Trade openness, uncertainty shocks and monetary policy

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Abstract

Motivation: When an economy opens up its trade to the world, it also exposes itself to the worldwide events. There is an extensive literature discussing the effect of trade openness on growth and development in an economy. There is also a literature showing the destabilizing effects (higher variability of the macro variables) of trade on an economy. Most of the results in this literature does the *ex-post* welfare analysis of the shocks. But it is also the case that the economies especially emerging markets and developing economies (EMDEs) become vulnerable to world wide shocks as their trade openness increases. This fact is very well recognized in the literature. But the study discussing the *ex-ante* risks and its associated outcomes due to the opening up of the economy is extremely limited. This paper attempts to fill this gap. We believe that the question of understanding the vulnerability to external shocks associated with trade openness of a country can be better understood in a model setup as it allows us to create a counterfactual scenarios more easily.

Research Questions: How does uncertainty shocks (both demand and supply side) present outside the domestic country affect the levels of the macroeconomic variables of the domestic country? What factors and characteristics affect the extent of the this vulnerability to external shocks as the economy opens up? Since a macro monetary model is used for this analysis, is there a role for the monetary policy in stabilizing the economy?

Methodology: To do this, we build a two country heterogenous new Keynesian dynamic stochastic general equilibrium model with complete asset markets and introduce uncertainty shocks to productivity (supply side) and preference (demand

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side) in the foreign economy. In macro models the uncertainty shocks are modelled as shocks to second moments to the variables. We do third order approximation of the model using Dynare and MATLAB as needed to get the complete effect of the uncertainty shocks as already discussed in literature. We simulate the data for 400 quarters to get the empirical moments to understand the long run impact of the uncertainty shocks. To understand the short term transmission of the shock across the economy we simulate the impulse response functions.

Results so far: In the baseline model it is observed that the uncertainty shock external to the country does affect the level of the macroeconomic variables under free trade in the long run as well as the short run as the domestic economy opens up its trade. One of the most important feature that determines whether the real variables of the domestic economy get affected is the flexibility of prices. Using the baseline model we observe that the real variables do not get affected when the prices are completely flexible as all nominal variables adjust completely here. On the other hand when the prices are sticky the real variables adjusts. When the agents in the domestic country anticipates an uncertainty shock they reduce their consumption, increase there precautionary savings, and the output contracts.

Work in progress:

- To make the model more close to reality, we are working on a version of the model where domestic producers are not price makers but price takers. How does this change of market power affect the welfare of an economy?
- What is the role of monetary policy in this? Assuming that the foreign country has a zero lower bound on the interest rates, does this changes the response of domestic monetary policy? Does the role of monetary policy vary with the change of exchange rate determination from floating to fixed exchange rate regime?
- We are also trying to understand the role of important parameters like coefficient of risk version and elasticity of demand on the welfare results.

Please find attached the presentation along.

Trade openess, Uncertainty shocks and Monetary policy

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Trade literature for developing countries I

The literature relating to trade openness is extremely vast.

1. Positive correlation between trade liberalization, growth and poverty reduction (Edwards(1993), Frankel & Romer(1999), Sachs & Warner(1995), Dollar & Kraay (2002), Cline(2004), Winters(2004)).
2. Negative effects of trade openness on poverty and inequality, even in the long run (Goldberg & Pavcnik(2004), Lundberg & Squire(2003) ,McCulloch, Winters, & Cirera(2001), Winters et al.(2004)).

Trade literature for developing countries II

3. "Destabilizing effect" with trade openness: High degree of trade openness leads to higher volatility on a wider set of outcome variables (aggregate income, consumption, employment, salaries, and prices), especially in developing countries (di Giovanni & Levchenko(2009), Easterly, Islam, & Stiglitz (2001), Loayza & Raddatz(2007) , Haddad, Lim, & Saborowski (2010), Hnatkovska & Loayza (2005), Loayza et al. (2007), Winters (2002)).

