Journal of International Money and Finance 72 (2017) 1–27

Contents lists available at ScienceDirect

Journal of International Money and Finance

journal homepage: www.elsevier.com/locate/jimf

Inattentive consumers and international business cycles

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ARTICLE INFO

Article history:
Available online 15 November 2016

JEL Classification:
F31
F41

Keywords:
Sticky information
Exchange rate volatility
Backus–Smith puzzle
Backus–Smith correlation

ABSTRACT

This paper presents and studies the properties of a sticky information exchange rate model where consumers and producers update their information sets infrequently. Introducing inattentive consumers has important implications. Through a mechanism resembling the limited participation models, exchange rate volatility observed in the data can be addressed for reasonable values of risk aversion. The model generates more persistence in output, consumption and employment which brings us closer to the data. Impulse responses to monetary shocks are hump shaped, consistent with the empirical evidence. Forecast errors of inattentive consumers provide a channel to reduce the correlation of relative consumption and real exchange rate. The decline in the correlation is quantitatively small for our benchmark model. Model generates a substantial amount of consumer forecast errors when producers are attentive and productivity shocks are persistent. This specification results in a large decline of the correlation of real exchange rate and relative consumption due to consumer inattentiveness. When trade elasticity is set to values at the low end of macro estimates or at higher values consistent with sectoral estimates, the correlation is in the negative territory with inattentive consumers.

1. Introduction

International cyclical fluctuations exhibit two distinctive features. First, empirical evidence indicates that nominal and real exchange rates have been excessively volatile relative to major economic

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http://dx.doi.org/10.1016/j.jimonfin.2016.11.003
0261-5606/

aggregates during the post-Bretton Woods period.[1] Second, the correlation between the real exchange rate and relative consumption is low or negative. These facts are hard to reconcile with standard macroeconomic theory. This paper presents a two country model with the assumption of infrequent information updating for consumers and producers. We show that sticky information on the consumer side provides a new mechanism to generate volatile exchange rates and to explain the correlation of real exchange rates and relative consumption.

Most common approach in the literature to address the exchange rate volatility is proposed by Chari et al. (2002). They exploit the positive and strict link between the ratio of marginal utilities of consumption and the real exchange rate that characterizes economies with complete markets. If risk aversion is sufficiently high, the variability of the ratio of home to foreign consumption observed in the data can correspond to large equilibrium movements in the real exchange rate. Corsetti et al. (2008a) label this strategy as "Risk Aversion Approach". However, the necessary amount of risk aversion required to address real exchange rate volatility is on the high end of business cycle calibrations.[2]

Theoretical models produce large and positive correlations between the real exchange rate and relative consumption, as the real exchange rate is tightly linked to the ratio of marginal utilities of consumption. Standard theory implies that consumption is higher wherever it is cheaper, in stark contrast with the data.[3] Real exchange rates in the data appreciate when domestic consumption is higher than foreign consumption, leading to a low and often negative correlation between real exchange rates and relative consumption. Therefore, consumption is higher where it is more expensive. This anomaly is known as Backus–Smith puzzle, and the correlation is referred to as Backus–Smith correlation.

This paper proposes a new approach to address these anomalies. We present and study the properties of a sticky information exchange rate model where consumers and producers update their information sets infrequently.[4] In our model economy, real exchange rate is linked to the marginal utilities of representative consumers when the consumers update their information sets each period. This relation is a result of the no-arbitrage condition between domestic and foreign currency bonds. When we introduce inattentive consumers to the model, real exchange rate is linked to marginal utilities of the subset of consumers who updated their information set. These agents are active participants of the bond market as they can re-optimize their consumption plans due to the arrival of new information.

Intuitively, when we consider a shock which alters the supply side in this economy, consumption plans of agents who did not receive an information update remain unchanged. The goods market is cleared by the demand response of adjusting consumers. As the probability of receiving an information update decreases, fraction of consumers who would respond to the current shocks will become lower and magnitude of the demand response for market clearing relative to the size of supply shock needs to increase. This is the key mechanism which generates the real exchange rate volatility. We observe that consumption of adjusting consumers is more volatile than aggregate consumption, and gets more volatile as we decrease the frequency of information updating for consumers. Since real

[1] We use data for the U.S. dollar and a synthetic aggregate of the Euro-zone to quantify exchange rate volatility. Similar patterns have been consistently uncovered between the US and other major OECD countries. See Chari et al. (2002).

[2] Chari et al. (2002) set the degree of risk aversion as 5, which corresponds to an elasticity of intertemporal substitution (EIS) of 0.2. Guvenen (2006) provides a comprehensive discussion on estimates of EIS, and the implications of EIS for real interest rates and consumption. Following a simple calculation through the Euler equation, a lower bound for the real interest rate can be calculated as the product of risk aversion and the growth rate of consumption. In the U.S. data, annual growth rate of consumption is around 2 percent. If risk aversion is set to 5, this implies a 10 percent lower bound for the annual real interest rate. This result is known as the "Risk-free Rate Puzzle". Furthermore, an upper bound for risk aversion is critical for calculations regarding the welfare costs of business cycles. By using consumption data, Lucas (2003) calculates an upper bound for risk aversion as 2.5.

[3] See Backus and Smith (1993) and Chari et al. (2002).

[4] Microfoundations of sticky information models rely on the *inattentiveness* framework proposed by Reis (2006a) and Reis (2006b). Agents are subject to an information processing and updating cost; therefore they optimally choose the duration between the updates in this setup. Once they update their information set, they learn all shocks and all variables up to that date. Sticky information models assume that information updating is exogenous. Micro evidence of inattentiveness is based on the data reported in public and professional forecaster surveys. Carroll (2003) shows that public expectations follow the forecasters' expectations with a lag. Mankiw et al. (2004) report that cross-section volatility of expectations is higher when the economy is hit by a large shock, consistent with inattentiveness.

exchange rate is determined by marginal utilities of adjusting consumers at each period, we observe higher volatility in real exchange rates. As a result, with an average information updating duration of 4 quarters, real exchange rates generated by the model are as volatile as in the data for a risk aversion[5] of 2.

Working on a set of models where we have producer side frictions[6] and assuming that consumers update their information set every period, we observe that the sticky information model is virtually identical to the sticky price model. Introducing inattentiveness to the consumer side brings the model in line with the data by (i) increasing the volatility of exchange rates, (ii) generating hump-shaped impulse responses[7] for quantities to a monetary shock, therefore increasing persistence and (iii) reducing the correlation between relative consumption and real exchange rates.

There have been numerous attempts in the literature to address Backus–Smith puzzle. An immediate solution seems to be moving away from efficiency in financial markets. Nevertheless, Chari et al. (2002) show that market-incompleteness alone is not sufficient to break the tight link between relative consumption and real exchange rates. Benigno and Thoenissen (2008) and Corsetti et al. (2008b) are prominent examples of studies[8] which attempt to explain the puzzle.

Models presented in Benigno and Thoenissen (2008) and Corsetti et al. (2008b) feature two sector models with non-tradable goods.[9] Asset market incompleteness plays a key role to generate strong wealth effects along with the existence of non-traded goods sector. Introducing non-traded goods allows for the possibility that, depending on the origin of the shock (i.e. traded versus non traded), real exchange rate and relative consumption across countries can move in opposite directions. Tradable sector shocks need to be more dominant relative to non tradable sector shocks to observe a negative Backus–Smith correlation. While overcoming the problem of an unrealistically high cross-correlation between relative consumption and the real exchange rate, real exchange rate volatility remains low[10] in these studies.

Comparing our results with other studies, our contribution in this study is twofold: (i) introducing inattentive consumers generates a mechanism which resembles limited asset market participation models to explain high exchange rate volatility, and (ii) forecast errors of inattentive consumers provide a channel to reduce Backus–Smith correlation. We observe that decline in Backus–Smith correlation is small with our benchmark model that features inattentive producers. Size of the decline depends on the size forecast errors stemming from consumer inattentiveness, and magnitude of the forecast errors depends on some factors. First, consumers have a fraction of prices in their information set when producers are assumed to be inattentive. Our numerical exercises show that assuming attentive producers leads to a larger decline in Backus–Smith correlation. Second,

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[5] Trabant and Uhlig (2010) refer to a value of 2 as a consensus in macro literature.

[6] Differences regarding the correlations of output and inflation, the speed of price response to monetary shocks are out of scope for this study. We concentrate on the moments which describe the international business cycles. Inflation dynamics under different assumptions on the producer side have been studied extensively for closed economy models. Mankiw and Reis (2002) show that inflation response to monetary shocks is delayed with sticky information models when monetary policy is described by a money growth rule. Keen (2007) shows that sticky information models do not generate this delayed response when monetary policy is described by an interest rate rule. Our result is consistent with that finding. Regarding the open economy setup, Crucini et al. (2010) examine the dynamics of goods level exchange rates by focusing on producer side rigidities. They present a hybrid model of sticky prices and sticky information with attentive consumers thereby introducing a "dual stickiness". Their model matches persistence and volatility of goods level exchange rates with a semi-log utility function which corresponds to risk aversion parameter of 1.

[7] See Kim (2001) and Landry (2009) for VAR evidence regarding the impulse responses to a monetary shock.

[8] Models presented in these studies are within the context of a standard canonical open economy model. Furthermore, issues related with trade elasticity are well covered.

[9] A direct comparison of these studies with our paper is not possible. We show that introducing inattentive consumers can improve results on Backus–Smith correlation under certain conditions using the same model through the paper, featuring only tradable goods. When we study an endowment model with non-tradable goods, we observed that imposing consumer inattentiveness yields a negative Backus–Smith correlation for a larger interval of trade elasticity. We also see that real exchange rate volatility is higher for all values of trade elasticity. Results are not reported here. We use a nested framework and the same model featuring only tradable goods through the paper.

[10] This outcome is more obvious in Benigno and Thoenissen (2008). Corsetti et al. (2008b) results exhibit low exchange rate volatility when results from the case of high trade elasticity with persistent shocks are reported.

using an example on the productivity level, we analytically show that increased shock persistence amplifies the size of forecast errors.

Considering these observations, we report a set of results on Backus–Smith correlation from our model where (i) producers are attentive and (ii) productivity shocks are persistent. Following Corsetti et al. (2008b), we consider trade elasticity as a key parameter for this exercise. We show that Backus–Smith correlation is in the negative territory with inattentive consumers, when trade elasticity is set to either at low end of macro estimates, or at higher level estimates which are consistent with disaggregated sectoral level estimates.

Organization of the paper is as follows. First, we introduce our model in a nested framework, where we distinguish a standard sticky price model and the proposed sticky information model. Next, we present results regarding the "Risk Aversion Approach"[11] by using sticky price and sticky information models with attentive consumers. We proceed by giving the results with inattentive consumers, discussing the mechanism that generates more exchange rate volatility. Then, we compare alternative models by reporting a set of business cycle moments. In this section, we also focus on the Backus–Smith correlation and provide a detailed discussion and set of results with attentive producers and persistent real shocks. Next section provides a discussion on the persistence of real exchange rates and a sensitivity analysis. Final section concludes.

