Scarring effects of trade policy uncertainty

Dmitry Brizhatyuk, Fabio Ghironi*

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Abstract

This paper studies the macroeconomic consequences of trade policy uncertainty with an emphasis on its productivity growth effects. We build a small open economy model with nominal rigidity, endogenous growth through the introduction of new products, and time-varying volatility of domestic import tariffs. Import tariff uncertainty shocks act as aggregate supply shocks. They cause a temporary improvement of the current account along with the real exchange rate appreciation in the medium run. In addition, an increase in import tariff uncertainty causes a sharp decline in the introduction of new intermediate products, which is detrimental to productivity growth and prolongs the effect of the shock. We show that endogenous risk premia in equity and bond markets is the key channel transmitting the shock to the broader economy and study role monetary policy in shaping it.

JEL Codes: E32, F13, F41, O40

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*First draft: May 2020. Brizhatyuk: Moody's Analytics, One Canada Square, Canary Wharf, London E14 5AB, UK or dmitry.brizhatyuk@gmail.com, http://dbrizhatyuk.github.io, Ghironi: Department of Economics, University of Washington, Savery Hall, Box 353330, Seattle, WA 98195, USA or ghiro@uw.edu, http://faculty.washington.edu/ghiro.

1 Introduction

The recent surge in the global trade policy uncertainty driven by the US protectionism is unprecedented (figure 1). The average level of the trade policy uncertainty index of Baker et al. (2016) since 2016 has increased by around 500% from its average level in 2000-2015. During the same period, the average contribution of trade policy uncertainty to the US stock market volatility has increased more than five-fold from 2% to 11%, according to Baker et al. (2019). Policymakers, investors, and executives routinely cited the trade policy uncertainty as one of the biggest threats to the economy at the time.[1] The research on aggregate effects of economic uncertainty that followed the seminal contribution of Bloom (2009) supports this point of view. Empirically, economic uncertainty, various measures of which are procyclical and fluctuate considerably over time, appears to be a quantitatively important driver of business cycles (figure 2).[2]

This paper contributes to this literature by studying the effects of import tariff uncertainty on macroeconomic fluctuations. To that end, we develop a small New Keynesian open-economy model deviating from the standard setting in two ways. First, import tariff is subject not only to standard level shocks but also to second-moment shocks (uncertainty shocks). To assess the effect of uncertainty shocks, we solve the model by perturbation methods based on a third-order approximation of its equilibrium conditions. Second, total factor productivity (TFP) in the model economy grows endogenously through forward-looking investment in the introduction of new products financed by equity. This feature provides a channel through which temporary uncertainty shocks can generate persistent effects on economic activity. The empirical literature indeed supports this relation. Specifically, the seminal contribution by Ramey and Ramey (1995) points out the robust negative relation between macroeconomic volatility and growth.[3] To further motivate this modeling choice, we estimate a quarterly US VAR that includes the following seven variables: a measure of economic uncertainty, real GDP, TFP, R&D spending, trade balance to GDP, real exchange rate, and the S&P 500 stock market index. As common in the literature, we use the CBOE S&P 100 volatility index (VXO) as a proxy to economic uncertainty and identify the uncertainty shock by short-run restrictions ordering this variable

[1] For instance, see the World Economic Outlook update by IMF (2019): "[G]lobal trade, investment, and output remain under threat from policy uncertainty, as well as from other ongoing trade tensions. Failure to resolve differences and a resulting increase in tariff barriers would lead to higher costs of imported intermediate and capital goods and higher final goods prices for consumers. Beyond these direct impacts, higher trade policy uncertainty and concerns over escalation and retaliation would lower business investment, disrupt supply chains, and slow productivity growth."

[2] See also Bloom et al. (2018), Gilchrist et al. (2014), and Jurado et al. (2015), among others.

[3] See also Aghion et al. (2010), Badinger (2010), Martin and Ann Rogers (2000), and Mobarak (2005), among others.

first. Figure 3 shows the responses to a stock market volatility shock. Although the increase in volatility is very short-lived and subsides after less than 10 quarters the corresponding decline in the GDP level is very persistent and about half of it can be attributed to the decline in the total factor productivity. Moreover, the shock is associated with the improvement of the trade balance and appreciation of the real exchange rate.

We use the model as a laboratory for an in-depth study of the effects and propagation channels of domestic import tariff uncertainty shocks. Simulations suggest that import tariff uncertainty shocks work as aggregate supply shocks: they are contractionary and inflationary. In the short run, they cause the current account to improve, whereas the real exchange rate depreciates on impact and then appreciates in the medium-run. Despite the uncertainty shock being transitory, it leaves a persistent scarring effect on the level of output and consumption by endogenously slowing down productivity growth. The results are robust to the type of nominal rigidity, or lack of thereof.

Our exercise highlights the crucial role of endogenous risk premia in shaping the dynamics. An increase in import tariff uncertainty causes foreign-currency bonds to become riskier relative to domestic bonds. As a result, the demand for foreign-currency bonds decreases, and the current account temporarily improves. A similar logic applies product creation financed by selling equity to households. The uncertainty shock increases the equity risk premium leading to a fall in the stock market value and a decrease in productivity-enhancing investment.

We conclude exploring the role of monetary policy in shaping the effects of the shock. The conduct of monetary policy affects the dynamics mainly through influencing the stochastic properties of firm equity returns. The Taylor rule with more focus on inflation stabilization, as opposed to output stabilization, introduces more equity risk and amplifies the productivity loss associated with the shock. Doing away with independent monetary policy and pegging the nominal exchange rate to the foreign currency eliminates this additional risk and dampens the long-run effect of the shock.

This paper relates to several strands of literature. First, we contribute to the literature on the effects of protectionism and trade policy uncertainty.[4] Second, we contribute to the literature that studies the effects of uncertainty shocks on economic activity.[5] Finally, we contribute to the literature on the relation between business cycles and endogenous growth.[6]

[4] Barattieri et al. (2018), Caldara et al. (2020), Crowley et al. (2018), Crowley et al. (2020), Handley and Limão (2017).

[5] Among others, see Fernández-Villaverde et al. (2011) and Ghironi and Ozhan (2020) who study uncertainty shocks in an open-economy environment, and Basu and Bundick (2017), Born and Pfeifer (2014), Fernández-Villaverde et al. (2015), Leduc and Liu (2016) who study uncertainty shocks in an closed-economy environment.

[6] Bonciani and Oh (2019), Comin and Gertler (2006), Comin et al. (2014), Queralto (2019)

Two papers are the closest to ours. Bonciani and Oh (2019) also consider the relation between uncertainty shocks and endogenous growth. Unlike the present work, their study focuses on the role of endogenous growth in amplifying the effects of demand uncertainty shocks in a closed-economy model with Epstein-Zin preference. Caldara et al. (2020) also study imports tariff uncertainty shocks using a dynamic general equilibrium model. This paper compliment theirs by focusing on the risk-premium channel of uncertainty shocks, its effect on product creation, and their interactions with monetary policy.

The rest of the paper is organized as follows. Section 2 lays down the model. Section 3 discusses calibration, simulation technique, and baseline results. Section 4 explores the main channels of the transmission mechanism of import tariff uncertainty shocks. Section 5 concludes.

2 The model

In this section we develop a small open economy model that we use to study macroeconomic effects of import tariff uncertainty shocks. The model features nominal price and wage rigidity with exports prices set in the domestic currency. International financial markets are incomplete and the home economy borrows from the rest of the worlds in foreign currency. Finally, the economy features endogenous growth through introduction of new varieties of intermediate products as in Romer (1990) and Comin and Gertler (2006). Figure 4 summarizes the structure of the model. Below we describe in detail the problems facing agents in the model economy.

2.1 Households

The home economy is populated with households $h \in [0, 1]$, each of which consumes a basket of Home and Foreign goods, and supplies labor. International asset markets are incomplete, non-contingent nominal bonds denominated in Foreign currency $B_t^*(h)$ are the only internationally traded asset. Households also trade non-contingent nominal bonds denominated in Home currency $B_t(h)$, which are only traded domestically. To pin down the steady-state net foreign asset position and stationary responses of the economy to temporary shocks, we follow Turnovsky (1985) and assume a quadratic cost of adjusting Foreign bond holding $AC_t^{B^*}(h) = \frac{\psi_B}{2}\left(\frac{B^*(h)_{t+1}}{P_t^* N_t}\right)^2 N_t rer_t$ denominated in foreign consumption units.[7]

Households are implicit owners of all firms in the economy. In particular, at time t each

[7] Since the economy exhibits growth, the bond adjustment cost is scaled by the stock of intermediate products N_t, which determines the BGP growth rate.

household buys $\iota_{t+1}(h)$ shares in a mutual fund of $N_t + N_{et}$ existing intermediate firms at the price of v_t per share and receives dividend income, $d_t(h)$ on shares from the previous period. Entrants at time t start producing and paying dividends only in time $t+1$. In each period existing firms and entrants are subject to an exit shock with probability δ_N.

As in Erceg et al. (2000), each household exert monopolistic power over the imperfectly substitutable labor variety it supplies. Households set the nominal wage $W_t(h)$ subject to firms demand $L_t(h) = (W_t(h)/W_t)^{-\theta_L} L_t$ and the quadratic adjustment cost of adjusting the nominal wage $AC_t^W(h) = \frac{\psi_W}{2}\left(\frac{W_t(h)}{W_{t-1}(h)\Pi^W} - 1\right)^2 \frac{W_t(h)}{P_t} L_t(h)$, where $\psi_W \geq 0$ governs the degree of nominal wage rigidity and Π^W is the steady-state gross inflation rate.

A generic household h maximizes its intertemporal utility

$$\max_{\left\{\substack{C_{t+k}(h),\iota_{t+k+1}(h),W_{t+k}(h),\\ B_{t+k}(h),B^*_{t+k}(h)}\right\}_{k=0}^{\infty}} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}(h), L_{t+k}(h))$$

subject to the following period budget constraint and firms labor demand:

$$C_t(h) + \iota_{t+1}(h)v_t(N_t + N_{et}) + \frac{B_{t-1}(h)}{P_t}(1+i_t) + \frac{\varepsilon_t B^*_{t-1}(h)}{P_t}(1+i^*_t) + AC_t^{B^*}(h) + AC_t^W(h) =$$

$$= \frac{W_t(h)}{P_t} L_t(h) + \iota_t(h)(v_t + d_t)N_t + \frac{B_t(h)}{P_t} + \frac{\varepsilon_t B^*_t(h)}{P_t} + d^w_t(h) + T(h)$$

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\theta_L} L_t,$$

where i_t and i^*_t are Home and Foreign nominal interest rates, $d^w_t(h)$ are profits from owing domestic wholesale firms, and T is the lump-sum rebate of the collected import tariffs and bond holding adjustment costs, which the households takes as given.

In order to simplify the notation, we anticipate symmetry of the equilibrium across households and omit the index h below. First order conditions with respect to Home and Foreign bonds imply:

$$\mathbb{E}_t \left(\beta_{t,t+1} \frac{1+r_t}{\Pi_{t+1}}\right) = 1 \tag{1}$$

$$\mathbb{E}_t \left(\beta_{t,t+1} \frac{rer_{t+1}}{rer_t} \frac{1+r^*_t}{\Pi^*_{t+1}}\right) = 1 - \psi_B \frac{B^*_t}{P^*_t N_t} \tag{2}$$

where $\beta_{t,t+1} = \beta \frac{U'_{C_{t+1}}}{U'_{C_t}}$ is the households stochastic discount factor and $rer_t = \frac{\epsilon_t P^*_t}{P_t}$ is the real exchange rate. Equity demand following from the first order condition with respect to share holdings ι_{t+1} is:

$$v_t = (1-\delta)\mathbb{E}_t \left[\beta_{t,t+1}(d_{t+1} + v_{t+1})\right] \tag{3}$$

When iterated forward, this expression implies that the present firm value equals to its expected discounted profit stream, adjusted for the fact that in each period a firm faces an exogenous probability of exiting the market δ: $v_t = \mathbb{E}_t \sum_{k=1}^{\infty} \beta_{t,t+k}(1-\delta)^k d_{t+k}$.

Finally, households monopolistic power in labor supply and the nominal wage adjustment cost imply a time-varying markup μ_t^W that introduces a wedge between the real wage and the marginal rate of substitution between consumption and labor:

$$\frac{W_t}{P_t} = \mu_t^W \frac{U'_{L_t}}{U'_{C_t}} \tag{4}$$

$$\mu_t^W = \frac{\theta_L}{(\theta_L - 1)\left(1 - \frac{\psi_W}{2}\left(\frac{\Pi_t^W}{\Pi^W} - 1\right)^2\right) + \psi_W\left(\frac{\Pi_t^W}{\Pi^W} - 1\right)\frac{\Pi_t^W}{\Pi^W} - \psi_W \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^W}{\Pi^W} - 1\right)\frac{\Pi_{t+1}^{W\,2}}{\Pi^W}\frac{L_{t+1}}{L_t}\right]} \tag{5}$$

2.2 Production

2.2.1 Final good basket

The final consumption-investment basket is a composite of Home and Foreign goods:

$$Y_t = \left[a^{\frac{1}{\theta}}(Y_t^H)^{\frac{\theta-1}{\theta}} + (1-a)^{\frac{1}{\theta}}(Y_t^F)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}},$$

where $Y_t^H = \left(\int_0^1 Y_t^H(j)^{\frac{\theta_H-1}{\theta_H}} dj\right)^{\frac{\theta_H}{\theta_H-1}}$ is the aggregate Home good sold domestically, $Y_t^F = \left(\int_0^1 Y_t^F(i)^{\frac{\theta_H-1}{\theta_H}} di\right)^{\frac{\theta_H}{\theta_H-1}}$ is the aggregate Foreign good, $a > 0.5$ is the home-bias parameter, θ governs the elasticity of substitution between Home and Foreign goods, and θ_H governs the elasticity of substitution between varieties of these goods. Let P_t^H denote the domestic price of the aggregate Home good, P^F denote the dock price of the aggregate Foreign good denominated in the domestic currency, and τ_t denote the domestic import tariff. The intratemporal optimization problem associated with the above basket then implies the aggregate price index $P_t = \left[a(P_t^H)^{1-\theta} + (1-a)(\tau_t P_t^F)^{1-\theta}\right]^{\frac{1}{1-\theta}}$, and demands for Home and Foreign goods are $Y_t^H = a\left(\frac{P_t^H}{P_t}\right)^{-\theta} Y_t$, and $Y_t^F = (1-a)\left((1+\tau_t)\frac{P_t^F}{P_t}\right)^{-\theta} Y_t$ respectively.

From now on, we denote foreign variables with a star and use lower-case price indices to denote relative prices, i.e. $p_t^H = \frac{P_t^H}{P_t}$. Let ϵ_t be the nominal exchange rate, then $rer_t = \frac{\epsilon P_t^*}{P_t}$ is the real exchange rate. Also assume that the law of one price (LOP henceforth) holds, i.e.

$P_t^F = \epsilon_t P_t^{F^*}$. Demand functions and the aggregate price index can be simplified as follows:

$$Y_t^H = a(p_t^H)^{-\theta} Y_t \tag{6}$$

$$Y_t^F = (1-a)(\tau_t p_t^{F^*} rer_t)^{-\theta} Y_t \tag{7}$$

$$a(p_t^H)^{1-\theta} + (1-a)(\tau_t p_t^{F^*} rer_t)^{1-\theta} = 1 \tag{8}$$

2.2.2 Wholesalers

Each monopolistically competitive wholesale firm $j \in (0,1)$ purchases homogeneous production sector good F_t at the price P_t^G and produces a differentiated variety sold to both home and foreign markets. Prices are sticky in the currency of the producer. That is, wholesalers set prices in domestic currency for the home of foreign markets, $P_t^H(j)$ and $P_t^{H^{*h}}(j)$ respectively, subject to nominal frictions. Following Rotemberg (1982), prices are sticky due to the presence of a quadratic price adjustment cost $AC_t^P(j) = \frac{\psi_P}{2}\left(\frac{P_t^H(j)}{P_{t-1}^H(j)\Pi^H} - 1\right)^2 \frac{P_t^H(j)}{P_t} Y_t^H(j)$ for the domestic market and $AC_t^{P^*}(j) = \frac{\psi_{P^*}}{2}\left(\frac{P_t^{H^{*h}}(j)}{P_{t-1}^{H^{*h}}(j)\Pi^{H^*}} - 1\right)^2 \frac{P_t^{H^{*h}}(j)}{P_t} Y_t^{H^*}(j)$ for the foreign market. Adjustment costs are paid in units of the aggregate basket, parameters $\psi_P \geq 0$ and $\psi_{P^*} \geq 0$ govern the degree of nominal rigidity, Π^H and Π^{H^*} are steady-state home-good inflation rates for the home and foreign markets.

