.

——— (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97, 586–606.

Söderberg, J. (2011): "Customer markets and the welfare effects of monetary policy," *Journal of Monetary Economics.*

Stango, V. (2002): "Pricing with consumer switching costs: Evidence from the credit card market," *The Journal of Industrial Economics*, 50, 475–492.

Taylor, J. (1993): "Discretion versus policy rules in practice," in *Carnegie-Rochester conference series on public policy*, Elsevier, vol. 39, 195–214.

——— (2001): "The role of the exchange rate in monetary-policy rules," *The American Economic Review*, 91, 263–267.

von Weizsäcker, C. (1984): "The costs of substitution," *Econometrica: Journal of the Econometric Society*, 52, 1085–1116.

Woodford, M. (2003): *Interest and prices*, Princeton University Press Princeton, NJ.

A Appendix: Model calculations

A.1 Demand functions and price indices

Maximizing equation (5) in the main text subject to household j's total expenditures

$$Z_t^j = P_{H,t}C_{H,t}^j + P_{F,t}C_{F,t}^j \,, \tag{A.1}$$

we have the following two first-order conditions:

$$C_{H,t}^j = (1-\omega_t)\left(\frac{P_{H,t}}{P_t}\right)^{-\gamma} C_t^j \tag{A.2}$$

$$C_{F,t}^j = \omega_t \left(\frac{P_{F,t}}{P_t}\right)^{-\gamma} C_t^j \,, \tag{A.3}$$

where we have defined the aggregate price index as the inverse of the Lagrange multiplier on the expenditures. Note that this definition of the price index implies that the expenditures can be written as $Z_t^j = P_t C_t^j$, and hence[20]

$$P_t C_t^j = P_{H,t}C_{H,t}^j + P_{F,t}C_{F,t}^j \,. \tag{A.4}$$

Inserting (A.2) and (A.3) into (A.4), we can derive the below expression for the aggregate price index.

$$
\begin{aligned}
P_t &= (1-\omega_t)P_{H,t}\left(\frac{P_{H,t}}{P_t}\right)^{-\gamma} + \omega_t P_{F,t}\left(\frac{P_{F,t}}{P_t}\right)^{-\gamma} && \text{(A.5)}\\
P_t &= \left[(1-\omega_t)P_{H,t}^{1-\gamma} + \omega_t P_{F,t}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} && \text{(A.6)}
\end{aligned}
$$

As we assume the preferences in the two countries to be the same, the *Foreign* demand functions and the price index have the exact same forms as the above, with all of the variables denoted by an asterisk and ω_t replaced by $(1-\omega_t^*)$.

A.2 The comparison model

Letting $h = 0$, implying that ω_t equals ν for all t, we obtain the standard DSGE model. The consumption aggregator becomes

$$C_t = \left[(1-\nu)^{\frac{1}{\tilde{\gamma}}} C_{H,t}^{\frac{\tilde{\gamma}-1}{\tilde{\gamma}}} + \nu^{\frac{1}{\tilde{\gamma}}} C_{F,t}^{\frac{\tilde{\gamma}-1}{\tilde{\gamma}}}\right]^{\frac{\tilde{\gamma}}{\tilde{\gamma}-1}} \,, \tag{A.7}$$

yielding the following demand equations:

$$
\begin{aligned}
C_{H,t} &= (1-\nu)\left(\frac{P_{H,t}}{P_t}\right)^{-\tilde{\gamma}} C_t && \text{(A.8)}\\
C_{F,t} &= \nu\left(\frac{P_{F,t}}{P_t}\right)^{-\tilde{\gamma}} C_t \,, && \text{(A.9)}
\end{aligned}
$$

[20] To derive this, combine (A.2) and (A.3) and solve for $P_{F,t}$ as a function of $P_{H,t}$. Then rearrange (A.2) as $C_t^j = (1-\omega_t)^{-\frac{1}{\gamma}} \frac{P_{H,t}}{P_t} C_{H,t}^{j\,\frac{1}{\gamma}} C_t^{j\,\frac{\gamma-1}{\gamma}}$. Insert the definition of the consumption index on the RHS, and substitute in the derived expression for $P_{F,t}$.

and price index

$$P_t = \left[(1-\nu)P_{H,t}^{1-\tilde{\gamma}} + \nu P_{F,t}^{1-\tilde{\gamma}}\right]^{\frac{1}{1-\tilde{\gamma}}} . \tag{A.10}$$

Note, however, that $\tilde{\gamma}$ now denotes the constant elasticity of substitution instead of the short-run one as in the model with $h > 0$ (denoted by γ), and should hence be calibrated as such. In the simulation exercises in the present paper, $\tilde{\gamma}$ is always calibrated so that it equals the long-run elasticity in the dynamic demand model, rendering the two models equal in the long run. Compared to the model with standard preferences, hence, the type of habits imposed here should be thought of as a short-run friction only.

A.3 The steady state

Here, the steady state around which the model is linearized is presented. A variable in the steady state is denoted by a bar. We assume that the steady-state values of all shocks are one, that net inflation is zero, i.e. the steady-state gross inflation is

$$\bar{\pi}_H = \bar{\pi}_F^* = 1 , \tag{A.11}$$

and that the countries are perfectly symmetric. Furthermore, we assume that the steady state is efficient, i.e. that the tax τ_t is chosen in such a way that it exactly offsets the distortion caused by the monopolistic power of the firms. Normalizing the prices so that $\bar{P}_H = \bar{P}_F$, we insure that the steady states of the model with habit formation and the one without will be the same, hence facilitating the comparison of the two models. Moreover, the price normalization will also allow us to more easily calibrate the long-run elasticity of international substitution as will be clear from Section A.4 below.

First, from the Euler equation (16) in the main text and its *Foreign* equivalent, we have that

$$\frac{1}{\bar{R}} = \frac{1}{\bar{R}^*} = \beta . \tag{A.12}$$

Next, given the normalization of the prices, the price index yields

$$\bar{P}^{1-\gamma} = (1-\bar{\omega})\bar{P}_H^{1-\gamma} + \bar{\omega}\bar{P}_H^{1-\gamma} = \bar{P}_H^{1-\gamma} . \tag{A.13}$$

This implies that

$$\frac{\bar{P}_H^*}{\bar{P}^*} = 1 = \frac{\bar{P}_F^*}{\bar{P}^*} . \tag{A.14}$$

The same holds true for the *Foreign* price index, implying

$$\frac{\bar{P}_H}{\bar{P}} = 1 = \frac{\bar{P}_F}{\bar{P}} . \tag{A.15}$$

Since, in steady state,

$$\bar{p}(i) = \bar{P}_H = \bar{S}\bar{P}_H^* , \tag{A.16}$$

we must have $\bar{P} = \bar{S}\bar{P}^*$, and so

$$\bar{Q} = \frac{\bar{S}\bar{P}^*}{\bar{P}} = 1 . \tag{A.17}$$

Then, assuming that $\psi = 1$, from the risk-sharing condition (27) we get

$$\bar{C} = \bar{C}^* . \tag{A.18}$$

Since $\bar{P}_H/\bar{P} = \bar{P}_F/\bar{P} = 1$, from demand we have that

$$\frac{\bar{C}_F}{\bar{C}} = \bar{\omega}\,, \tag{A.19}$$

implying that $\bar{\omega}$ equals the steady-state import share. Furthermore, inserting the steady state demand equations,

$$\begin{aligned}
\frac{\bar{C}_H}{\bar{C}} &= (1-\bar{\omega}) = \frac{(1-\nu)^{1-h}\left(\frac{\bar{C}_H}{\bar{C}}\right)^h}{\bar{\Omega}} = \frac{1-\nu}{\bar{\Omega}^{\frac{1}{1-h}}} && \text{(A.20)}\\
\frac{\bar{C}_F}{\bar{C}} &= \bar{\omega} = \frac{\nu^{1-h}\left(\frac{\bar{C}_F}{\bar{C}}\right)^h}{\bar{\Omega}} = \frac{\nu}{\bar{\Omega}^{\frac{1}{1-h}}} && \text{(A.21)}
\end{aligned}$$

into the steady state expression for Ω, we have

$$\begin{aligned}
\bar{\Omega} &= (1-\nu)^{1-h}\left(\frac{1-\nu}{\bar{\Omega}^{\frac{1}{1-h}}}\right)^h + \nu^{1-h}\left(\frac{\nu}{\bar{\Omega}^{\frac{1}{1-h}}}\right)^h \\
&= (1-\nu)\bar{\Omega}^{-\frac{h}{1-h}} + -\nu\bar{\Omega}^{-\frac{h}{1-h}} \\
&= \bar{\Omega}^{-\frac{h}{1-h}} \\
\bar{\Omega} &= 1\,. && \text{(A.22)}
\end{aligned}$$

Then,

$$\bar{\omega} = \frac{\nu^{1-h}\left(\frac{\bar{C}_F}{\bar{C}}\right)^h}{\bar{\Omega}} = \nu^{1-h}\bar{\omega}^h = \nu\,, \tag{A.23}$$

and hence the steady-state import share is given solely by the parameter ν.

The market clearing conditions yield

$$\begin{aligned}
\bar{Y} &= \bar{C}_H + \bar{C}_H^* && \text{(A.24)}\\
\bar{Y}^* &= \bar{C}_F + \bar{C}_F^*\,. && \text{(A.25)}
\end{aligned}$$

Inserting the demand functions and noting again that the steady state relative prices equal 1, we obtain

$$\bar{Y} = (1-\bar{\omega})\bar{C} + \bar{\omega}\bar{C}^* = \bar{C} \tag{A.26}$$

Absent price rigidities, or absent any shocks to the economy, the firms set their prices as a constant markup over marginal cost. Substituting for wages and labor using technology in the household's first-order condition (17), we can then write

$$\bar{Y}^{\phi}\bar{C}^{\theta} = \frac{\bar{W}}{\bar{P}} = \frac{(\sigma-1)(1-\bar{\tau})}{\sigma}\frac{\bar{P}_H}{\bar{P}} = \frac{1}{\bar{\mu}} = 1\,, \tag{A.27}$$

where the efficiency of the steady state requires that $\bar{\tau} = 1/(1-\sigma)$. Using (A.26), it is easy to see that $\bar{Y} = 1$. Having solved for $\bar{Y}$ the rest of the steady-state variables are straightforward to compute.

A.4 Deriving the long-run elasticity of substitution

With the assumed consumption preferences, in the presence of habit formation, the short-run elasticity of substitution is as straightforward to compute as in the standard DSGE model, and is given by[21]

$$\frac{d\left(\frac{C_{F,t}}{C_t}\right)}{d\left(\frac{P_{F,t}}{P_t}\right)} \cdot \frac{\frac{P_{F,t}}{P_t}}{\frac{C_{F,t}}{C_t}} = -\gamma \,. \tag{A.28}$$

The long-run elasticity of substitution, defined as

$$\Gamma \equiv \frac{d\left(\frac{\bar{C}_F}{\bar{C}}\right)}{d\left(\frac{\bar{P}_F}{\bar{P}}\right)} \frac{\frac{\bar{P}_F}{\bar{P}}}{\frac{\bar{C}_F}{\bar{C}}} \,, \tag{A.29}$$

is however somewhat harder to evaluate in the present setting. In order to arrive at an expression for Γ, we will need to employ implicit differentiation. Note that we are interested in the elasticity of substitution in the proximity of the assumed steady state, as given in Section A.3, and so it will be assumed that the steady-state price normalization holds. This considerably simplifies the final expression for Γ, making it a constant instead of a function of steady-state variables. Moreover, since the entire analysis of the model is based on its log-linearized form and hence only accurate for relatively small deviations from a constant steady state, this restriction on Γ adds no new assumptions but rather relies on the assumed constancy of the model-implied steady state.

To simplify notation in the calculations of this section, we begin by defining

$$\frac{C_{F,t}}{C_t} \equiv D_{F,t} \qquad \frac{P_{F,t}}{P_t} \equiv T_{F,t} \tag{A.30}$$

$$\frac{C_{H,t}}{C_t} \equiv D_{H,t} \qquad \frac{P_{H,t}}{P_t} \equiv T_{H,t} \,. \tag{A.31}$$

Then, writing the steady state demand of *Home* goods as

$$\bar{D}_F - \frac{\nu}{\left((1-\nu)^{1-h}\bar{D}_H^h + \nu^{1-h}\bar{D}_F^h\right)^{\frac{1}{1-h}}} \bar{T}_F^{-\frac{\gamma}{1-h}} = 0 \,, \tag{A.32}$$

we can totally differentiate with respect to $\bar{T}_F$ to obtain

$$\begin{aligned} 0 \;=\; & \frac{\gamma}{1-h}\bar{D}_F\bar{T}_F^{-1} + \left(1 + \frac{h}{1-h}\frac{\nu^{1-h}}{\bar{\Omega}}\bar{D}_F^h\right)\frac{d\bar{D}_F}{d\bar{T}_F} \\ & + \frac{h}{1-h}\frac{(1-\nu)^{1-h}}{\bar{\Omega}}\bar{D}_F\bar{D}_H^{h-1}\frac{d\bar{D}_H}{d\bar{T}_F} \,, \end{aligned} \tag{A.33}$$

where

$$\bar{\Omega} \equiv (1-\nu)^{1-h}\bar{D}_H^h + \nu^{1-h}\bar{D}_F^h \,. \tag{A.34}$$

---

[21] Of course, the short-run elasticity can equally well be defined as $\frac{d\left(\frac{C_{H,t}}{C_t}\right)}{d\left(\frac{P_{H,t}}{P_t}\right)} \cdot \frac{\frac{P_{H,t}}{P_t}}{\frac{C_{H,t}}{C_t}}$, which would yield the exact same results. The same is true for the definition of the elasticity in the long run.