2. Model

We start by describing the economy where consumers update their information set every period. That is, consumers are assumed to be *attentive*. Then, we describe the economy with inattentive consumers. For producers, we summarize the price-setting problem[12] under two alternative assumptions: the first setup features sticky prices (infrequent *price* updating), while the second assumes sticky information (infrequent *information* updating). Our benchmark model features inattentive consumers and inattentive producers (IC-IP model). Alternative models are also introduced for comparison. We can summarize underlying assumptions as follows: (i) Attentive consumers and sticky prices (AC-SP model) and (ii) Attentive consumers and inattentive producers (AC-IP model).

2.1. Households

2.1.1. Environment

The world economy consists of two countries, home and foreign,[13] each specialized in the production of a composite traded good. Households maximize lifetime utility,

$$\max E_t \sum_{s=0}^{\infty} \beta^s U(C_{t+s}, N_{t+s})$$

subject to a sequence of budget constraints, which is expressed in domestic currency units as

$$W_t N_t + \Pi_t + B_t + e_t D_t \geq P_t C_t + \nu_{t,t+1} B_{t+1} + e_t \; q_{t,t+1} \; D_{t+1} + e_t \; \Theta_b(D_{t+1}) \tag{1}$$

where W_t is the nominal wage rate and N_t is the labor supply. P_t represents the price index for home country and C_t is the composite[14] consumption good. Π_t is the profits of domestic[15] intermediate goods

[11] Regarding the "Elasticity Approach" mentioned by Corsetti et al. (2008a), we observe the price-quantity volatility trade-off in our results. We compare our mechanism with the "Risk Aversion Approach" of Chari et al. (2002) when we report results from models with producer side frictions. See Backus et al. (1995) and Corsetti et al. (2008a) for further discussion.

[12] We assume time-dependent price/information updating.

[13] Countries are assumed to be of equal size.

[14] Home and foreign goods are aggregated by a constant elasticity of substitution index following Armington (1969).

[15] Domestic firms are assumed to be owned by home consumers.

producers. B_t is the amount of nominal bonds held by domestic consumers between time t and $t+1$, and $v_{t,t+1}$ is the time t price of the bond which pays one unit of home currency at time $t+1$. D_t is the amount of foreign currency nominal bonds held by domestic consumers between time t and $t+1$, and $q_{t,t+1}$ is the price of the foreign currency bond. Home and foreign households can trade these discount bonds and e_t is the nominal exchange rate. Consumers incur convex costs of holding bonds of other country which are given as $\Theta_b(D)=\frac{\theta_b}{2}D^2$ and $\Theta_b(B)=\frac{\theta_b}{2}B^2$. Budget constraint for the foreign consumer is given by

$$W_t^*N_t^*+\frac{1}{e_t}B_t^*+\Pi_t^*+D_t^*\geq P_t^*C_t^*+\frac{1}{e_t}v_{t,t+1}\,B_{t+1}^*+\frac{1}{e_t}\Theta_b(B_{t+1}^*)+q_{t,t+1}D_{t+1}^* \tag{2}$$

Foreign country variables are denoted with an asterisk, and foreign country budget constraint is expressed in foreign currency units. Decision variables for the households are bond holdings and labor supply.

2.1.2. Composite consumption index

Consumption preferences are described by the following composite index of domestic and imported bundles of goods:

$$C_t\equiv\left[(1-\gamma)^{\frac{1}{\eta}}C_{H,t}^{\frac{\eta-1}{\eta}}+\gamma^{\frac{1}{\eta}}C_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where $\eta>0$ is the elasticity of substitution between domestic and foreign goods. Weight of imported goods in the consumption basket[16] is determined by γ. Each consumption bundle $C_{H,t}$ and $C_{F,t}$ is composed of imperfectly substitutable varieties, with elasticity of substitution $\nu>1$. Optimal allocation of expenditure between each variety of goods yields,

$$C_{H,t}(i)=\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\nu}C_{H,t};\quad C_{F,t}(i)=\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\nu}C_{F,t}.$$

where each variety is indexed by i, $C_{H,t}\equiv\left[\int_0^1 C_{H,t}(i)^{\frac{\nu-1}{\nu}}di\right]^{\frac{\nu}{\nu-1}}$ and $C_{F,t}\equiv\left[\int_0^1 C_{F,t}(i)^{\frac{\nu-1}{\nu}}di\right]^{\frac{\nu}{\nu-1}}$. Optimal expenditure allocation on home and foreign goods gives,

$$C_{H,t}=(1-\gamma)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}C_t;\quad C_{F,t}=\gamma\left(\frac{P_{F,t}}{P_t}\right)^{-\eta}C_t.$$

where $P_t\equiv\left[(1-\gamma)P_{H,t}^{1-\eta}+\gamma P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the price index. We can express the log-linearized[17] inflation dynamics as follows,

$$\hat{\pi}_t=(1-\gamma)\hat{\pi}_{H,t}+\gamma\hat{\pi}_{F,t} \tag{4}$$

where hat notation represents the log-deviations from steady state.

[16] For the foreign country, goods produced at home country are the import goods. Therefore, γ determines the share of home goods in the foreign consumption basket.

[17] Log-linearization is around the zero-inflation steady state, assuming symmetry across home and foreign countries.

2.1.3. Optimality conditions

We denote the marginal utility of consumption by λ^c and the marginal disutility of labor as λ^n. We obtain the foreign country gross nominal interest rate from the first order conditions of home and foreign consumers for foreign currency bond holdings,

$$R_t^{*-1} \equiv q_{t,t+1} = \beta E_t\left[\frac{\lambda_{t+1}^{c*}}{\lambda_t^{c*}}\frac{P_t^*}{P_{t+1}^*}\right] = \beta E_t\left[\frac{\lambda_{t+1}^{c}}{\lambda_t^{c}}\frac{P_t}{P_{t+1}}\frac{e_{t+1}}{e_t}\right] - \Theta_b(D_{t+1})' \quad (5)$$

Using the first order condition of home currency bond holdings, gross nominal interest rate for home country is defined as follows,

$$R_t^{-1} \equiv v_{t,t+1} = \beta E_t\left[\frac{\lambda_{t+1}^{c}}{\lambda_t^{c}}\frac{P_t}{P_{t+1}}\right] \quad (6)$$

No-arbitrage condition for foreign currency bonds, definitions of the interest rates and log-linearizing the results give us the uncovered interest parity condition,

$$\hat{R}_t - \hat{R}_t^* = E_t\Delta\hat{e}_{t+1} - \theta_b\tilde{D}_{t+1} \quad (7)$$

where tilde variables correspond to level deviations from the steady state. We define the real exchange rate as $rer_t \equiv e_t\frac{P_t^*}{P_t}$, and we can express the real exchange rate dynamics in terms of marginal utilities as follows,

$$E_t\Delta\hat{rer}_{t+1} = E_t\Delta\hat{\lambda}_{t+1}^* - E_t\Delta\hat{\lambda}_{t+1} + \theta_b\tilde{D}_{t+1} \quad (8)$$

Labor supply is determined by the static first order condition, which sets the real wages equal to the marginal rate of substitution between consumption and leisure,

$$\frac{W_t}{P_t} = -\frac{\lambda_t^n}{\lambda_t^c} \quad (9)$$

2.2. Consumers with sticky information

In this section we describe the decision making process of the household under inattentiveness assumption. Household solves a two-step problem. Allocating the best bundle of varieties for the composite consumption good is the *intra-temporal* decision, and consumption amount of the composite good for each period is the *inter-temporal* decision. We assume that household is composed of a shopper–planner pair. The shopper makes the intra-temporal decision by observing the relative prices of varieties. The planner solves the inter-temporal problem. Every period, the planner observes[18] the amount of domestic and foreign bonds, $B_{t,j}$ and $D_{t,j}$. Here, the second index is the number of periods by which the information set is outdated. We assume that consumers sign an insurance contract so that they all start each period with the same wealth, $B_{t,j} = B_t$ and $D_{t,j} = D_t$. The payments from this contract are $\tau_{t,j}$. This way, we do not have to track[19] the wealth distribution. If she knows all variables up to date *t*, the probability of updating her information set at date *t+1* is 1 – δ. We can state the problem of the attentive consumer as follows:

[18] We assume that shopper and planner do not share any information.

[19] We can track the wealth distribution by assuming a staggered information updating setup. To avoid the computational burden, we assume this transfer scheme following Mankiw and Reis (2006).

$$V(B_t, D_t) = \max_{\{C_{t+i,i}, W_{t+i,i}\}} \sum_{i=0}^{\infty} \beta^i \delta^i U(C_{t+i,i}, N_{t+i,i}) + \beta(1-\delta) \sum_{i=0}^{\infty} \beta^i \delta^i V(B_{t+i+1}, D_{t+i+1}) \tag{10}$$

First term is the expected discounted utility if the planner never updates her information set again. Second term is the sum of continuation values over all possible future dates at which planner may update the information, where probability of receiving an information update *i* periods later is $(1-\delta)\delta^i$. Attentive planner decides on a consumption plan for each period without any information update. For the labor market, a wage rate for future periods is posted along with the assumption that each household is a monopolistic supplier of a specific labor variety. Sequence of budget constraints is given by

$$W_{t+i,i}N_{t+i,i} + B_{t+i} + e_{t+i}D_{t+i} + \Pi_{t+i} \geq P_{t+i}C_{t+i,i} + \nu_{t+i,t+i+1}B_{t+i+1} + q_{t+i,t+i+1}e_{t+i}D_{t+i+1} + e_{t+i}\Theta_b(D_{t+i+1}) + \tau_{t+i,i} \tag{11}$$

Information frictions on the consumer side implies that the price of domestic currency bond is determined by the marginal utility of attentive consumers,

$$R_t^{-1} \equiv \nu_{t,t+1} = \beta E_t \left[\frac{\lambda^c_{t+1,0}}{\lambda^c_{t,0}} \frac{P_t}{P_{t+1}} \right] \tag{12}$$

Defining the real interest rate as $rr_t \equiv R_t \dfrac{P_t}{P_{t+1}}$ and log-linearization around the steady state gives the following optimality conditions

$$\hat{\lambda}^c_{t,0} = E_t \left[\hat{\lambda}^c_{t+1,0} + \hat{r}r_t \right] \tag{13}$$

$$\hat{\lambda}^c_{t,j} = E_{t-j} \hat{\lambda}^c_{t,0} \tag{14}$$

Aggregate consumption is obtained by using the weights of information cohorts in the population, $\hat{c}_t = \sum_{j=0}^{\infty}(1-\delta)\delta^j \hat{c}_{t,j}$. In this economy, the no-arbitrage condition for the foreign currency bonds include marginal utilities of the attentive consumers,

$$q_{t,t+1} = \beta E_t \left[\frac{\lambda^{c*}_{t+1,0}}{\lambda^{c*}_{t,0}} \frac{P^*_t}{P^*_{t+1}} \right] = \beta E_t \left[\frac{\lambda^c_{t+1,0}}{\lambda^c_{t,0}} \frac{P_t}{P_{t+1}} \frac{e_{t+1}}{e_t} \right] - \Theta'_b(D_{t+1}) \tag{15}$$

Log-linearizing this equation and using the real exchange rate definition, the real exchange rate dynamics is given by

$$E_t \Delta r\hat{e}r_{t+1} = E_t \Delta \hat{\lambda}^{c*}_{t+1,0} - E_t \Delta \hat{\lambda}^c_{t+1,0} + \theta_b \tilde{D}_{t+1} \tag{16}$$

2.3. Labor market with sticky information

We assume that each household is a monopolistic supplier of a specific labor variety. The demand for the labor variety *j* is given by $N_{t,j} = \left(\dfrac{W_{t,j}}{W_t}\right)^{-\chi} N_t$, where χ is the elasticity of substitution between labor varieties. The planner posts a nominal wage rate using the available information. Using results from the consumption decision and plugging in the demand for labor variety, we obtain the following condition for wage posting in the case of attentive consumers,

$$\frac{W_{t,0}}{P_t} = -\mu_\chi \frac{\lambda^n_{t,0}}{\lambda^c_{t,0}} \tag{17}$$

where $\mu_\chi = \dfrac{\chi}{\chi - 1}$ is the markup over the marginal rate of substitution between consumption and leisure. Agents who have outdated information post wages by forecasting the decision of attentive agents

$$\hat{w}_{t,j} = E_{t-j}\hat{w}_{t,0} \tag{18}$$

The aggregate nominal wage rate is given by $\hat{w}_t = \sum_{j=0}^{\infty}(1-\delta)\delta^j \hat{w}_{t,j}$.