Each wholesaler sets prices for the domestic and foreign markets to maximize the future expected stream of its period profits $d_t^w(j)$:

$$\max_{\left\{\substack{P^H(j)_{t+k},\\ P^{H^{*h}}(j)_{t+k}}\right\}_{k=0}^{\infty}} \mathbb{E}_t \sum_{k=0}^{\infty} \beta_{t,t+k} \left[\frac{P_{t+k}^H(j)}{P_t} Y_{t+k}^H(j) + \frac{P_{t+k}^{H^{*h}}(j)}{P_t} Y_{t+k}^{H^*}(j) - \frac{P_{t+k}^G}{P_t} F_{t+k}(j) - AC_{t+k}(j) - \Gamma\right],$$

subject to demands $Y_t^H(j) = \left(P_t^H(j)/P_t^H\right)^{-\theta_H} Y_t^H$ and $Y_t^{H^*}(j) = \left(P_t^{H^*}(j)/P_t^{H^*}\right)^{-\theta_{H^*}} Y_t^{H^*}$, where the price for the foreign market is $P_t^{H^*} = P_t^{H^{*h}}(j)/\epsilon_t$; the resource constraint $Y_t^H(j) + Y_t^{H^*}(j) = F_t(j)$; and price adjustment costs $AC_t(j) = AC_t^P(j) + AC_t^{P^*}(j)$. To ensure zero steady state profit in this sector and rule out entry, I assume that production involves a fixed cost $\Gamma = \frac{1}{\theta_H}(p^H Y^H + p^{H^{*h}} Y^{H^*})$.

Conjecturing a symmetric equilibrium where all wholesale firms are alike, we drop the index j below. The optimal relative price on the domestic and the foreign markets is a time-varying markup over the real marginal cost p_t^G:

$$p_t^H = \mu_t^H p_t^G \tag{9}$$

$$p_t^{H^*} = \mu_t^{H^*} \frac{p_t^G}{rer_t} \tag{10}$$

where markups on the home and foreign markets are

$$\mu_t^H = \frac{\theta_H}{(\theta_H - 1)\left(1 - \frac{\psi_P}{2}\left(\frac{\Pi_t^H}{\Pi^H} - 1\right)^2\right) + \psi_P \frac{\Pi_t^H}{\Pi^H}\left(\frac{\Pi_t^H}{\Pi^H} - 1\right) - \psi_P \mathbb{E}_{\mathrm{t}}\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^H}{\Pi^H} - 1\right)\frac{\Pi_{t+1}^{H\,2}}{\Pi^H}\frac{Y_{t+1}^H}{Y_t^H}\right]} \tag{11}$$

$$\mu_t^{H^*} = \frac{\theta_{H^*}}{(\theta_{H^*} - 1)\left(1 - \frac{\psi_P}{2}\left(\frac{\Pi_t^{H^*}}{\Pi^{H^*}} - 1\right)^2\right) + \psi_{P^*} \frac{\Pi_t^{H^*}}{\Pi^{H^*}}\left(\frac{\Pi_t^{H^*}}{\Pi^{H^*}} - 1\right) - \psi_{P^*} \mathbb{E}_{\mathrm{t}}\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^{H^*}}{\Pi^{H^*}} - 1\right)\frac{\Pi_{t+1}^{H^*\,2}}{\Pi^{H^*}}\frac{Y_{t+1}^{H^*}}{Y_t^{H^*}}\right]} \tag{12}$$

When $\psi_p = 0$ wholesale prices are flexible and the markup is constant over the business cycle $\mu^H = \frac{\theta_H}{\theta_H - 1}$, and $\mu^{H^*} = \frac{\theta_{H^*}}{\theta_{H^*} - 1}$. Home good inflation for both home and foreign markets can be expressed as follows:

$$\Pi_t^H = \frac{P_t^H}{P_{t-1}^H} = \frac{p_t^H}{p_{t-1}^H}\Pi_t \tag{13}$$

$$\Pi_t^{H^*} = \frac{P_t^{H^*h}}{P_{t-1}^{H^*h}} = \frac{p_t^{H^*}}{p_{t-1}^{H^*}}\frac{rer_t}{rer_{t-1}}\Pi_t \tag{14}$$

2.2.3 Domestic producers

A representative firm in this perfectly competitive sector operates a production function that combines a unit mass of differentiated labor, $L_t = \left(\int_0^1 L_t(h)^{(\theta_L - 1)/\theta_L} dh\right)^{\theta_L/(\theta_L - 1)}$ and bundle of differentiated intermediate product $x_t(\omega) \in [0, N_t]$, $X_t = \left(\int_0^{N_t} x_t(\omega)^{(\theta_x - 1)/\theta_x} d\omega\right)^{\theta_x/(\theta_x - 1)}$:

$$F_t(L_t, X_t) = Z_t L_t^\alpha X_t^{1-\alpha} = Z_t L_t^\alpha \int_0^{N_t} x_t(\omega)^{1-\alpha} d\omega \tag{15}$$

For growth to be of labor-augmenting form, the elasticity of substitution between varieties of the differentiated intermediate input should equal the inverse of labor share $\theta_x = \frac{1}{\alpha}$. As described further, positive externalities in developing blueprints of intermediate goods generate balanced growth. Following Romer (1990) endogenous growth model, the expanding mass of intermediate products, N_t, brings about efficiency gains to diversity implied by the CES aggregator and increases the measured TFP.

Given input prices the representative firm maximizes its profit:

$$\max_{x_t(\omega),L_t}\left[\frac{P_t^G}{P_t}Z_tL_t^\alpha\int_0^{N_t}x_t(\omega)^{1-\alpha}d\omega-\int_0^{N_t}\frac{P_t^x(\omega)}{P_t}x_t(\omega)d\omega-\frac{W_t}{P_t}L_t\right]$$

Resulting input demands are the following:

$$\frac{W_t}{P_t}=p_t^G\alpha Z_tL_t^{\alpha-1}\int_0^{N_t}x_t(\omega)^{1-\alpha}d\omega \tag{16}$$

$$p_t^x(\omega)=p_t^G(1-\alpha)Z_tL_t^\alpha x_t(\omega)^{-\alpha}$$

In addition, the CES labor aggregator L_t implies demand for an individual labor variety of a standard form: $L_t(h)=\left(\frac{W_t(h)}{W_t}\right)^{-\theta_L}L_t$.

2.2.4 Intermediate good sector

The intermediate sector is populated with monopolistically competitive firms $\omega\in[0,N_t]$, each of which requires A^{-1} units of the aggregate final good to produce a unit of intermediate good. One should not take this setup literally. The correct interpretation of this formal description is that the forgone final good is never manufactured. The resources that would have been used to produce the forgone output are used instead to manufacture intermediate goods.

In order to simplify the notation, we anticipate symmetry of the equilibrium across intermediate firms and omit the index ω from now on. Each intermediate sector firm maximizes profit subject to production sector's demand:

$$\max_{\{P_{t+j}^x\}}\mathbb{E}_t\sum_{j=0}^{\infty}\beta_{t,t+1+j}\left[\frac{P_{t+j}^x}{P_{t+j}}x_{t+j}-\frac{P_{t+j}^H}{P_{t+j}}\frac{x_{t+j}}{A}\right]\quad \text{s.t.}\quad p_t^x=p_t^G(1-\alpha)Z_tL_t^\alpha x_t^{-\alpha}$$

From this problem it follows that the optimal quantity of a generic intermediate good, x_t, its price, p_t^x, and the firm's real profit, d_t, are the following:

$$x_t=\left(A(1-\alpha)^2Z_t/\mu_t^H\right)^{\frac{1}{\alpha}}L_t \tag{17}$$

$$d_t=\alpha p_t^x x_t=\frac{\alpha}{(1-\alpha)A}p_t^Hx_t \tag{18}$$

$$p_t^x=\frac{1}{1-\alpha}\frac{p_t^H}{A}$$

Positive profit in this sector motivates entry. To open a firm an entrepreneur needs to buy a blueprint for a new variety at the price of p_t^b from innovators, which is financed by selling equity shares to households. Free entry to this sector implies that in equilibrium firms value equals the blueprint price $v_t=p_t^b$

2.2.5 *Innovators*

The sector of innovators involves inventing blueprints for new types of intermediate goods. The sector is populated with the unbounded mass of potential innovators. Let S_t be the total innovation spending and ϕ_t^i be the innovators individual productivity parameter, which each innovator take as given. The individual production function blueprints of intermediate goods is then $N_{et}^i = \phi_t^i S_t^i$. However, the aggregate innovators productivity ϕ_t depends on the existing stock of knowledge, measured by the number of existing intermediate goods, N_t. As in Romer (1990), this knowledge spillover externality is responsible for the existence of the balanced growth path in the model. In line with Comin and Gertler (2006), I include a congestion externally $N_t^\rho S_t^{1-\rho}$ that allows to control for the aggregate elasticity of blueprints output with respect to innovation spending. The resulting aggregate innovators productivity is:

$$\phi_t = \phi \frac{N_t}{N_t^\rho S_t^{1-\rho}},$$

where $S_t = \int S_t^i di$. The aggregate production function of innovators is then $N_{et} = \phi N_t \left(\frac{S_t}{N_t}\right)^\rho$. Perfectly competitive innovators set the price of blueprints p_t^b to maximize their expected discounted stream of profit:

$$\max_{\{S_{t+j}^i\}_{j=0}^\infty} \mathbb{E}_t \sum_{j=0}^\infty \beta_{t,t+j} \left(p_{t+j}^b \phi_{t+j} S_{t+j}^i - S_{t+j}^i\right)$$

The optimal price then is $p_t^b = \phi_t^{-1}$. Together with the intermediate sector free-entry condition this leads to the following expression that pins down intermediate firm value:

$$v_t = \phi^{-1} \left(\frac{S_t}{N_t}\right)^{\rho-1} \tag{19}$$

As in Bilbiie et al. (2012), we assume a time-to-build lag: newly invented blueprints are adopted with a one-period lag. At each period existing varieties of the intermediate good face a constant probability of becoming obsolete δ_N. The resulting law of motion for the stock of intermediate goods is $N_t = (1-\delta)(N_{t-1} + N_{et})$, where $N_{et} = \int N_{et}^i di$. The positive knowledge spillover externality in the innovation sector gives rise to variety-driven endogenous growth, which rate equals to:

$$g_t = \frac{N_t}{N_{t-1}} = (1-\delta)\left(1 + \phi \left(\frac{S_t}{N_t}\right)^\rho\right) \tag{20}$$

The endogenous growth rate g_t varies over the business cycle depending on the level of innovation spending S_t, which is determined in general equilibrium.

2.3 Monetary policy

The economy operates under the flexible exchange rate with monetary policy conducted through interest rate setting. The domestic policy rate is governed by the following Taylor rule:

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\Pi} \left(\frac{GDP_t}{GDP_t^{BGP}}\right)^{\phi_Y}\right)^{1-\rho_i}, \tag{21}$$

Parameters $\phi_Y \geq 0$ and $\phi_\Pi > 0$ govern the policy response to changes in GDP and inflation; $\rho_i \in [0, 1)$ determines the degree of interest rate smoothing. Note that the above rule responds to changes in the domestic GDP relative to its balanced growth path. In other words, the monetary authority does not respond to endogenous changes in the productivity growth, which is consistent with how central banks tend to conduct monetary policy.

2.4 Rest of the world

The rest of the world is modeled in a reduced from, with foreign variables taken by the small open economy as given. In particular, the foreign real interest rate is $\frac{1+i_t^*}{\Pi_t^*}$; the foreign-good price in foreign currency is p^{F*}; and the foreign economy is assumed to supply as much traded good as demanded by the home economy.

The aggregate consumption-investment basket in Foreign is assumed to have a symmetric form $Y_t^* = \left[a^{\frac{1}{\theta}}(Y_t^{F*})^{\frac{\theta-1}{\theta}} + (1-a)^{\frac{1}{\theta}}(Y_t^{H*})^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$, which implies that the exports demand for Home is $Y_t^{H*} = (1-a)\left(\frac{P_t^{H*}}{P_t^*}\right)^{-\theta} Y_t^*$. Given the real exchange rate definition and the LOP assumption it can be rearranged as:

$$Y_t^{H*} = (1-a)\left(p_t^{H^*}\right)^{-\theta} Y_t^* \tag{22}$$

Finally, the foreign economy is assumed to be growing at a constant rate equal to the steady-state growth rate of the home economy $g^* = g$. For simplicity, we assume no technological spillovers between Home and Foreign. As such, any fluctuations in the growth rate in Home lead to permanent differences in levels. Define the ratio of Home to Foreign intermediate good varieties as $n_t = \frac{N_t^*}{N_t}$, then:

$$\frac{n_t}{n_{t-1}} = \frac{N_t^*}{N_{t-1}^*}\frac{N_{t-1}}{N_t} = \frac{g^*}{g_{t-1}} \tag{23}$$

2.5 Closing the model

The description of equilibrium conditions of the model is concluded with the following accounting identities. The aggregate basket of domestic and imported goods is used for consumption, investment in product creation, and paying adjustment costs:

$$Y_t = C_t + S_t + AC_t^W + AC_t^P + AC_t^{P^*} \tag{24}$$

The domestic good is demanded both from home and foreign economies:

$$GDP_t = F_t - N_t \frac{x_t}{A} = Y_t^H + Y_t^{H*} \tag{25}$$

As described in appendix A.1, equilibrium conditions imply that the dynamics of net foreign assets is governed by the following accounting identity:

$$p_t^{F^*} Y_t^F - p_t^{H^*} Y_t^{H^*} = \frac{B_t^*}{P_t^*} - \frac{1 + i_{t-1}^*}{\Pi_t^*} \frac{B_{t-1}^*}{P_{t-1}^*} \tag{26}$$

Finally, a representative household owns owns all intermediate firms $\iota_{t+1} = \iota_t = 1$, and is being rebated collected foreign bond adjustment costs along with domestic import tariff $T = \tau_t p_t^{F*} rer_t Y_t^F + AC_t^{B^*}$. Domestic bonds are in zero net supply $B_t = 0 \; \forall t$.

Equilibrium conditions allow to simplify the production function as $F_t = \Omega N_t Z_t^{\frac{1}{\alpha}} (\mu_t^G)^{\frac{\alpha-1}{\alpha}} L_t$, where $\Omega = A^{\frac{1-\alpha}{\alpha}} (1-\alpha)^{\frac{2(1-\alpha)}{\alpha}}$. Changes in domestic output are ultimately driven by the following factors:

$$\begin{aligned} \Delta F_t &= \Delta TFP_t + \Delta L_t \\ \Delta TFP_t &= \underbrace{\frac{1}{\alpha} \Delta Z_t}_{\text{TFP shock}} + \underbrace{\Delta N_t}_{\text{Innovation}} - \underbrace{\frac{1-\alpha}{\alpha} \Delta \mu_t^G}_{\text{Markup}} \end{aligned}$$

The model features endogenous growth at the rate of $g_{t+1} = \frac{N_{t+1}}{N_t}$. To solve the model using perturbation techniques, I define stationary lower-case counterparts to the variables that exhibit growth as $y_t = \frac{Y_t}{N_t}$, $c_t = \frac{C_t}{N_t}$. Note that real wage $\frac{W_t}{P_t}$ exhibits growth due to endogenous productivity improvements. As such, I define detrended real wage as $w_t = \frac{W_t}{P_t N_t}$, from which it follows that nominal wage inflation can be expressed as

$$\Pi_t^W = \frac{w_t}{w_{t-1}} g_{t-1} \Pi_t. \tag{27}$$

Equilibrium definition: equations (1-27) determine 27 endogenous variables $(y_t, x_t, y_t^H, y_t^{H*}, y_t^F, f_t, c_t, \Pi_t, \Pi_t^H, \Pi^{H_t^*}, \Pi_t^W, p_t^H, p_t^{H^*}, p_t^F, \mu_t^H, \mu_t^{H^*}, s_t, v_t, d_t, g_t, n_t, L_t, w_t, \mu_t^W, b_t^*, rer_t, i_t)$ as a function of endogenous states and exogenous disturbances. Table 1 lists all equilibrium conditions of the economy.

3 Model calibration and simulation

3.1 Calibration

We assume a standard period utility separable in consumption and labor $U(C_t, L_t) = \ln(C_t) - \chi\frac{L_t^{1+\epsilon_L}}{1+\epsilon_L}$ with Frisch elasticity of labor supply $\epsilon_L = 1$. Steady-state real interest rate equals to $R = \beta/g^{\gamma}$. We assume the steady-state real interest rate of 4%, BGP growth rate of 1%, and set the households discount factor to $\beta = 0.9927$ accordingly. Elasticity of substitution between home and foreign goods $\theta = 1.5$, a common choice in the RBC literature, and home bias parameter is set to $a = 0.65$. Following Schmitt-Grohé and Uribe (2003), the foreign bond adjustment cost parameter is set to a very low value of $\psi_B = 0.00074$, which ensures the stationarity of the net foreign asset position but does not significantly interfere with the broader model dynamics.

Moving to the production side of the economy, we set labor share to the conventional value of $\alpha = 0.7$. Elasticity of substitution between intermediate goods is then set to $\theta_x = \alpha^{-1}$ so that growth takes the labor-augmenting form. The elasticity of substitution between varieties of labor $\theta_L = 11$ to set the steady-state nominal wage markup at 10%, one other conventional choice in the literature. Following the same consideration, the elasticity of substitution between home good varieties for home and foreign markets is $\theta_H = \theta_{H^*} = 11$. Based on the results of Born and Pfeifer (2016), we set the nominal wage and price adjustment costs to $\psi_W = \psi_P = \psi_{P^*} = 120$ to replicate, in a linearized setting, the slope of the Phillips curve derived using Calvo stickiness with an average price duration of about a year. As in Ghironi and Melitz (2005), product exit rate is set to $\delta_N = 0.025$. The concavity of the innovation production function is $\rho = 0.9$, as in Kung (2015). Productivity of innovators is calibrated to match the annual TFP growth of 1%, which implies $\phi = 0.144$.