Similarly, writing the demand of *Foreign* goods as

$$\bar{D}_H - \frac{1-\nu}{\left((1-\nu)^{1-h}\bar{D}_H^h + \nu^{1-h}\bar{D}_F^h\right)^{\frac{1}{1-h}}}\bar{T}_{H,t}^{-\frac{\gamma}{1-h}} = 0\,, \tag{A.35}$$

we can differentiate to get

$$\begin{aligned} 0 \;=\; & \frac{\gamma}{1-h}\bar{D}_H\bar{T}_H^{-1}\frac{d\bar{T}_H}{d\bar{T}_F} + \frac{h}{1-h}\frac{\nu^{1-h}}{\bar{\Omega}}\bar{D}_H\bar{D}_F^{h-1}\frac{d\bar{D}_F}{d\bar{T}_F} \\ & + \left(1 + \frac{h}{1-h}\frac{(1-\nu)^{1-h}}{\bar{\Omega}}\bar{D}_H^h\right)\frac{d\bar{D}_H}{d\bar{T}_F}\,. \end{aligned} \tag{A.36}$$

Finally, the price index

$$\bar{T}_H - \left(1 + \frac{\nu^{1-h}\bar{D}_F^h}{(1-\nu)^{1-h}\bar{D}_H^h}\left(1 - \bar{T}_F^{1-\gamma}\right)\right)^{\frac{1}{1-\gamma}} = 0\,, \tag{A.37}$$

when differentiated, yields

$$\begin{aligned} 0 \;=\; & \frac{d\bar{T}_H}{d\bar{T}_F} + \frac{\nu^{1-h}\bar{D}_F^h}{(1-\nu)^{1-h}\bar{D}_H^h}\bar{T}_H^{\gamma}\bar{T}_F^{-\gamma} \\ & - \frac{1}{1-\gamma}\frac{h\nu^{1-h}\bar{D}_F^{h-1}}{(1-\nu)^{1-h}\bar{D}_H^h}\bar{T}_H^{\gamma}\left(1 - \bar{T}_F^{1-\gamma}\right)\frac{d\bar{D}_F}{d\bar{T}_F} \\ & + \frac{1}{1-\gamma}\frac{h\nu^{1-h}\bar{D}_F^h}{(1-\nu)^{1-h}\bar{D}_H^{h+1}}\bar{T}_H^{\gamma}\left(1 - \bar{T}_F^{1-\gamma}\right)\frac{d\bar{D}_H}{d\bar{T}_F}\,. \end{aligned} \tag{A.38}$$

Equations (A.33)–(A.38) form a system of equations from which we can solve for $\frac{d\bar{D}_F}{d\bar{T}_F}$ and thereby also for Γ. After some tedious algebra,[22] we obtain the following complicated expression for the long-run elasticity of substitution:

$$\frac{d\bar{D}_F}{d\bar{T}_F}\frac{\bar{T}_F}{\bar{D}_F} = \frac{A_1}{A_2}\,, \tag{A.39}$$

where

$$\begin{aligned} A_1 \;=\; & \frac{1-\gamma}{h}\bar{T}_F^{1-\gamma} - \frac{\gamma}{h}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{(1-\nu)}\bar{T}_H^{\frac{\gamma h}{1-h}} + \frac{\gamma}{h}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{(1-\nu)}\bar{T}_F^{1-\gamma}\bar{T}_H^{\frac{\gamma h}{1-h}} \\ & + \frac{(1-\gamma)(1-h)}{h^2}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{\nu}\bar{T}_H^{\frac{\gamma h}{1-h}}\bar{T}_H^{1-\gamma} \\ & + \frac{(1-\gamma)}{h}\frac{(1-\nu)}{\nu}\left(\frac{\bar{T}_F}{\bar{T}_H}\right)^{\frac{\gamma h}{1-h}}\bar{T}_H^{1-\gamma}\,, \end{aligned} \tag{A.40}$$

[22] I first insert equation (A.38) into (A.36), rearrange and then combine (A.33) with the resulting expression. Thereafter, I solve for $\frac{d\bar{D}_F}{d\bar{T}_F}$, multiply by $\frac{\bar{T}_F}{\bar{D}_F}$ and simplify, to obtain equation (A.39) in the text.

and

$$
\begin{aligned}
A_2 &= 1-\bar{T}_F^{1-\gamma}+\frac{(1-h)}{h}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{(1-\nu)}\bar{T}_H^{\frac{\gamma h}{1-h}}+\frac{\nu}{(1-\nu)}\left(\frac{\bar{T}_F}{\bar{T}_H}\right)^{-\frac{\gamma h}{1-h}} \\
&\quad -\frac{(1-h)}{h}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{(1-\nu)}\bar{T}_F^{1-\gamma}\bar{T}_H^{\frac{\gamma h}{1-h}}-\frac{\nu}{1-\nu}\bar{T}_F^{1-\gamma}\left(\frac{\bar{T}_F}{\bar{T}_H}\right)^{-\frac{\gamma h}{1-h}} \\
&\quad -\left(\frac{1-h}{h}\right)^2\frac{1-\gamma}{\gamma}\frac{\bar{\Omega}^{\frac{1}{1-h}}}{\nu}\bar{T}_F^{\frac{\gamma h}{1-h}}\bar{T}_H^{1-\gamma} \qquad \text{(A.41)} \\
&\quad -\frac{1-h}{h}\frac{1-\gamma}{\gamma}\bar{T}_H^{1-\gamma}-\frac{1-h}{h}\frac{1-\gamma}{\gamma}\frac{1-\nu}{\nu}\left(\frac{\bar{T}_F}{\bar{T}_H}\right)^{\frac{\gamma h}{1-h}}\bar{T}_H^{1-\gamma}.
\end{aligned}
$$

While the above expression is neither intuitive nor easy to handle, when the steady-state price normalization is imposed, we obtain

$$
\frac{d\bar{D}_F}{d\bar{T}_F}\frac{\bar{T}_F}{\bar{D}_F}=\frac{A_3}{A_4}, \tag{A.42}
$$

where

$$
\begin{aligned}
A_3 &= \frac{1-\gamma}{h}-\frac{\gamma}{h}\frac{1}{(1-\nu)}+\frac{\gamma}{h}\frac{1}{(1-\nu)} \qquad \text{(A.43)} \\
&\quad +\frac{(1-\gamma)(1-h)}{h^2}\frac{1}{\nu}+\frac{(1-\gamma)}{h}\frac{(1-\nu)}{\nu},
\end{aligned}
$$

and

$$
\begin{aligned}
A_4 &= \frac{(1-h)}{h}\frac{1}{(1-\nu)}+\frac{\nu}{(1-\nu)}-\frac{(1-h)}{h}\frac{1}{(1-\nu)}-\frac{\nu}{1-\nu} \qquad \text{(A.44)} \\
&\quad -\left(\frac{1-h}{h}\right)^2\frac{1-\gamma}{\gamma}\frac{1}{\nu}-\frac{1-h}{h}\frac{1-\gamma}{\gamma}-\frac{1-h}{h}\frac{1-\gamma}{\gamma}\frac{1-\nu}{\nu}.
\end{aligned}
$$

Simplifying,

$$
\begin{aligned}
\frac{d\bar{D}_F}{d\bar{T}_F}\frac{\bar{T}_F}{\bar{D}_F} &= -\frac{\frac{1-\gamma}{h}+\frac{(1-\gamma)(1-h)}{h^2}\frac{1}{\nu}+\frac{(1-\gamma)}{h}\frac{(1-\nu)}{\nu}}{\left(\frac{1-h}{h}\right)^2\frac{1-\gamma}{\gamma}\frac{1}{\nu}+\frac{1-h}{h}\frac{1-\gamma}{\gamma}+\frac{1-h}{h}\frac{1-\gamma}{\gamma}\frac{1-\nu}{\nu}} \\
&= -\frac{\nu\gamma h+(1-h)\gamma+(1-\nu)\gamma h}{(1-h)^2+\nu h(1-h)+h(1-h)(1-\nu)} \\
&= -\frac{\gamma}{1-h}. \qquad \text{(A.45)}
\end{aligned}
$$

Hence, in the proximity of the assumed steady state, the long-run elasticity is a function of the short-run elasticity γ and the degree of habit formation h. The parameter h, when different from zero, allows for a separation of the two elasticities and is the only parameter governing the size of the long-run elasticity, given some chosen value for the short-run one (or, alternatively, the other way around).

A.5 The log-linearized model

In this section, the log-linearized model is summarized. For details on the steady-state relationships, needed for the log-linearization of some of the model expression, see Section A.3 of this appendix. Note that, as in Section A.4, for notational simplicity we define $T_{F,t} \equiv P_{F,t}/P_t$ and $T_{H,t} \equiv P_{H,t}/P_t$. Moreover, $T^*_{F,t} \equiv P^*_{F,t}/P^*_t$ and $T^*_{H,t} \equiv P^*_{H,t}/P^*_t$.

Log-linearizing, the *Home* Euler equation (16) becomes[23]

$$\mathrm{E}_t\, \hat{C}_{t+1} - \hat{C}_t = \frac{1}{\theta}\left[\hat{R}_t - \mathrm{E}_{t+1}\,\hat{\pi}_{t+1} + \hat{\xi}_{t+1} - \hat{\xi}_t\right], \tag{A.46}$$

and noting that in steady state we have $\bar{\omega} = \nu$, the log-linearized price index (7) becomes

$$0 = (1-\nu)\hat{T}_{H,t} + \nu\left(\hat{T}_{F,t} + \hat{Q}_t\right), \tag{A.47}$$

i.e. equal to the log-linearized price index in the standard DSGE model. Denoting the denominator in ω_t by Ω_t, log-linearization yields

$$\hat{\omega}_t = h\hat{C}_{F,t-1} - h\hat{C}_{t-1} - \hat{\Omega}_t\,, \tag{A.48}$$

and

$$\hat{\Omega}_t = (1-\nu)\,h\hat{C}_{H,t-1} + \nu h\hat{C}_{F,t-1} - h\hat{C}_{t-1}\,. \tag{A.49}$$

Combining with the log-linearized demand functions, finally yields the below log-linear expression for ω_t.

$$\hat{\omega}_t = h\hat{\omega}_{t-1} + (1-\nu)\,h\gamma\hat{T}_{H,t-1} - (1-\nu)\,h\gamma\hat{T}^*_{F,t-1} - (1-\nu)\,h\gamma\hat{Q}_{t-1} \tag{A.50}$$

The log-linearized *Home* economy resource constraint can be written as

$$\hat{Y}_t = -\gamma\hat{T}_{H,t} - \nu\hat{\omega}_t + (1-\nu)\,\hat{C}_t + \nu\hat{\omega}^*_t + \nu\hat{C}^*_t + \nu\gamma\widehat{Q}_t\,, \tag{A.51}$$

where we have used the log-linearized demand functions and made use of the steady-state relationships $\bar{C} = \bar{C}^*$, $\bar{C}^* = \bar{Y}^*$, $\bar{Q} = 1, \bar{T}^*_F = 1$ and $\bar{\omega} = \bar{\omega}^* = \nu$. To conclude the log-linearization of the demand side of the model, we finally note that the optimal risk-sharing condition becomes

$$\hat{C}_t = \frac{1}{\theta}\left(\hat{\xi}_t - \hat{\xi}^*_t + \hat{Q}_t\right) + \hat{C}^*_t\,. \tag{A.52}$$

The supply side of the model is summarized by one recursive price setting equation – a New Keynesian Phillips Curve (NKPC) – for each country. We can write the log-linearized version of equation (22) as

$$\begin{aligned}\hat{p}^o_{H,t} \;=\; & \frac{1-\alpha\beta}{1+\sigma\varphi}\left(\varphi\hat{Y}_t - (1+\varphi)\,\hat{X}_t + \hat{\mu}_t - \hat{\xi}_t + \theta\hat{C}_t - \hat{T}_{H,t}\right) \\ & + \alpha\beta\hat{\pi}_{H,t+1} + \alpha\beta\hat{p}^o_{H,t+1}\,.\end{aligned} \tag{A.53}$$

Using that equation (24) implies

$$\hat{p}^o_{H,t} = \frac{\alpha}{1-\alpha}\hat{\pi}_{H,t}\,, \tag{A.54}$$

[23] A hat on a variable denotes its log deviation from the steady-state value, while the steady-state value itself is denoted by a bar above the variable so that, for some variable Z, $\hat{Z}_t \equiv \log Z_t - \log \bar{Z}$.

we obtain the following first-order approximation of the *Home* NKPC:

$$\hat{\pi}_{H,t} = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha(1+\sigma\varphi)}\left(\varphi\hat{Y}_t - (1+\varphi)\hat{X}_t + \hat{\mu}_t - \hat{\xi}_t + \theta\hat{C}_t - \hat{T}_{H,t}\right) + \beta\hat{\pi}_{H,t+1}\,. \tag{A.55}$$

We now have a dynamic system of equations that contains equations (A.46), (A.47), (A.50), (A.51), (A.55) and their *Foreign* equivalents, as well as equation (A.52). To close the model, we furthermore need to include the log-linearized monetary policy rule

$$\hat{R}_t = \rho_R\hat{R}_{t-1} + (1-\rho_R)\left(\mu_\pi\hat{\pi}_{H,t} + \mu_Y(\hat{Y}_t - \hat{Y}_t^n)\right) + \hat{\varepsilon}_t\,, \tag{A.56}$$

and the following relationship between relative prices and inflation

$$\hat{\pi}_{H,t} = \hat{T}_{H,t} - \hat{T}_{H,t-1} + \hat{\pi}_t\,, \tag{A.57}$$

along with their *Foreign* equivalents. We now have a system of 15 equations with 19 unknowns[24], not yet having specified the processes for the 4 persistent shocks present in the model. Including the following stochastic *Home* shock processes,

$$\hat{X}_t = \rho_X\hat{X}_{t-1} + \epsilon_t^X \tag{A.58}$$

$$\hat{\xi}_t = \rho_\xi\hat{\xi}_{t-1} + \epsilon_t^\xi\,, \tag{A.59}$$

and an equivalent set of *Foreign* ones, we obtain a complete linear system with a total of 19 equations and 19 unknowns.

[24]The unknown variables are: $\hat{C}$, $\hat{C}^*$, $\hat{\omega}$, $\hat{\omega}^*$, $\hat{\pi}$, $\hat{\pi}^*$, $\hat{\pi}_H$, $\hat{\pi}_F^*$, $\hat{Y}$, $\hat{Y}^*$, $\hat{R}$, $\hat{R}^*$, $\hat{T}_H$, $\hat{T}_F^*$, $\hat{Q}$, $\hat{\xi}$, $\hat{\xi}^*$, $\hat{X}$, $\hat{X}^*$. Note that we have assumed that $\hat{\varepsilon}$, $\hat{\varepsilon}^*$, $\hat{\mu}$ and $\hat{\mu}^*$ are given by some i.i.d. processes.