2.4. Producers

Intermediate goods are produced by labor. Production function for the domestic producer of variety i is given by

$$Y_H(i) = A_t N_t(i)^{\zeta} \tag{19}$$

where aggregate productivity process follows an AR(1) process: $A_t = \rho_A A_{t-1} + \epsilon_{A,t}$. Demand from the domestic country for the variety produced by firm i is given by

$$Y_H(i) = \left\{\frac{P_H(i)}{P_H}\right\}^{-\nu} Y_H \tag{20}$$

We assume that firms set prices in buyers' currencies to maximize their expected profits.

2.4.1. Producers under sticky price assumption

Producers are attentive, they update their information set every period. They update their *prices* when they receive a Calvo signal. The probability of updating their prices is 1 – θ, while prices stay constant with probability θ. They set prices in the local currencies for domestic and foreign country to maximize their expected profits:

$$\max_{P_H(i),P_H^*(i)} \sum_{k=0}^{\infty}\theta^k E_t\left[\nu_{t,t+k}\left\{P_{H,t}(i)Y_{H,t+k}(i) - W_{t+k}\left(\frac{Y_{H,t+k}(i)}{A_t}\right)^{\frac{1}{\zeta}}\right\}\right]$$
$$+\sum_{k=0}^{\infty}\theta^k E_t\left[\nu_{t,t+k}\left\{e_{t+k}P_{H,t}^*(i)Y_{H,t+k}^*(i) - W_{t+k}\left(\frac{Y_{H,t+k}^*(i)}{A_t}\right)^{\frac{1}{\zeta}}\right\}\right].$$

Using the demand for the variety, the first order condition for home prices of locally produced goods is

$$\sum_{k=0}^{\infty}\theta^k E_t\left[\nu_{t,t+k}Y_{H,t+k}(i)\left\{P_{H,t}(i) - \frac{\nu}{\nu-1}\frac{W_{t+k}}{\zeta A_{t+k}^{\frac{1}{\zeta}}}Y_{H,t+k}^{\frac{1-\zeta}{\zeta}}\right\}\right] = 0 \tag{21}$$

Imposing symmetry, log-linearizing and rearranging, we can express the final result as a sticky price Philips curve relation between the real marginal cost and inflation,

$$\hat{\pi}_{H,t} = \kappa\,\Omega\,\hat{mc}_{H,t} + \beta E_t \hat{\pi}_{H,t+1} \tag{22}$$

where $\kappa \equiv \frac{(1-\theta\beta)(1-\theta)}{\theta}$, $\Omega \equiv \frac{\zeta}{\zeta+(1-\zeta)\nu}$ and real marginal cost is $\hat{mc}_{H,t} \equiv \hat{W}_t - \hat{P}_{H,t} + \frac{1-\zeta}{\zeta}\hat{Y}_{H,t} - \frac{1}{\zeta}\hat{A}_t$. Import inflation for the foreign country is given by

$$\hat{\pi}_{H,t}^* = \kappa\,\Omega\,[\hat{mc}_{H,t}^* - \hat{e}_t] + \beta E_t[\hat{\pi}_{H,t+1}^*] \tag{23}$$

where real marginal cost is defined as $\hat{mc}_{H,t}^* \equiv \hat{W}_t - \hat{P}_{H,t}^* + \frac{1-\zeta}{\zeta}\hat{Y}_{H,t}^* - \frac{1}{\zeta}\hat{A}_t$.

2.4.2. Producers under sticky information assumption

Firms update their *information set* with probability $1-\theta$ each period. They proceed using their outdated information with probability θ. The firm which sets the price at time t according to the information received j periods ago solves the following static problem:

$$\max_{P_H(j),P_H^*(j)} E_{t-j}\left[P_{H,t}(j)Y_{H,t}(j)-W_t\left(\frac{Y_{H,t}(j)}{A_t}\right)^{\frac{1}{\zeta}}\right]+E_{t-j}\left[e_tP_{H,t}^*(j)Y_{H,t}^*(j)-W_t\left(\frac{Y_{H,t}^*(j)}{A_t}\right)^{\frac{1}{\zeta}}\right].$$

In this case, home country inflation for domestic goods is obtained by aggregating information cohorts across firms. Final expression for home inflation rate of domestic goods is,

$$\hat{\pi}_{H,t}=\frac{1-\theta}{\theta}\Omega\hat{mc}_{H,t}+\frac{1-\theta}{\theta}\left(\sum_{j=1}^{\infty}\theta^jE_{t-j}[\Omega\Delta\hat{mc}_{H,t}+\hat{\pi}_{H,t}]\right) \tag{24}$$

Import inflation in the foreign country is

$$\hat{\pi}_{H,t}^*=\frac{1-\theta}{\theta}\Omega(\hat{mc}_{H,t}^*-\hat{e}_t)+\frac{1-\theta}{\theta}\left(\sum_{j=1}^{\infty}\theta^jE_{t-j}[\Omega(\Delta\hat{mc}_{H,t}^*-\Delta\hat{e}_t)+\hat{\pi}_{H,t}^*]\right) \tag{25}$$

Regarding the inflation dynamics, we observe a forward looking relation with sticky prices. Current inflation is a function of the expectation of future inflation rate. On the other hand, we observe that inflation is a function of lagged expectations of current inflation with the sticky information assumption. We discuss the implications of the different price setting mechanisms by assuming attentive consumers and different price setting mechanisms in our results section.

2.5. Monetary policy and market clearing

Interest rates follow a Taylor rule with a stochastic component:

$$\hat{R}_t=\rho_R\hat{R}_{t-1}+(1-\rho_R)[\psi_\pi\hat{\pi}_t+\psi_y\hat{y}_t]+\epsilon_{R,t} \tag{26}$$

$$\hat{R}_t^*=\rho_R\hat{R}_{t-1}^*+(1-\rho_R)[\psi_\pi\hat{\pi}_t^*+\psi_y\hat{y}_t^*]+\epsilon_{R,t}^* \tag{27}$$

Market clearing conditions are given by

$$Y_t=C_{H,t}+C_{H,t}^* \tag{28}$$

$$Y_t^*=C_{F,t}+C_{F,t}^* \tag{29}$$

We close the model by defining the monetary policy rules and imposing the market clearing conditions.

2.6. Parametrization and calibration strategy

We log-linearize the system around the zero-inflation steady state, which yields a system of second order difference equations in the case of sticky price models. These systems can be solved by standard methods outlined in Klein (2000). Sticky information models include the lagged expectations of variables. We can write our models in the following form:

Table 1
Benchmark parameter values.

Description	Parameter	Value
Risk aversion	σ	2
Frisch elasticity	ϕ	0.5
Discount factor	β	0.995
Elasticity of substitution		
Goods	ν	10
Labor varieties	χ	10
Home and foreign	η	1.5
Import share	γ	0.06
Price/information stickiness		
Producers	θ	0.75
Consumers	δ	0.75
Portfolio adjustment cost	θ_b	0.001
Monetary policy rule		
Inertia	ρ_R	0.85
Inflation	ψ_π	1.5
Output	ψ_y	0.5
Corr($\epsilon_R, \epsilon_{R^*}$)		0.5
Productivity process		
Persistence	ρ_A	0.95
St.dev.	σ_A	0.7
Corr($\epsilon_A, \epsilon_{A^*}$)		0.25

Notes: Countries are assumed to be symmetric in terms of parameters and exogenous processes. The standard deviation of monetary shock is set to target output volatility.

$$AE_tY_{t+1} + B_0Y_t + \sum_{i=1}^{I} B_iE_{t-i}Y_t + CY_{t-1} + GW_t = 0 \tag{30}$$

where Y_t is vector of endogenous variables and W_t is vector of exogenous variables with a law of motion $W_t = NW_{t-1} + \epsilon_t$. The solution is in the form of $Y_t = \sum_{j=0}^{\infty} \Theta_j \epsilon_{t-j}$. We can manipulate this structure by plugging the solution into the system and truncating at a large number of lags. This reduces the model to a block tridiagonal structure which can be easily solved.[20] We report the theoretical moments[21] of the models studied in this paper.

Our choice of the parameter values is summarized in Table 1. We assume a utility function of the form

$$U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \xi \frac{N_t^{1+1/\phi}}{1+1/\phi} \tag{31}$$

Notice that utility is separable between consumption and leisure.

For the preference parameters, we assume a discount factor $\beta = 0.995$, which implies an annual real return of 2 percent at steady state.[22] The curvature parameter of the utility function (σ) determines the degree of risk aversion. We set this parameter as 2 for our benchmark calibration. Regarding the home bias in the consumption basket, γ is set to 0.06 following Chari et al. (2002).

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[20] Earlier literature introduced lagged expectations as new variables to the endogenous state vector. This approach increases the computational burden, and accuracy depends on the number of lags included. Meyer-Gohde (2010) provides a new solution method for this class of models.

[21] We apply a two-sided filter following King and Rebelo (1993) to obtain the HP-filtered theoretical moments.

[22] Steady state labor supply is determined by ξ, log-linearized solution does not depend on this parameter.

Table 2
Sticky information: consumers.