Finally, we assume the steady-state inflation rate of 2% and set the parameters of the Taylor rule to $\phi_\Pi = 1.5$, $\phi_Y = 0.1$, and $\rho_i = 0.7$. Table 2 summarizes the choice of parameters.

3.2 Shocks and the solution method

Home and foreign import tariffs are governed by the following process that allows for both level and volatility shocks:[8]

$$\tau_t = (1-\rho_\tau) + \rho_\tau \tau_{t-1} + \sigma_t^\tau \varepsilon_t^\tau$$
$$\sigma_t^\tau = (1-\rho_{\sigma^\tau})\sigma^\tau + \rho_{\sigma^\tau}\sigma_{t-1}^\tau + \sigma^{\sigma^\tau}\varepsilon_t^{\sigma^\tau}$$

We borrow parameters of the import tariff process from Barattieri et al. (2018) and set $\sigma_\tau = 0.0176$, $\rho_\tau = 0.56$. The import tariff shock ε_t^τ then involves a 1.75% on-impact increase in tariff that returns to its initial level in about 8 quarters. Import tariff uncertainty shocks are innovations to the variance of the import tariff shock $\varepsilon_t^{\sigma^\tau}$. As such, in what follows we study effects a temporary increase in variance of the tariff shock, holding the level of import tariff constant. For illustrative purposes, we consider a large but short-lived uncertainty shock setting $\sigma^{\sigma^\tau} = 5\sigma^\tau$ and $\rho_{\sigma^\tau} = 0.75$.

We solve the model by perturbation methods bases on a third-order approximation of its equilibrium conditions. As discussed in Fernández-Villaverde et al. (2011), studying independent effects of uncertainty shocks requires at least a third-order approximation of policy functions, as the first-order approximation features certainty equivalence and the second-order approximation captures the effect of uncertainty only through its interaction with level shocks.[9] Furthermore, higher-order approximation terms shift the ergodic distribution of endogenous variables of the model away from the deterministic steady state. As such, we follow previous literature and calculate impulse responses in deviations from the stochastic steady state, defined as a point in the state-space where agents choose to remain in the absence of shocks but incorporating the risk of shocks in the future.

[8] Both processes are defined in levels, as opposed to logs, to avoid the problem of non-existing moments, as discussed in Andreasen (2010), and to prevent volatility shock from affecting the average import tariff level via Jensen's inequality.

[9] Higher order approximations often generate explosive dynamics even when the corresponding linearized system is stable. To alleviate this problem we employ the pruning method that involves eliminating terms of order higher than the approximation order when the system is iterated forward. Pruning was first introduced by Kim et al. (2008) for second-order approximations and then generalized by Andreasen et al. (2017).

3.3 Baseline simulation

3.3.1 Import tariff level shock

We first study an unexpected increase in the domestic import tariff in order to compare predictions of the model with the existing results in the literature. Figure 5 shows the effect of a temporary increase in home import tariff. The import tariff shock acts as a negative supply shock: output falls and CPI inflation increases. Moreover, there is a short-lived improvement in the current account. To understand the inflationary effect of this shock recall the CPI index:

$$P_t = \left[a(P_t^H)^{1-\theta} + (1-a)(\tau_t \varepsilon_t P_t^{F^*})^{1-\theta}\right]^{\frac{1}{1-\theta}}$$

Higher tariff τ_t increases import prices faced by domestic consumers. This effect is only partially mitigated by appreciation of the nominal exchange rate. As a result, domestic CPI inflation increases.

The effect of the import tariff shock on output is shaped by three factors: (i) reduction in real income, which is contractionary; (ii) expenditure-switching towards domestic goods as imported goods become relatively more expensive, which is expansionary; and (iii) the response of monetary policy that faces a trade-off between stabilizing inflation and output. In general equilibrium, the first effect dominates the second and output falls. The reduction in real income stems primarily from a fall in investment in product creation. Since it requires both domestically-produced and imported components, an increase in import tariff makes investment in product creation more costly. Appendix B shows the effect of a tariff increase in an economy without product creation investment, in which case the contractionary effect of the shock disappears. The above results largely follow the conclusions of Barattieri et al. (2018).

3.3.2 Import tariff uncertainty shock

Figure 6 shows responses of the baseline economy to an import tariff uncertainty shock. Similarly to the tariff level shock, it is contractionary and inflationary raising the trade-off between stabilizing inflation and output for monetary policy. The sharp initial increase in CPI inflation is primarily driven by on-impact depreciation of the real exchange rate, while the continuing inflationary effect is due to the increase in the domestic-good price level.

The contractionary effect is shaped by several factors. First, an increase in uncertainty renders foreign-exchange borrowing riskier and generates inefficient capital outflow. However, the associated depreciation of the real exchange rate induces expenditure-switching towards domestic goods and partially offsets the contractionary effect of capital outflow. Second, there is an on-impact fall in innovation spending, which is very significant relative to the decline in consumption. As we discuss further, the response of innovation spending is primarily driven by the endogenous increase in equity risk. Under nominal rigidity, the equilibrium is demand-determined in the short-run so that the on-impact fall in innovation spending exacerbates the immediate contraction in the economic activity. Finally, over time the initial drop in innovation spending translates into a persistent decline in the TFP level, which prolongs the negative effect of the shock on consumption and output as well as causes the persistent appreciation of the real exchange rate in the medium-run. We explore these channels in more detail in the following sections.

Finally, appendix B illustrates that both short-run and persistent negative effects of the shock are very sensitive to its persistence. For instance, increasing the persistence parameter to $\rho_{\sigma_\tau} = 0.85$ from the baseline value of 0.75 amplifies responses to the shock by more than twofold.

4 Exploring the mechanism

4.1 The role of endogenous growth

Figure 7 compares the baseline simulation to a counterfactual with no endogenous growth. The first immediately obvious difference is the lack of persistent negative effect on the level of output and consumption as well as the medium-run appreciation of the real exchange rate, all of which are driven by the endogenous decline in productivity growth in the baseline simulation. The difference in the short-run responses is driven by a combination of demand and supply forces. Recall that the aggregate demand for home-produced goods comes from domestic consumers, domestic innovators, and the rest of the world. Shutting down endogenous growth excludes the aggregate demand component – innovation spending – that contracts the most in the baseline economy. Although domestic consumption still decreases due to precautionary saving, it is compensated by an increase in the export demand increases due to the real exchange rate depreciation, causing the aggregate demand to increase. Moreover, an increase in uncertainty induces precautionary labor supply: other factors equal, households increase their labor supply when the marginal utility of consumption goes up.

The role of this precautionary labor supply becomes clear when you do away with the wealth effect by assuming Greenwood et al. (1988) preferences with period utility function $U_t(C_t, L_t) =$

$\left(\left(C_t - \chi \Upsilon_t \frac{L_t^{1+\epsilon_L}}{1+\epsilon_L}\right)^{1-\gamma} - 1\right)/(1-\gamma)$, where $1/\gamma$ is the elasticity of intertemporal substitution and $1/\epsilon_L$ is the Frisch elasticity of labor supply. As in Queralto (2019), the disutility of labor is governed by the following process: $\Upsilon_t = \Upsilon_{t-1}^{\rho_\Upsilon} N_t^{1-\rho_\Upsilon}$ with ρ_Υ governs its responsiveness to changes in productivity growth. This setting ensures that the BGP with constant hours exists but limits the wealth effect in labor supply due to medium-run swings in growth.[10] We set $\rho_\Upsilon = 0.95$ so that the short-run wealth effect in labor supply is minimal. Appendix B presents responses to an import tariff uncertainty shock under the GHH preference. Doing away with the wealth effect in labor supply not only amplifies responses to the shock in the baseline model but also preserves the contractionary effect when the endogenous growth mechanism is shut down.

4.2 The role of convexity of import demand

An import tariff uncertainty shock is contractionary. However, it generates an unrealized expectation of expansion. Figure 8 illustrates this by comparing the actual dynamics of variables with the dynamics of their expected next-period values. To understand this effect recall import demand implied by the CES aggregator, equation (7): $Y_t^F = (1-a)(\tau_t p_t^{F^*} rer_t)^{-\theta} Y_t$. Since the elasticity of substitution between home and foreign goods is $\theta > 0$, the imports demand is convex in import tariff. Therefore, other factors fixed, higher import tariff uncertainty increases expected imports demand by Jensen's inequality similarly to what would happen due to a decrease in an expected tariff level. In general equilibrium, this effect dominates and causes an expected — but unrealized — expansionary effect. This feature would be important for understanding the dynamics of forward-looking variables discussed below.

4.3 The role of time-varying risk premia

Uncertainty shocks introduce time-varying risk premia in asset returns. The three relevant assets in the present model are domestic bonds, foreign-currency bonds, and intermediate firm equity. An increase in import tariff uncertainty causes foreign-currency bonds and equity to become riskier relative to domestic bonds, which contributes to an improvement in the country's

[10] As noted by Benhabib et al. (1991), the GHH preference can be interpreted as a reduced form of an economy with home production. The disutility of work then consists of the forgone output in-home production, which increases in the long-run as productivity improvements in the formal sector spill over to home production. However, to the extent this process takes time, the disutility of labor exhibits inertia. Jaimovich and Rebelo (2009) suggest a similar preference specification that allows us to parameterize the short-run wealth effect on the labor supply

net current account and to a decrease in product creation investment.

To illustrate the current account effects this channel, we assume log-normality and express demand for foreign-exchange bonds, equation (2), as follows:

$$\underbrace{\left(\mathrm{Var}_t \Delta \mathsf{c}_{t+1} - \mathbb{E}_t \Delta \mathsf{c}_{t+1} - \mathsf{g}_t\right)}_{\text{Discounting}} + \underbrace{\left(\mathsf{R}^*_{t+1} + \mathbb{E}_t \Delta \mathsf{rer}_{t+1}\right)}_{\text{t+1 return}} - \underbrace{\mathrm{Cov}_t\left(\Delta \mathsf{c}_{t+1}, \Delta \mathsf{rer}_{t+1}\right)}_{\text{Foreign exchange risk premium}} \approx 0, \tag{28}$$

where we took into account that the foreign interest rate R^*_t follows a deterministic process and used sans-serif font to denote log-deviations of variables from the steady state, see appendix A.2 for details. The demand for foreign-exchange bonds is affected by the foreign exchange risk premium: conditional covariance between consumption growth and the change in the real exchange rate. A positive covariance means that the asset tends to yield high returns in states of nature when consumption is high thus not providing a good hedge against consumption fluctuations. For this reason, the demand for foreign-currency bonds is decreasing in the foreign exchange risk premium.

How does the foreign-exchange risk premium respond to an import tariff uncertainty shock? Panel (a) of figure 9 reports relevant impulse responses. The shock increases the foreign exchange risk premium and makes foreign bonds riskier. To understand this recall that import tariff level shocks cause the real exchange rate to appreciate so that foreign bonds are a bad hedge against this shock. An increase in import tariff uncertainty amplifies this property and decreases the demand for foreign bonds. As a result, the current account temporarily improves as the economy decreases holdings of foreign debt. In general equilibrium, this reduction in foreign debt causes a combination of a fall in consumption and a fall product creation investment.

The dynamics real exchange rate and current account can be further interpreted through the lens of the following equality:

$$\left(\mathsf{R}^*_{t+1} + \mathbb{E}_t \Delta \mathsf{rer}_{t+1}\right) - \mathbb{E}_t \mathsf{R}_{t+1} \approx \underbrace{\mathrm{Cov}_t\left(\Delta \mathsf{c}_{t+1}, \Delta \mathsf{rer}_{t+1}\right) - \mathrm{Cov}_t\left(\Delta \mathsf{c}_{t+1}, \mathsf{R}_{t+1}\right)}_{\text{Foreign exchange vs domestic bond risk premium}}, \tag{29}$$

which is implied by equations (1) and (2) under the assumption of log-normality, see appendix A.2. The left hand side of the expression is the difference in ex ante real returns between foreign and home bonds, which equals to zero when the uncovered interest rate parity (UIP) holds. The right hand side represents the hedging property of foreign-currency bonds relative to domestic bonds, measured by conditional covariances of returns with consumption growth. Deviations from the UIP arise when one asset is a better hedge against the consumption risk than the other.

Panel (b) of figure 9 visualizes deviation from the UIP in response to an import tariff uncertainty shock based on equation (29). The shock causes foreign bonds to become more risky than domestics bonds. As a result, the real exchange rate is expected to depreciate by more than predicted by the UIP so that foreign bonds deliver a higher expected return to compensate for risk.

A similar logic applies to product creation financed by selling equity to households. Using equation (3) and the definition of the risk-free rate R_t^f excess return on equity can be expressed as follows:

$$\mathbb{E}_t \mathsf{R}_{t+1}^{\mathsf{equity}} - \mathsf{R}_{t+1}^{\mathsf{f}} = \underbrace{\mathrm{Cov}_t \left(\Delta \mathsf{c}_{t+1}, \mathsf{R}_{t+1}^{\mathsf{equity}} \right)}_{\text{Equity risk premium}}, \tag{30}$$

where $R_{t+1}^{equity} = (v_{t+1} + d_{t+1})/v_t$ denotes equity return, see appendix A.3 for details. Panel (a) of figure 10 illustrates that the shock increases equity risk premium. Higher risk requires equity to exhibit excess return to compensate for it. Current firm price then v_t falls to deliver higher expected return. The shock also causes an increase in the implied equity return volatility calculated in annualized percentage term as follows $VXO_t = 100\sqrt{4\mathrm{Var}_t(R_{t+1}^{equity})}$ by about 3%.

How large is the contribution of risk to the firm value dynamics? Assuming log-normality, current firm value can be expressed as follows:

$$\mathsf{v}_t = \underbrace{(\mathrm{Var}_t \Delta \mathsf{c}_{t+1} - \mathbb{E}_t \Delta \mathsf{c}_{t+1} - \mathsf{g}_t)}_{\text{Discounting}} + \underbrace{\mathbb{E}_t \mathsf{P}_{t+1}^{\mathsf{e}}}_{\text{t+1 payoff}} - \underbrace{\mathrm{Cov}_t \left(\Delta \mathsf{c}_{t+1}, \mathsf{P}_{t+1}^{\mathsf{e}} \right)}_{\text{t+1 equity payoff risk}}, \tag{31}$$

where $P_{t+1}^e = v_{t+1} + d_{t+1}$ denotes the next-period payoff. Panel (b) of figure 10 plots the dynamics of firm value components in response to an import tariff volatility shock. The expected next-period payoff increases due to the anticipated expansionary effect, as discussed in section 4.2. However, this effect is roughly canceled out by a decrease in the stochastic discount factor of households that experience a temporary fall in consumption. As a result, the majority of the realized decrease in firm value is due to the increased equity risk.

Finally, risk premium wedges affect not only the responses of the economy to shocks but also the stochastic steady state. Our higher-order solution of the model allows us to capture how risk affects the ergodic distribution of endogenous variables. Appendix B includes the comparison between deterministic and stochastic steady states. At the stochastic steady state, compared to the deterministic steady state, the economy improves its net foreign asset position as holding foreign debt is risky. As a result, consumption is higher and the labor supply is lower due to the wealth effect. Even a moderate long-run import tariff risk that we consider in the baseline simulation has a non-negligible effect on endogenous variables.

Note that the mechanisms described in this section do not rely on nominal rigidity. As pointed out by Basu and Bundick (2017) uncertainty shocks are often counterfactually expansionary in closed-economy models without nominal rigidity since precautionary saving leads to an increase in investment. Nominal rigidity makes equilibrium demand-determined in the short run and causes precautionary savings to be contractionary. Price and/or nominal wage rigidity hence is deemed to be a necessary ingredient for uncertainty shocks to have an empirically-relevant negative effect on output. Our exercise shows that this logic does not necessarily hold in the open-economy context. Figure 11 compares the responses of the economy to an import tariff uncertainty shock under various assumptions about nominal rigidity. Although rigid prices and/or nominal waged do amplify the effects of the shock by rendering the equilibrium demand-determined in the short run, the results remain qualitatively the same even in the flexible economy.

4.4 The risk channel of monetary policy

One of the channels through which policy can influence real allocations is by systematically affecting stochastic properties of asset returns and hence relevant risk premia.[11] In this section we focus on the role of monetary policy and exchange-rate regimes.