B Appendix: A second-order approximation of welfare

In this appendix, we derive the second-order approximation of the representative agent's welfare, which we also assume to be the objective function of the central bank. The derivation is based on the methodology laid out in Benigno and Woodford (2008) and applied to a two-country setting by Benigno and Benigno (2006).

We start by taking a simple second-order approximation of the welfare functions, obtaining expressions which still contain some linear terms. To be able to eliminate these, we then need to take second-order approximations also of the model equations. In order to keep this system as small as possible, I rewrite the model in terms of the nine endogenous variables $\hat{Y}_t$, $\hat{C}_t$, $\hat{T}_{H,t}$, $\hat{\omega}_t$, $\hat{Y}_t^*$, $\hat{C}_t^*$, $\hat{T}_{F,t}^*$, $\hat{\omega}_t^*$ and $\hat{Q}_t$, and the six shocks $\hat{X}_t$, $\hat{\xi}_t$, $\hat{\mu}_t$, $\hat{X}_t^*$, $\hat{\xi}_t^*$ and $\hat{\mu}_t^*$. We hence need the second-order approximations of the demand equations, the definitions of the time-varying degree of openness, the price indices, and the price setting decisions, for both *Home* and *Foreign*, as well as the risk sharing equation bringing the two economies together.

Throughout this appendix, we will make extensive use of the column vectors of the model variables and shocks, x_t and ζ_t respectively, defined as:

$$x_t' = \begin{bmatrix} \hat{Y}_t & \hat{C}_t & \hat{T}_{H,t} & \hat{\omega}_t & \hat{Y}_t^* & \hat{C}_t^* & \hat{T}_{F,t}^* & \hat{\omega}_t^* & \hat{Q}_t \end{bmatrix} \tag{B.60}$$

$$\zeta_t' = \begin{bmatrix} \hat{X}_t & \hat{\xi}_t & \hat{\mu}_t & \hat{X}_t^* & \hat{\xi}_t^* & \hat{\mu}_t^* \end{bmatrix} . \tag{B.61}$$

B.1 Utility

The individual's lifetime utility function for individual j is given by equation (1) in the main text, where u and v take on the functional forms given by (2) and (3), while the technology is given by expression (13). Given the assumption that there are equally many firms as there are households, we can index the firms in such a way that $i = j$. Then we can write utility as

$$U_t^j = E_t \sum_{t=0}^{\infty} \beta^t \left\{ u\left(C_t^j; \xi_t\right) - v\left(Y_t(i); X_t\right) \right\} , \tag{B.62}$$

where

$$v\left(Y_t(i); X_t\right) = \frac{1}{1+\varphi} X_t^{-1-\varphi} \left(Y_t(i)\right)^{1+\varphi} . \tag{B.63}$$

The welfare function of country *Home* is then given by

$$\mathbb{W} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[u\left(C_t; \xi_t\right) - \int_0^1 v\left(Y_t(i); X_t\right) di \right] \right\} , \tag{B.64}$$

where $C_t^j = C_t$ for all j because of the complete-market assumption.

Taking a second-order approximation of the consumer's per-period utility from consumption then yields

$$u\left(C_t; \xi_t\right) \simeq u_C\left(\bar{C}\right) \bar{C} \left(\hat{C}_t + \frac{1}{2}\left(1-\theta\right) \hat{C}_t^2 + \hat{C}_t \hat{\xi}_t \right) + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) , \tag{B.65}$$

where $\mathcal{O}\left(||\zeta||^3\right)$ denotes terms that are of third order or higher (in the norm of the shocks), and $t.i.p.$ denotes terms independent of policy. The per-period disutility function v, in turn, yields

$$v\left(Y_t\left(i\right);X_t\right) \simeq v_Y\bar{Y}\left(\hat{Y}_t\left(i\right)+\frac{1}{2}\left(1+\varphi\right)\hat{Y}_t\left(i\right)^2-\left(1+\varphi\right)\hat{Y}_t\left(i\right)\hat{X}_t\right) + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) . \tag{B.66}$$

In order to obtain an expression for the disutility function in terms of aggregate production Y_t, we first need to approximate the output aggregator. Following Woodford (2003), ch. 6, we denote by $E_i\hat{y}_t\left(i\right)$ the mean value of $\hat{y}_t\left(i\right)$ across all differentiated goods at time t, and by $var_i\left(\hat{y}_t\left(i\right)\right)$ the corresponding variance. Then,

$$\hat{Y}_t \simeq E_i\hat{y}_t\left(i\right)+\frac{1}{2}\left(\frac{\sigma-1}{\sigma}\right)var_i\left(\hat{y}_t\left(i\right)\right)+\mathcal{O}\left(||\hat{y}||^3\right) . \tag{B.67}$$

Integrating (B.66) over i, and inserting (B.67) along with the relationship

$$E_i\left(\hat{y}_t\left(i\right)\right)^2 = \left(E_i\hat{y}_t\left(i\right)\right)^2+var_i\left(\hat{y}_t\left(i\right)\right) , \tag{B.68}$$

we have

$$\int_0^1 v\left(Y_t\left(i\right);X_t\right)di = \tag{B.69}$$
$$u_c\bar{C}\bar{\mu}^{-1}\left(\hat{Y}_t+\frac{1}{2}\left(1+\varphi\right)\hat{Y}_t^2-\left(1+\varphi\right)\hat{Y}_t\hat{X}_t+\frac{1}{2}\left(\sigma^{-1}+\varphi\right)var_i\left(\hat{y}_t\left(i\right)\right)\right)$$
$$+t.i.p.+\mathcal{O}\left(||\hat{y},\zeta||^3\right) ,$$

where we have used the steady-state relationship

$$v_Y\bar{Y} = u_C\bar{C}\frac{\left(\sigma-1\right)\left(1-\bar{\tau}\right)}{\sigma} = \frac{u_c\bar{C}}{\bar{\mu}} , \tag{B.70}$$

and followed the notation in Benigno and Benigno (2006) in defining

$$\frac{1}{\mu_t} \equiv \frac{\sigma-1}{\sigma}\left(1-\tau_t\right) . \tag{B.71}$$

Note that we have assumed that there is a subsidy in place such that $\bar{\mu}=1$, rendering the steady state efficient. Any value of $\mu_t > 0$ would instead yield an inefficiently low production level. Following Woodford (2003), we can write[25]

$$\sum_{t=0}^{\infty}\beta^{t}var_{i}\left(\hat{y}_{t}\left(i\right)\right)=\frac{\alpha}{\left(1-\alpha\right)\left(1-\alpha\beta\right)}\sigma^{2}\sum_{t=0}^{\infty}\beta^{t}\pi_{H,t}^{2}+t.i.p.+\mathcal{O}\left(||\Delta_{-1}^{1/2},\zeta||^{3}\right) \tag{B.72}$$

and, defining

$$\eta\equiv\frac{\left(1-\alpha\right)\left(1-\alpha\beta\right)}{\alpha}\,,$$

we finally obtain the following approximation of the welfare function for the *Home* country:

$$\begin{aligned}\mathbb{W} &= u_{C}\left(\bar{C}\right)\bar{C}E_{0}\left\{\sum_{t=0}^{\infty}\beta^{t}\left[\hat{C}_{t}-\bar{\mu}^{-1}\hat{Y}_{t}+\frac{1}{2}\left(1-\theta\right)\hat{C}_{t}^{2}-\frac{1}{2}\bar{\mu}^{-1}\left(1+\varphi\right)\hat{Y}_{t}^{2}\right.\right. \qquad \text{(B.73)}\\ &\left.\left.+\hat{C}_{t}\hat{\xi}_{t}+\bar{\mu}^{-1}\left(1+\varphi\right)\hat{Y}_{t}\hat{X}_{t}-\frac{1}{2}\bar{\mu}^{-1}\eta^{-1}\sigma\left(1+\sigma\varphi\right)\pi_{H,t}^{2}\right]\right\}+t.i.p.+\mathcal{O}\left(||\zeta||^{3}\right)\,.\end{aligned}$$

Rewriting in vector-matrix form,

$$\begin{aligned}\mathbb{W} &= u_{C}\left(\bar{C}\right)\bar{C}E_{0}\left\{\sum_{t=0}^{\infty}\beta^{t}\left[z_{x}'x_{t}-\frac{1}{2}x_{t}'Z_{x}x_{t}-x_{t}'Z_{\zeta}\zeta_{t}-\frac{1}{2}z_{\pi_{H}}\pi_{H,t}^{2}\right]\right\}\\ &+t.i.p.+\mathcal{O}\left(||\zeta||^{3}\right)\,, \qquad \text{(B.74)}\end{aligned}$$

where

$$z_{x}'=\begin{bmatrix}-\bar{\mu}^{-1} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix}\,,$$

---

[25] From p. 396, chapter 6 in Woodford (2003), we know that

$$\sum_{t=0}^{\infty}\beta^{t}var_{i}\left(\hat{y}_{t}\left(i\right)\right)=\sigma^{2}\sum_{t=0}^{\infty}\beta^{t}var_{i}\left(\hat{p}_{t}\left(i\right)\right)=\sigma^{2}\sum_{t=0}^{\infty}\beta^{t}\Delta_{t}\,,$$

and that $var_{i}\left(\hat{p}_{t}\left(i\right)\right)=\Delta_{t}$ evolves over time according to

$$\Delta_{t}=\alpha\Delta_{t-1}+\frac{\alpha}{1-\alpha}\pi_{H,t}^{2}+\mathcal{O}\left(||\Delta_{t-1}^{1/2},\zeta||^{3}\right)\,.$$

Integrating forward starting from any initial degree of price dispersion Δ_{-1} in the period before the policy is chosen, Woodford shows that the degree of price dispersion under the new policy, in any time period $t\geq 0$, is given by

$$\Delta_{t}=\alpha^{t+1}\Delta_{-1}+\sum_{t=0}^{t}\alpha^{t-s}\left(\frac{\alpha}{1-\alpha}\right)\pi_{H,t}^{2}+\mathcal{O}\left(||\Delta_{t-1}^{1/2},\zeta||^{3}\right)\,.$$

Since the first term is independent of policy, taking the discounted value over all periods $t\geq 0$, we have

$$\sum_{t=0}^{\infty}\beta^{t}\Delta_{t}=\frac{\alpha}{\left(1-\alpha\right)\left(1-\alpha\beta\right)}\sum_{t=0}^{\infty}\beta^{t}\pi_{H,t}^{2}+t.i.p.+\mathcal{O}\left(||\Delta_{-1}^{1/2},\zeta||^{3}\right)\,.$$

$$Z_x = \begin{bmatrix} \bar{\mu}^{-1}(1+\varphi) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -(1-\theta) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Z_\zeta = \begin{bmatrix} -\bar{\mu}^{-1}(1+\varphi) & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$z_{\pi_H} = \bar{\mu}^{-1}\eta^{-1}\sigma(1+\sigma\varphi) ,$$

and x_t' and ζ_t' are defined as in (B.60) and (B.61) above.

Similarly, for the *Foreign* economy, the welfare function is given by

$$\begin{aligned} \mathbb{W}^* \quad = \quad & u_C(\bar{C})\bar{C}E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[\hat{C}_t^* - \bar{\mu}^{-1}\hat{Y}_t^* + \frac{1}{2}(1-\theta)\left(\hat{C}_t^*\right)^2 - \frac{1}{2}\bar{\mu}^{-1}(1+\varphi)\left(\hat{Y}_t^*\right)^2\right.\right. \\ & \left.\left. + \hat{C}_t^*\hat{\xi}_t^* + \bar{\mu}^{-1}(1+\varphi)\hat{Y}_t^*\hat{X}_t^* - \frac{1}{2}\bar{\mu}^{-1}\eta^{-1}\sigma(1+\sigma\varphi)\left(\pi_{F,t}^*\right)^2\right]\right\} \\ & + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) , \end{aligned} \tag{B.75}$$

which in vector-matrix form becomes

$$\begin{aligned} \mathbb{W}^* \quad = \quad & u_C(\bar{C})\bar{C}E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[z_x^{*\prime}x_t - \frac{1}{2}x_t'Z_x^*x_t - x_t'Z_\zeta^*\zeta_t - \frac{1}{2}z_{\pi_F}^*\left(\pi_{F,t}^*\right)^2\right]\right\} \\ & + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) , \end{aligned} \tag{B.76}$$

where

$$z_x^{*\prime} = \begin{bmatrix} 0 & 0 & 0 & 0 & -\bar{\mu}^{-1} & 1 & 0 & 0 & 0 \end{bmatrix} ,$$

$$Z_x^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \bar{\mu}^{-1}(1+\varphi) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -(1-\theta) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Z_{\zeta}^{*} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\bar{\mu}^{-1}(1+\varphi) & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

and

$$z_{\pi_F}^{*} = \bar{\mu}^{-1}\eta^{-1}\sigma(1+\sigma\varphi) .$$

B.2 The demand equations

Using equations (6), (9), (10) and (12) in the main text along with the definition of the real exchange rate, the second-order approximation of the total demand for *Home* goods, equation (14), can be written as

$$\begin{aligned} \hat{Y}_t = \; & (1-\nu)\hat{C}_t - \gamma\hat{T}_{H,t} - \nu\hat{\omega}_t + \nu\hat{C}_t^{*} + \nu\hat{\omega}_t^{*} + \nu\gamma\hat{Q}_t \\ & + \frac{1}{2}\nu(1-\nu)\hat{C}_t^2 - \frac{1}{2}\nu(1+\nu)\hat{\omega}_t^2 + \frac{1}{2}\nu(1-\nu)\left(\hat{C}_t^{*}\right)^2 \\ & + \frac{1}{2}\nu(1-\nu)(\hat{\omega}_t^{*})^2 + \frac{1}{2}\nu(1-\nu)\gamma^2\hat{Q}_t^2 \\ & - \nu^2\hat{C}_t\hat{\omega}_t - \nu(1-\nu)\hat{C}_t\hat{C}_t^{*} - \nu(1-\nu)\hat{C}_t\hat{\omega}_t^{*} - \nu(1-\nu)\gamma\hat{C}_t\hat{Q}_t \\ & + \nu^2\hat{\omega}_t\hat{C}_t^{*} + \nu^2\hat{\omega}_t\hat{\omega}_t^{*} + \nu^2\gamma\hat{\omega}_t\hat{Q}_t + \nu(1-\nu)\hat{C}_t^{*}\hat{\omega}_t^{*} \\ & + \nu(1-\nu)\gamma\hat{C}_t^{*}\hat{Q}_t + \nu(1-\nu)\gamma\hat{\omega}_t^{*}\hat{Q}_t + \mathcal{O}\left(||\zeta||^3\right), \end{aligned} \tag{B.77}$$