	Data	AC-SP	AC-IP	IC-IP	IC-IP
Degree of consumer information stickiness (δ)	–	0	0	0.5	0.75
$2\frac{Var(c_t - c_{t-1})}{Var(c_t - c_{t-2})}$	0.73	1.19	1.20	0.83	0.72
$\rho(\Delta c_t)$	0.36	-0.16	-0.17	0.21	0.39

Notes: We report the unfiltered ratio of variances for consumption growth and the autocorrelation of consumption growth for different models. Second column is the sticky price model with attentive consumers (AC-SP), and others are results from the benchmark sticky information (featuring inattentive consumers and producers, IC-IP) model for varying degrees of stickiness on the consumer side. Average duration of information updating is $\frac{1}{1-\delta}$. All models are calibrated to match HP-filtered US output volatility by changing the standard deviation of the monetary shock.

The Frisch elasticity of labor supply is determined by ϕ. Following the evidence[23] from micro-econometric studies, we use $\phi = 0.5$ for our exercises. Elasticity of substitution between home and foreign goods (η) is set to 1.5, following Backus et al. (1994) and Chari et al. (2002).

The elasticity of substitution across the varieties of goods, v, is set to 10. This is consistent with a price markup of 11 percent as documented in the U.S. data by Basu (1996). The elasticity of substitution among labor varieties is set to 10, following Mankiw and Reis (2006). We set the degree of price/information stickiness for the producers to $\theta = 0.75$. This implies an average duration of 4 quarters for price/information updating.

We follow Chari et al. (2002) to describe our exogenous productivity processes. Assuming symmetry across countries, we set the persistence and standard deviation of the productivity shocks as $\rho_A = 0.95$, and $\sigma_A = 0.7$ percent respectively. Cross-country correlation of productivity shocks is set to 0.25. For the monetary policy rule, we use $\rho_R = 0.85$, $\psi_\pi = 1.5$ and $\psi_y = 0.5$. We check the sensitivity of real exchange rate volatility using alternative Taylor rule parameters.

We follow Chari et al. (2002) regarding the calibration strategy.[24] We choose the standard deviation of the monetary shocks so that the volatility of output is the same in the model as in the U.S. data[25] for each specification. We set the cross-country correlation of monetary shocks as 0.5 and assume the shock is symmetric for the rest of the world, i.e. the standard deviation of the foreign country monetary shock is the same.

To pin down the degree of information stickiness on the consumer side, we carry out an exercise with consumption growth following Mankiw and Reis (2006). If consumption[26] follows a random walk, then the variance of growth rate from t to $t+2$ should be twice as the variance of the growth rate from t to $t+1$. However, in the U.S. data, we observe that $\left(2 \times \frac{Var(c_t - c_{t-1})}{Var(c_t - c_{t-2})}\right)$ is equal to 0.73, which means consumption adjusts gradually[27] to the shocks driving the economy. Furthermore, if consumption follows a random walk, the autocorrelation of consumption growth should be 0. Positive autocorrelation observed in the data indicates a gradual adjustment as well. We calibrate our sticky price and sticky information models to match output volatility as described above. Results are reported in Table 2. We find that the variance ratio is greater than 1 for our sticky price model and sticky information model with attentive consumers and we observe that autocorrelation of consumption growth is negative for both models. Information stickiness on the consumer side helps us to bring the model closer to the

[23] See Chetty et al. (2011).
[24] Results are robust to alternative calibration strategies, such as using estimated Taylor rule parameters.
[25] Details of data sources are described in the Appendix.
[26] Transformed by taking the logarithm of the data.
[28] Mankiw and Reis (2006) use $\frac{std(c_t - c_{t-1})}{std(c_t - c_{t-4})}$ as a calibration target.

data for these two moments.[28] Mankiw and Reis (2006) and Reis (2009) report estimation results for US and Europe, for closed economy models. The range for δ in these studies is between 0.64 and 0.92. We report results for $\delta = 0.5$ and $\delta = 0.75$ for our exercises, and we set $\delta = 0.75$ for our benchmark[29] calibration.

Looking at our alternative models, setting $\delta = 0$ is equivalent to assuming attentive consumers. For the sticky price model (AC-SP), we always assume attentive consumers. Benchmark model with inattentive consumers and producers (IC-IP) collapses to the model with attentive consumers and inattentive producers (AC-IP) when δ is set to 0.

3. Results

We start with numerical results of "Risk Aversion Approach" to address real exchange rate volatility and explain the underlying mechanism. We assume attentive consumers for this exercise. Then, we present the new approach proposed in this paper by introducing inattentive consumers. Next, we report business cycle statistics for alternative models. We show that different forms of rigidity in price setting behavior produce similar results regarding international business cycles. Then, we discuss the business cycle statistics of our benchmark sticky information model with information frictions on both consumer and producer side. Finally, we provide a detailed discussion on the Backus–Smith correlation by using our model with attentive producers and persistent real shocks.

3.1. Real exchange rate volatility with attentive consumers

First, we derive the relationship between real exchange rate volatility and the level of risk aversion for models with attentive consumers. This exercise helps to understand the dynamics of the "Risk Aversion Approach" a′ la Chari et al. (2002). Real exchange rate dynamics are driven by the growth rates[30] of the marginal utilities of home and foreign consumers

$$E_t \Delta \hat{rer}_{t+1} = E_t \Delta \hat{\lambda}^*_{t+1} - E_t \Delta \hat{\lambda}_{t+1} + \theta_b \tilde{D}_{t+1} \tag{32}$$

We define an auxiliary variable[31] to obtain a closed form expression for real exchange rate volatility: $\widetilde{rer}_t^{levels} = \hat{\lambda}_t^{c*} - \hat{\lambda}_t^{c}$. With separable utility, $\hat{\lambda}_t^{c} = -\sigma \hat{c}_t$, we can express the auxiliary variable for the real exchange rate in terms of relative consumption, $\widetilde{rer}_t^{levels} = \sigma(\hat{c}_t - \hat{c}_t^*)$. Dividing by the variance of output, expanding the relative consumption variance and imposing symmetry gives

[28] This example with a random walk consumption process provides useful insight into understanding the gradual response of real variables to shocks. Unlike Mankiw and Reis (2006), our model does not have a permanent technology shock; therefore we do not have any reason to expect our model to generate a random walk consumption process. We use these statistics as a measure of adjustment speed to the shocks.

[30] Average duration of information updating is given by $\frac{1}{1-\delta}$. Setting $\delta = 0.75$ is consistent with the findings of Carroll (2003). He estimates a model of information diffusion using public and forecaster survey data, and reports that public expectations follow forecasters' expectations with a one year lag.

[30] Effect of net foreign asset position arising from the portfolio adjustment cost assumption is very small. This assumption ensures the stationarity of the real exchange rates. Chari et al. (2002) impose borrowing constraints.

[31] Auxiliary variable and closed form expressions are only for developing intuition on these results. We report the moments by using the actual model. To obtain the closed form expressions, we replace the consumption growth rates with the levels in equation 32 and drop the net foreign asset variable. We should note that this variable corresponds to the real exchange rates when we assume complete markets. Incomplete markets assumption is necessary when the consumers are inattentive, because consumers would be able to insure themselves against the risk of having outdated information with state contingent assets. In this case, model would collapse into a representative agent setup. We compare incomplete market models for all specifications. Earlier versions of this paper report results of complete markets model with attentive consumers. We find that results are similar for the complete markets setup and bond economy. See Baxter and Crucini (1995) for a detailed discussion on the implications of alternative asset market specifications in open economy models.

Table 3
Risk aversion approach.

	Data	AC-SP model			AC-IP model		
Risk aversion	–	1	3	5	1	3	5
std($\hat{rer}$)	4.47	1.14	3.29	5.40	1.22	3.40	5.53
std($\hat{c}$)	0.84	1.04	1.04	1.04	1.05	1.05	1.05
std($\hat{c}-\hat{c}^*$)	0.75	1.12	1.10	1.09	1.19	1.14	1.12
corr($\hat{c},\hat{c}^*$)	0.47	0.41	0.43	0.44	0.36	0.41	0.43

Notes: Sticky price (AC-SP) and sticky information (AC-IP) models with attentive consumers calibrated to match HP-filtered US output volatility by changing the standard deviation of the monetary shock. All series are logged and HP-filtered. Standard deviations are normalized by dividing the output volatility. We report volatility of real exchange rates, consumption, relative consumption and cross country consumption correlation for varying degrees of risk aversion.

$$\frac{std\left(\widetilde{rer}^{levels}\right)}{std(y)} = RISK\ AVERSION \times \sqrt{2(1-corr(\hat{c},\hat{c}^*))}\,\frac{std(\hat{c})}{std(y)} \tag{33}$$

This relation shows a direct link between the level of risk aversion (parametrized as σ) and real exchange rate volatility.

We report the theoretical moments of the model[32] in Table 3. We observe that cross country consumption correlation and volatility of consumption are not the main driving forces when we change the level of risk aversion. We also observe that volatility of relative consumption declines as we increase the degree of risk aversion and we need to set risk aversion parameter as 5 to match the real exchange rate volatility with the data. This result does not change whether we impose a sticky price or sticky information structure for the producer side.

3.2. Real exchange rate volatility with inattentive consumers

When we have sticky information on the consumer side, the real exchange rate is determined by an asset pricing condition based on the marginal utilities of attentive consumers. Defining $\widetilde{rer}_t^{levels,0} = \lambda_{t,0}^{c*} - \lambda_{t,0}^{c}$ and following similar steps to the case with attentive consumers yields

$$\frac{std\left(\widetilde{rer}^{levels,0}\right)}{std(y)} = RISK\ AVERSION \times \sqrt{2(1-corr(c_0,c_0^*))}\,\frac{std(\hat{c}_0)}{std(y)} \tag{34}$$

This equation links the volatility of real exchange rate with the attentive consumer's consumption. Aggregate consumption response is a weighted average of the responses from all information cohorts, $\hat{c}_t^{agg} = (1-\delta)\sum_{i=0}^{\infty}\delta^i\hat{c}_{t,i}$. We can express the consumption response of an agent who updated her information set i periods ago as her expectation of the long rate conditioning on the available information, that is $\hat{c}_{t,i} = -\frac{1}{\sigma}E_{t-i}\widehat{lr}_t$. The long rate is defined as $\widehat{lr}_t = \sum_{j=0}^{\infty}\widehat{rr}_{t+j}$.

We start by establishing that the volatility of attentive consumers' consumption is at least as high as aggregate consumption. For any moving average process x_t, $\text{var}(x_t) > \text{var}(E_{t-j}x_t)$ when $j > 0$. Since we can express our model solution as a moving average process, then $\text{var}\left(\widehat{lr}_t\right) > \text{var}\left(E_{t-j}\widehat{lr}_t\right)$ for $j > 0$. It is easy to show that var $\text{var}(c_0) > \text{var}(c_j)$ for $j > 0$. It follows that aggregate consumption is less volatile than the consumption of attentive consumers, $\text{var}(c_0) > \text{var}(c^{agg})$ for $\delta > 0$. We can also analytically show that volatility of attentive consumers' consumption increases as we increase the degree of

[32] Auxiliary variable (rer^{levels}) is defined to obtain closed form expressions about the real exchange rate volatility. We report the moments of actual real exchange rates and other variables after calibrating the models.

Table 4
Real exchange rate volatility with inattentive consumers.