What is the role of exchange-rate arrangements in shaping the effects of the import tariff uncertainty shock? We conclude that the fixed exchange rate regime exacerbates the short-run contractionary effects of the shock but alleviates the persistent endogenous decline in the TFP level. From a technical standpoint, the fixed exchange rate regime is implemented as follows. When pegging the exchange rate, the home country forgoes its monetary policy autonomy and the Taylor rule (21) no longer applies. Instead, as pointed out by Benigno et al. (2007), the fixed exchange rate regime is implemented by the home central bank credibly committing to the following reactive rule:

$$1 + i_t = (1 + i_t^*) f\left(\frac{\varepsilon_t}{\bar{\varepsilon}}\right),$$

where the function $f(\cdot)$ is continuous, monotone non-decreasing, differentiable, strictly increasing in a neighborhood of $\varepsilon_t = \bar{\varepsilon}$, and $f(1) = 1$. In equilibrium, the nominal exchange rate is fixed, $\varepsilon_t = \varepsilon_{t-1} = \bar{\varepsilon}$, and the dynamics of the real exchange rate is solely driven by the cross-country inflation differential and the home interest rate is pegged to the foreign interest

[11] See for example discussions by Benigno et al. 2011, Hassan et al. 2016, and de Groot (2014)

rate:

$$\frac{rer_t}{rer_{t-1}} = \frac{\Pi_t^*}{\Pi_t}\frac{\varepsilon_t}{\varepsilon_{t-1}} = \frac{\Pi_t^*}{\Pi_t} \tag{32}$$

Figure 12 compares responses of the baseline flexible exchange rate economy to the fixed exchange rate counterfactual. The immediate contractionary effect of the shock is exacerbated relative to the baseline. The reason lies in the dynamics of the real exchange rate. In the baseline flexible exchange rate economy the real exchange rate depreciates in the short run. Under producer-currency pricing the depreciation of the real exchange induces expenditure-switching towards domestic goods, which, other factors equal, boosts domestic demand and output. The fixed exchange rate regime diminished this expansionary channel and increases the on-impact decline in output. Similarly, the muted short-run response of the real exchange rate under the fixed exchange rate regime causes the response of CPI inflation to be much flatter than in the baseline economy. Finally, the fixed exchange rate regime eliminates the risk differential between home and foreign bonds by rendering $\mathrm{Cov}_t\left(\Delta c_{t+1}, \Delta rer_{t+1}\right) = \mathrm{Cov}_t\left(\Delta c_{t+1}, R_{t+1}\right) = \mathrm{Cov}_t\left(\Delta c_{t+1}, \Pi_{t+1}\right)$. As a result, the UIP violation described in equation (29) disappears.

Although amplified in the short-run, the effects of the import tariff uncertainty shock is smaller in the medium-run under the fixed exchange rate regime. Recall that the persistent effect of the shock is driven by the endogenous decrease in TFP, the lion's share of which is due to the equity risk channel described by equations (30) and (31). Under the fixed exchange rate regime the equity risk increases by less than in the baseline economy hence the persistent endogenous productivity loss in smaller.

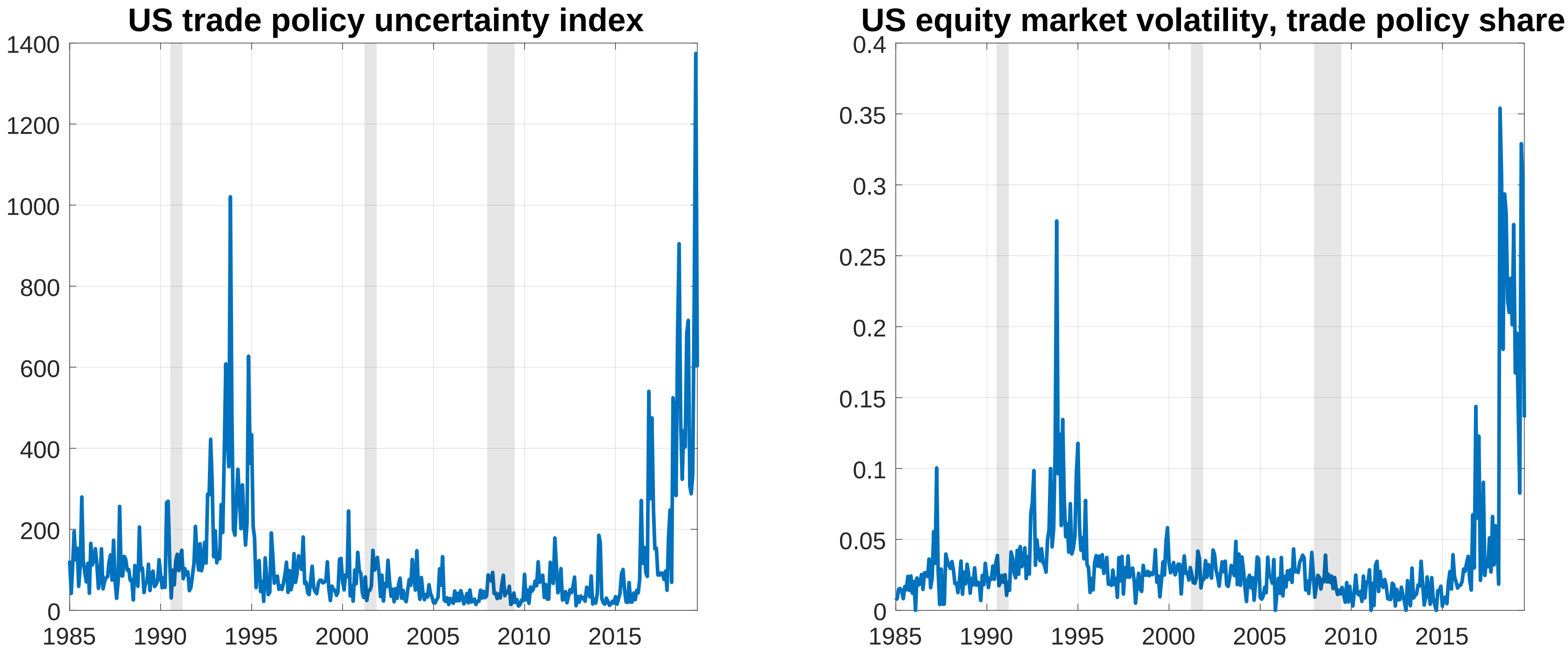
We conclude by assessing the role of parameters of the monetary policy rule, equation (21), when the exchange rate is flexible. Our results suggest that a greater focus on inflation stabilization, as opposed to output stabilization, exacerbates the endogenous decrease in productivity. Figure 13 compares responses under different values of the interest rate response to CPI inflation (ϕ_Π) and deviations of output from its balanced growth path (ϕ_Y). Greater values of ϕ_Π magnify the equity risk and drive the result.

5 Conclusion

Trade tensions, even when not resulting in tariff increases, are detrimental to the economy by generating policy uncertainty. We study trade policy uncertainty in a dynamic general equilibrium framework and conclude that it is inflationary, contractionary, and causes a temporary improvement in the current account. Although short-lived, economic uncertainty shocks has the potential to generate long-lasting effects by impeding business creation that drives productivity growth. We emphasize the key role of endogenous risk premia in transmitting uncertainty shock to the real economy.

The present setting can be extended along several dimensions. First, a two-country small open economy model would allow us to study the effects of foreign imports tariff uncertainty, a scenario relevant for small open economies that are subject to the global trade tensions. Second, one other margin of adjustment to trade policy uncertainty that is likely to be important is the endogenous selection of heterogeneous firms in and out of exporting, which can be modeled along with Ghironi and Melitz (2005). We are working on extensions to address these issues.

Figure 1: US trade policy uncertainty [cited on page 2]



Note: the trade policy uncertainty index is from Baker et al. (2016); the trade policy equity market volatility is from Baker et al. (2019)

Figure 2: US economic uncertainty [cited on page 2]

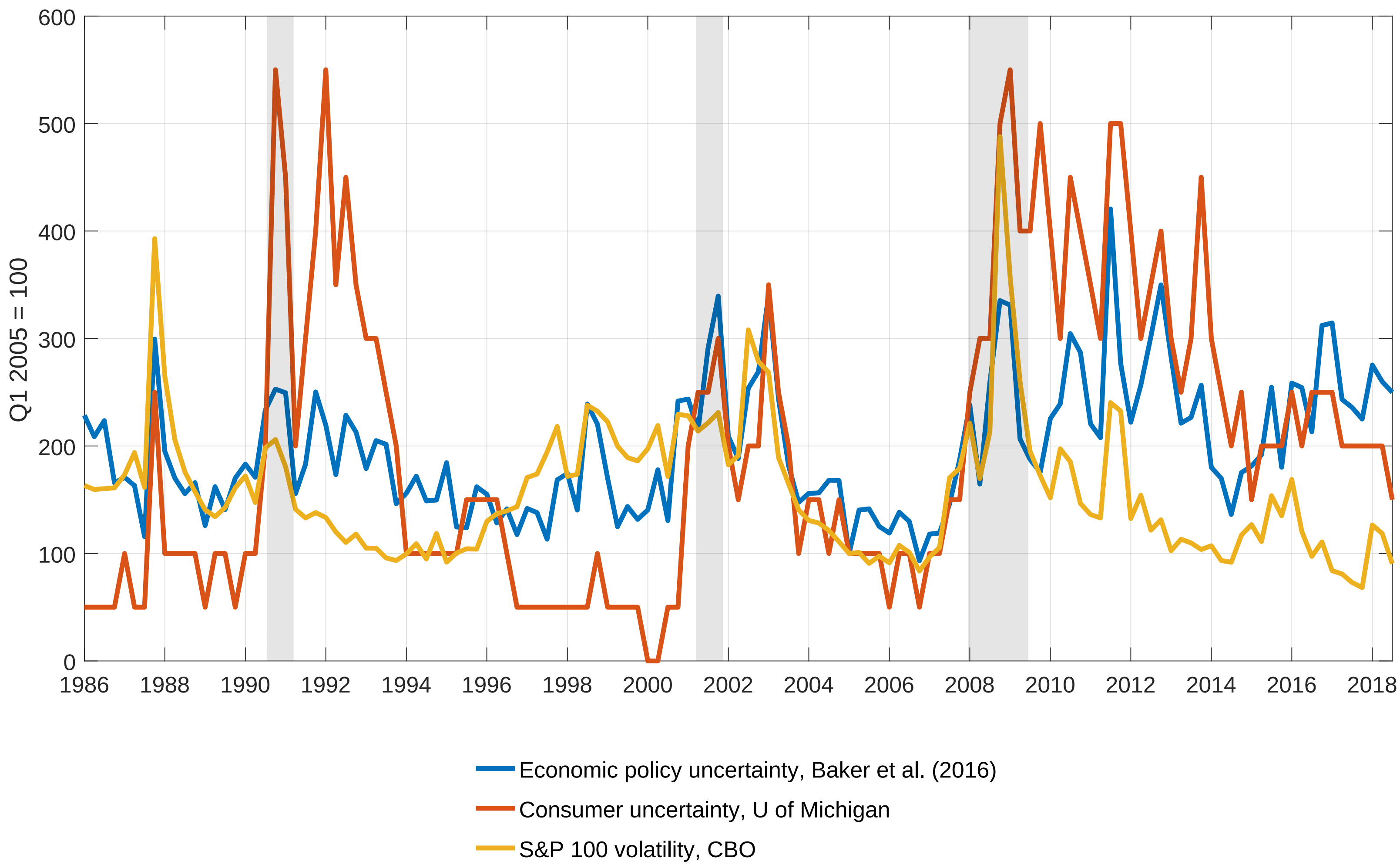
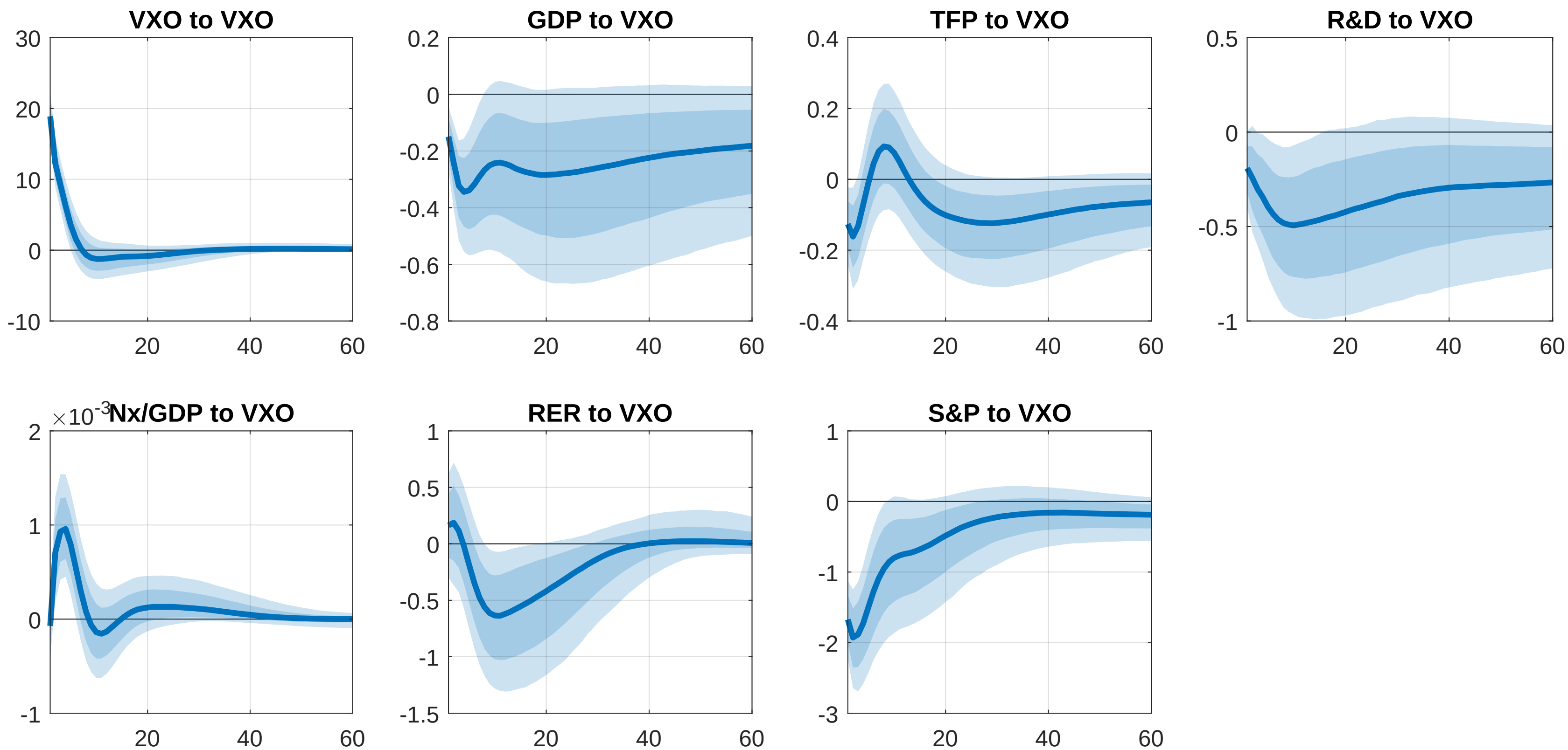


Figure 3: US VAR, responses to stock market volatility shock [cited on page 3]



Note: 7-variable VAR, (1) CBOE S&P 100 volatility index; (2) real GDP; (3) total factor productivity; (4) real R&D spending; (5) trade balance to GDP; (6) real exchange rate index; (7) S&P 500 index. Volatility shock identified with short-run restriction with VXO index ordered first. Impulse responses are in log deviations times 100, except for trade balance to GDP, which is in levels. Shaded areas correspond to 68% and 90% confidence intervals.

Figure 4: Baseline model flow chart [cited on page 4]