where we have made use of the steady-state relationships $\bar{C}^{*} = \bar{C}$, $\bar{C} = \bar{Y}$, $\bar{Q} = 1, \bar{T}_H = 1$, and $\bar{\omega} = \bar{\omega}^{*} = \nu$. In vector-matrix form, this becomes

$$\sum_{t=0}^{\infty}\beta^t\left[m_x'x_t + \frac{1}{2}x_t'M_x x_t + x_t'M_{\zeta}\zeta_t\right] + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) = 0, \tag{B.78}$$

where

$$m_x' = \begin{bmatrix} -1 & (1-\nu) & -\gamma & -\nu & 0 & \nu & 0 & \nu & \nu\gamma \end{bmatrix},$$

$$M_x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \nu(1-\nu) & 0 & -\nu^2 & 0 & -\nu(1-\nu) & 0 & -\nu(1-\nu) & -\nu(1-\nu)\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\nu^2 & 0 & -\nu(1+\nu) & 0 & \nu^2 & 0 & \nu^2 & \nu^2\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\nu(1-\nu) & 0 & \nu^2 & 0 & \nu(1-\nu) & 0 & \nu^2\gamma & \nu(1-\nu)\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\nu(1-\nu) & 0 & \nu^2 & 0 & \nu^2\gamma & 0 & \nu(1-\nu) & \nu(1-\nu)\gamma \\ 0 & -\nu(1-\nu)\gamma & 0 & \nu^2\gamma & 0 & \nu(1-\nu)\gamma & 0 & \nu(1-\nu)\gamma & \nu(1-\nu)\gamma^2 \end{bmatrix},$$

and

$$M_{\zeta} = 0 .$$

Proceeding in the same way, we obtain the following expression for the total demand for *Foreign* goods

$$\begin{aligned} Y_t^* &= \nu\hat{C}_t + \nu\hat{\omega}_t + (1-\nu)\hat{C}_t^* - \gamma\hat{T}_{F,t}^* - \nu\hat{\omega}_t^* - \nu\gamma\hat{Q}_t \\ &+\frac{1}{2}\nu(1-\nu)\hat{C}_t^2 + \frac{1}{2}\nu(1-\nu)\hat{\omega}_t^2 + \frac{1}{2}\nu(1-\nu)\left(\hat{C}_t^*\right)^2 \\ &-\frac{1}{2}\nu(1+\nu)(\hat{\omega}_t^*)^2 + \frac{1}{2}\nu(1-\gamma)\gamma^2\hat{Q}_t^2 \\ &+\nu(1-\nu)\hat{C}_t\hat{\omega}_t - \nu(1-\nu)\hat{C}_t\hat{C}_t^* + \nu^2\hat{C}_t\hat{\omega}_t^* - \nu(1-\nu)\gamma\hat{C}_t\hat{Q}_t \\ &-\nu(1-\nu)\hat{\omega}_t\hat{C}_t^* + \nu^2\hat{\omega}_t\hat{\omega}_t^* - \nu(1-\nu)\gamma\hat{\omega}_t\hat{Q}_t - \nu^2\hat{C}_t^*\hat{\omega}_t^* \\ &+\nu(1-\nu)\gamma\hat{C}_t^*\hat{Q}_t - \nu^2\gamma\hat{\omega}_t^*\hat{Q}_t + \mathcal{O}\left(||\zeta||^3\right), \end{aligned} \tag{B.79}$$

which in vector-matrix form becomes

$$\sum_{t=0}^{\infty}\beta^t\left[m_x^{*\prime}x_t + \frac{1}{2}x_t' M_x^* x_t + x_t' M_\zeta^* \zeta_t\right] + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) = 0\,, \tag{B.80}$$

where

$$m_x^{*\prime} = \begin{bmatrix}0 & \nu & 0 & \nu & -1 & (1-\nu) & -\gamma & -\nu & -\nu\gamma\end{bmatrix},$$

$$M_x^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \nu(1-\nu) & 0 & \nu(1-\nu) & 0 & -\nu(1-\nu) & 0 & \nu^2 & -\nu(1-\nu)\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \nu(1-\nu) & 0 & \nu(1-\nu) & 0 & -\nu(1-\nu) & 0 & \nu^2 & -\nu(1-\nu)\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\nu(1-\nu) & 0 & -\nu(1-\nu) & 0 & \nu(1-\nu) & 0 & -\nu^2 & \nu(1-\nu)\gamma \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \nu^2 & 0 & \nu^2 & 0 & -\nu^2 & 0 & -\nu(1+\nu) & -\nu^2\gamma \\ 0 & -\nu(1-\nu)\gamma & 0 & -\nu(1-\nu)\gamma & 0 & \nu(1-\nu)\gamma & 0 & -\nu^2\gamma & \nu(1-\gamma)\gamma^2 \end{bmatrix},$$

and

$$M_\zeta^* = 0\,.$$

B.3 The time-varying degree of openness

Writing the definition of ω_t, as given in equation (6) in the main text, in terms of Ω_t, it is obvious that the log-linear approximation

$$\hat{\omega}_t = h\hat{C}_{F,t-1} - h\hat{C}_{t-1} - \hat{\Omega}_t \tag{B.81}$$

coincides with the second-order approximation. We still, however, need to derive a second-order approximation for Ω_t. In terms of C_H and C_F, this can be written as

$$\begin{aligned} \hat{\Omega}_t &= (1-\nu)h\hat{C}_{H,t-1} + \nu h\hat{C}_{F,t-1} - h\hat{C}_{t-1} \\ &+\frac{1}{2}\nu(1-\nu)h^2\hat{C}_{H,t-1}^2 + \frac{1}{2}\nu(1-\nu)h^2\hat{C}_{F,t-1}^2 \\ &-\nu(1-\nu)h^2\hat{C}_{H,t-1}\hat{C}_{F,t-1} + \mathcal{O}\left(||\zeta||^3\right). \end{aligned} \tag{B.82}$$

We next need to derive the second-order approximations of (9) and (10) in the main text. An approximation of equation (9), lagged one period, yields

$$\hat{C}_{H,t-1} = -\frac{\nu}{1-\nu}\hat{\omega}_{t-1} - \gamma\hat{T}_{H,t-1} + \hat{C}_{t-1} - \frac{1}{2}\frac{\nu}{(1-\nu)^2}\hat{\omega}_{t-1}^2\,. \tag{B.83}$$

For equation (10), the second-order approximation will coincide with the log-linear one. Noting that

$$\hat{T}_{F,t} = \hat{Q}_t + \hat{T}^*_{F,t}\,, \tag{B.84}$$

and lagging one period, we have

$$\hat{C}_{F,t-1} = \hat{\omega}_{t-1} - \gamma\hat{Q}_{t-1} - \gamma\hat{T}^*_{F,t-1} + \hat{C}_{t-1}\,. \tag{B.85}$$

In order to keep the final number of variables scarce, which will simplify the computations of the loss equation, we substitute (B.82), (B.83), and (B.85) into (B.81). Leading one period forward, we finally arrive at the following expression for *Home* openness:

$$\begin{aligned}
\hat{\omega}_t \;=\; & -(1-\nu)\gamma\hat{T}_{H,t} + h^{-1}\hat{\omega}_{t+1} + (1-\nu)\gamma\hat{T}^*_{F,t} + (1-\nu)\gamma\hat{Q}_t \\
& + \frac{1}{2}\nu(1-\nu)h\gamma^2\hat{T}^2_{H,t} - \frac{1}{2}\left(\frac{\nu(1-h)}{1-\nu}\right)\hat{\omega}_t^2 \\
& + \frac{1}{2}\nu(1-\nu)h\gamma^2\hat{Q}_t^2 + \frac{1}{2}\nu(1-\nu)h\gamma^2\hat{T}^{*2}_{F,t} \\
& + \nu h\gamma\hat{T}_{H,t}\hat{\omega}_t - \nu(1-\nu)h\gamma^2\hat{T}_{H,t}\hat{T}^*_{F,t} \\
& - \nu(1-\nu)h\gamma^2\hat{T}_{H,t}\hat{Q}_t - \nu h\gamma\hat{\omega}_t\hat{Q}_t \\
& - \nu h\gamma\hat{\omega}_t\hat{T}^*_{F,t} + \nu(1-\nu)h\gamma^2\hat{Q}_t\hat{T}^*_{F,t}\,.
\end{aligned} \tag{B.86}$$

We can hence rewrite the above equation in vector-matrix form as follows:

$$\sum_{t=0}^{\infty}\beta^t\left[n_x' x_t + \frac{1}{2}x_t' N_x x_t + x_t' N_\zeta \zeta_t + n_\omega \hat{\omega}_{t+1}\right] + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) = 0\,. \tag{B.87}$$

Here, x_t and ζ_t are defined as before, and

$$n_x' = \begin{bmatrix} 0 & 0 & -(1-\nu)\gamma & -1 & 0 & 0 & (1-\nu)\gamma & 0 & (1-\nu)\gamma \end{bmatrix},$$

$$N_x = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \nu(1-\nu)h\gamma^2 & \nu h\gamma & 0 & 0 & -\nu(1-\nu)h\gamma^2 & 0 & -\nu(1-\nu)h\gamma^2 \\
0 & 0 & \nu h\gamma & -\frac{\nu(1-h)}{1-\nu} & 0 & 0 & -\nu h\gamma & 0 & -\nu h\gamma \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -\nu(1-\nu)h\gamma^2 & -\nu h\gamma & 0 & 0 & \nu(1-\nu)h\gamma^2 & 0 & \nu(1-\nu)h\gamma^2 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -\nu(1-\nu)h\gamma^2 & -\nu h\gamma & 0 & 0 & \nu(1-\nu)h\gamma^2 & 0 & \nu(1-\nu)h\gamma^2
\end{bmatrix},$$

$$N_\zeta = 0\,,$$

and

$$n_\omega = \frac{1}{h}\,.$$

Note that the only variable in (B.87) not dated t, $\hat{\omega}_{t+1}$, comes in linearly. For the purpose of eliminating the linear terms from the welfare function, we will subtract an appropriate linear combination of the remaining equations, such that the linear terms obtaining from it will exactly equal the negative of the linear terms from the welfare function, resulting in an expression for welfare consisting of only second-order terms. To that end, we will use the sum from time $t = 0$ to infinity of each of the model equations. Note that we can rewrite the above expression as

$$\sum_{t=0}^{\infty} \beta^t \left[n_x' x_t + \frac{1}{2} x_t' N_x x_t + x_t' N_\zeta \zeta_t + \frac{n_\omega}{\beta} \hat{\omega}_t - \frac{n_\omega}{\beta} \hat{\omega}_{t_0} \right] + t.i.p. + \mathcal{O}\left(||\zeta||^3 \right) = 0 \,. \tag{B.88}$$

Rewriting,

$$\tilde{V}_{t_0} = \sum_{t=0}^{\infty} \beta^t \left[\tilde{n}_x' x_t + \frac{1}{2} x_t' N_x x_t + x_t' N_\zeta \zeta_t \right] + t.i.p. + \mathcal{O}\left(||\zeta||^3 \right) \,, \tag{B.89}$$

where now

$$\tilde{n}_x' = \begin{bmatrix} 0 & 0 & -(1-\nu)\gamma & \frac{1-h\beta}{h\beta} & 0 & 0 & (1-\nu)\gamma & 0 & (1-\nu)\gamma \end{bmatrix} \,,$$

and

$$\tilde{V}_{t_0} = \frac{1}{h\beta} \hat{\omega}_{t_0} \,.$$

Since $\hat{\omega}_t$ is predetermined, we have that $\tilde{V}_{t_0}$ is independent of any policy implemented at time t_0 or later.