	Data	AC-IP	IC-IP	IC-IP
Consumer information stickiness (δ)	–	0	0.5	0.75
std($\hat{rer}$)	4.47	2.32	3.15	4.66
std($\hat{c}^{agg}$)	0.84	1.05	1.00	0.99
std($\hat{c} - \hat{c}^*$)	0.75	1.16	1.04	0.96
std($\hat{c}_0$)	–	1.05	1.54	2.40
corr($\hat{c}_0$, $\hat{c}_0^*$)	–	0.39	0.47	0.52

Notes: Benchmark sticky information model (IC-IP, with inattentive consumers and producers) is calibrated to match the standard deviation of HP-filtered US output for varying degrees of information stickiness on the consumer side (δ). Average duration of information updating is $\frac{1}{1-\delta}$. The degree of information stickiness on the producer side (θ) is set to 0.75 and the level of risk aversion is 2. All volatilities are normalized by dividing the output volatility. All series are logged and HP-filtered. Standard deviations of real exchange rates, aggregate consumption, relative consumption, consumption of attentive consumers and cross country consumption correlation (attentive consumers) are reported.

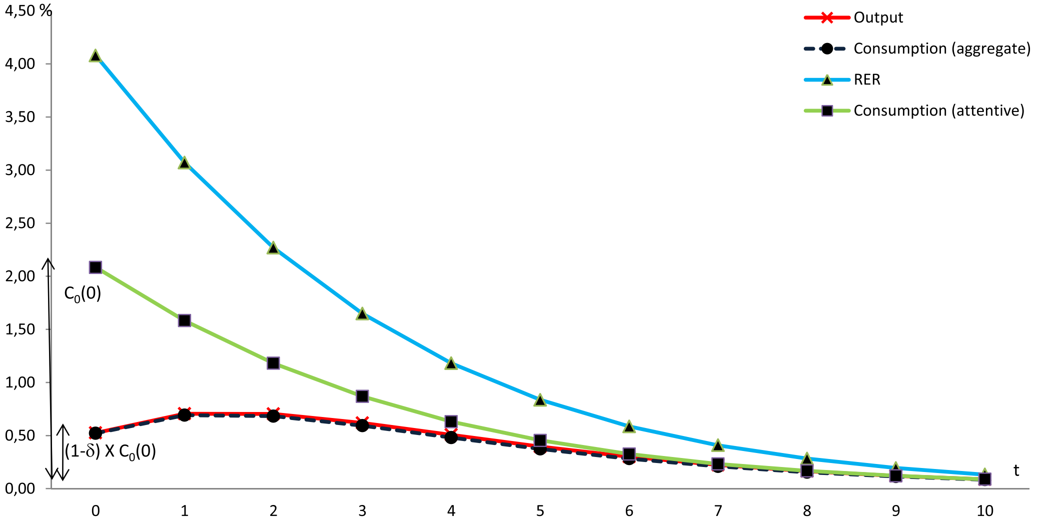

Fig. 1. Inattentive consumers: impulse response to home monetary shock.

information stickiness on the consumer side. Numerical results for varying degrees of information stickiness on the consumer side are reported in Table 4.

To understand the intuition, we plot the impulse response to a one unit negative innovation[33] which decreases home interest rate in Fig. 1. Output and aggregate consumption move very closely. On impact, only the consumers who updated their information set in the current period have this shock in their information set. Therefore, aggregate consumption response is a fraction of the attentive consumer's response. The consumption plans of inattentive consumers remain the same since they do not have information on that. Supply response to clear the goods market is relatively small compared to the case where all consumers are attentive. As the fraction of attentive consumers goes down, output response necessary to clear the markets decreases. Consequently, attentive consumers' consumption is more volatile than the aggregate consumption and output. Since the real exchange rate is deter-

[33] 1 unit negative shock to Taylor rule, ε_R.

Table 5
Selected business cycle moments with inattentive consumers.

	Data	Benchmark	Attentive consumers	
		IC-IP	AC-SP	AC-IP
Consumer information stickiness (δ)	–	0.75	0	0
Output volatility	1.68	1.68	1.68	1.68
Volatilities (relative to GDP)				
Consumption	0.84	0.99	1.04	1.05
Employment	0.77	1.75	1.66	1.73
Real exchange rate	4.47	4.66	2.22	2.32
Nominal exchange rate	4.67	4.71	2.52	2.65
Net exports	0.24	0.05	0.12	0.16
Autocorrelations				
Output	0.89	0.84	0.54	0.53
Consumption	0.90	0.84	0.54	0.53
Employment	0.93	0.81	0.54	0.56
Real exchange rate	0.84	0.59	0.54	0.55
Nominal exchange rate	0.85	0.61	0.59	0.59
Net exports	0.86	0.94	0.76	0.83
Correlations				
Cross-country				
Output	0.60	0.48	0.53	0.54
Consumption	0.47	0.53	0.43	0.39
Employment	0.55	0.41	0.47	0.46
Real exchange rate and				
Nominal exchange rate	0.99	0.99	0.87	0.91
Relative consumption	–0.15	0.87	1.00	1.00
Output and net exports	–0.55	0.31	–0.26	–0.24

Notes: All series are logged and HP-filtered. IC-IP model is the benchmark sticky information model with inattentive consumers and producers. AC-SP model is the sticky price model with attentive consumers. AC-IP model features attentive consumers, and inattentive producers. The standard deviation of monetary shock is set to target output volatility.

mined by the marginal utilities of attentive consumers, we observe higher volatility in real exchange rates.

3.3. Calibration results and impulse responses

We focus on the business cycle moments and international transmission of monetary shocks in this section. To understand the effect of imposing different frictions on the producer side, we compare the sticky price model and the sticky information model with attentive consumers. Next, we discuss the business cycle properties of the benchmark model with inattentive consumers and present the results under different degrees of trade elasticity. Finally, we discuss our results on the Backus–Smith correlation and report a set of results with attentive producers and persistent real shocks.

3.3.1. Attentive consumers

Table 5 reports business cycle moments for alternative models. Comparing models with attentive consumers, we observe that the form of the friction on the producer side has a small effect on the moments[34] generated by the model.

For models with attentive consumers, we observe that consumption and employment are more volatile[35] in the model compared to the data. Net exports are less volatile than the data, but we should note that the volatility of net exports is sensitive to the degree of home bias. Models with attentive

[34] See Keen (2007) for a comparison of sticky price and sticky information models with a closed economy setup.
[35] For simplicity, we abstract from capital accumulation. Chari et al. (2002) target consumption volatility by changing an investment adjustment cost parameter.

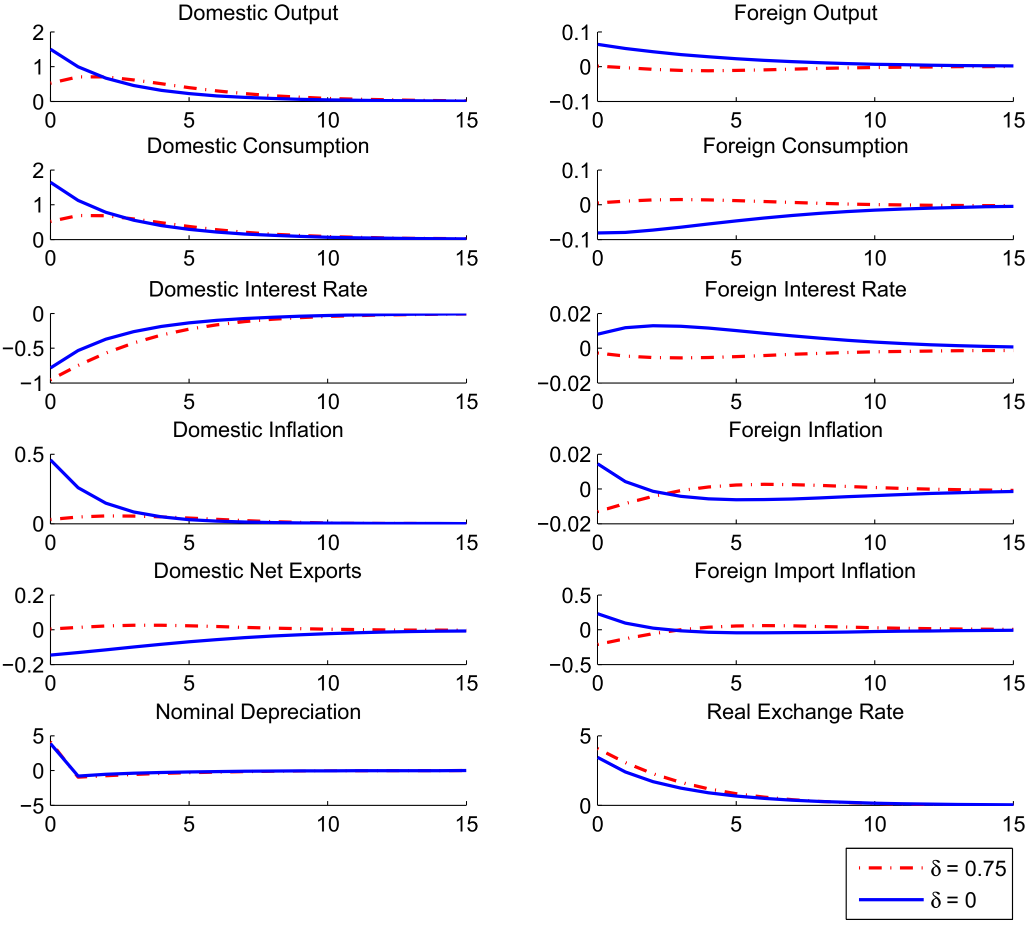

Fig. 2. Sticky information model with inattentive consumers.

consumers generate less persistence in quantities and prices compared to the data. Models with attentive consumers capture the fact that cross country consumption correlation is lower than output correlation. The real exchange rate and relative consumption exhibit perfect correlation contradicting the data.

Since monetary shocks play the dominant role in determining the dynamics of our model, we focus on the impulse responses to a home monetary shock[36] to understand the effect of introducing inattentive consumers. Fig. 2 plots the impulse response functions for the sticky information model with attentive consumers and our benchmark model with inattentive consumers and producers.

[36] Direction of the impulse responses to a productivity shock remains the same across the models for key variables. When home productivity increases, prices of home goods decrease. This leads to a rise in demand for home goods, which raises home and foreign consumption. Home consumption increases less than home output. By the decline in home inflation, the home interest rate decreases. Since demand shifts away from foreign goods, foreign output and inflation decrease. By the monetary policy rule, foreign interest rate goes down. The increase in home (attentive) consumption is greater than foreign (attentive) consumption. We observe hump shaped impulse responses, due to the negative comovement between output and inflation combined with the feedback from the interest rate rule. See Steinsson (2008) for a more comprehensive discussion of real shocks.