Higher volatility has been shown to have a negative relation with long-run growth and welfare (Ramey and Ramey (1995) , Hnatkovska & Loayza (2005)

Trade literature for developing countries III

4. No significant relationship between an increased degree of trade interdependence and domestic macroeconomic volatility (Caldero ‘n, Loayza, & Schmidt-Hebbel(2005)), Cavallo(2007) Kose & Yi(2006)

All the papers mentioned here do ex-post analysis of shocks present due to trade openness The literature on trade openness, shocks, and uncertainty is not very well studied. Magrini, Montalbano and Winters (2018) recently show that there are ex-ante risks due to trade exposure in Vietnam and these risks affect the consumption growth.

- The first contribution of this paper is to fill this gap in literature.

Uncertainty and Macro models

- Recently macro literature has introduced uncertainty shocks as a shock to second moment of the variable. It has been shown that these shocks to second order moments effects the levels of macro real variables
- Bloom (2009) –Studies effect of aggregate uncertainty on economy.
- Fernandez-Villaverde (2011) – Effect of uncertainty in real interest rate on the levels of macroeconomic variables in emerging markets.
- Basu and Bundick (2017))–Effect of uncertainty in demand on the levels of macroeconomic variables.

Research Questions

- Using a two country new Keynesian macro monetary model we try to answer following questions, (which I think can be answered best in a theoretical setup)
- Does the uncertainty shocks (both supply side and demand side) present outside an economy affect the domestic country level macro variables and welfare as the degree of trade openness increases.
- What are the domestic country specific structures, factors and characteristics that can affect there degree of "vulnerability" to these uncertain exogenous shocks.
- Role of monetary policy

Features of the basic model

1. Two country open economy NK-DSGE model. Let us assume a continuum of households in the world with domestic sector D and foreign sector F from $[0, 1]$ The a continuum of domestic sector exist over $[0, n]$ and that of foreign sector from $[n, 1]$. (see Benigno(2010))
   - Domestic households exist from $[0, n]$ produce good D
   - Foreign households exist from $[n, 1]$ produce good F
2. Heterogeneity of preference and demand structure between domestic and foreign households
3. Productivity and preference is characterized by time-varying volatility shocks

Households (Domestic)

The domestic households maximize following utility function (see Fernandez-Villaverde et al. (2011))

$$\max U(C_t, H_{D,t}) = \frac{\Upsilon_{D,t}\left(C_t\right)^{1-\nu_D}}{1-\nu_D} - \omega_D \frac{\left(H_{D,t}\right)^{1+\eta_D}}{1+\eta_D} \tag{1}$$

subject to constraint,

$$W_{D,t}H_{D,t} + profit_t = P_t C_t + B_t - E_t\left\{B_{t+1}M_{t,t+1}\right\} \tag{2}$$

where $M_{t,t+1}$ is the stochastic discount factor. In above equation, C_t is the aggregate basket of goods a domestic household consumes,

$$C_t = \left[(\mu_D)^{1/\xi_D}\left(C_{D,t}\right)^{\frac{\xi_D-1}{\xi_D}} + (1-\mu_D)^{1/\xi_D}\left(C_{F,t}\right)^{\frac{\xi_D-1}{\xi_D}}\right]^{\frac{\xi_D}{\xi_D-1}} \tag{3}$$

Assuming complete asset markets using Chari et. al. (2001) .

Households (Foreign)

Similarly, the foreign households maximize following utility function

$$\max U(C_t^*, H_{F,t}) = \frac{\Upsilon_{F,t}\left(C_t^*\right)^{1-\nu_F}}{1-\nu_F} - \omega_F \frac{\left(H_{F,t}\right)^{1+\eta_F}}{1+\eta_F} \tag{4}$$

subject to constraint,

$$W_{F,t}H_{F,t} + profit_t^* = P_t^* C_t^* + B_t^* - E_t\left\{B_{t+1}^* M_{t,t+1}^*\right\} \tag{5}$$

where $M_{t,t+1}^*$ is the stochastic discount factor. In above equation, C_t^* is the aggregate basket of goods a foreign household consumes,

$$C_t^* = \left[(\mu_F)^{1/\xi_F}\left(C_{D,t}^*\right)^{\frac{\xi_F-1}{\xi_F}} + (1-\mu_F)^{1/\xi_F}\left(C_{F,t}^*\right)^{\frac{\xi_F-1}{\xi_F}}\right]^{\frac{\xi_F}{\xi_F-1}} \tag{6}$$

Following Benigno (2010),

$$1-\mu_D = (1-n)\chi \quad ; \quad \mu_F = n\chi \tag{7}$$

where $\chi \in [0,1]$ is the parameter capturing degree of openness. $\chi = 0$ means autarky and $\chi = 1$ means free trade.