For the *Foreign* economy we instead have

$$\omega_t^* = \frac{\nu^{1-h} \left(\frac{C_{H,t-1}^*}{C_{t-1}^*} \right)^h}{\Omega_t^*} \,, \tag{B.90}$$

where

$$\Omega_t^* = (1-\nu)^{1-h} \left(\frac{C_{F,t-1}^*}{C_{t-1}^*} \right)^h + \nu^{1-h} \left(\frac{C_{H,t-1}^*}{C_{t-1}^*} \right)^h \,. \tag{B.91}$$

Using the same reasoning as with $\hat{\omega}_t$ above, we obtain

$$\begin{aligned} \hat{\omega}_t^* \;=\; & (1-\nu)\gamma \hat{T}_{H,t} - (1-\nu)\gamma \hat{T}_{F,t}^* + h^{-1} \hat{\omega}_{t+1}^* + (1-\nu)\gamma \hat{Q}_t \\ & + \frac{1}{2} \nu (1-\nu) h \gamma^2 \hat{T}_{H,t}^2 + \frac{1}{2} \nu (1-\nu) h \gamma^2 \hat{T}_{F,t}^{*2} \\ & - \frac{1}{2} \frac{\nu (1-h)}{1-\nu} \hat{\omega}_t^{*2} + \frac{1}{2} \nu (1-\nu) h \gamma^2 \hat{Q}_t^2 \\ & + \nu (1-\nu) h \gamma^2 \hat{T}_{H,t} \hat{Q}_t - \nu h \gamma \hat{T}_{H,t} \hat{\omega}_t^* \\ & - \nu (1-\nu) h \gamma^2 \hat{T}_{H,t} \hat{T}_{F,t}^* + \nu h \gamma \hat{T}_{F,t}^* \hat{\omega}_t^* \\ & - \nu (1-\nu) h \gamma^2 \hat{T}_{F,t}^* \hat{Q}_t - \nu h \gamma \hat{\omega}_t^* \hat{Q}_t \,, \end{aligned} \tag{B.92}$$

or, analogously to expression (B.89),

$$\tilde{V}_{t_0}^* = \sum_{t=0}^{\infty} \beta^t \left[\tilde{n}_x^{*\prime} x_t + \frac{1}{2} x_t' N_x^* x_t + x_t' N_\zeta^* \zeta_t \right] + t.i.p. + \mathcal{O}\left(||\zeta||^3 \right) \,, \tag{B.93}$$

where

$$\tilde{n}_x^{*\prime} = \begin{bmatrix} 0 & 0 & (1-\nu)\gamma & 0 & 0 & 0 & -(1-\nu)\gamma & \frac{1-h\beta}{h\beta} & (1-\nu)\gamma \end{bmatrix},$$

$$N_x^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \nu(1-\nu)h\gamma^2 & 0 & 0 & 0 & -\nu(1-\nu)h\gamma^2 & -\nu h\gamma & \nu(1-\nu)h\gamma^2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\nu(1-\nu)h\gamma^2 & 0 & 0 & 0 & \nu(1-\nu)h\gamma^2 & \nu h\gamma & -\nu(1-\nu)h\gamma^2 \\ 0 & 0 & -\nu h\gamma & 0 & 0 & 0 & \nu h\gamma & -\frac{\nu(1-h)}{1-\nu} & -\nu h\gamma \\ 0 & 0 & \nu(1-\nu)h\gamma^2 & 0 & 0 & 0 & -\nu(1-\nu)h\gamma^2 & -\nu h\gamma & \nu(1-\nu)h\gamma^2 \end{bmatrix},$$

$$N_\zeta^* = 0,$$

and

$$\tilde{V}_{t_0}^* = \frac{1}{h\beta}\hat{\omega}_{t_0}^*.$$

B.4 The risk sharing equation

Under the assumption that $\psi' = 1$, a log-linearization of equation (28) in the main text yields the exact log-linear expression

$$\hat{C}_t = \frac{1}{\theta}\hat{\xi}_t - \frac{1}{\theta}\hat{\xi}_t^* + \frac{1}{\theta}\hat{Q}_t + \hat{C}_t^*, \tag{B.94}$$

making the first- and second-order approximations identical. Rewriting in vector-matrix form, we have

$$\sum_{t=0}^{\infty}\beta^t\left[a_x' x_t\right] + t.i.p. = 0, \tag{B.95}$$

where x_t and ζ_t are again defined as before, and

$$a_x' = \begin{bmatrix} 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & \theta^{-1} \end{bmatrix}.$$

B.5 The price indices

Rewriting the *Home* price index (7) in terms of relative prices, we have

$$T_{H,t}^{1-\gamma} = \frac{1}{1-\omega_t} - \frac{\omega_t}{1-\omega_t}T_{F,t}^{1-\gamma}. \tag{B.96}$$

Taking a second-order approximation, and using (B.84) to substitute for $T_{F,t}$ yields

$$\begin{aligned} \hat{T}_{H,t} = & -\frac{\nu}{1-\nu}\hat{Q}_t - \frac{\nu}{1-\nu}\hat{T}_{F,t}^* - \frac{1}{2}\frac{\nu(1-\gamma)}{(1-\nu)^2}\hat{Q}_t^2 - \frac{1}{2}\frac{\nu(1-\gamma)}{(1-\nu)^2}\left(\hat{T}_{F,t}^*\right)^2 \\ & -\frac{\nu(1-\gamma)}{(1-\nu)^2}\hat{Q}_t\hat{T}_{F,t}^* - \frac{\nu}{(1-\nu)^2}\hat{\omega}_t\hat{Q}_t - \frac{\nu}{(1-\nu)^2}\hat{\omega}_t\hat{T}_{F,t}^* + \mathcal{O}\left(\|\zeta\|^3\right). \end{aligned} \tag{B.97}$$

Rewriting in vector-matrix form, we then have

$$\sum_{t=0}^{\infty} \beta^t \left[b_x' x_t + \frac{1}{2} x_t' B_x x_t + x_t' B_\zeta \zeta_t \right] + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) = 0\,, \tag{B.98}$$

where

$$b_x' = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 & 0 & -\frac{\nu}{1-\nu} & 0 & -\frac{\nu}{1-\nu} \end{bmatrix},$$

$$B_x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{\nu}{(1-\nu)^2} & 0 & -\frac{\nu}{(1-\nu)^2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{\nu}{(1-\nu)^2} & 0 & 0 & -\frac{\nu(1-\gamma)}{(1-\nu)^2} & 0 & -\frac{\nu(1-\gamma)}{(1-\nu)^2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{\nu}{(1-\nu)^2} & 0 & 0 & -\frac{\nu(1-\gamma)}{(1-\nu)^2} & 0 & -\frac{\nu(1-\gamma)}{(1-\nu)^2} \end{bmatrix},$$

and

$$B_\zeta = 0\,.$$

The *Foreign* price index, using

$$\hat{T}^*_{H,t} = \hat{T}_{H,t} - \hat{Q}_t\,, \tag{B.99}$$

instead yields

$$\begin{aligned} \hat{T}^*_{F,t} \;=\; & -\frac{\nu}{1-\nu}\hat{T}_{H,t} + \frac{\nu}{1-\nu}\hat{Q}_t - \frac{1}{2}\frac{\nu(1-\gamma)}{(1-\nu)^2}\hat{T}^2_{H,t} - \frac{1}{2}\frac{\nu(1-\gamma)}{(1-\nu)^2}\hat{Q}_t^2 \\ & + \frac{\nu(1-\gamma)}{(1-\nu)^2}\hat{T}_{H,t}\hat{Q}_t - \frac{\nu}{(1-\nu)^2}\hat{T}_{H,t}\hat{\omega}^*_t + \frac{\nu}{(1-\nu)^2}\hat{\omega}^*_t\hat{Q}_t + \mathcal{O}\left(||\zeta||^3\right)\,. \end{aligned} \tag{B.100}$$

Rewriting in vector-matrix form, we have

$$\sum_{t=0}^{\infty} \beta^t \left[b_x^{*\prime} x_t + \frac{1}{2} x_t' B_x^* x_t + x_t' B_\zeta^* \zeta_t \right] + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) = 0\,, \tag{B.101}$$

where

$$b_x^{*\prime} = \begin{bmatrix} 0 & 0 & -\frac{\nu}{1-\nu} & 0 & 0 & 0 & -1 & 0 & \frac{\nu}{1-\nu} \end{bmatrix},$$

$$B_x^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{\nu}{(1-\nu)^2} & \frac{\nu(1-\gamma)}{(1-\nu)^2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{\nu}{(1-\nu)^2} & 0 & 0 & 0 & 0 & 0 & \frac{\nu}{(1-\nu)^2} \\ 0 & 0 & \frac{\nu(1-\gamma)}{(1-\nu)^2} & 0 & 0 & 0 & 0 & \frac{\nu}{(1-\nu)^2} & -\frac{\nu(1-\gamma)}{(1-\nu)^2} \end{bmatrix},$$

and

$$B^*_\zeta = 0\,.$$

B.6 Price setting

When setting its prices, the firm maximizes

$$\max_{p_{t(i)}} E_t \sum_{z=0}^{\infty} (\alpha\beta)^z \Lambda_{t,t+z} \left((1-\tau_{t+z})\, p_t(i)\, Y_{t+z}(i) - W_{t+z} L_{t+z}(i)\right) , \tag{B.102}$$

where

$$\Lambda_{t,t+z} = E_t \frac{u_C(C_{t+z})}{P_{t+z}} \frac{P_t}{u_C(C_t)} , \tag{B.103}$$

$$Y_{t+z}(i) = \left(\frac{p_t(i)}{P_{H,t+z}}\right)^{-\sigma} Y_{t+z} , \tag{B.104}$$

and

$$W_t = \frac{L_t^{\varphi}}{\xi_t C_t^{-\theta}} P_t\,. \tag{B.105}$$

Denoting by $p^o_{H,t+z} = p_t(i)/P_{H,t+z}$ the relative optimal price at time $t+z$ of a firm that last reoptimized its prices in period t, we can write the solution to the above problem on the following form:

$$p^o_{H,t} = \left(\frac{K_t}{F_t}\right)^{\frac{1}{1+\sigma\varphi}} , \tag{B.106}$$

where

$$K_t \equiv E_t \left\{\sum_{z=0}^{\infty} (\alpha\beta)^z k_{t,t+z}\right\} \tag{B.107}$$

$$F_t \equiv E_t \left\{\sum_{z=0}^{\infty} (\alpha\beta)^z f_{t,t+z}\right\} \tag{B.108}$$

and, introducing the notation $P_{t,t+z} \equiv P_{H,t}/P_{H,t+z}$,

$$k_{t,t+z} \equiv (1+\varphi)\, \mu_{t+z} P_{t,t+z}^{-\sigma(1+\varphi)} Y_{t+z}^{1+\varphi} X_{t+z}^{-(1+\varphi)} \tag{B.109}$$

$$f_{t,t+z} \equiv P_{t,t+z}^{1-\sigma} \xi_{t+z} C_{t+z}^{-\theta} Y_{t+z} T_{H,t+z}\,. \tag{B.110}$$

Proceeding as in Benigno and Woodford (2008), we can write the exact log-linear expression for $p^o_{H,t}$ as

$$(1+\sigma\varphi)\, \hat{p}^o_{H,t} = \hat{K}_t - \hat{F}_t\,. \tag{B.111}$$

A second-order expansion of F_t and K_t, next, yields,

$$\hat{F}_t + \frac{1}{2}\hat{F}_t^2 = (1-\alpha\beta)\, E_t \left\{\sum_{z=0}^{\infty} (\alpha\beta)^z \left(\hat{f}_{t,t+z} + \frac{1}{2}\hat{f}^2_{t,t+z}\right)\right\} + \mathcal{O}\left(||\zeta||^3\right) \tag{B.112}$$

$$\hat{K}_t + \frac{1}{2}\hat{K}_t^2 = (1-\alpha\beta)\, E_t \left\{\sum_{z=0}^{\infty} (\alpha\beta)^z \left(\hat{k}_{t,t+z} + \frac{1}{2}\hat{k}^2_{t,t+z}\right)\right\} + \mathcal{O}\left(||\zeta||^3\right) . \tag{B.113}$$

Plugging in (B.112) and (B.113) into (B.111), we have

$$\begin{aligned}(1+\sigma\varphi)\,\hat{p}^o_{H,t} &= (1-\alpha\beta)\,E_t\left\{\sum_{z=0}^{\infty}(\alpha\beta)^z\left(\hat{k}_{t,t+z}-\hat{f}_{t,t+z}\right)\right\}\\ &\quad+\frac{(1-\alpha\beta)}{2}E_t\left\{\sum_{z=0}^{\infty}(\alpha\beta)^z\left(\hat{k}_{t,t+z}-\hat{f}_{t,t+z}\right)\left(\hat{k}_{t,t+z}+\hat{f}_{t,t+z}\right)\right\}\\ &\quad+\frac{1}{2}\left(\hat{F}_t-\hat{K}_t\right)\left(\hat{F}_t+\hat{K}_t\right)+\mathcal{O}\left(||\zeta||^3\right). \end{aligned}\tag{B.114}$$

Note next that, in an exact log-linear form,

$$\hat{k}_{t,t+z} = \hat{\mu}_{t+z}-\sigma(1+\varphi)\,\hat{P}_{t,t+z}+(1+\varphi)\,\hat{Y}_{t+z}-(1+\varphi)\,\hat{X}_{t+z}\tag{B.115}$$

$$\hat{f}_{t,t+z} = (1-\sigma)\,\hat{P}_{t,t+z}+\hat{\xi}_{t+z}-\theta\hat{C}_{t+z}+\hat{Y}_{t+z}+\hat{T}_{H,t+z}\,,\tag{B.116}$$

and so

$$\begin{aligned}\hat{k}_{t,t+z}-\hat{f}_{t,t+z} &= -(1+\sigma\varphi)\,\hat{P}_{t,t+z}+\varphi\hat{Y}_{t+z}-(1+\varphi)\,\hat{X}_{t+z}\\ &\quad+\theta\hat{C}_{t+z}+\hat{\mu}_{t+z}-\hat{\xi}_{t+z}-\hat{T}_{H,t+z}\,,\end{aligned}\tag{B.117}$$

and

$$\begin{aligned}\hat{k}_{t,t+z}+\hat{f}_{t,t+z} &= (2+\varphi)\,\hat{Y}_{t+z}-(1+\varphi)\,\hat{X}_{t+z}+(1-2\sigma-\sigma\varphi)\,\hat{P}_{t,t+z}\\ &\quad-\theta\hat{C}_{t+z}+\hat{\mu}_{t+z}+\hat{\xi}_{t+z}+\hat{T}_{H,t+z}\\ &= \Upsilon_{t+z}+(1-2\sigma-\sigma\varphi)\,\hat{P}_{t,t+z}\,,\end{aligned}\tag{B.118}$$

where

$$\Upsilon_{t+z}\equiv(2+\varphi)\,\hat{Y}_{t+z}-(1+\varphi)\,\hat{X}_{t+z}-\theta\hat{C}_{t+z}+\hat{\mu}_{t+z}+\hat{\xi}_{t+z}+\hat{T}_{H,t+z}\,.\tag{B.119}$$

Substituting into (B.114) and rearranging, we arrive at

$$\begin{aligned}\frac{1+\sigma\varphi}{1-\alpha\beta}\hat{p}^o_{H,t} &= -\frac{1}{2}(1+\sigma\varphi)\,\hat{p}^o_{H,t}Z_t+E_t\left\{\sum_{z=0}^{\infty}(\alpha\beta)^z\left(\hat{k}_{t,t+z}-\hat{f}_{t,t+z}\right)\right\} \qquad \text{(B.120)}\\ &\quad+\frac{1}{2}E_t\left\{\sum_{z=0}^{\infty}(\alpha\beta)^z\left(\hat{k}_{t,t+z}-\hat{f}_{t,t+z}\right)\cdot\left[\Upsilon_{t+z}+(1-2\sigma-\sigma\varphi)\,\hat{P}_{t,t+z}\right]\right\}\\ &\quad+\mathcal{O}\left(||\zeta||^3\right),\end{aligned}$$

where

$$Z_t\equiv\sum_{z=0}^{\infty}(\alpha\beta)^z\left[\Upsilon_{t+z}+(1-2\sigma-\sigma\varphi)\,\hat{P}_{t,t+z}\right].\tag{B.121}$$