When we look at the model with attentive consumers, we observe that home consumption increases following a decline in the interest rate. Due to increased demand from home consumers, output and inflation rise in both countries. Foreign interest rate increases as a result of monetary policy response to the rise in output and inflation. Foreign consumption decreases as a result of the increase in the interest rate. Transmission of a monetary shock is negative in consumption and positive in output. This helps to explain the fact that cross country output correlation is higher than that of consumption in the data. As the shock dissipates, quantities and real exchange rates return to their steady state values monotonically. Therefore, our model with attentive consumers generates low persistence in quantities. Real exchange rate persistence is also low since it is tightly linked to relative consumption in this model.

3.3.2. Inattentive consumers

We observe that nominal and real exchange rate volatility[37] is magnified with inattentive consumers and the persistence of quantities and prices becomes closer to the data.[38] Since real exchange rates are determined by the attentive consumer's consumption instead of aggregate consumption, inattentiveness on the consumer side provides a channel for a lower Backus–Smith correlation. We use the auxiliary variable for real exchange rates again to obtain a closed form expression: $\widetilde{rer}_t^{levels,0} \equiv \sigma \times (\hat{c}_{t,0} - \hat{c}^*_{t,0})$. We aggregate consumption from information cohorts and define forecast errors on the real exchange rate movements as $\tilde{f}_{t,j} = \widetilde{rer}_t^{levels,0} - E_{t-j}\widetilde{rer}_t^{levels,0}$. We obtain the following relation which links the auxiliary variable for the real exchange rates and relative consumption,

$$\widetilde{rer}_t^{levels,0} = RISK\ AVERSION \times (c_t - c_t^*) + (1-\delta)\sum_{j=1}^{\infty} \delta^j \tilde{f}_{j,t} \tag{35}$$

This expression shows that the correlation of real exchange rates and relative consumption depends on the size of forecast errors made by the agents who have outdated information. However, calibration results show that size of the decline is quantitatively small. This channel is further investigated in the next section. Inattentive consumer models perform less well on some issues compared to the models with attentive consumers. The cross country consumption correlation is higher than that of output, and we obtain procyclical net exports.

To understand the dynamics, we look at the impulse responses from the benchmark sticky information model in Fig. 2 to compare with the sticky information model with attentive consumers. Since we previously investigated the results on exchange rate volatility, we skip the distinction between aggregate consumption and consumption of the attentive consumer here. Demand from home consumers increases gradually in this case. Consumers react to the monetary shock as they update their information set. Therefore, the decline in home output and consumption is not as fast as in the full information case. These dynamics help us to get more persistence in quantities, moving the model closer to the data. We also observe that the gradual adjustment of home demand changes the nature of the transmission dynamics for a monetary shock. The direction of inflation response in foreign country changes with inattentive consumers. A larger nominal exchange rate depreciation[39] creates a decline in imported goods inflation in the foreign country. The decline in the inflation is reflected in interest rates, which leads to a positive consumption response as opposed to the negative one for the case with attentive consumers. Weak demand response also leads to a decline in the consumption of import goods in the home country since foreign goods became more expensive for home consumers due to the depreciation. This leads to a positive net exports response at home country with inattentive consumers.

Introducing inattentive consumers generates a positive transmission in consumption and a negative transmission in output in response to a monetary shock; therefore cross-country consumption

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37 We refer to the volatilities relative to the output volatility.

38 Results are reported in Table 5.

39 Nominal depreciation response is larger with respect to the inflation rates compared to the model with attentive consumers.

Table 6
Selected business cycle moments with different trade elasticities.

	Data	IC-IP	IC-IP	IC-IP
Trade elasticity (η)	–	1.5	0.5	5
Output volatility	1.68	1.68	1.68	1.68
Volatilities (relative to GDP)				
Consumption	0.84	0.99	1.01	0.91
Employment	0.77	1.75	1.74	1.75
Real exchange rate	4.47	4.66	4.91	4.05
Nominal exchange rate	4.67	4.71	4.61	4.03
Net exports	0.24	0.05	0.03	0.20
Autocorrelations				
Output	0.89	0.84	0.84	0.84
Consumption	0.90	0.84	0.84	0.81
Employment	0.93	0.81	0.81	0.58
Real exchange rate	0.84	0.59	0.60	0.58
Nominal exchange rate	0.85	0.61	0.58	0.58
Net exports	0.86	0.94	0.80	0.89
Correlations				
Cross-country				
Output	0.60	0.48	0.54	0.31
Consumption	0.47	0.53	0.50	0.60
Employment	0.55	0.41	0.46	0.29
Real exchange rate and				
Nominal exchange rate	0.99	0.99	0.99	0.99
Relative consumption	-0.15	0.87	0.87	0.87
Output and net exports	-0.55	0.31	-0.39	0.55

Notes: All series are logged and HP-filtered. IC-IP model is the benchmark sticky information model with inattentive consumers and producers. The standard deviation of monetary shock is set to target output volatility.

correlation is higher than that of output. This result is sensitive to the elasticity of substitution between home and foreign goods. When we calibrate our benchmark model for a lower trade elasticity (by setting $\eta = 0.5$), we obtain counter-cyclical net exports, and cross country correlation of output is higher than that of consumption. Results from using different levels of import elasticity in the benchmark model are reported in Table 6. We observe higher exchange rate volatility with lower trade elasticity. Net exports become more volatile for higher levels of trade elasticity.

Aside from parametrization, abstracting from capital is also an important influence on our results. Countercyclical trade flucututations reflect in large part on the dynamics of capital formation: expansions are associated with investment booms financed by borrowing from international capital markets. Since we assume labor is the only production input, moments of net exports are hard to capture with our model. Overall, our results show that introducing inattentive consumers to a standard open economy model fits the data better in many dimensions.

3.4. Backus–Smith correlation with attentive producers and persistent real shocks

In this study, we report the quantitative results of the models with frictions on the producer side. This approach enables us to compare the results with other studies[40] building on models with nominal rigidities. We observe the improvement to address international business cycle dynamics by introducing consumer inattentiveness. Our model provides a channel to reduce the Backus–Smith correlation through the forecast errors of inattentive consumers,[41] but decline in the correlation is small under the benchmark model. In this section, we focus on the class of models with attentive producers to

[40] See Chari et al. (2002).
[41] Equation 35 quantitatively elaborates this channel.

further investigate the dynamics driving the Backus–Smith correlation. We discuss the results on Backus–Smith correlation with the benchmark model below. Then, we present a set of results with attentive producers and persistent real shocks.

3.4.1. *Discussion of results on Backus–Smith correlation with the benchmark model*

Structure of the price-setting block of the benchmark model is one of the reasons for the small decline in the Backus–Smith correlation. If a producer updated her information set *j* periods ago, she sets the price as $E_{t-j}p_t$. This price is in the information set of consumers who updated their information set *j* periods ago or in the later periods. Overall, this fact significantly reduces the size of forecast errors by the consumers. Since forecast errors are smaller, the effect of consumer inattentiveness on Backus–Smith correlation is dampened.

Another important factor which determines the impact of consumer inattentiveness on the Backus–Smith correlation is the persistence[42] of shock processes. We conduct the following exercise to understand how shock persistence affects the size of forecast errors. We focus on the forecast errors on the level of productivity and calculate the population weighted forecast error variance. To simplify the analysis, we assume that level of productivity is the only observable variable for the agents. Using the population weights of information cohorts, and $E_{t-i}A_t = \rho_A^i A_{t-i}, \forall i \geq 0$, we can define the forecast error on the productivity level as

$$\tilde{f}_t^A = (1-\delta)[A_t - A_t] + (1-\delta)\delta[A_t - \rho_A A_{t-1}] + (1-\delta)\delta^2[A_t - \rho_A^2 A_{t-2}] + (1-\delta)\delta^3[A_t - \rho_A^3 A_{t-3}] + \ldots + (1-\delta)\delta^j[A_t - \rho_A^j A_{t-j}] + \ldots \tag{36}$$

Some algebra and substitutions yield the following expression,

$$\tilde{f}_t^A = (1-\delta)\sum_{i=1}^{\infty}\delta^i \sum_{j=0}^{i-1}\rho_A^j \epsilon_{A,t-j} \tag{37}$$

Variance of forecast errors is,

$$var\left(\tilde{f}^A\right) = (1-\delta)^2 \sum_{i=1}^{\infty}\delta^{2i}\sum_{j=0}^{i-1}\rho_A^{2j}\sigma_A^2 \tag{38}$$

This expression shows that forecast error variance of productivity level is increasing in the persistence of the productivity process.

This exercise on the level of productivity implies that more persistence in the productivity process leads to a larger forecast error variance. Larger forecast error variance with more persistent shocks can potentially lead to a more pronounced impact of consumer inattentiveness on the correlation of real exchange rate and relative consumption.

These observations motivate us to re-investigate our results with attentive producers and more persistent productivity processes. We also consider trade elasticity as a key parameter during this re-examination, taking into account the reported sensitivities in the literature[43] and differing views[44] on the level of trade elasticity.

[42] The literature shows that persistence of productivity shocks play a key role on the quantitative ability of international business cycle models to generate strong wealth effects which helps to address the Backus–Smith puzzle. Benigno and Thoenissen (2008) and Corsetti et al. (2008b) are examples of this approach. However, the mechanism outlined in this paper is quite different from these studies. The forecast error channel is more pronounced when shocks are more persistent.

[43] See Corsetti et al. (2008b) and Benigno and Thoenissen (2008).

[44] More disaggregate analyses find higher elasticities. Furthermore, time series analyses generally find lower elasticities relative to cross-sectional studies and long-run estimates are higher than short-run estimates.

Table 7
Backus–Smith correlation and real exchange rate volatility with attentive producers.

	Attentive consumers ($\delta = 0$)	Inattentive consumers ($\delta = 0.5$)	Inattentive consumers ($\delta = 0.75$)
Backus–Smith correlation			
Trade elasticity			
$\eta = 0.5$	0.99	0.83	0.70
$\eta = 1.5$	1.00	0.98	0.77
$\eta = 5$	0.99	0.86	0.64
Real exchange rate volatility			
Trade elasticity			
$\eta = 0.5$	2.92	3.22	5.84
$\eta = 1.5$	1.35	1.35	2.87
$\eta = 5$	0.61	0.69	1.24

Notes: All series are logged and HP-filtered. We report the correlation of relative consumption and real exchange rate, and standard deviation of real exchange rates (relative to output). Data display a correlation of –0.15 and standard deviation ratio is 4.47. Monetary shock volatilities are set to zero, $\sigma_R = \sigma_R^* = 0$ and we keep the productivity shock volatilities constant, $\sigma_A = \sigma_A^* = 0.7$. Producers are assumed to be attentive ($\theta = 0$). Persistence of real shocks are kept at the benchmark level ($\rho_A = \rho_A^* = 0.95$).

3.4.2. Results with attentive producers and persistent real shocks

We report Backus–Smith correlations for an interval[45] of trade elasticity in Fig. 3. We observe that a negative Backus–Smith correlation can be achieved with inattentive consumers for plausible levels of trade elasticity when the shocks are persistent.