Consumption bundles

The consumption bundles $C_{D,t}$, $C_{F,t}$, $C^*_{D,t}$ and $C^*_{F,t}$ is an aggregate over variety i

$$C_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C_{D,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}; \quad (8)$$

$$C_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}} \int_n^1 \left(C_{F,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}; \quad (9)$$

$$C^*_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C^*_{D,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}; \quad (10)$$

$$C^*_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}} \int_n^1 \left(C^*_{F,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}. \quad (11)$$

First order conditions

- Domestic households

$$\lambda_{D,t} = \Upsilon_{D,t} \left(C_t\right)^{-(\nu_D)} \tag{12}$$

$$\lambda_{D,t} = \omega^D \frac{\left(H_{D,t}\right)^{\eta_D}}{w_{D,t} T_{D,t}} \tag{13}$$

$$\lambda_{D,t} E_t \left\{\pi_{t+1}\right\} = \beta \left(1 + R_{D,t}\right) E_t \left\{\lambda_{D,t+1}\right\} \tag{14}$$

where $T_{D,t} = \frac{P_{D,t}}{P_t}$.

- Foreign households

$$\lambda_{F,t} = \Upsilon_{F,t} \left(C_t^*\right)^{-(\nu_F)} \tag{15}$$

$$\lambda_{F,t} = \omega^F \frac{Q_t \left(H_{F,t}\right)^{\eta_F}}{w_{F,t} T_{F,t}} \tag{16}$$

$$\lambda_{F,t} E_t \left\{\pi^*_{t+1}\right\} = \beta \left(1 + R_{F,t}\right) E_t \left\{\lambda_{F,t+1}\right\} \tag{17}$$

where $T_{D,t} = \frac{P_{F,t}}{P_t}$ and $Q_t = \frac{X_t P_t^*}{P_t}$ (Q_t is real exchange rate and X_t is the nominal exchange rate)

Demand Functions I

Aggregate demand for $C_{D,t}$, $C_{F,t}$, $C^*_{D,t}$ and $C^*_{F,t}$ are,

$$C_{D,t} = \mu_D \left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D} C_t \tag{18}$$

$$C_{F,t} = (1-\mu_D) \left(\frac{P_{F,t}}{P_t}\right)^{-\xi_D} C_t \tag{19}$$

$$C^*_{D,t} = \mu_F \left(\frac{P^*_{D,t}}{P^*_t}\right)^{-\xi_F} C^*_t \tag{20}$$

$$C^*_{F,t} = (1-\mu_F) \left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\xi_F} C^*_t \tag{21}$$

where aggregate prices are,

$$P_t = \left[\mu_D \left(P_{D,t}\right)^{1-\xi_D} + (1-\mu_F) \left(P_{F,t}\right)^{1-\xi_D}\right]^{\frac{1}{1-\xi_D}} \tag{22}$$

$$P^*_t = \left[\mu_F \left(P^*_{D,t}\right)^{1-\xi_F} + (1-\mu_F) \left(P^*_{F,t}\right)^{1-\xi_F}\right]^{\frac{1}{1-\xi_F}} \tag{23}$$

Demand Functions II

Demand for each variety of consumption good by domestic house holds and foreign households,

$$C_{D,t}(i) = \left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C_{D,t}; \tag{24}$$

$$\text{where } P_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n \left(P_{D,t}(i)\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}}; \tag{25}$$

$$C_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} C_{F,t}; \tag{26}$$

$$\text{where } P_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 \left(P_{F,t}(i)\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}} \tag{27}$$

Demand Functions III

Continued..

$$C^*_{D,t}(i) = \left(\frac{1}{n}\right)\left(\frac{P^*_{D,t}(i)}{P^*_{D,t}}\right)^{-\sigma} C^*_{D,t}; \tag{28}$$

$$\text{where } P^*_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n \left(P^*_{D,t}(i)\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}}; \tag{29}$$

$$C^*_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\sigma} C^*_{F,t}; \tag{30}$$

$$\text{where } P^*_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 \left(P^*_{F,t}(i)\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}} \tag{31}$$

Note: $P_{D,t}(i) = X_t P^*_{D,t}(i)$ and $P_{F,t}(i) = X_t P^*_{F,t}(i)$.