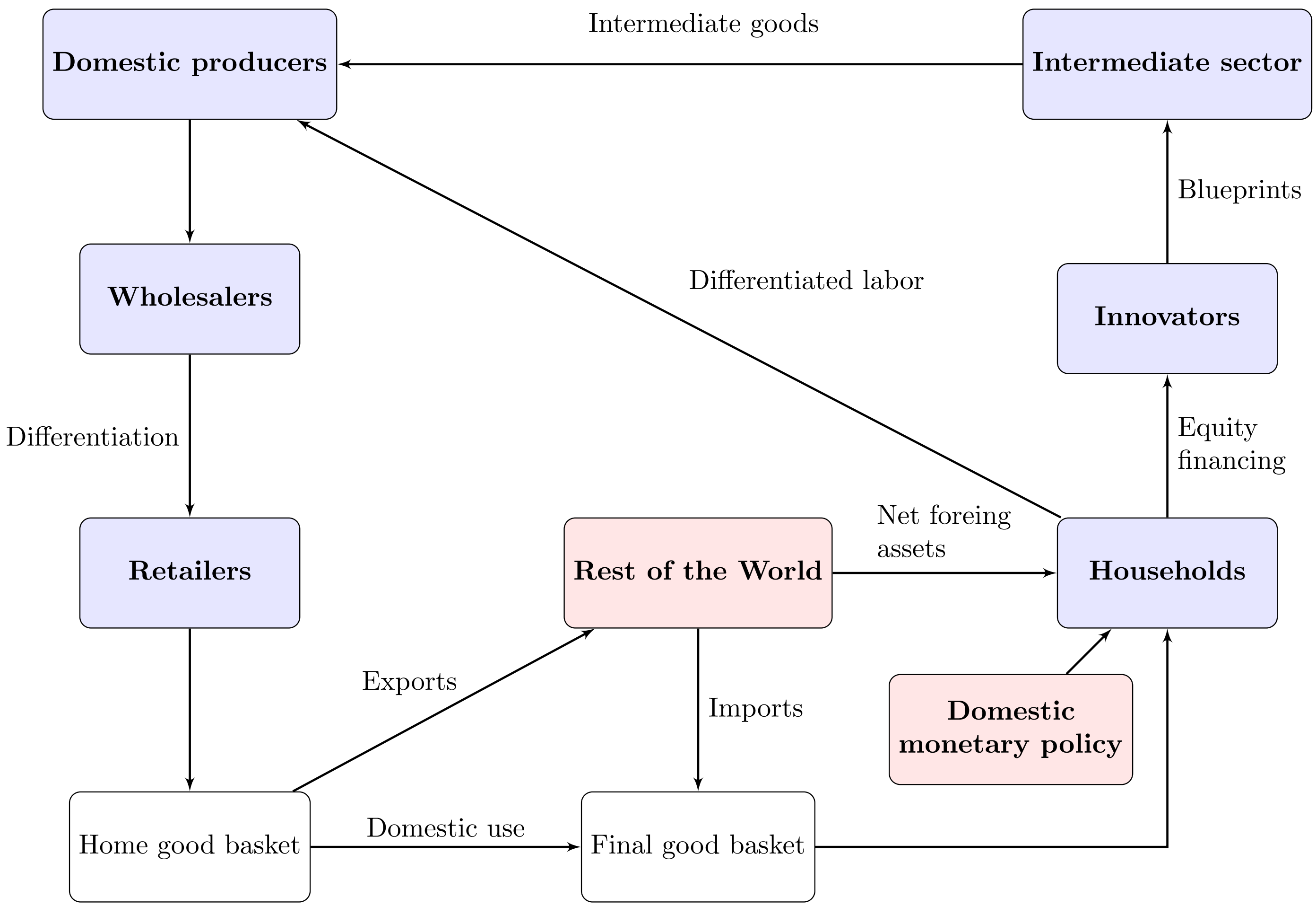


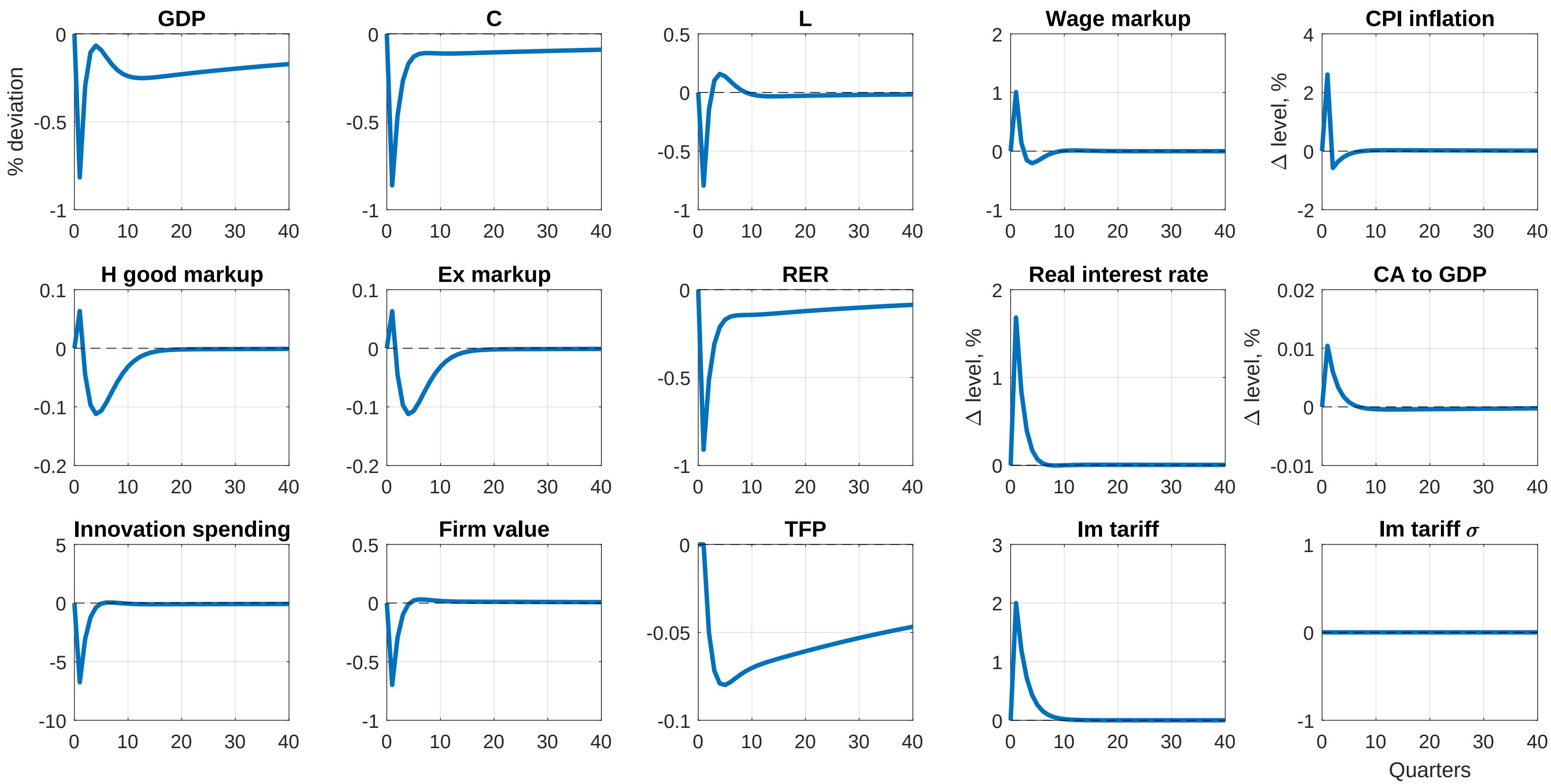
Table 1: Model summary [cited on page 13]

1. Aggregate market clearing	$y_t = c_t + s_t + AC_t^w + AC_t^p + AC_t^{p^*}$
2. Home good market clearing	$f_t - \frac{x_t}{A} = y_t^H + y_t^{H*}$
3. Net foreign assets	$p_t^{F^*} y_t^F - p_t^{H^*} y_t^{H^*} = b_t^* - \frac{1+i_{t-1}^*}{\Pi_t^*} b_{t-1}^* / g_t$
4. Domestic bonds Euler	$\mathbb{E}_t \left(\beta_{t,t+1} \frac{1+i_{t+1}}{\Pi_{t+1}} \right) = 1$
5. Foreign bonds Euler	$\mathbb{E}_t \left(\beta_{t,t+1} \frac{rer_{t+1}}{rer_t} \frac{1+i_{t+1}^*}{\Pi_{t+1}^*} \right) = 1 - \psi_B b_{t+1}^*$
6. Labor demand	$w_t = p_t^G \alpha Z_t L_t^{\alpha-1} x_t^{1-\alpha}$
7. Labor supply	$w_t = \mu_t^W \frac{U'_{L_t}}{U'_{C_t}}$
8. Wage markup	$\mu_t^W = \frac{\theta_L}{(\theta_L - 1)\left(1 - \frac{\psi_W}{2}\left(\frac{\Pi_t^W}{\Pi^W} - 1\right)^2\right) + \psi_W \left(\frac{\Pi_t^W}{\Pi^W} - 1\right)\frac{\Pi_t^W}{\Pi^W} - \psi_W \mathbb{E}_t \left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^W}{\Pi^W} - 1\right)\frac{\Pi_{t+1}^{W\,2}}{\Pi^W}\frac{L_{t+1}}{L_t}\right]}$
9. Wage inflation	$\Pi_t^W = \frac{w_t}{w_{t-1}} g_t \Pi_t$
10-11. Domestic good price	Home market: $p_t^H = \mu_t^H p_t^G$, Foreign market: $p_t^{H^*} = \mu_t^{H^*} \frac{p_t^G}{rer_t}$
12-13. Home good inflation	Home market: $\Pi_t^H = \frac{p_t^H}{p_{t-1}^H} \Pi_t$, Foreign market: $\Pi_t^{H^*} = \frac{p_t^{H^*}}{p_{t-1}^{H^*}} \frac{rer_t}{rer_{t-1}} \Pi_t$
14-15. Price markup	Home: $\mu_t^H = \frac{\theta_H}{(\theta_H - 1)\left(1 - \frac{\psi_P}{2}\left(\frac{\Pi_t^H}{\Pi^H} - 1\right)^2\right) + \psi_P \frac{\Pi_t^H}{\Pi^H}\left(\frac{\Pi_t^H}{\Pi^H} - 1\right) - \psi_P \mathbb{E}_t \left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^H}{\Pi^H} - 1\right)\frac{\Pi_{t+1}^{H\,2}}{\Pi^H}\frac{Y_{t+1}^H}{Y_t^H}\right]}$ Foreign: $\mu_t^{H^*} = \frac{\theta_{H^*}}{(\theta_{H^*} - 1)\left(1 - \frac{\psi_{P^*}}{2}\left(\frac{\Pi_t^{H^*}}{\Pi^{H^*}} - 1\right)^2\right) + \psi_{P^*} \frac{\Pi_t^{H^*}}{\Pi^{H^*}}\left(\frac{\Pi_t^{H^*}}{\Pi^{H^*}} - 1\right) - \psi_{P^*} \mathbb{E}_t \left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\left(\frac{\Pi_{t+1}^{H^*}}{\Pi^{H^*}} - 1\right)\frac{\Pi_{t+1}^{H^*\,2}}{\Pi^{H^*}}\frac{Y_{t+1}^{H^*}}{Y_t^{H^*}}\right]}$
16. Equity demand	$v_t = (1-\delta)\mathbb{E}_t \left[\beta_{t,t+1}(d_{t+1} + v_{t+1})\right]$
17. Equity supply	$\phi s_t^{\rho-1} v_t = 1$
18. Intermediate firm profit	$d_t = \frac{\alpha}{A(1-\alpha)} p_t^H x_t$
19. TFP growth	$g_t = (1-\delta)\left(1 + \phi(s_t)^\rho\right)$
20. Intermediate output	$x_t = \left(A(1-\alpha)^2 Z_t / \mu_t^H\right)^{\frac{1}{\alpha}} L_t$
21. Home good output	$f_t = Z_t L_t^\alpha x_t^{1-\alpha}$
22. Relative prices	$a(p_t^H)^{1-\theta} + (1-a)(\tau_t p_t^{F*} rer_t)^{1-\theta} = 1$
23. Exports demand	$y_t^{H^*} = (1-a)\left(p_t^{H^*}\right)^{-\theta} y_t^* n_t$
24. Imports demand	$y_t^F = (1-a)\left(\tau_t p_t^{F^*} rer_t\right)^{-\theta} y_t$
25. Home-good demand	$y_t^H = a\left(p_t^H\right)^{-\theta} y_t$
26. Taylor rule	$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_R} \left((\Pi_t/\Pi)^{\phi_\Pi}(gdp_t/gdp)^{\phi_y}\right)^{(1-\rho_R)}$
27. Relative productivity	$\frac{n_t}{n_{t-1}} = \frac{1}{g_{t-1}}$

TABLE 2: STRUCTURAL PARAMETERS [cited on page 13]

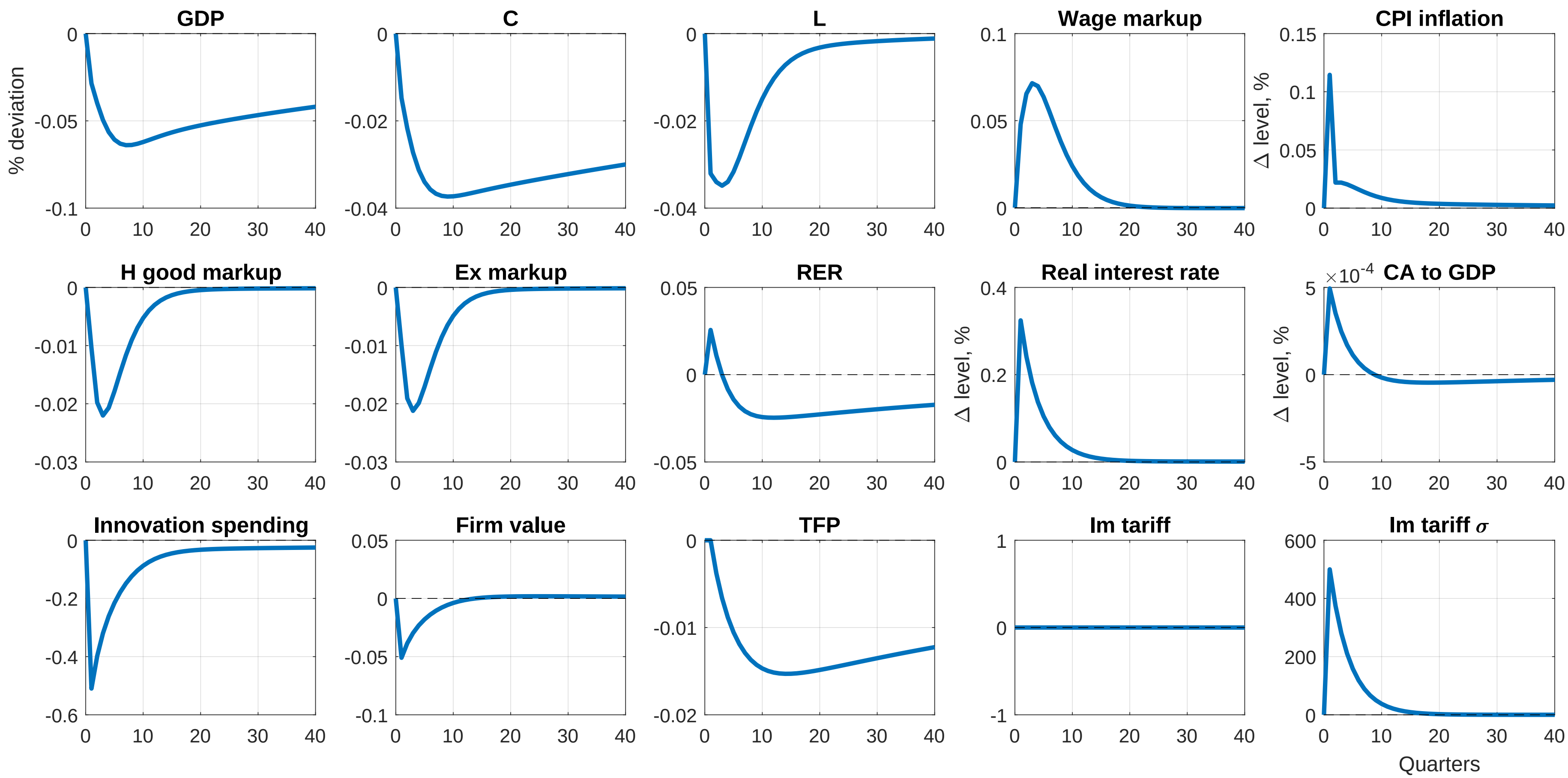
			Source / target
β	Discount factor	0.9927	4% annual real interest rate
ϵ_L	Inverse of Frisch elasticity of labor supply	1	Conventional
a	Home bias	0.65	Conventional
α	Labor share	0.7	Conventional
ρ	Innovation output elasticity	0.9	Kung (2015)
δ	Intermediate sector exit rate	0.025	Bilbiie et al. (2012)
θ	Elasticity of substitution, home-foreign	1.5	Backus et al. (1994)
θ_x	Elasticity of substitution, intermediate goods	10/7	BGP requirement $\theta_x = \frac{1}{\alpha}$
θ_L	Elasticity of substitution, labor varieties	11	10% steady-state wage markup
θ_H	Elasticity of substitution, retail goods	11	10% steady-state price markup
ψ_P	Domestic price adjustment cost	120	4-quarter average Calvo price ridigity equivalent, home
ψ_{P^*}	Exports price adjustment cost	120	4-quarter average Calvo price ridigity equivalent, foreign
ψ_W	Wage adjustment cost	120	4-quarter average Calvo nominal wage ridigity equivalent
ψ_B	Bond holding adjustment cost	0.00074	Schmitt-Grohé and Uribe (2003)
ϕ_y ; ϕ_π; ρ_r	Taylor rule parameters	0.1; 1.5; 0.7	
ϕ	Innovators productivity	0.144	Annual TFP growth = 1%
$1/A$	Intermediate sector marginal cost	1	Normalization
χ	Disutility of labor scale	0.754	Normalization, $L = 1$
$\bar{Z}$	Final sector productivity	2.25	Normalization, $GDP = 1$

Figure 5: Responses to a home import tariff shock [cited on page 15]