Top panel of Fig. 3 reports Backus–Smith correlations obtained from the models with attentive consumers ($\delta = 0$) and inattentive consumers ($\delta = 0.75$) where shock persistence is at the benchmark level ($\rho_A = \rho_A^* = 0.95$). Results show that forecast errors stemming from consumer inattentiveness have a limited impact for this case. Table 7 reports Backus–Smith correlations and real exchange rate volatilities at the low ($\eta = 0.5$) and high ($\eta = 5$) ends of the interval considered for trade elasticity as well as the benchmark calibration value ($\eta = 1.5$) for varying degrees of consumer inattentiveness. Results indicate that model with attentive producers generates larger forecast errors compared to the benchmark model with inattentive producers, but Backus–Smith correlation is still in the positive territory when productivity shock persistence is at the benchmark level.

As suggested by the calculations on the productivity case, the impact of forecast errors become more pronounced when the shock persistence is higher.[46] Considering the lower panel in Fig. 3, where shock persistences are set to 0.994, imposing inattentive consumers to the model yields a substantial decline in the Backus–Smith correlation. The correlation is at the negative territory when trade elasticity level is either at the low end of macro estimates, or at higher values which are consistent with sectoral level estimates. Table 8 reports Backus–Smith correlations and real exchange rate volatilities when shocks are persistent.

Comparing the model with attentive consumers and inattentive consumers, results in Fig. 4, Table 7 and Table 8 show that introducing inattentive consumers to the model yields an increase in real exchange rate volatility for all values of trade elasticity and different values of shock persistence.

As a result, we observe negative levels of Backus–Smith correlation along with amplified values of real exchange rate volatility with our benchmark inattentive consumer model, when (i) productivity persistence is high, (ii) producers are attentive and (iii) trade elasticity is either at the low end of macro estimates, or higher values which are consistent with sectoral level estimates.

[45] We consider values between 0.5 and 5 for trade elasticity parameter (η). We set the standard deviation of monetary policy shocks to zero ($\sigma_R = \sigma_R^* = 0$) and standard deviations of productivity processes are kept constant at the benchmark calibration values through this exercise.

[46] Following Baxter (1995), we consider 0.994 as the highest value of productivity persistence for our exercise.

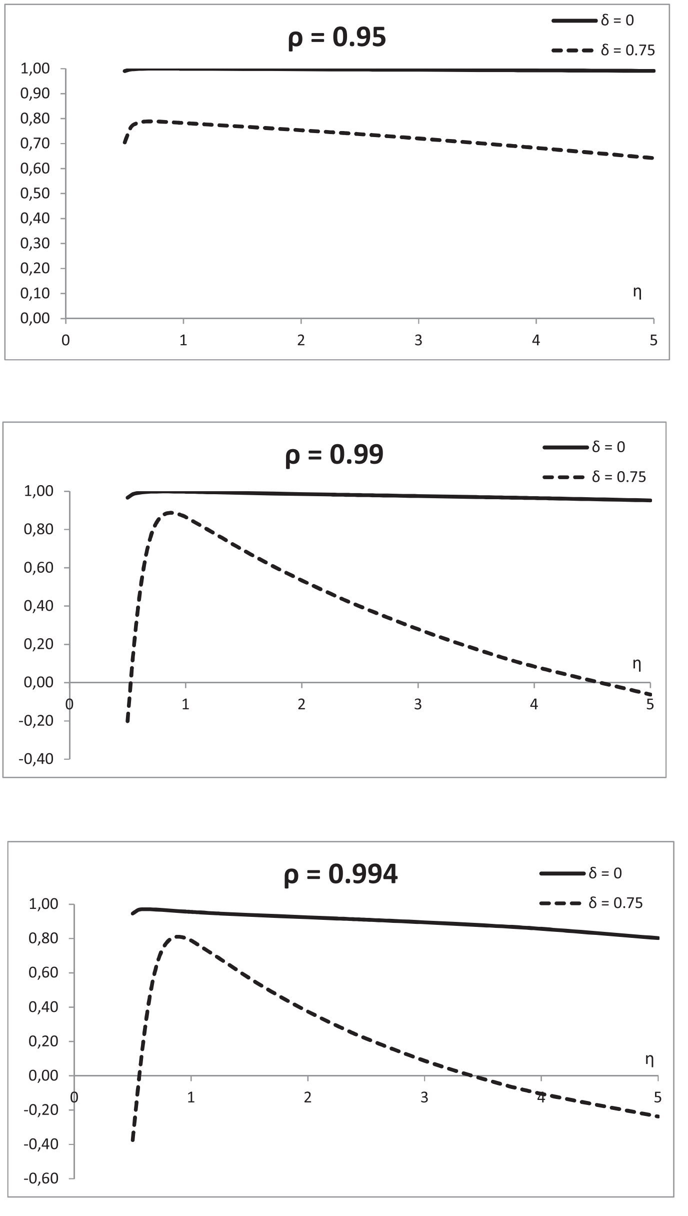

Fig. 3. Backus–Smith correlation with real shocks and attentive producers.

Considering the other attempts to explain Backus–Smith puzzle, strong wealth effects generated with asset market incompleteness and introducing non-tradable goods are key aspects of Benigno and Thoenissen (2008) and Corsetti et al. (2008b). Corsetti et al. (2008b) also emphasize the role of trade elasticity and persistence of the shock processes. Either a low level of trade elasticity or a combination of high trade elasticity and persistent productivity shocks is necessary to induce low risk sharing across countries. In both cases, asset market incompleteness allow traded goods productivity shocks to generate the positive wealth effect, which explains why relative consumption may increase when

Table 8
Backus–Smith correlation and real exchange rate volatility: persistent real shocks and attentive producers.

	Attentive consumers ($\delta = 0$)	Inattentive consumers ($\delta = 0.5$)	Inattentive consumers ($\delta = 0.75$)
Backus–Smith correlation			
Trade elasticity			
$\eta = 0.5$	0.95	–0.04	–0.38
$\eta = 1.5$	0.94	0.68	0.57
$\eta = 5$	0.80	0.11	–0.24
Real exchange rate volatility			
Trade Elasticity			
$\eta = 0.5$	6.33	6.55	8.65
$\eta = 1.5$	0.90	1.75	2.28
$\eta = 5$	0.20	1.03	1.29

Notes: All series are logged and HP-filtered. We report the correlation of relative consumption and real exchange rate, and standard deviation of real exchange rates (relative to output). Data display a correlation of -0.15 and standard deviation ratio is 4.47. Monetary shock volatilities are set to zero, $\sigma_R = \sigma_R^* = 0$ and we keep the productivity shock volatilities constant, $\sigma_A = \sigma_A^* = 0.7$. Producers are assumed to be attentive ($\theta = 0$). Persistence of productivity shocks are set to $\rho_A = \rho_A^* = 0.994$.

the real exchange rate appreciates. When we closely examine the results from Benigno and Thoenissen (2008) and Corsetti et al. (2008b), we observe that while being successful to generate negative values for Backus–Smith correlation, volatility of international prices, such as real exchange rate and terms of trade, remain at very low levels.

The mechanism proposed in this study is different and relies on the forecast errors generated by consumer inattentiveness. Regarding the persistence of shocks, we show that the impact of consumer inattentiveness on the Backus–Smith correlation is more pronounced when the productivity shocks are more persistent. Moreover, our results show that introducing inattentive consumers also generates more volatile exchange rates through a mechanism which resembles limited asset market participation models.

4. Discussion and sensitivity analysis

We examine the sensitivity of our results under alternative specifications, and conduct some exercises which can provide insight into further improvement of model results in this section. First, we report the persistence of output, consumption and real exchange rate under different monetary policy rule specifications. We present peak points of impulse responses to a monetary policy shock. A sensitivity analysis on the real exchange rate volatility where we consider changes in other model parameters is presented in this section. We also include the results with habit formation and attentive consumers to emphasize the distinction from assuming inattentiveness on the consumer side. We show that real exchange rate volatility declines as we increase the level of habit formation.

4.1. Monetary policy specification

We examine the role of monetary policy specification by changing the parameters of our benchmark monetary policy rule. We report the results on the persistence and peak points of impulse responses to a monetary policy shock in Table 9. We observe that these results are highly sensitive to the inertia in the monetary policy. As the inertia in the monetary policy increases, the model generates higher persistence in the output, consumption and real exchange rates. Peak point of real exchange rate response remains to be on impact, but output and consumption impulse responses exhibit a more pronounced hump. A more passive monetary policy (lower ψ_π) delays the peak point of output response by one period, but we do not see a substantial change in the persistence of output, consumption and real exchange rate. On the other

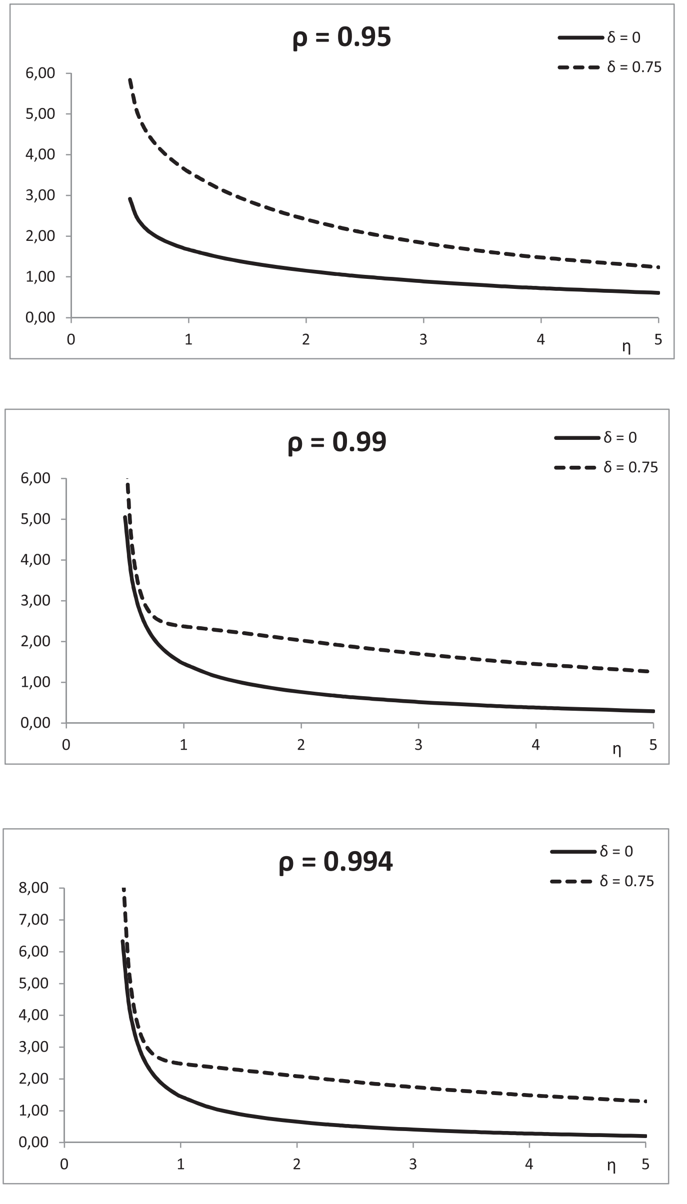

Fig. 4. Real exchange rate volatility with real shocks and attentive producers.

hand, as the interest rate becomes more responsive to the output fluctuations (higher ψ_y), we observe a decline in the persistence of output, consumption and real exchange rate.