Complete asset market condition

Complete asset market condition, here it is assumed that their are state-contingent bonds denominated in home currency. Both the domestic as well as the foreign households hold these bonds denominated in home currency.

$$\frac{U'_{C,t+1}}{U'_{C,t}}\frac{P_t}{P_{t+1}} = \frac{U'_{C^*,t+1}}{U'_{C^*,t}}\frac{X_t}{X_{t+1}}\frac{P^*_t}{P^*_{t+1}}$$

Writing recursively it we get,

$$\begin{aligned} Q_{t+1} &= X_0\frac{U'_{C,0}}{U'_{C^*,0}}\frac{P^*_0}{P_0}\frac{U'_{C^*,t+1}}{U'_{C,t+1}} \\ Q_{t+1} &= \kappa\frac{\left(C^*_{t+1}\right)^{-\nu_F}}{\left(C_{t+1}\right)^{-\nu_D}} \end{aligned}$$

Note, $Q_{t+1} = \frac{P^*_{t+1}X_{t+1}}{P_{t+1}}$ (implying that the real exchange rate depends on the ratios of marginal utilities) and κ is the initial condition, the ratio of marginal utilities at the beginning.

Some price relations

$$\text{Terms of trade, } T_t = \frac{P_{F,t}}{P_{D,t}} \tag{32}$$

$$\pi_t^* = \pi_{F,t}^* \frac{\left[\mu_F \left(T_t\right)^{\xi_F - 1} + \left(1 - \mu_F\right)\right]^{\left(\frac{1}{1-\xi_F}\right)}}{\left[\mu_F \left(T_{t-1}\right)^{\xi_F - 1} + \left(1 - \mu_F\right)\right]^{\left(\frac{1}{1-\xi_F}\right)}} \tag{33}$$

$$T_{F,t} = \left[\frac{1 - \mu_D \left(T_{D,t}\right)^{(1-\xi_D)}}{1 - \mu_D}\right]^{\left(\frac{1}{1-\xi_D}\right)} \tag{34}$$

Real exchange rate, (35)

$$Q_t = \frac{\left[\mu_F + \left(1 - \mu_F\right)\left(T_t\right)^{1-\xi_F}\right]^{\left(\frac{1}{1-\xi_F}\right)}}{\left[\mu_D + \left(1 - \mu_D\right)\left(T_t\right)^{1-\xi_D}\right]^{\left(\frac{1}{1-\xi_D}\right)}}, \tag{36}$$

Production (Domestic households)

Assume each households produce all the varieties i of good D

$$Y_{D,t}(i) = A_{D,t} H_{D,t}(i) \tag{37}$$

where,

$$A_{D,t} = (1-\rho_D)\,\overline{A}_D + \rho_D A_{D,t-1} + u_{D,t-1}\epsilon_{D,t} \tag{38}$$

$$u_{D,t} = \left(1-\rho_{\sigma_D}\right)\overline{u}_D + \rho_{\sigma_D} u_{D,t-1} + \varkappa_D \zeta_{D,t} \tag{39}$$

$$\max \sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(\underline{P}_{D,t}(i)\, Y_{D,t+k}(i) - MC_{D,t+k}\, Y_{D,t+k}(i)\right) \tag{40}$$

$$\text{where } Y_{D,t+k}(i) = \left(\frac{\underline{P}_{D,t}(i)}{P_{D,t+k}}\right)^{-\sigma} Y_{D,t+k} \tag{41}$$

Production (Foreign households)

$$Y_{F,t}(i) = A_{F,t} H_{F,t}(i) \tag{42}$$

$$\text{where, } A_{F,t} = (1-\rho_F)\,\overline{A}_F + \rho_F A_{F,t-1} + u_{F,t-1}\epsilon_{F,t} \tag{43}$$

$$u_{F,t} = (1-\rho_{\sigma F})\,\overline{u}_F + \rho_{\sigma_F} u_{F,t-1} + \varkappa_F \zeta_{F,t} \tag{44}$$

$$\max \sum_{k=0}^{\infty} \alpha_F M^*_{t,t+k} \left(\underline{P}^*_{F,t}(i)\, Y_{F,t+k}(i) - MC_{F,t+k}\, Y_{F,t+k}(i) \right) \tag{45}$$

$$\text{where } Y_{F,t+k}(i) = \left(\frac{\underline{P}^*_{F,t}(i)}{P^*_{F,t+k}} \right)^{-\sigma} Y_{F,t+k} \tag{46}$$