Defining

$$z_{t+z}\equiv\hat{k}_{t,t+z}-\hat{f}_{t,t+z}+(1+\sigma\varphi)\,\hat{P}_{t,t+z}\,,\tag{B.122}$$

and noting that $P_{t,t} \equiv P_{H,t}/P_{H,t} = 1$ and hence $\hat{P}_{t,t} = 0$, we can write (B.120) recursively as

$$\begin{aligned}
&\frac{1+\sigma\varphi}{1-\alpha\beta}\hat{p}^o_{H,t} = z_t + \alpha\beta\frac{1+\sigma\varphi}{1-\alpha\beta}\left(\hat{p}^o_{H,t+1} - \hat{P}_{t,t+1}\right) - \frac{1}{2}\left(1+\sigma\varphi\right)\hat{p}^o_{H,t}Z_t \\
&+ \frac{\alpha\beta}{2}\left(1+\sigma\varphi\right)\hat{p}^o_{H,t+1}Z_{t+1} + \frac{1}{2}z_t\Upsilon_t \qquad \text{(B.123)} \\
&+ \frac{\alpha\beta}{2}E_t\left\{\sum_{z=0}^{\infty}\left(\alpha\beta\right)^z\left[\left(1-2\sigma-\sigma\varphi\right)\left(1+\sigma\varphi\right)\left(-\hat{P}^2_{t,t+1} - 2\hat{P}_{t,t+1}\hat{P}_{t+1,t+1+z}\right)\right.\right. \\
&\left.\left.-\left(1+\sigma\varphi\right)\hat{P}_{t,t+1}\Upsilon_{t+1+z} + \left(1-2\sigma-\sigma\varphi\right)\hat{P}_{t,t+1}z_{t+1+z}\right]\right\} + \mathcal{O}\left(||\zeta||^3\right) .
\end{aligned}$$

The term in brackets in the last equation can be rewritten as

$$\begin{aligned}
&\frac{\alpha\beta}{2}E_t\left\{\sum_{z=0}^{\infty}\left(\alpha\beta\right)^z\hat{P}_{t,t+1}\cdot\right. \\
&\left.\left[\left(1-2\sigma-\sigma\varphi\right)\left[\left(1+\sigma\varphi\right)\left(-\hat{P}_{t,t+1} - \hat{P}_{t+1,t+1+z}\right) + z_{t+1+z}\right]\right]\right\} \\
&= \frac{\alpha\beta}{2}\frac{\left(1-2\sigma-\sigma\varphi\right)\left(1+\sigma\varphi\right)}{1-\alpha\beta}E_t\left\{\left(\hat{p}^o_{H,t+1} - \hat{P}_{t,t+1}\right)\hat{P}_{t,t+1}\right\} , \qquad \text{(B.124)}
\end{aligned}$$

which implies that

$$\begin{aligned}
\frac{1+\sigma\varphi}{1-\alpha\beta}\hat{p}^o_{H,t} \;=\; & z_t + \alpha\beta\frac{1+\sigma\varphi}{1-\alpha\beta}\left(\hat{p}^o_{H,t+1} - \hat{P}_{t,t+1}\right) + \frac{1}{2}z_t\Upsilon_t \qquad \text{(B.125)} \\
& -\frac{1}{2}\left(1+\sigma\varphi\right)\hat{p}^o_{H,t}Z_t + \frac{\alpha\beta}{2}\left(1+\sigma\varphi\right)E_t\left\{\left(\hat{p}^o_{H,t+1} - \hat{P}_{t,t+1}\right)Z_{t+1}\right\} \\
& +\frac{\alpha\beta}{2\left(1-\alpha\beta\right)}\left(1-2\sigma-\sigma\varphi\right)\left(1+\sigma\varphi\right)E_t\left\{\left(\hat{p}^o_{H,t+1} - \hat{P}_{t,t+1}\right)\hat{P}_{t,t+1}\right\} \\
& +\mathcal{O}\left(||\zeta||^3\right) .
\end{aligned}$$

We continue with taking a second-order expansion of the law of motion for the price index, as given in equation (24), which yields

$$\hat{p}^o_{H,t} \;=\; \frac{\alpha}{1-\alpha}\hat{\pi}_{H,t} - \frac{1}{2}\left(1-\sigma\right)\frac{\alpha}{\left(1-\alpha\right)^2}\hat{\pi}^2_{H,t} + \mathcal{O}\left(||\zeta||^3\right) . \qquad \text{(B.126)}$$

Inserting (B.126) into (B.125), and using that $\hat{P}_{t,t+1} = -\hat{\pi}_{H,t+1}$, we have

$$\begin{aligned}
\hat{\pi}_{H,t} \;=\; & \frac{1-\sigma}{2}\frac{1}{1-\alpha}\hat{\pi}^2_{H,t} + \kappa z_t + \beta\hat{\pi}_{H,t+1} - \frac{1-\sigma}{2}\frac{\alpha\beta}{1-\alpha}E_t\left\{\hat{\pi}^2_{H,t+1}\right\} \\
& +\frac{1}{2}\kappa z_t\Upsilon_t - \frac{1}{2}\left(1-\alpha\beta\right)\hat{\pi}_{H,t}Z_t + \frac{\beta}{2}\left(1-\alpha\beta\right)E_t\left\{\hat{\pi}_{H,t+1}Z_{t+1}\right\} \qquad \text{(B.127)} \\
& -\frac{\beta}{2}\left(1-2\sigma-\sigma\varphi\right)E_t\left\{\hat{\pi}^2_{H,t+1}\right\} + \mathcal{O}\left(||\zeta||^3\right) ,
\end{aligned}$$

where we have defined

$$\kappa \equiv \frac{\left(1-\alpha\right)\left(1-\alpha\beta\right)}{\alpha\left(1+\sigma\varphi\right)} .$$

Integrating equation (B.127) forward from $t = t_0$ and rearranging, we can write the above sum as

$$
\begin{aligned}
V_{t_0} \quad = \quad & E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} z_t + \frac{1}{2} E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} z_t \Upsilon_t \\
& + \frac{\sigma(1+\varphi)}{2\kappa} E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \hat{\pi}_{H,t}^2 + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) \ ,
\end{aligned}
\tag{B.128}
$$

where

$$
V_{t_0} \equiv \kappa^{-1} \left[\hat{\pi}_{H,t_0} - \frac{1-\sigma}{2(1-\alpha)} \hat{\pi}_{H,t_0}^2 + \frac{1}{2}(1-\alpha\beta) \hat{\pi}_{H,t_0} Z_{t_0} + \frac{\sigma(1+\varphi)}{2} \hat{\pi}_{H,t_0}^2 \right] , \tag{B.129}
$$

and

$$
Z_t \quad = \quad \Upsilon_t + \frac{\alpha\beta}{1-\alpha\beta}(1 - 2\sigma - \sigma\varphi) \pi_{H,t+1} + \alpha\beta E_t Z_{t+1} \, . \tag{B.130}
$$

Substituting back in z_t and Υ_t, we can finally write

$$
\begin{aligned}
V_{t_0} \quad = \quad & E_{t_0} \left\{ \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[\varphi \hat{Y}_t + \theta \hat{C}_t - \hat{T}_{H,t} - (1+\varphi) \hat{X}_t + \hat{\mu}_t - \hat{\xi}_t + \frac{1}{2} \varphi (2+\varphi) \hat{Y}_t^2 \right. \right. \\
& \qquad - \frac{1}{2} \theta^2 \hat{C}_t^2 - \frac{1}{2} \hat{T}_{H,t}^2 + \theta \hat{Y}_t \hat{C}_t - \hat{Y}_t \hat{T}_{H,t} + \theta \hat{C}_t \hat{T}_{H,t} \\
& \qquad \left. \left. - (1+\varphi)^2 \hat{Y}_t \hat{X}_t + (1+\varphi) \hat{Y}_t \hat{\mu}_t - \hat{Y}_t \hat{\xi}_t + \theta \hat{C}_t \hat{\xi}_t - \hat{\xi}_t \hat{T}_{H,t} \right] \right\} \\
& + \frac{\sigma(1+\varphi)}{2\kappa} E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \hat{\pi}_{H,t}^2 + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) \, .
\end{aligned}
\tag{B.131}
$$

Using vector-matrix notation,

$$
\begin{aligned}
V_{t_0} \quad = \quad & E_{t_0} \left\{ \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[f_x' x_t + \frac{1}{2} x_t' F_x x_t + x_t' F_\zeta \zeta_t + \frac{1}{2} f_{\pi_H} \pi_{H,t}^2 \right] \right\} \\
& + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) \ ,
\end{aligned}
\tag{B.132}
$$

where

$$
f_x' = \begin{bmatrix} \varphi & \theta & -1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} ,
$$

$$
F_x = \begin{bmatrix}
\varphi(2+\varphi) & \theta & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\theta & -\theta^2 & \theta & 0 & 0 & 0 & 0 & 0 & 0 \\
-1 & \theta & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix} ,
$$

$$F_{\zeta}=\begin{bmatrix}-(1+\varphi)^{2} & -1 & (1+\varphi) & 0 & 0 & 0\\ 0 & \theta & 0 & 0 & 0 & 0\\ 0 & -1 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix},$$

and

$$f_{\pi_H}=\sigma(1+\varphi)\kappa^{-1}.$$

For the *Foreign* economy, we instead have

$$\begin{aligned}V^{*}_{t_0} &= E_{t_0}\left\{\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left[\varphi\hat{Y}^{*}_{t}+\theta\hat{C}^{*}_{t}-\hat{T}^{*}_{F,t}-(1+\varphi)\hat{X}^{*}_{t}+\hat{\mu}^{*}_{t}-\hat{\xi}^{*}_{t}+\frac{1}{2}\varphi(2+\varphi)\left(\hat{Y}^{*}_{t}\right)^{2}\right.\right.\\ &\qquad -\frac{1}{2}\theta^{2}\left(\hat{C}^{*}_{t}\right)^{2}-\frac{1}{2}\left(\hat{T}^{*}_{F,t}\right)^{2}+\theta\hat{Y}^{*}_{t}\hat{C}^{*}_{t}-\hat{Y}^{*}_{t}\hat{T}^{*}_{F,t}+\theta\hat{C}^{*}_{t}\hat{T}^{*}_{F,t}\\ &\qquad \left.\left.-(1+\varphi)^{2}\hat{Y}^{*}_{t}\hat{X}^{*}_{t}+(1+\varphi)\hat{Y}^{*}_{t}\hat{\mu}^{*}_{t}-\hat{Y}^{*}_{t}\hat{\xi}^{*}_{t}+\theta\hat{C}^{*}_{t}\hat{\xi}^{*}_{t}-\hat{\xi}^{*}_{t}\hat{T}^{*}_{F,t}\right]\right\}\\ &\quad +\frac{\sigma(1+\varphi)}{2\kappa}E_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left(\hat{\pi}^{*}_{F,t}\right)^{2}+t.i.p.+\mathcal{O}\left(||\zeta||^{3}\right), \end{aligned} \tag{B.133}$$

where

$$\begin{aligned}V^{*}_{t_0} &\equiv \kappa^{-1}\left[\hat{\pi}^{*}_{F,t_0}-\frac{1-\sigma}{2(1-\alpha)}\left(\hat{\pi}^{*}_{F,t_0}\right)^{2}\right.\\ &\qquad \left.+\frac{1}{2}(1-\alpha\beta)\hat{\pi}^{*}_{F,t_0}Z^{*}_{t_0}+\frac{\sigma(1+\varphi)}{2}\left(\hat{\pi}^{*}_{F,t_0}\right)^{2}\right],\end{aligned} \tag{B.134}$$

and

$$\begin{aligned}Z^{*}_{t} &= (2+\varphi)\hat{Y}^{*}_{t}-(1+\varphi)\hat{X}^{*}_{t}-\theta\hat{C}^{*}_{t}+\hat{\mu}^{*}_{t}+\hat{\xi}^{*}_{t}\\ &\quad +\hat{T}^{*}_{F,t}+\frac{\alpha\beta}{1-\alpha\beta}(1-2\sigma-\sigma\varphi)\pi^{*}_{F,t+1}+\alpha\beta E_{t}Z^{*}_{t+1}.\end{aligned} \tag{B.135}$$

Rewriting in vector-matrix form,

$$\begin{aligned}V^{*}_{t_0} &= E_{t_0}\left\{\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left[f^{*\prime}_{x}x_t+\frac{1}{2}x'_tF^{*}_{x}x_t+x'_tF^{*}_{\zeta}\zeta_t+\frac{1}{2}f^{*}_{\pi_F}\left(\pi^{*}_{F,t}\right)^{2}\right]\right\}\\ &\quad +t.i.p.+\mathcal{O}\left(||\zeta||^{3}\right),\end{aligned} \tag{B.136}$$

where

$$f^{*\prime}_{x}=\begin{bmatrix}0 & 0 & 0 & 0 & \varphi & \theta & -1 & 0 & 0\end{bmatrix},$$

$$F_x^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \varphi(2+\varphi) & \theta & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & \theta & -\theta^2 & \theta & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & \theta & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$F_\zeta^* = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -(1+\varphi)^2 & -1 & (1+\varphi) \\ 0 & 0 & 0 & 0 & \theta & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

and

$$f_{\pi_F}^* = \sigma(1+\varphi)\kappa^{-1}.$$

B.7 Deriving the loss function

Given the functions (B.74) and (B.76) and the second-order approximations of the variables entering vector x_t, we can derive a welfare function for each of the two countries. To that end, we need to eliminate the linear terms from the welfare functions using an appropriate linear combination of the second-order approximations to the constraints. Explicitly, we need to solve

$$\Phi\Upsilon = z_x \tag{B.137}$$

and

$$\Phi\Upsilon^* = z_x^* \tag{B.138}$$

for Υ and Υ^*, respectively, where we have collected the linear terms from the constraints in the (9×9) matrix

$$\Phi \equiv \begin{bmatrix} f_x & m_x & b_x & n_x & f_x^* & m_x^* & b_x^* & n_x^* & a_x \end{bmatrix}. \tag{B.139}$$