We report the results on the real exchange rate volatility under different monetary policy rules in Table 10. We observe that real exchange rate volatility increases as the monetary policy is more responsive (higher ψ_y) to output movements. We find that real exchange rate volatility is amplified as we impose inattentiveness on the consumer side and this result is robust to different monetary policy rule specifications.

Table 9
Monetary policy specification and persistence.

	$\rho(y)$	$\rho(c)$	$\rho(rer)$	Peak(y)	Peak(c)	Peak(rer)
$\rho_R = 0.85, \psi_\pi = 1.5, \psi_\pi = 0.5$	0.84	0.84	0.59	2	2	1
$\boldsymbol{\rho_R = 0.75}, \psi_\pi = 1.5, \psi_y = 0.5$	0.78	0.77	0.51	2	2	1
$\boldsymbol{\rho_R = 0.95}, \psi_\pi = 1.5, \psi_y = 0.5$	0.90	0.90	0.70	4	4	1
$\rho_R = 0.85, \boldsymbol{\psi_\pi = 1.01}, \psi_y = 0.5$	0.85	0.85	0.61	3	2	1
$\rho_R = 0.85, \boldsymbol{\psi_\pi = 2}, \psi_y = 0.5$	0.84	0.83	0.59	2	2	1
$\rho_R = 0.85, \psi_\pi = 1.5, \boldsymbol{\psi_y = 0}$	0.88	0.87	0.65	3	3	1
$\rho_R = 0.85, \psi_\pi = 1.5, \boldsymbol{\psi_y = 1}$	0.81	0.81	0.56	2	2	1

Notes: All series are logged and HP-filtered. Output, consumption and real exchange rate persistence in the data are 0.89, 0.90 and 0.85, respectively. We also report the peak points of output, consumption and real exchange rate to a home monetary shock. Benchmark sticky information model with inattentive consumers and producers is calibrated to match the standard deviation of HP-filtered US output. We set $\delta = 0.75$ and $\theta = 0.75$. Top row presents results with the benchmark Taylor rule. Parameter values changed for this exercise are marked with bold font in the following rows.

Table 10
Monetary policy specification and real exchange rate volatility.

	Attentive consumers ($\delta = 0$)	Inattentive consumers ($\delta = 0.75$)
$\rho_R = 0.85, \psi_\pi = 1.5, \psi_\pi = 0.5$	2.32	4.66
$\boldsymbol{\rho_R = 0.75}, \psi_\pi = 1.5, \psi_y = 0.5$	2.26	5.35
$\boldsymbol{\rho_R = 0.95}, \psi_\pi = 1.5, \psi_y = 0.5$	2.45	3.77
$\rho_R = 0.85, \boldsymbol{\psi_\pi = 1.01}, \psi_y = 0.5$	2.75	4.61
$\rho_R = 0.85, \boldsymbol{\psi_\pi = 2}, \psi_y = 0.5$	2.26	4.67
$\rho_R = 0.85, \psi_\pi = 1.5, \boldsymbol{\psi_y = 0}$	2.15	4.15
$\rho_R = 0.85, \psi_\pi = 1.5, \boldsymbol{\psi_y = 1}$	2.43	4.96

Notes: All series are logged and HP-filtered. We report the ratio of standard deviation of the real exchange rate relative to the output volatility. This ratio is 4.47 in the data. We use the benchmark sticky information model with inattentive consumers and producers. Models are calibrated to match the standard deviation of HP-filtered US output. Top row presents results with the benchmark Taylor rule. Parameter values changed for this exercise are marked with bold font in the following rows.

4.2. Robustness of exchange rate volatility result

We report the volatility of real exchange rates under alternative specifications in Table 11. Although there are some changes in the other business cycle properties, we observe that real exchange rate volatility amplification result survives under different specifications regarding the degree of information stickiness on the producer side, the production function, the level of import share in preferences and the level of trade elasticity.

Finally, we introduce external habit formation into our utility function to emphasize the difference from sticky information assumption on the consumer side. We show that habit formation and consumer inattentiveness have opposite effects on real exchange rate volatility, although both slow down the response of aggregate consumption to shocks. Marginal utility of consumption with habit formation is given by $\hat{\lambda}^c = -\sigma(\hat{c}_t - h\hat{c}_{t-1})$. We report the results for varying degrees of habit formation. As the degree of habit increases, we observe that marginal utilities become less volatile. Numerical results are reported in Table 12, showing that habit formation reduces the volatility of real exchange rates.

5. Conclusion

We present and study the properties of a model which imposes infrequent information updating for consumers and producers. Comparing a sticky price and sticky information model with attentive consumers, we find that the form of frictions on the producer side has a small effect for the moments

Table 11
Real exchange rate volatility under alternative specifications.

	Attentive consumers ($\delta = 0$)	Inattentive consumers ($\delta = 0.75$)
Benchmark model	2.32	4.66
CRS production function ($\zeta = 1$)	2.37	3.84
Lower trade elasticity ($\eta = 0.5$)	2.18	4.91
Higher trade elasticity ($\eta = 5$)	2.76	4.05
Attentive producers ($\theta = 0$)	1.36	2.87
Lower rigidity on producers ($\theta = 0.5$)	2.36	4.19
Higher import share ($\gamma = 0.12$)	2.67	4.54

Notes: Standard deviation of real exchange rates (relative to output) under alternative specifications are reported. This ratio is 4.47 in the data. Benchmark sticky information model (IC-IP, with inattentive consumers and producers) is calibrated to match the standard deviation of HP-filtered US output for varying degrees of information stickiness on the consumer side (δ). Average duration of information updating is $\frac{1}{1-\delta}$. For the benchmark model; (i) production function is decreasing returns to scale with $\zeta = 2/3$, (ii) trade elasticity (η) is 1.5, (iii) degree of information stickiness on the producer side (θ) is 0.75, and (iv) import share (γ) is 0.06.

Table 12
Real exchange rate volatility with habit formation.

	h = 0	h = 0.5	h = 0.75
AC-SP model	2.22	1.60	1.32
AC-IP model	2.32	1.72	1.46

Notes: Standard deviation of real exchange rates (relative to output) under varying degrees of habit formation are reported. This ratio is 4.47 in the data. Models are calibrated to match the standard deviation of HP-filtered US output. The degree of information/price stickiness on the producer side(θ) is set to 0.75. Consumers are assumed to be attentive. AC-SP model introduces sticky prices and the AC-IP model features inattentive producers. Risk aversion is set to 2.

which describe the international business cycles. On the other hand, imposing sticky information on the consumer side provides a new mechanism to address the exchange rate volatility without setting the degree of risk aversion too high.

Introducing inattentive consumers exhibits a similar mechanism to the limited participation models of asset pricing literature. In this framework, exchange rates are linked to the relative consumption of the subset of consumers who updated their information set in the current period. Their consumption is more volatile than aggregate consumption because inattentive consumers cannot adjust their consumption plans to the current shocks. As the frequency of information updating falls, we observe more volatility in their consumption. This increases the volatility of marginal utilities of adjusting consumers, resulting in more volatile exchange rates. Setting the degree of risk aversion at a consensus value, where the intertemporal elasticity of substitution is 0.5, an average duration of 4 quarters between information updates can account for the exchange rate volatility observed in the data.

Sticky information on the consumer side brings the model closer to the data in other dimensions as well. We observe hump shaped impulse responses to monetary shocks, which increase the persistence of output, consumption and employment. We observe that these hump shapes in impulse response functions are more pronounced when inertia in the monetary policy is high.

The decline in the correlation of relative consumption and real exchange rates due to the forecast errors of inattentive consumers is small under the benchmark model. We show that size of forecast errors depends on the assumption of inattentive producers and persistence of productivity shocks. After identifying the reasons for this result, we reinvestigate our results with attentive producers and persistent productivity shocks. We show that the correlation is in the negative territory with inattentive consumers when trade elasticity is set to values at the low end of macro estimates or at higher values consistent with sectoral estimates of trade elasticity.

Possible extensions to improve the fit of the model are introducing capital into the production function and having non-tradable goods in the consumption basket. Furthermore, imposing staggered information updating and solving for the level of net foreign assets can allow us to examine the implications for current account dynamics. These extensions might be useful to improve the model's performance, and reinvestigate some policy questions in the field of international finance.

Acknowledgements

I would like to thank the editor, Menzie Chinn, and anonymous referees for their comments and suggestions. Feedback from Mark Aguiar, Mark Bils, Yongsung Chang, Hande Kucuk-Yesil and Alan Stockman is gratefully acknowledged. I would also like to thank seminar participants at the Central Bank of Turkey, Federal Reserve Board of Governors, Magyar Nemzeti Bank, Sabanci University, T.O.B.B. University, University of Rochester, 2012 Computing in Economics and Finance conference by Society of Computational Economics and 2012 European Economic Association meetings for discussions and comments. The views expressed in this paper are those of the author and do not necessarily represent the official views of the Central Bank of the Republic of Turkey.

Appendix. Data

Data are quarterly. Our sample period is between 1973Q1 and 2009Q4. Data sources are the FRED2 database from the Federal Reserve Bank of St. Louis, Area Wide Model (AWM) of the European Central Bank, OECD Economic Outlook and International Financial Statistics (IFS) by the IMF. All series are logged and HP-filtered. The ratio of net exports to GDP is filtered without using a log transformation.

US Output Real GDP series is obtained from GDPC96-Fred2.

Euro Area Output YER-AWM series is used for real output.

US Price Index Quarterly series based on Consumer Price Index for All Urban Consumers CPIAUCSL-Fred2. Monthly series are converted to quarterly by arithmetic averaging.

Euro Area Price Index Based on harmonized index, HICP-AWM.

US Consumption Real consumption series is obtained from PCECC96-Fred2.

Euro Area Consumption PCR-AWM series is used for real consumption.

US Employment . CE16OV-Fred2 series for civilian employment.

Euro Area Employment LNN-AWM series for employment.

Exchange Rates Prior to 1999, fixed conversion rates between the national currency units and the Euro are weighted[47] by real GDP shares. Data source is the IFS database, and the calculation gives an artificial bilateral exchange rate. The Euro-Dollar exchange rate is used after 1999. Prior to 1999, we define the nominal exchange rate as $E_t \equiv \Pi_{i=1}^{n}(f_i E_{i,t})^{w_i}$. We calculate the real exchange rate as $RER_t = \frac{E_t P_{EU}}{P_{US}}$.

US Net Exports Ratio of difference between exports (EXPGSC96) and imports (IMPGSC96) to real GDP.

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[47] The weights are Austria = 0.03, Belgium = 0.036, Finland = 0.017, France = 0.201, Germany = 0.283, Greece = 0.025, Ireland = 0.015, Italy = 0.195, Luxembourg = 0.003, The Netherlands = 0.06, Portugal = 0.024, Spain = 0.111.

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