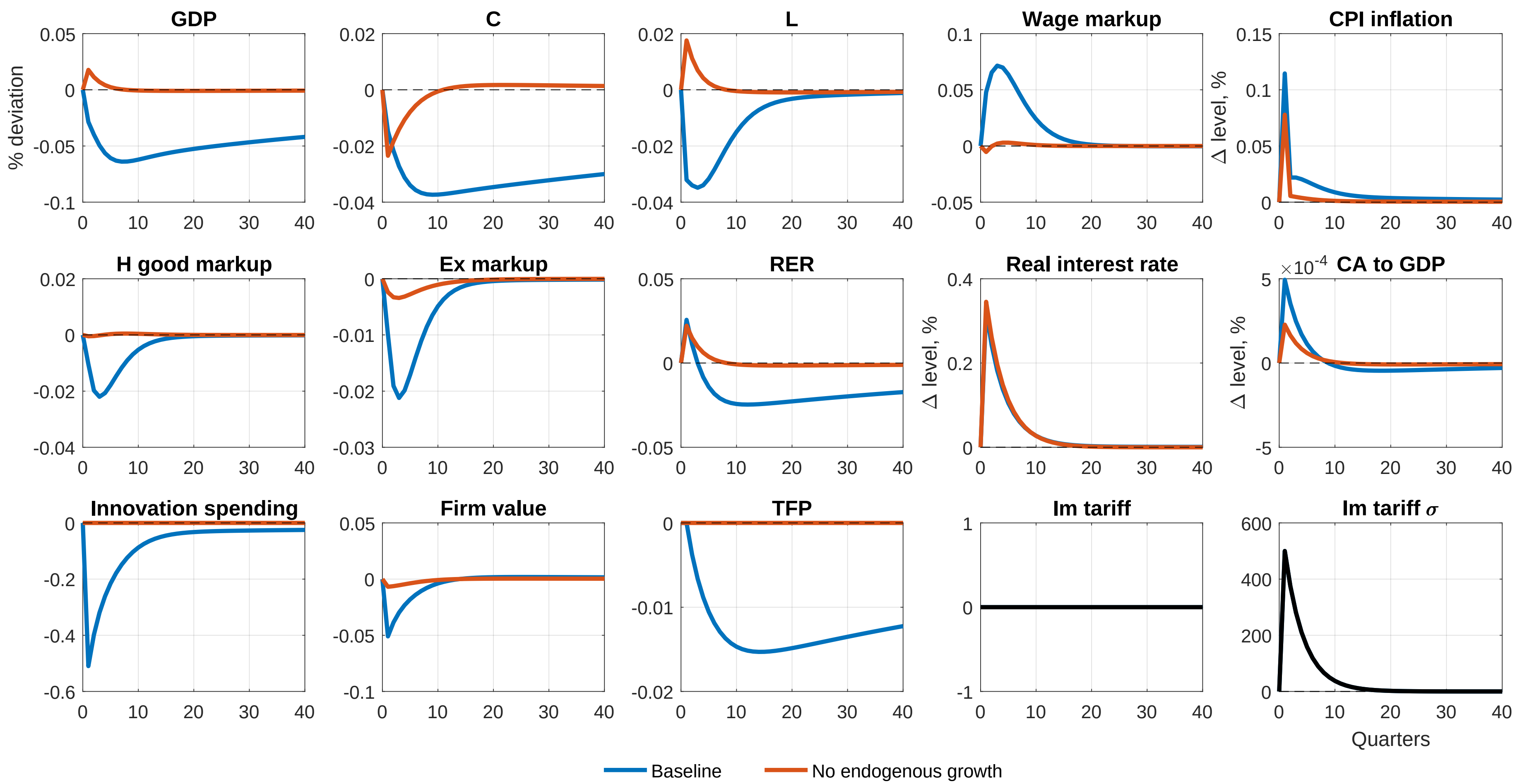
Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

Figure 6: Responses to a home import tariff uncertainty shock [cited on page 15]



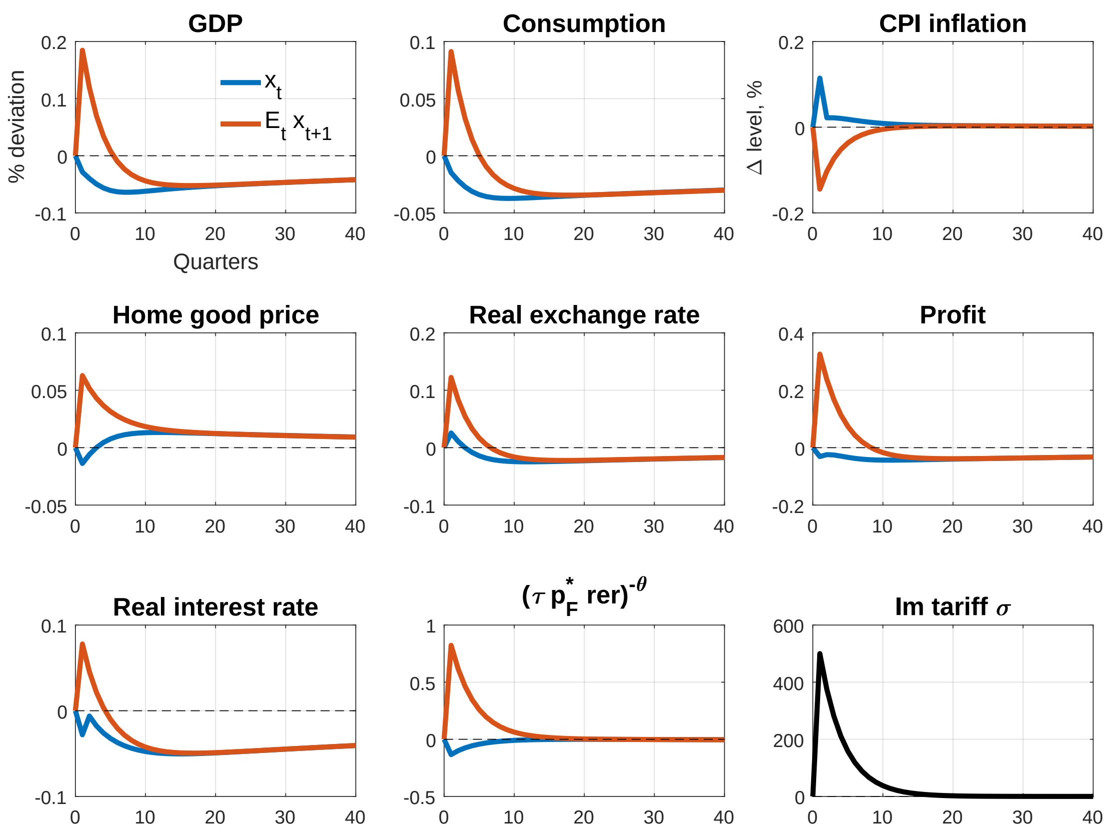
Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

Figure 7: Responses to a home import tariff uncertainty shock, the role of endogenous growth [cited on page 16]



Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

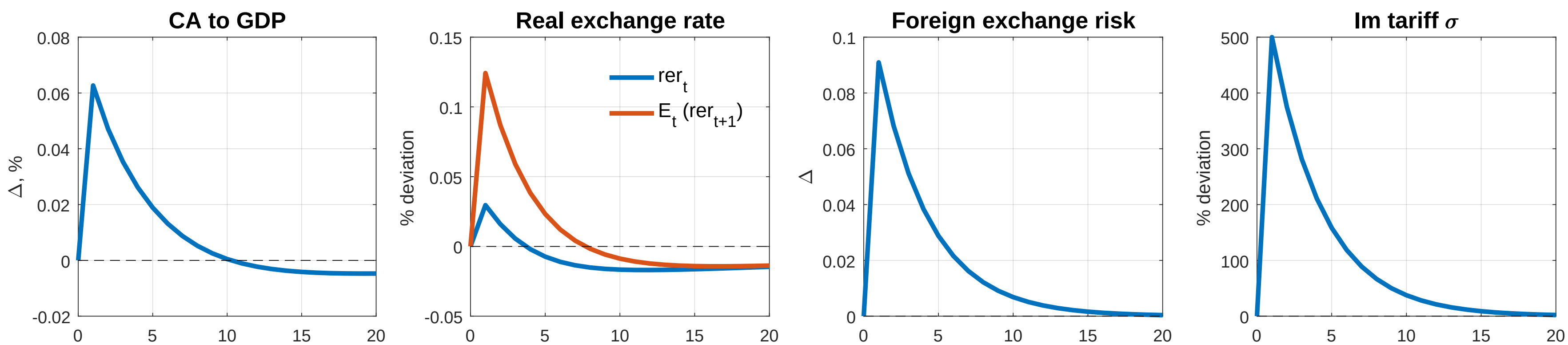
Figure 8: Responses to a home import tariff uncertainty shock, the role of convexity of imports demand [cited on page 17]



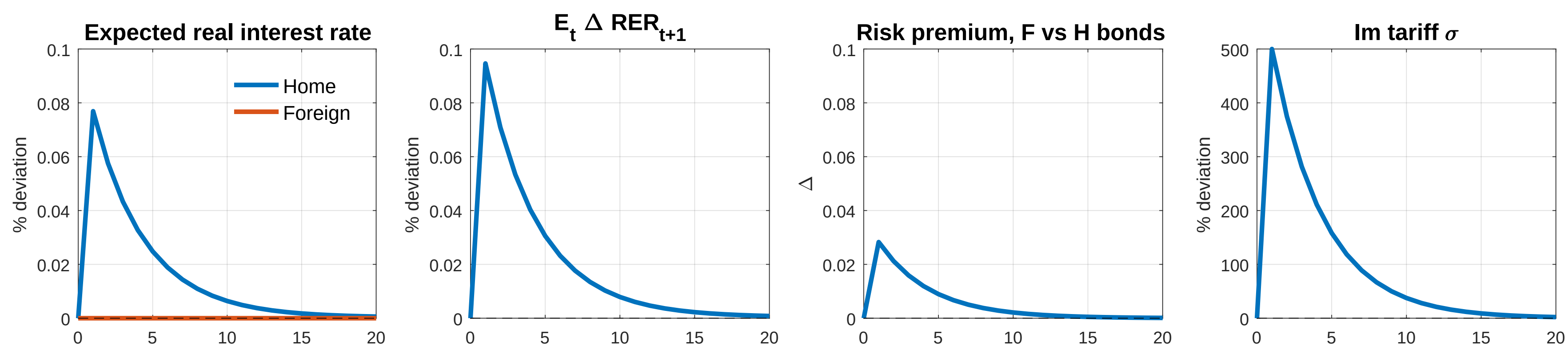
Note: the figure compares actual responces of variables to responces of their next-period expected values. The difference is driven primarily by the convexity if the import demand in tariff: $Y_t^F = (1-a)(\tau_t p_t^{F^*} rer_t)^{-\theta} Y_t$. An increase in the tariff uncertainty increases the expecded impors demand and generated an expected — but unrealized — expansion.

Figure 9: Responses to a home import tariff uncertainty shock, the role of foreign exchange risk [cited on page 18]

(a) Net foreign asset dynamics



(b) Violation of the uncovered interest rate parity

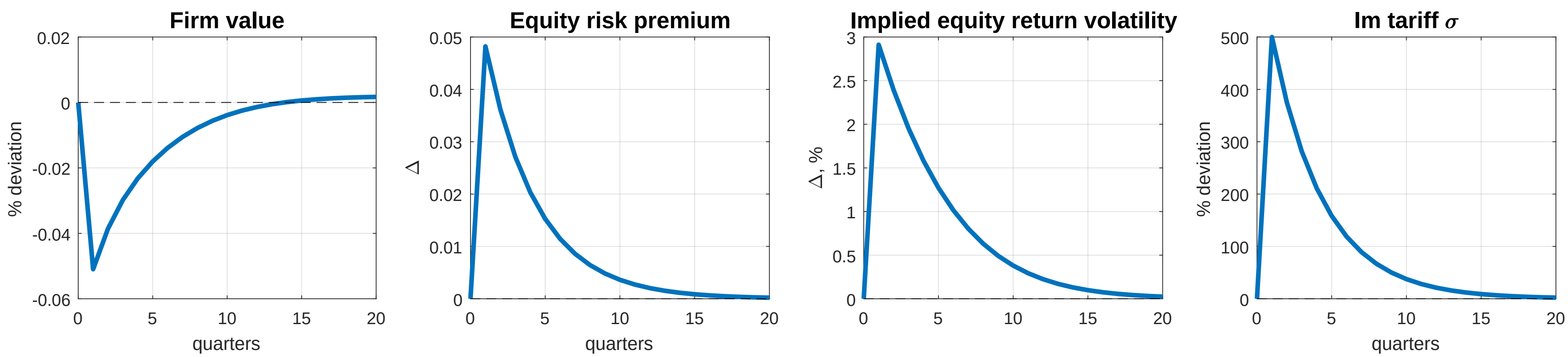


Note: (a) plots the current account effect of FX risk $\underbrace{\left(\mathrm{Var}_t \Delta c_{t+1} - \mathbb{E}_t \Delta c_{t+1} - g_t\right)}_{\text{Discounting}} + \underbrace{\left(R^*_{t+1} + \mathbb{E}_t \Delta rer_{t+1}\right)}_{\text{t+1 payoff}} - \underbrace{\mathrm{Cov}_t\left(\Delta c_{t+1}, \Delta rer_{t+1}\right)}_{\text{Foreign exchange risk}} \approx 0$

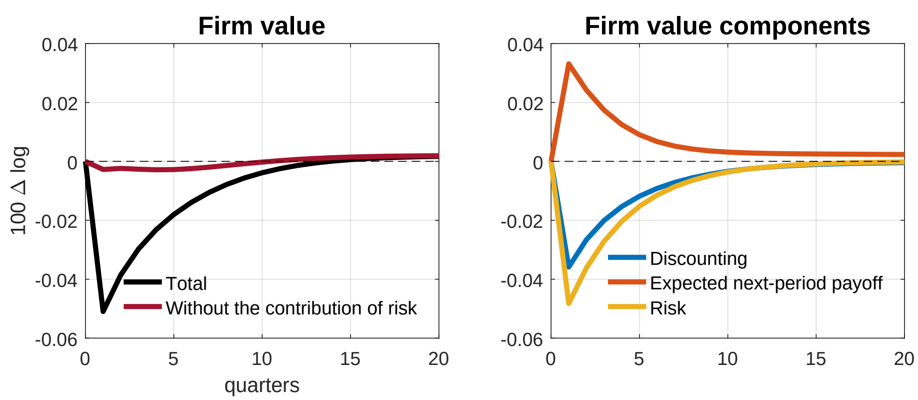
(b) plots UIP violation $\left(R^*_{t+1} + \mathbb{E}_t \Delta rer_{t+1}\right) - \mathbb{E}_t R_{t+1} \approx \underbrace{\mathrm{Cov}_t\left(\Delta c_{t+1}, \Delta rer_{t+1}\right) - \mathrm{Cov}_t\left(\Delta c_{t+1}, R_{t+1}\right)}_{\text{Foreign exchange vs domestic bond risk premium}}$

Figure 10: Responses to a home import tariff uncertainty shock, the role of equity risk [cited on page 19]

(a) Equity risk premium



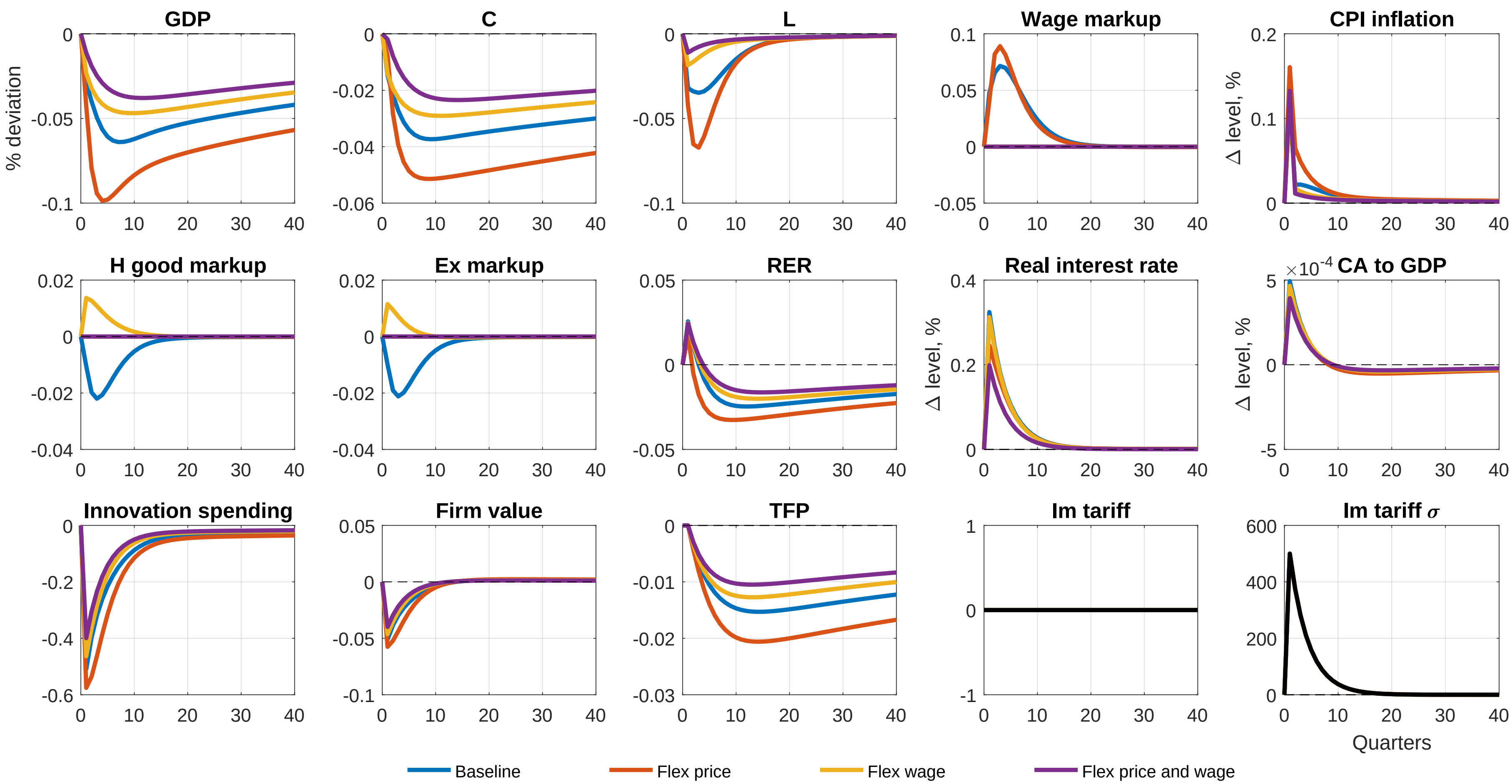
(b) Firm value decomposition



Note: (a) excess equity return over the risk-free real rate $\mathbb{E}_t \mathrm{R}^{\mathrm{equity}}_{\mathrm{t+1}} - \mathrm{R}^{\mathrm{f}}_{\mathrm{t+1}} = \mathrm{Cov}_t\left(\Delta \mathrm{c}_{\mathrm{t+1}}, \mathrm{R}^{\mathrm{equity}}_{\mathrm{t+1}}\right)$, where $R^{equity}_{t+1} = \frac{v_{t+1}+d_{t+1}}{v_t}$; Implied equity return volatility is in annualized percentage terms $VXO_t = 100\sqrt{4\mathrm{Var}_t(R^{equity}_{t+1})}$