Since z_x and z_x^* are given by the following (9×1) vectors,

$$z_x' = \begin{bmatrix} -\bar{\mu}^{-1} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.140}$$
$$z_x^{*\prime} = \begin{bmatrix} 0 & 0 & 0 & 0 & -\bar{\mu}^{-1} & 1 & 0 & 0 & 0 \end{bmatrix}, \tag{B.141}$$

we know that Υ and Υ^* must be (9×1) vectors as well. They can be computed by pre-multiplying both sides of (B.137) and (B.138) by the inverse of Φ as follows,

$$\Phi^{-1}\Phi\Upsilon = \Phi^{-1}z_x \Leftrightarrow \Upsilon = \Phi^{-1}z_x \tag{B.142}$$
$$\Phi^{-1}\Phi\Upsilon^* = \Phi^{-1}z_x^* \Leftrightarrow \Upsilon^* = \Phi^{-1}z_x^*, \tag{B.143}$$

where the second equality on each row makes use of the fact that $\Phi^{-1}\Phi = I$.[26]

Having solved for Υ and Υ^*, we can proceed to deriving the final loss function, i.e. the negative of the welfare function, containing only quadratic terms. The loss function of *Home* is then given by

$$\begin{aligned} \mathbb{L} \;&=\; u_C\left(\bar{C}\right)\bar{C}E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[\frac{1}{2}x_t'\mathbb{L}_x x_t + x_t'\mathbb{L}_\zeta\zeta_t + \frac{1}{2}l_{\pi_H}\pi_{H,t}^2\right]\right\} \\ &\quad + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) , \end{aligned} \tag{B.144}$$

where

$$\mathbb{L}_x = Z_x + \Upsilon_1 F_x + \Upsilon_2 M_x + \Upsilon_3 B_x + \Upsilon_4 N_x + \Upsilon_5 F_x^* + \Upsilon_6 M_x^* + \Upsilon_7 B_x^* + \Upsilon_8 N_x^* ,$$

$$\mathbb{L}_\zeta = Z_\zeta + \Upsilon_1 F_\zeta + \Upsilon_5 F_\zeta^* ,$$

$$l_{\pi_H} = z_{\pi_H} + \Upsilon_1 f_{\pi_H} ,$$

and where a subscript on Υ denotes the index of its rows, so that Υ_1 denotes the first row of Υ, Υ_2 the second, etc. Similarly, the loss function of *Foreign* is given by

$$\begin{aligned} \mathbb{L}^* \;&=\; u_C\left(\bar{C}\right)\bar{C}E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[\frac{1}{2}x_t'\mathbb{L}_x^* x_t + x_t'\mathbb{L}_\zeta^*\zeta_t + \frac{1}{2}l_{\pi_F}^*\left(\pi_{F,t}^*\right)^2\right]\right\} \\ &\quad + t.i.p. + \mathcal{O}\left(||\zeta||^3\right) , \end{aligned} \tag{B.145}$$

where

$$\mathbb{L}_x^* = Z_x^* + \Upsilon_1^* F_x + \Upsilon_2^* M_x + \Upsilon_3^* B_x + \Upsilon_4^* N_x + \Upsilon_5^* F_x^* + \Upsilon_6^* M_x^* + \Upsilon_7^* B_x^* + \Upsilon_8^* N_x^* ,$$

$$\mathbb{L}_\zeta^* = Z_\zeta^* + \Upsilon_1^* F_\zeta + \Upsilon_5^* F_\zeta^* ,$$

and

$$l_{\pi_F}^* = z_{\pi_F}^* + \Upsilon_5^* f_{\pi_F}^* .$$

The final objective function for the monetary authorities is then defined as

$$\mathbb{L}^W \equiv -\mathbb{W}^W = \frac{1}{2}\mathbb{L} + \frac{1}{2}\mathbb{L}^* , \tag{B.146}$$

with $\mathbb{L}$ and $\mathbb{L}^*$given by expressions (B.144) and (B.145) above.

[26]Due to the size of the matrix Φ, I refrain from computing its inverse analytically and evaluate it symbolically instead. For the same reason, I also present the solution only in vector-matrix form.

C Appendix: Impulse responses to monetary-policy and markup shocks

In this appendix, we briefly discuss the shocks to monetary policy and the price markup. These are displayed and discussed in the same order as the technology and consumption preference shocks presented in the main text. The solid lines are the responses from the benchmark, dynamic demand model, and the dotted lines are the responses from the standard DSGE model plotted for comparison. Moreover, in Figures C.4 and C.5, where the responses generated with both the classical Taylor rule and with optimal monetary policy are presented in the same graphs, the thinner lines correspond to the Taylor rule, while the thicker ones correspond to optimal monetary policy.

We begin by focusing on the impulse responses to *Home* shocks under the Taylor rule, presented in Figures C.1–C.2. Just as in the cases of technology and consumption preference shocks, we here see that the responses of production and, in particular, net exports are less pronounced in the dynamic demand model than in the comparison model, while the responses of exchange rates are somewhat magnified. This can be explained using the same reasoning as for the shocks discussed in the main text: as the international substitution effect is now reduced in the short run, implying an initially weaker response in quantities, the required change in the international relative prices is relatively larger. Note, further, that the effects of the non-persistent monetary policy and markup shocks are much more long-lived in the dynamic demand model than in the standard DSGE model. The immediate response to the shock is muted in the dynamic demand model, due to the presence of the additional short-term rigidity. Any deviation from the steady state that does occur, will however take longer to peter out. While the effect in the standard DSGE model disappears instantly with the shock, in the dynamic demand model it can take up to 12 periods before the effects on exchange rates and output have died out entirely.

Moving on to the markup shock under optimal monetary policy, presented in Figure C.3, we find that the responses following the shock are all quite small. With the tradeoff between inflation and output gap stabilization present in both models, the output gap deviation is somewhat larger in the standard DSGE model than in the model with dynamic demand. The responses of the exchange rates and the terms of trade, as well as the under optimal policy required change in the interest rate, are however much stronger in the presence of habits, just as for the two other shocks discussed in the main text.[27]

[27] Note that, since monetary policy is assumed to be conducted in an optimal way at all times, the shock to the interest rate is irrelevant in this setting.

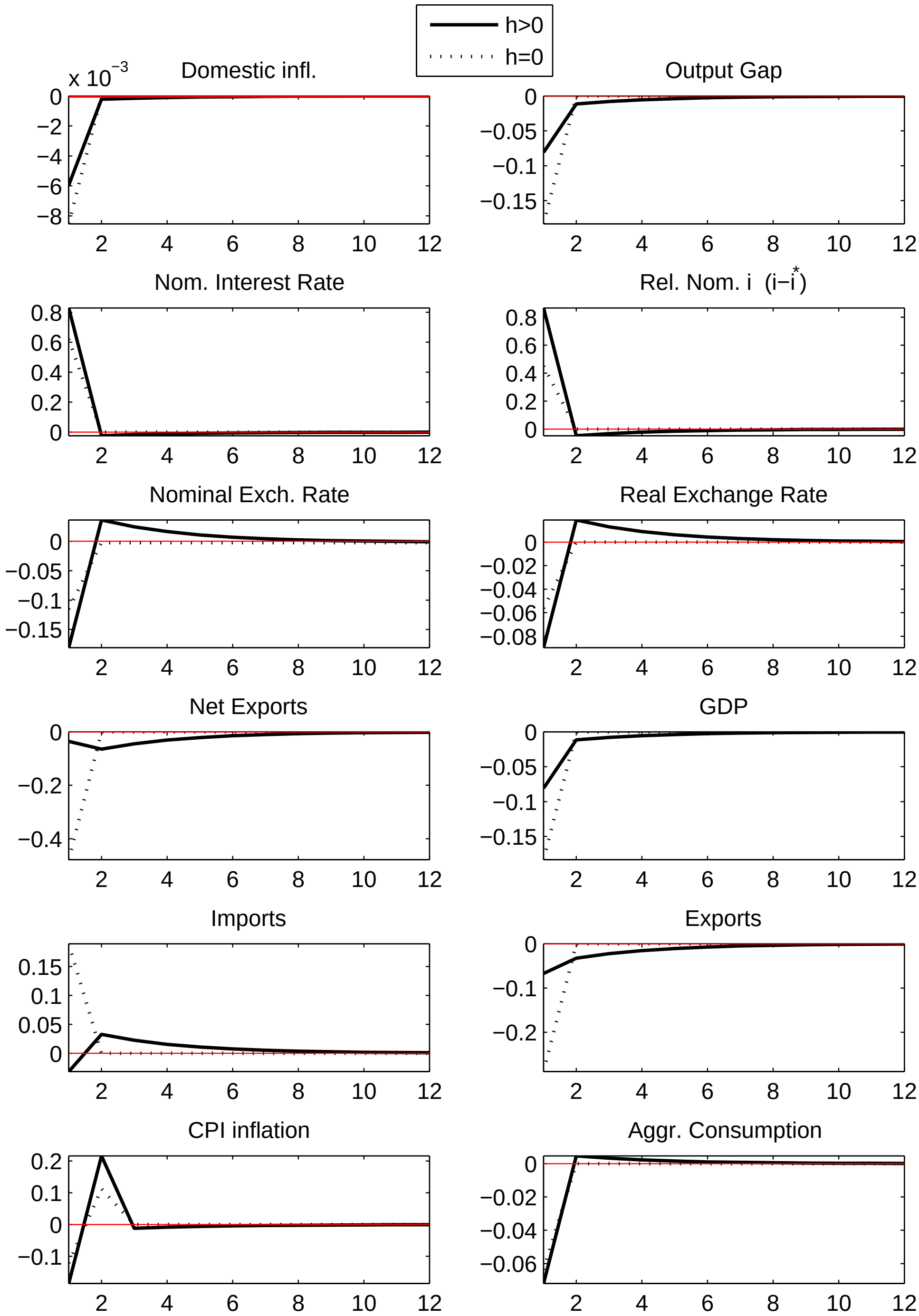

Figure C.1: Impulse responses to a contractionary shock to *Home* monetary policy under the classical Taylor rule

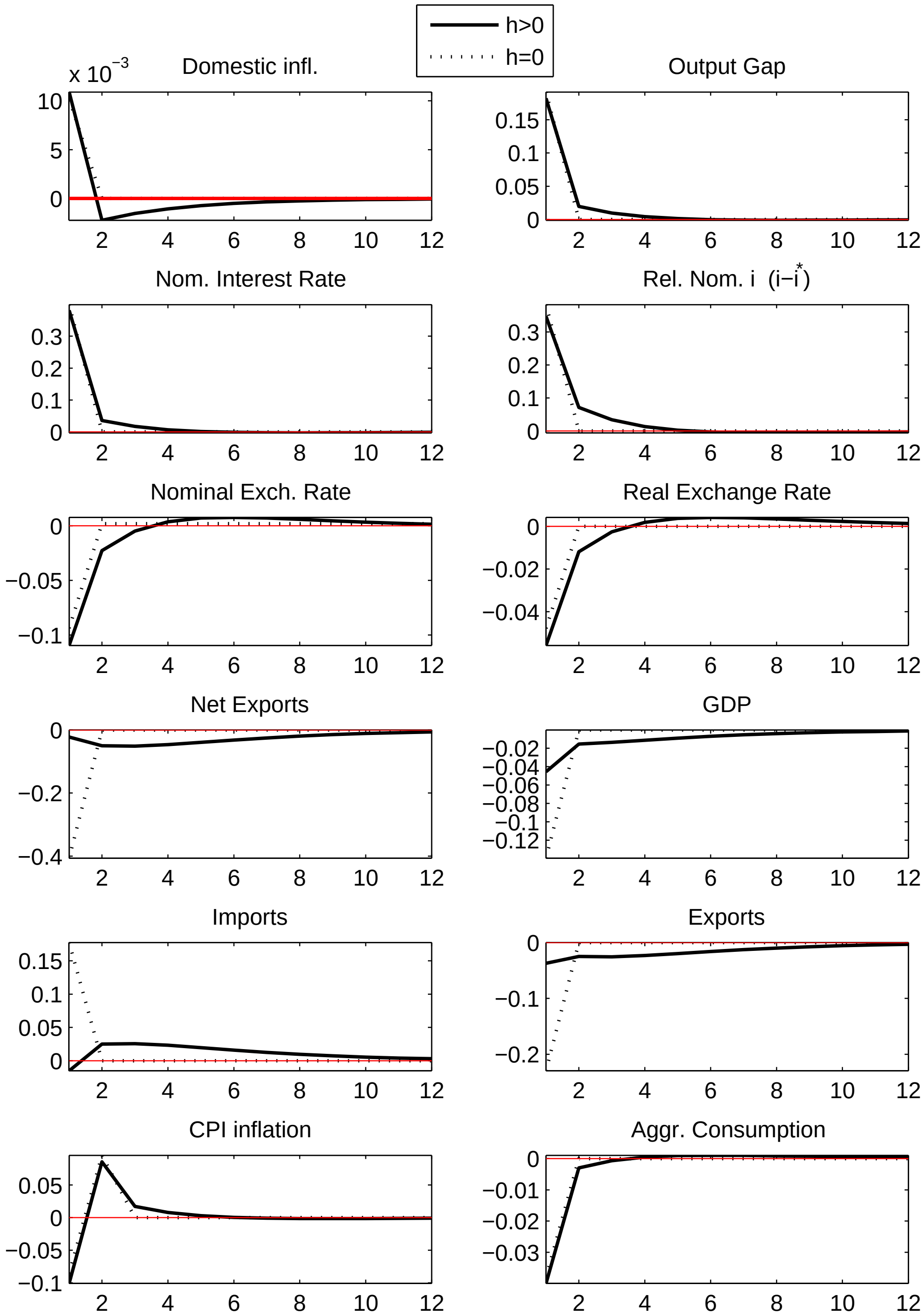

Figure C.2: Impulse responses to a unit shock to the *Home* price markup under the classical Taylor rule