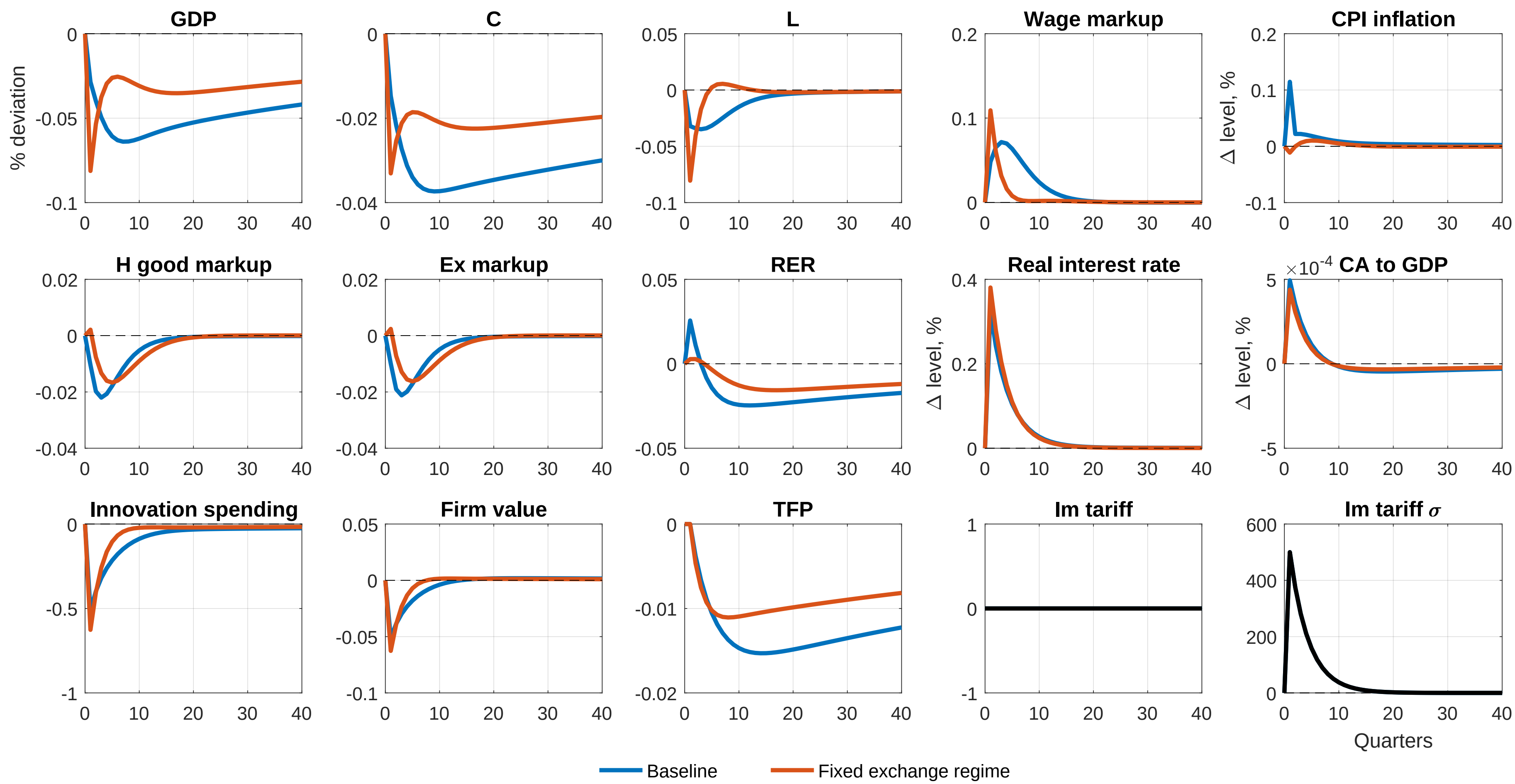
(b) plots the firm value decomposition $\mathrm{v_t} = \underbrace{(\mathrm{Var}_t \Delta \mathrm{c}_{\mathrm{t+1}} - \mathbb{E}_t \Delta \mathrm{c}_{\mathrm{t+1}} - \mathrm{g_t})}_{\text{Discounting}} + \underbrace{\mathbb{E}_t \mathrm{P}^{\mathrm{e}}_{\mathrm{t+1}}}_{\text{t+1 payoff}} - \underbrace{\mathrm{Cov}_t\left(\Delta \mathrm{c}_{\mathrm{t+1}}, \mathrm{P}^{\mathrm{e}}_{\mathrm{t+1}}\right)}_{\text{t+1 equity payoff risk}}$, where $P^e_{t+1} = v_{t+1} + d_{t+1}$

Figure 11: Responses to a home import tariff uncertainty shock, the role of nominal rigidity [cited on page 20]



Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

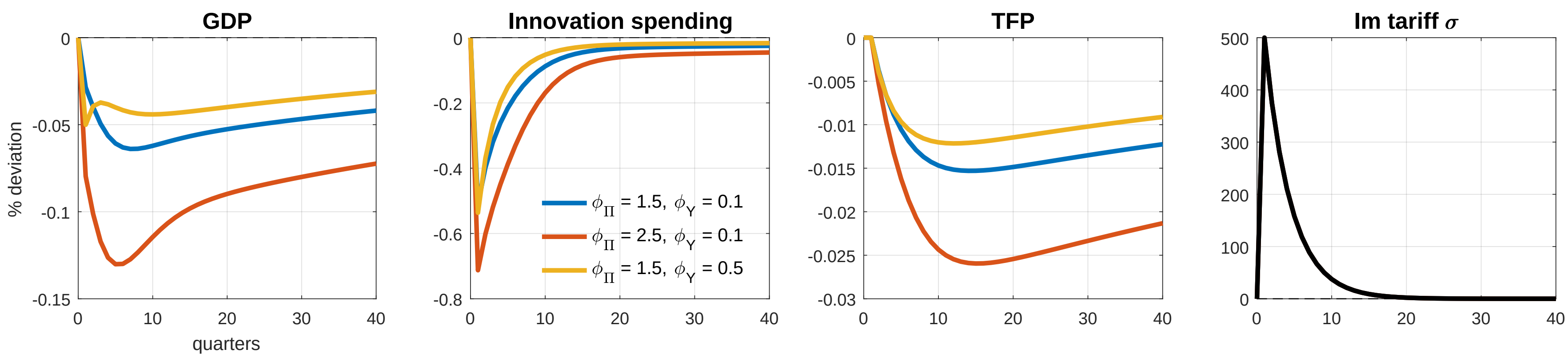
Figure 12: Responses to a home import tariff uncertainty shock, fixed exchange rate regime [cited on page 21]



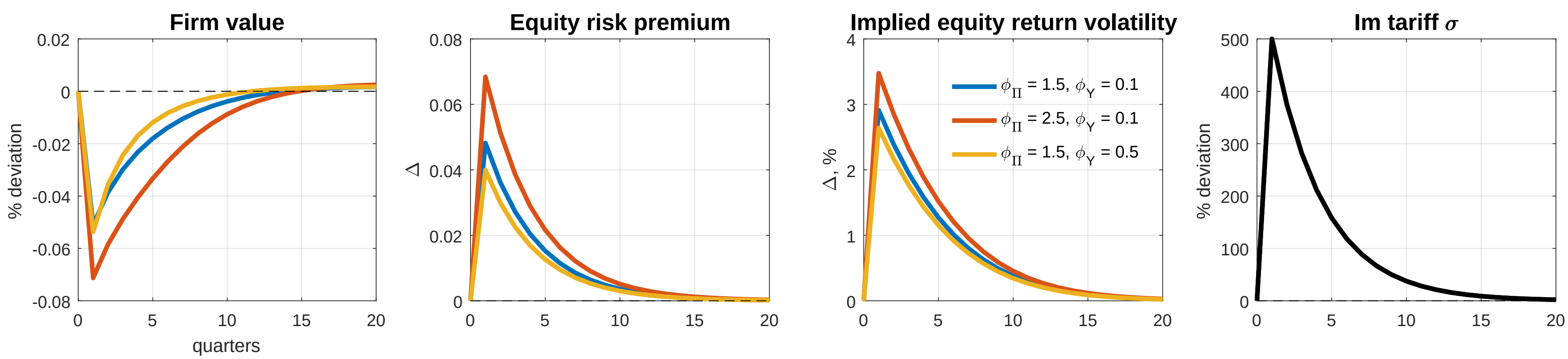
Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

Figure 13: Responses to a home import tariff uncertainty shock, the role of Taylor rule parameters [cited on page 21]

(a) Productivity growth response under different Taylor rule parameters



(b) Equity risk response under different Taylor rule parameters



Note: monetary policy is conducted through interest rate setting;

The risk-free nominal interest rate is governed by the following rule $\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\Pi} \left(\frac{GDP_t}{GDP_t^{BGP}}\right)^{\phi_Y} \right)^{1-\rho_i}$;

The interest rate smoothing parameter is held at $\rho_i = 0.7$ in each scenario.

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A Derivations

A.1 Net foreign assets law of motion

Start with the households budget constraint:

$$C_t + v_t N_{et} + AC_t^{B^*} + AC_t^W = \frac{W_t}{P_t} L_t + d_t N_t + \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right) + d_t^w + T$$

Taking into account equilibrium the lump-sum transfer $T = \tau_t p_t^F Y_t^F + AC_t^{B^*}$, innovation spending $S_t = v_t N_{et}$, and wholesale firms profit $d_t^w = (p_t^H - p_t^G)(Y_t^H + N_t x_t / A) + (p_t^{H^*h} - p_t^G) Y_t^{H^*} - AC_t^P - AC_t^{P^*} - \Gamma$ one can simplify it as follows:

$$C_t + S_t + AC_t^W = \frac{W_t}{P_t} L_t + d_t N_t + \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right) + p_t^H (Y_t^H + N_t \frac{x_t}{A}) +$$
$$p_t^{H^*h} Y_t^{H^*} - p^G (Y_t^H + N_t \frac{x_t}{A} + Y_t^{H^*}) - (AC_t^P + AC_t^{P^*} + \Gamma) + \tau_t p_t^F Y_t^F$$

Then, use the final good market clearing $Y_t = C_t + S_t + AC_t^W + AC_t^P + AC_t^{P^*} + \Gamma$ to get:

$$Y_t = \frac{W_t}{P_t} L_t + d_t N_t + \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right) + p_t^H (Y_t^H + N_t \frac{x_t}{A}) + p_t^{H^*h} Y_t^{H^*} -$$
$$p^G (Y_t^H + N_t \frac{x_t}{A} + Y_t^{H^*}) + \tau_t p_t^F Y_t^F$$

Total spending on the aggregate consumption good inclusive of the import tariff is $P_t Y_t = P_t^H Y_t^H + (1 + \tau_t) P_t^F Y_t^F$, which allows to simplify the expression further:

$$p_t^F Y_t^F - p_t^{H^*h} Y_t^{H^*} = \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right) + \frac{W_t}{P_t} L_t + d_t N_t + p_t^H N_t \frac{x_t}{A} - p^G (Y_t^H + N_t \frac{x_t}{A} + Y_t^{H^*})$$

Substitute in the domestic good market clearing condition $F_t = Y_t^H + Y_t^{H^*} + N_t \frac{x_t}{A}$

$$p_t^F Y_t^F - p_t^{H^*h} Y_t^{H^*} = \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right) + \frac{W_t}{P_t} L_t + d_t N_t + p_t^H N_t \frac{x_t}{A} - p^G F_t$$

Production sector firms operate on a perfectly competitive market with zero profits, which implies $p_t^G F_t = N_t p^x x_t + \frac{W_t}{P_t} L_t = N_t \left(d_t + p_t^H x_t / A \right) + \frac{W_t}{P_t} L_t$. Use this identity to cancel out terms:

$$p_t^F Y_t^F - p_t^{H^*h} Y_t^{H^*} = \varepsilon_t \left(\frac{B_t^*}{P_t} - (1 + i_{t-1}^*) \frac{B_{t-1}^*}{P_t} \right)$$

Finally, use the definition of the real exchange rate $rer_t = \frac{\varepsilon_t P_t^*}{P_t}$ and the fact that $p_t^{H^*h} = rer_t p_t^{H^*}$ and $p_t^F = rer_t p_t^{F^*}$ to get:

$$p_t^{F^*} Y_t^F - p_t^{H^*} Y_t^{H^*} = \frac{B_t^*}{P_t^*} - \frac{1 + i_{t-1}^*}{\Pi_t^*} \frac{B_{t-1}^*}{P_{t-1}^*} \tag{A.1}$$

A.2 Foreign exchange risk

In what follows we assume log-normality and use the fact that for an arbitrary log-normal variable x_t the following holds true: $\log(\mathbb{E}_t x_t) = \mathbb{E}_t(\log x_t) + \frac{1}{2}\mathrm{Var}_t(\log x_t)$.

Start with the Euler equation for foreign currency bonds (2) and the assumption of log utility in consumption. Take logs:

$$\log\beta - \log g_t + \log \mathbb{E}_t \left(\frac{c_t}{c_{t+1}} \frac{rer_{t+1}}{rer_t} R_{t+1}^* \right) = \log(1 - \psi b_{t+1}^*) \approx 0,$$

which under the assumption of log-normality becomes:

$$\log\beta - \log g_t + \mathbb{E}_t \log \left(\frac{c_t}{c_{t+1}} \frac{rer_{t+1}}{rer_t} R_{t+1}^* \right) + \frac{1}{2} \mathrm{Var}_t \log \left(\frac{c_t}{c_{t+1}} \frac{rer_{t+1}}{rer_t} R_{t+1}^* \right) \approx 0$$

$$\begin{aligned} &\log\beta - \log g_t - \mathbb{E}_t \log \left(\frac{c_{t+1}}{c_t} \right) + \mathbb{E}_t \log \left(\frac{rer_{t+1}}{rer_t} \right) + \mathbb{E}_t \log R_{t+1}^* + \\ &\qquad \frac{1}{2} \left(\mathrm{Var}_t \log \left(\frac{c_{t+1}}{c_t} \right) + \mathrm{Var}_t \log \left(\frac{rer_{t+1}}{rer_t} \right) + \mathrm{Var}_t \log R_{t+1}^* \right) + \\ &\qquad \mathrm{Cov}_t \left(\log R_{t+1}^*, \log \left(\frac{rer_{t+1}}{rer_t} \right) \right) - \mathrm{Cov}_t \left(\log \left(\frac{c_{t+1}}{c_t} \right), \log \left(\frac{rer_{t+1}}{rer_t} R_{t+1}^* \right) \right) \approx 0 \end{aligned}$$

The fact that $\mathbb{E}_t(\log x_t) = \log(\mathbb{E}_t x_t) - \frac{1}{2}\mathrm{Var}_t(\log x_t)$ allows to simplify the expression further:

$$\begin{aligned} &\log\beta - \log g_t - \log \mathbb{E}_t \left(\frac{c_{t+1}}{c_t} \right) + \log \mathbb{E}_t \log \frac{rer_{t+1}}{rer_t} + \log \mathbb{E}_t \log R_{t+1}^* + \mathrm{Var}_t \log \frac{c_{t+1}}{c_t} + \\ &\qquad \mathrm{Cov}_t \left(\log R_{t+1}^*, \log \left(\frac{rer_{t+1}}{rer_t} \right) \right) - \mathrm{Cov}_t \left(\log \frac{c_{t+1}}{c_t}, \log \left(\frac{rer_{t+1}}{rer_t} R_{t+1}^* \right) \right) \approx 0 \end{aligned}$$

Using sans serif font to denote log deviations from the steady state (e.g. $\mathbb{E}_t \mathsf{x}_{t+1} = \log \mathbb{E}_t x_{t+1} - \log x$), we arrive at the following expression:

$$\begin{aligned} &(\mathrm{Var}_t \Delta\mathsf{c}_{t+1} - \mathbb{E}_t \Delta\mathsf{c}_{t+1} - \mathsf{g}_t) + (\mathbb{E}_t \mathsf{R}_{t+1}^* + \mathbb{E}_t \Delta\mathsf{rer}_{t+1}) + \\ &\qquad \mathrm{Cov}_t \left(\mathsf{R}_{t+1}^*, \Delta\mathsf{rer}_{t+1} \right) - \mathrm{Cov}_t \left(\Delta\mathsf{c}_{t+1}, \Delta\mathsf{rer}_{t+1} + \mathsf{R}_{t+1}^* \right) \approx 0 \end{aligned}$$

Finally, if the foreign real interest rate follows a deterministic process we get:

$$(\mathrm{Var_t}\mathsf{\Delta c_{t+1}} - \mathbb{E}_\mathrm{t}\mathsf{\Delta c_{t+1}} - \mathsf{g_t}) + (\mathsf{R^*_{t+1}} + \mathbb{E}_\mathrm{t}\mathsf{\Delta rer_{t+1}}) - \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{\Delta rer_{t+1}}\right) \approx 0 \tag{A.2}$$

Similarly, the assumption of log-normality allows to transform the Euler equation for domestic bonds (1) as follows:

$$\log\beta - \log g_t - \mathbb{E}_\mathrm{t}\log\left(\frac{c_{t+1}}{c_t}\right) + \mathbb{E}_\mathrm{t}\log R_{t+1} + \frac{1}{2}\left(\mathrm{Var_t}\log\left(\frac{c_{t+1}}{c_t}\right) + \mathrm{Var_t}\log R_{t+1}\right) - \mathrm{Cov_t}\left(\log\left(\frac{c_{t+1}}{c_t}\right), \log R_{t+1}\right) = 0$$

$$\log\beta - \log g_t - \mathbb{E}_\mathrm{t}\log\left(\frac{c_{t+1}}{c_t}\right) + \log\mathbb{E}_\mathrm{t}R_{t+1} - \mathrm{Cov_t}\left(\log\left(\frac{c_{t+1}}{c_t}\right), \log R_{t+1}\right) = 0$$

$$(\mathrm{Var_t}\mathsf{\Delta c_{t+1}} - \mathbb{E}_\mathrm{t}\mathsf{\Delta c_{t+1}} - \mathsf{g_t}) + \mathbb{E}_\mathrm{t}\mathsf{R_{t+1}} - \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{R_{t+1}}\right) = 0 \tag{A.3}$$

Take the difference between (A.2) and (A.3) to show that UIP violation is linked to the relative risk premia:

$$(\mathbb{E}_\mathrm{t}\mathsf{R^*_{t+1}} + \mathbb{E}_\mathrm{t}\mathsf{\Delta rer_{t+1}}) - \mathbb{E}_\mathrm{t}\mathsf{R_{t+1}} \approx \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{\Delta rer_{t+1}}\right) - \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{R_{t+1}}\right) \tag{A.4}$$

A.3 Equity risk

Start with a first-order condition for equity holdings (3) and take logs:

$$\log(\beta(1-\delta)) - \log g_t + \log\mathbb{E}_\mathrm{t}\left(\frac{c_t}{c_{t+1}}R^{equity}_{t+1}\right) = 0,$$

where $R^{equity}_{t+1} = \frac{d_{t+1}+v_{t+1}}{v_t}$. Assuming log-normality and using sans serif font to denote log deviations from the steady state we get:

$$\log(\beta(1-\delta)) - \log g_t - \mathbb{E}_\mathrm{t}\log\left(\frac{c_{t+1}}{c_t}\right) + \mathbb{E}_\mathrm{t}\log R^{equity}_{t+1} + \frac{1}{2}\left(\mathrm{Var_t}\log\left(\frac{c_{t+1}}{c_t}\right) + \mathrm{Var_t}\log R^{equity}_{t+1}\right) - \mathrm{Cov_t}\left(\log\left(\frac{c_{t+1}}{c_t}\right), \log R^{equity}_{t+1}\right) = 0$$

$$(\mathrm{Var_t}\mathsf{\Delta c_{t+1}} - \mathbb{E}_\mathrm{t}\mathsf{\Delta c_{t+1}} - \mathsf{g_t}) + \mathbb{E}_\mathrm{t}\mathsf{R^{equity}_{t+1}} - \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{R^{equity}_{t+1}}\right) = 0$$

The risk-free rate R^f_{t+1} is such that $(\mathrm{Var_t}\mathsf{\Delta c_{t+1}} - \mathbb{E}_\mathrm{t}\mathsf{\Delta c_{t+1}} - \mathsf{g_t}) + \mathsf{R^f_{t+1}} = 0$ and so

$$\mathbb{E}_\mathrm{t}\mathsf{R_{t+1}} - \mathsf{R^f_{t+1}} = \mathrm{Cov_t}\left(\mathsf{\Delta c_{t+1}}, \mathsf{R_{t+1}}\right), \tag{A.5}$$

from which it follows that the excess return on equity is

$$\mathbb{E}_t R^{equity}_{t+1} - R^f_{t+1} = \mathrm{Cov}_t\left(\Delta c_{t+1}, R^{equity}_{t+1}\right) \tag{A.6}$$

Similarly, equation (3) can be used to decompose the current firm value v_t as follows:

$$v_t = (\mathrm{Var}_t \Delta c_{t+1} - \mathbb{E}_t \Delta c_{t+1} - g_t) + \mathbb{E}_t P^e_{t+1} - \mathrm{Cov}_t\left(\Delta c_{t+1}, P^e_{t+1}\right) \tag{A.7}$$

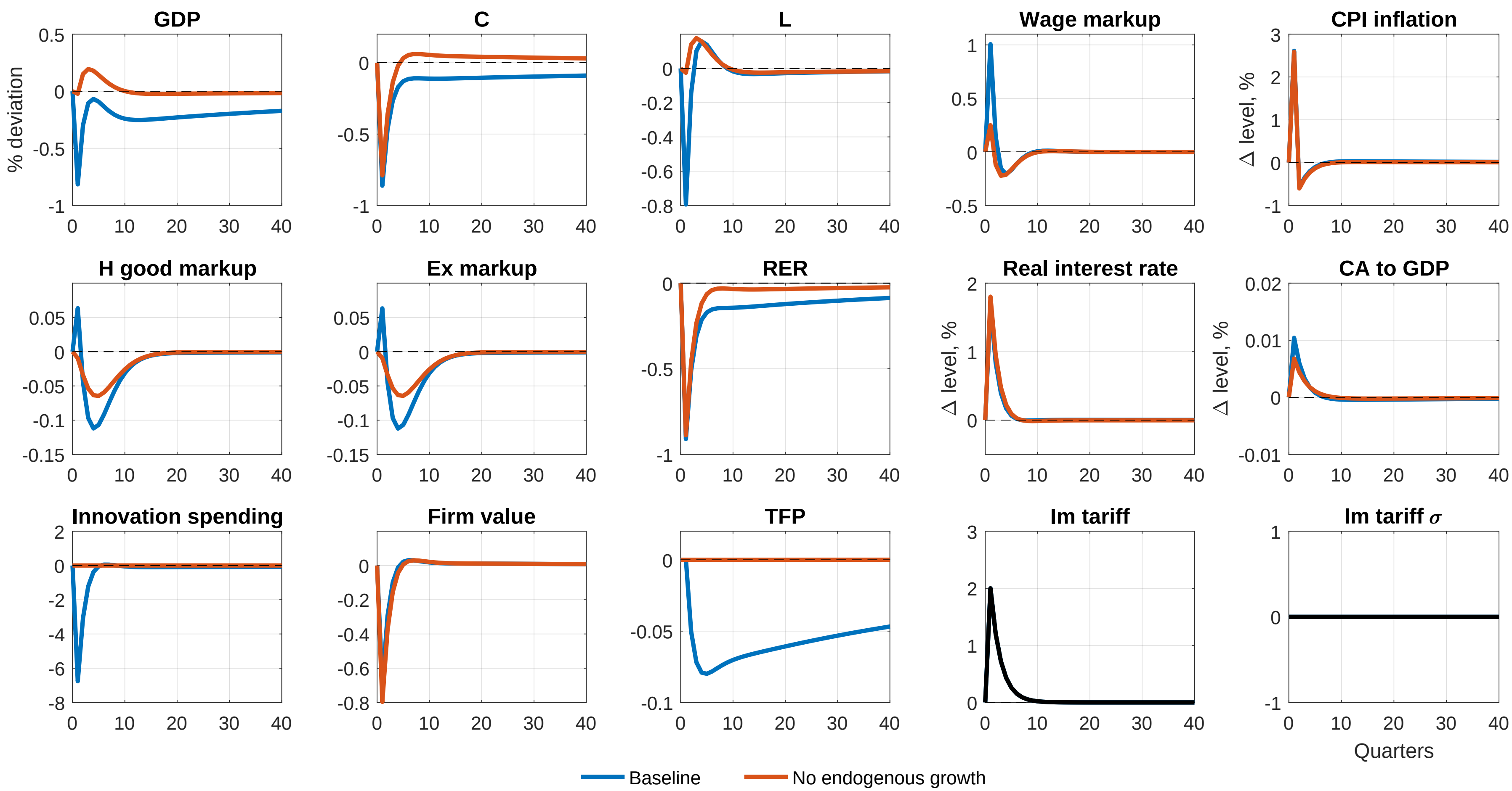
where $P^e_{t+1} = v_{t+1} + d_{t+1}$ denotes the $t+1$ payoff from holding equity, which includes the equity price and the dividend.

B Additional results

TABLE 3: DETERMINISTIC VS STOCHASTIC STEADY STATE [cited on page and 19]

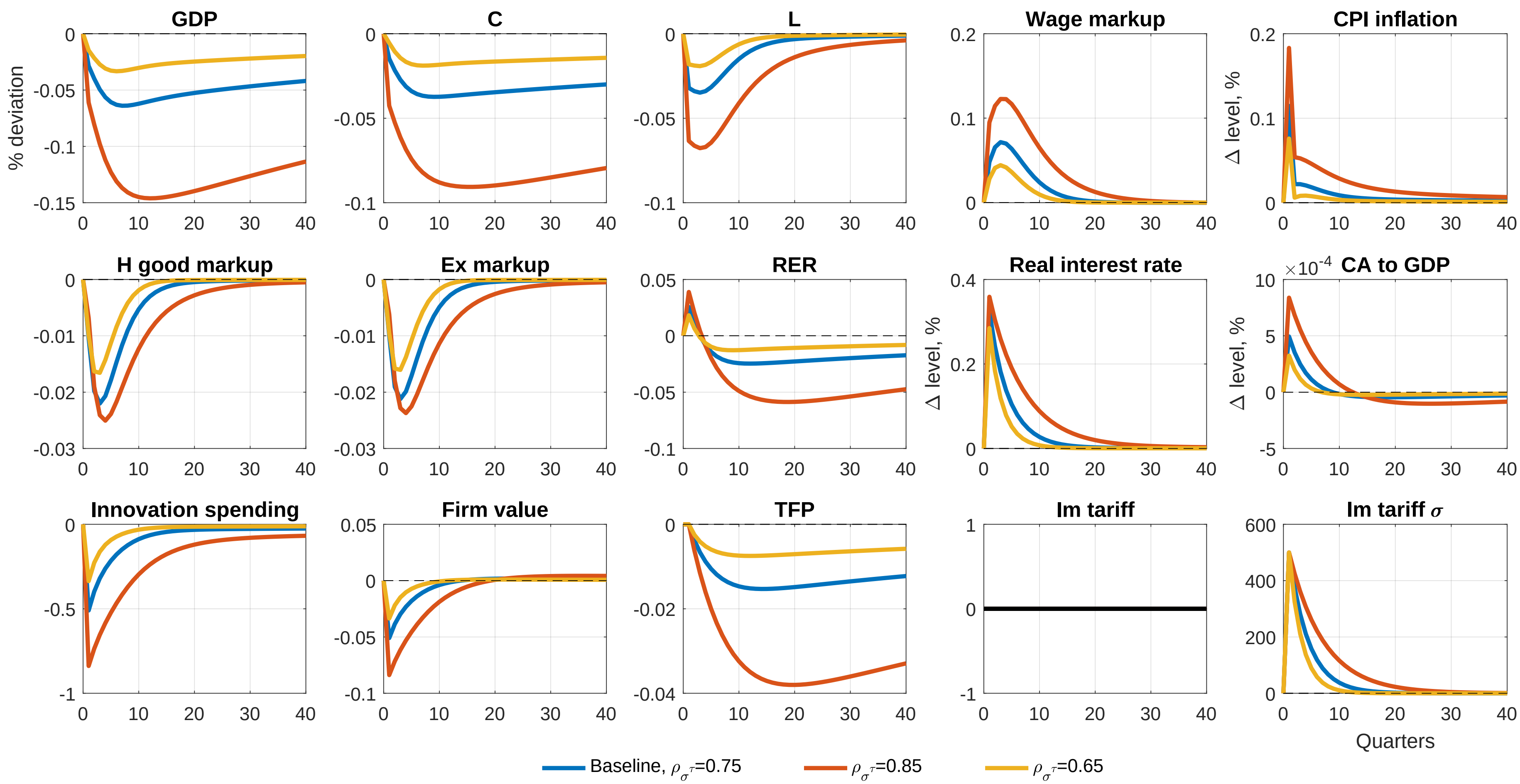
		Deterministic steady state	Stochastic steady state	Δ
f	GDP	1.0000	0.9997	-0.0286%
c	Consumption	0.8360	0.8369	0.1056%
s	Innovation spending	0.1640	0.1640	0.0031%
L	Labor	1.0000	0.9997	-0.0286%
b/f	NFA to GDP, %	0.0000	0.0031	0.0031

Figure 14: Responses to a home import tariff shock, the role of innovation spending [cited on page 15]



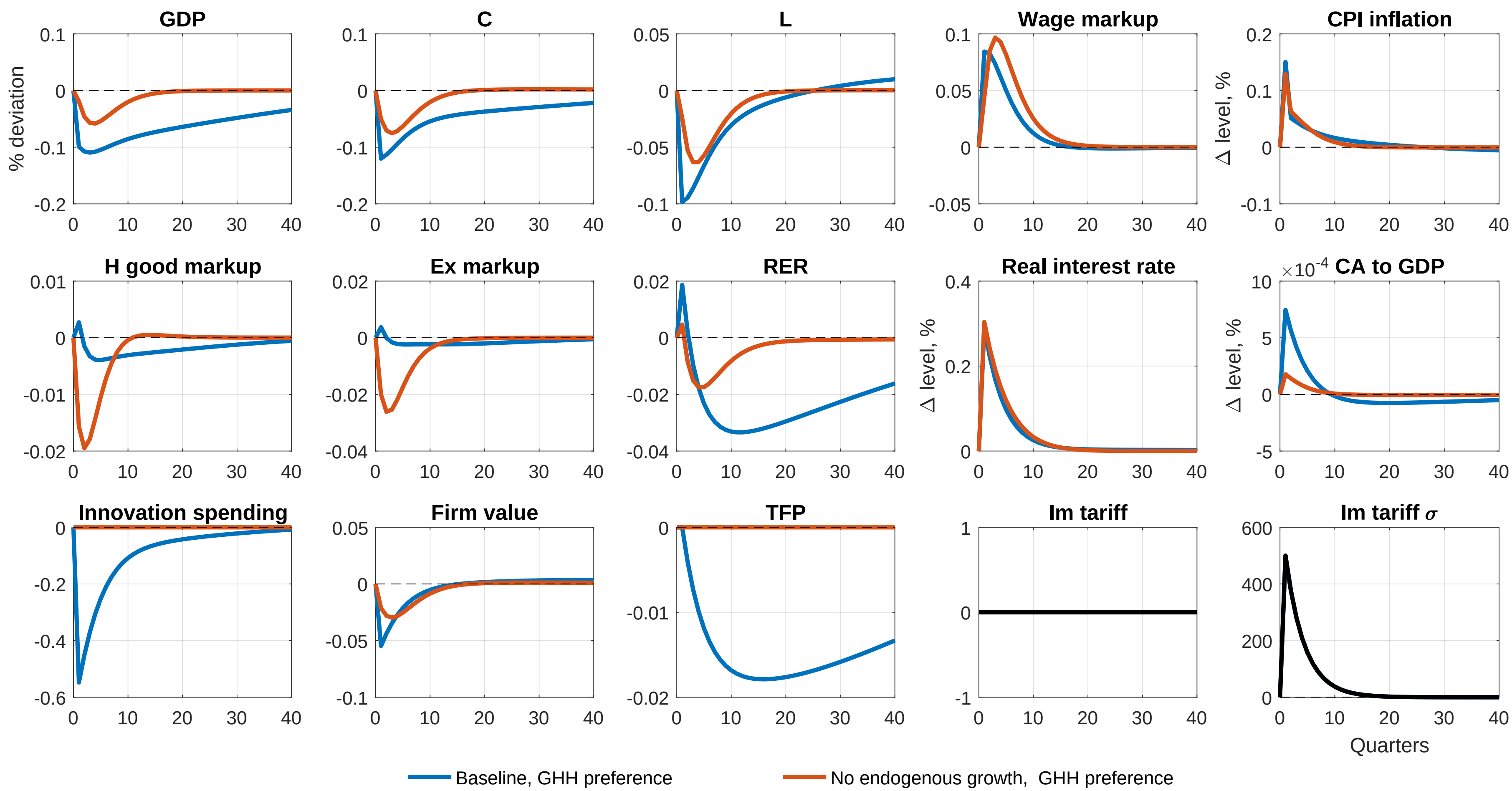
Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.

FIGURE 15: RESPONSES TO A HOME IMPORT TARIFF UNCERTAINTY SHOCK, THE ROLE OF SHOCK'S PERSISTENCE [cited on page 16]



Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized. $\sigma_t^\tau = (1-\rho_{\sigma^\tau})\sigma^\tau + \rho_{\sigma^\tau}\sigma_{t-1}^\tau + \sigma^{\sigma^\tau}\varepsilon_t^{\sigma^\tau}$

Figure 16: Responses to a home import tariff uncertainty shock, GHH preference [cited on page 17]



Note: impulse responses in log deviations from the stochastic steady state, unless otherwise noted. Inflation rate and the real interest rate are annualized.