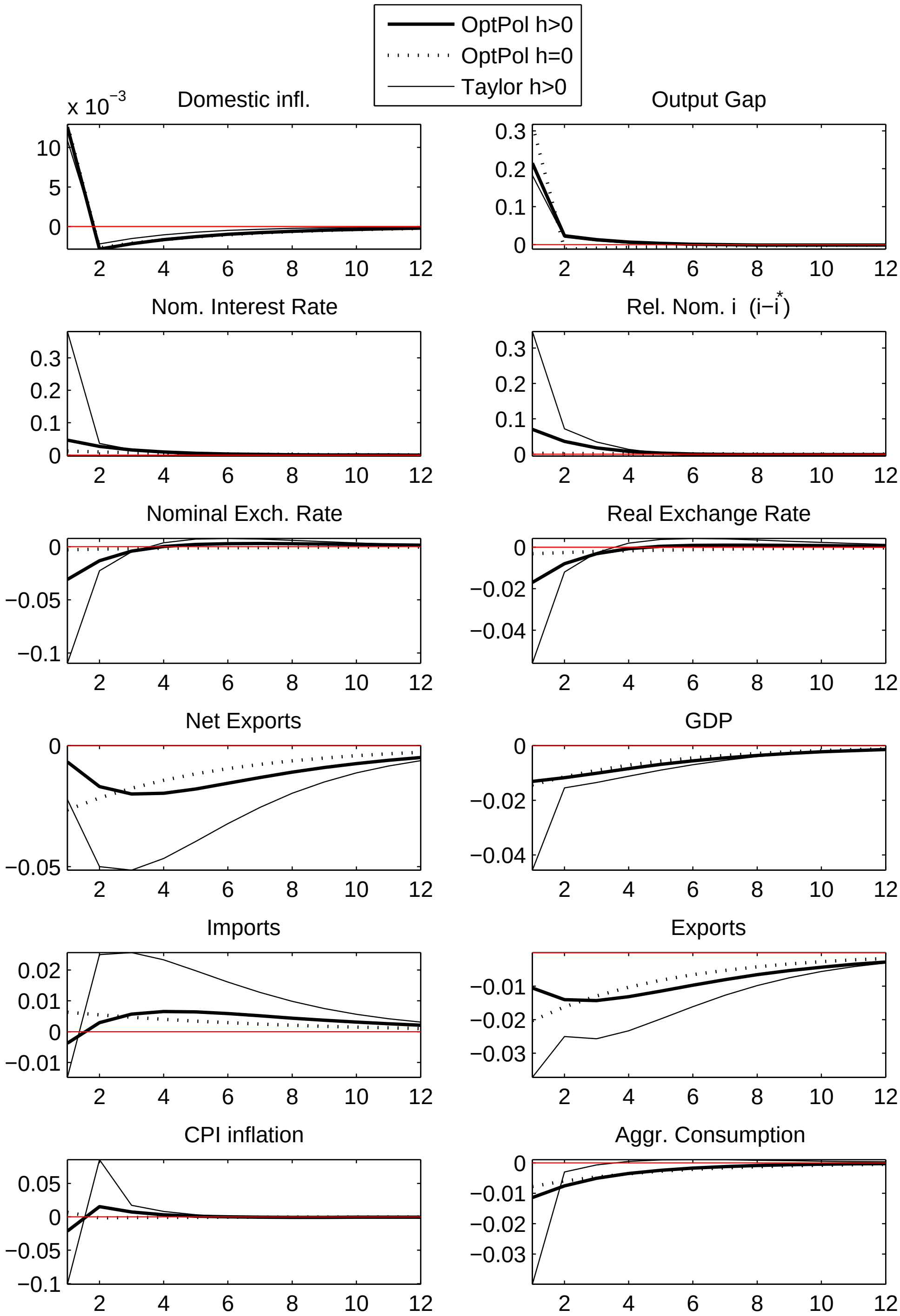

Figure C.3: Impulse responses to a unit shock to the Home price markup under optimal monetary policy

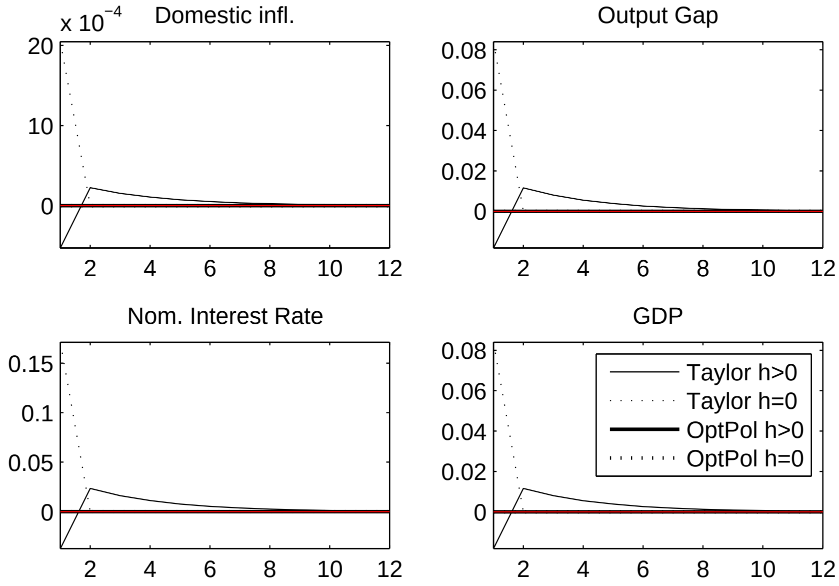

Figure C.4: Impulse responses to a contractionary shock to *Foreign* monetary policy

Finally, the spillover effects of the shocks to the *Foreign* interest rate and markup are presented in Figures C.4–C.5 and briefly discussed here. Focusing first on the solution with the Taylor rule, we see that the shock to the *Foreign* interest rate, has initially less pronounced but longer lasting spillover effects in the presence of dynamic demand. Moreover, the initial responses of all of the plotted variables have been reversed. This is due to the fact that very little substitution takes place immediately after the shock, making the income effect dominate and hence lowering consumption for both types of goods. Some substitution towards the cheaper *Home* good does occur, nevertheless, tilting relative demand towards *Home*. When the effect of shock disappears after one quarter, with habits present, the change in relative demand is not immediately reverted, causing the demand for *Home* goods to stay above steady state for approximately 8 quarters instead of 1. That the responses are prolonged applies to the markup shock as well, the effect of which on inflation and output lasts for approximately 12 quarters. The initial responses are again muted relative to the standard DSGE model.

Turning our attention to the responses under optimal monetary policy, we note that the price markup shock turns out to have smaller spillover effects, calling for a less aggressive monetary policy reaction in the presence of dynamic demand, although the responses to this shock remain small in both models. The short-lived rise in the *Foreign* markup leaves total demand largely unaffected, creating only a small increase in demand of the more expensive *Foreign* good. As discussed above, in relation to the responses generated from models containing a Taylor rule, whatever the size of the distortions in the model with dynamic demand, they will take longer to restore – independently of the assumptions made on monetary policy.

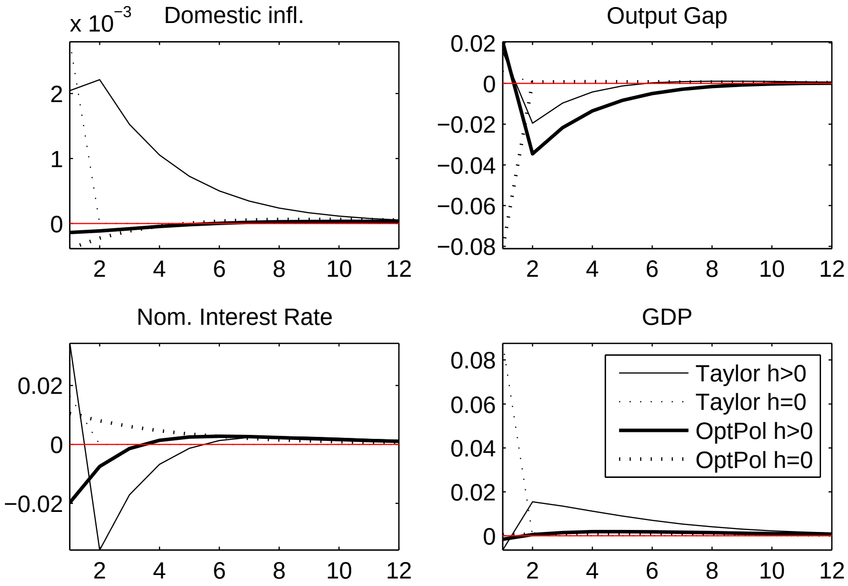

Figure C.5: Impulse responses to a unit shock to the *Foreign* price markup

D Appendix: Sensitivity analysis

Table D.1: Persistence, correlations and volatility of selected variables in the dynamic demand model, varying the calibration

	Base-line	**Habit formation**		**Risk aversion**		**Openness**	
		$h = 0.8$	$h = 0.95$	$\theta = 1$	$\theta = 3$	$\nu = 0.2$	$\nu = 0.3$
Autocorrelations							
$autocorr(Y)$	0.80	0.81	0.77	0.75	0.84	0.79	0.81
$autocorr(C)$	0.68	0.67	0.68	0.67	0.68	0.67	0.68
$autocorr(Q)$	0.63	0.56	0.68	0.62	0.64	0.64	0.63
$autocorr(\Delta S)$	-0.12	-0.17	-0.11	-0.14	-0.12	-0.13	-0.12
$autocorr(TT)$	0.63	0.56	0.68	0.62	0.64	0.64	0.63
$autocorr(R)$	0.26	0.22	0.24	0.24	0.27	0.25	0.27
$autocorr(IM)$	0.88	0.88	0.85	0.82	0.91	0.89	0.87
$autocorr(EX)$	0.88	0.88	0.84	0.81	0.91	0.89	0.87
Correlations							
$corr(Y, NX)$	0.67	0.78	0.46	0.40	0.80	0.63	0.70
$corr(Y, EX)$	0.90	0.94	0.83	0.81	0.94	0.86	0.94
$corr(Y, IM)$	-0.29	-0.50	0.08	0.19	-0.56	-0.27	-0.29
$corr(IM, EX)$	-0.57	-0.71	-0.30	-0.20	-0.76	-0.63	-0.51
$corr(C, Q)$	0.35	0.28	0.41	0.41	0.34	0.42	0.29
Correlations							
$corr(Y, Y^*)$	-0.12	-0.33	0.20	0.23	-0.40	-0.08	-0.15
$corr(C, C^*)$	0.61	0.70	0.53	0.46	0.65	0.52	0.70
Volatility							
$std(C)/std(Y)$	0.74	0.63	0.89	0.92	0.61	0.78	0.71
$std(Q)/std(Y)$	1.10	0.75	1.52	0.81	1.27	1.38	0.85
$std(\Delta S)/std(Y)$	1.86	1.40	2.39	1.40	2.15	1.93	1.81
$std(TT)/std(Y)$	2.20	1.51	3.04	1.63	2.55	2.29	2.12
$std(R)/std(Y)$	0.39	0.33	0.45	0.27	0.46	0.39	0.40
$std(IM)/std(Y)$	1.44	1.53	1.32	1.24	1.60	1.60	1.32
$std(EX)/std(Y)$	1.43	1.53	1.31	1.23	1.59	1.59	1.31

Note: The results are based on simulations of the model with habit formation, changing one parameter at a time while keeping all other parameters fixed. The header in the six rightmost columns displays the calibration change compared to the baseline calibration. We maintain the assumption of symmetry across countries, and so each change in calibration is done equally for both *Home* and *Foreign*.

Table D.2: Persistence, correlations and volatility of selected variables in the dynamic demand model and the model with import adjustment costs

	Dynamic demand		**Import adj. costs**		**Standard DSGE**	**Data**		
	$h = 0.9$	$h = 0.95$	$\phi_M = 2$	$\phi_M = 5$	$h = 0$	*Sweden*	*UK*	*US*
Autocorrelations								
$autocorr(Y)$	0.80	0.77	0.82	0.76	0.67	0.86	0.89	0.88
$autocorr(C)$	0.67	0.68	0.60	0.61	0.68	0.77	0.84	0.91
$autocorr(Q)$	0.63	0.68	0.49	0.58	0.66	0.75	0.85	0.72
$autocorr(\Delta S)$	-0.12	-0.11	-0.04	0.09	-0.14	0.23	0.31	0.18
$autocorr(TT)$	0.63	0.68	0.55	0.58	0.66	0.63	0.85	0.75
$autocorr(R)$	0.25	0.24	0.20	0.23	0.18	0.87	0.86	0.91
$autocorr(IM)$	0.88	0.85	0.87	0.83	0.66	0.84	0.76	0.87
$autocorr(EX)$	0.88	0.84	0.87	0.82	0.66	0.97	0.70	0.85
Correlations								
$corr(Y, NX)$	0.67	0.46	0.81	0.83	0.88	-0.26	-0.26	-0.20
$corr(Y, EX)$	0.90	0.83	0.95	0.95	0.97	0.90	0.58	0.81
$corr(Y, IM)$	-0.29	0.08	-0.57	-0.60	-0.73	0.85	0.68	0.92
$corr(IM, EX)$	-0.57	-0.30	-0.76	-0.76	-0.86	0.94	0.88	0.83
$corr(C, Q)$	0.35	0.41	0.65	0.86	0.19	-0.12	0.53	-0.20
Correlations								
$corr(Y, Y^*)$	-0.12	0.20	-0.39	-0.50	-0.60	0.86^{US}	0.81^{SE}	0.87^{UK}
$corr(C, C^*)$	0.61	0.53	0.06	-0.52	0.79	0.82^{US}	0.82^{SE}	0.74^{UK}
Volatility								
$std(C)/std(Y)$	0.74	0.59	0.76	1.03	0.47	0.65	0.86	0.80
$std(Q)/std(Y)$	1.10	1.52	2.00	3.58	0.38	2.14	3.37	2.37
$std(\Delta S)/std(Y)$	1.86	2.39	1.58	2.40	0.62	1.41	1.81	1.83
$std(TT)/std(Y)$	2.20	3.04	1.67	2.70	0.76	1.19	2.21	2.28
$std(R)/std(Y)$	0.39	0.45	0.41	0.93	0.19	0.54	0.67	0.87
$std(IM)/std(Y)$	1.44	1.32	1.58	1.45	1.68	2.66	3.04	3.59
$std(EX)/std(Y)$	1.43	1.31	1.58	1.45	1.68	2.25	3.07	3.43

Note: The results in the third and fourth numerical columns are based on simulations of the model with import adjustment costs as given in footnote 19 in the main text. The parameter ϕ_M is calibrated to the same value for both the *Home* and the *Foreign* economy, maintaining again the assumption of symmetry across countries.

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