Optimal price setting: Calvo pricing

- Domestic firms: Aggregate prices

$$P_{D,t}(i) = \left[\alpha_D \left(P^*_{D,t-1}(i)\right)^{-\sigma} + (1-\alpha_D)\left(\underline{P}_{D,t}(i)\right)^{-\sigma}\right]^{-\frac{1}{\sigma}} \tag{47}$$

where,

$$\underline{P}_{D,t}(i) = \frac{\sigma}{\sigma-1}\frac{\sum_{k=0}^{\infty}\alpha_D M_{t,t+k} MC_{D,t+k} Y_{D,t+k}(i)}{\sum_{k=0}^{\infty}\alpha_D M_{t,t+k} Y_{D,t+k}(i)} \tag{48}$$

- Foreign firms: Aggregate prices

$$P^*_{F,t}(i) = \left[\alpha_F \left(P^*_{F,t-1}(i)\right)^{-\sigma} + (1-\alpha_F)\left(\underline{P}^*_{F,t}(i)\right)^{-\sigma}\right]^{-\frac{1}{\sigma}} \tag{49}$$

where,

$$\underline{P}^*_{F,t}(i) = \frac{\sigma}{\sigma-1}\frac{\sum_{k=0}^{\infty}\alpha_F M^*_{t,t+k} MC_{F,t+k} Y_{F,t+k}(i)}{\sum_{k=0}^{\infty}\alpha_F M^*_{t,t+k} Y_{F,t+k}(i)} \tag{50}$$

Recursive form price setting I

For domestic firms,

$$\underline{\pi}_{D,t} = \frac{\sigma}{(\sigma-1)}\pi_{D,t}\frac{X_{D,t}}{Z_{D,t}} \tag{51}$$

$$X_{D,t} = \lambda_t Y_{D,t} T_{D,t} mc_{D,t} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma} X_{D,t+1} \tag{52}$$

$$Z_{D,t} = \lambda_t Y_{D,t} T_{D,t} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma+1} Z_{D,t+1} \tag{53}$$

$$\pi_{D,t} = \left[\alpha_D + (1-\alpha_D)\left(\underline{\pi}_{D,t}\right)^{(1-\sigma)}\right]^{\left(\frac{1}{1-\sigma}\right)} \tag{54}$$

Recursive form price setting II

For foreign firms,

$$\underline{\pi}_{F,t} = \frac{\sigma}{(\sigma-1)}\pi^*_{F,t}\frac{X_{F,t}}{Z_{F,t}} \tag{55}$$

$$X_{F,t} = \lambda^*_t Y_{F,t}\frac{T_{F,t}}{Q_t}mc_{F,t} + \alpha_F\beta\left(\pi^*_{F,t+1}\right)^{\sigma}X_{F,t+1} \tag{56}$$

$$Z_{F,t} = \lambda^*_t Y_{F,t}\frac{T_{F,t}}{Q_t} + \alpha_F\beta\left(\pi^*_{F,t+1}\right)^{\sigma+1}Z_{F,t+1} \tag{57}$$

$$\pi^*_{F,t} = \left[\alpha_F + (1-\alpha_F)\left(\underline{\pi}_{F,t}\right)^{(1-\sigma)}\right]^{\left(\frac{1}{1-\sigma}\right)} \tag{58}$$

Aggregates I

- Goods market equilibrium,

Domestic country:

$$Y_{D,t} = (T_{D,t})^{-\xi_D} \left[\mu C_t + \mu^* \left(\frac{1-n}{n} \right) (T_{D,t})^{\xi_D - \xi_F} (Q_t)^{\xi_F} C_t^* \right] \quad (59)$$

Foreign country

$$Y_{F,t} = (T_{F,t})^{-\xi_D} \left[(1-\mu) \left(\frac{n}{1-n} \right) C_t + (1-\mu^*) (T_{F,t})^{\xi_D - \xi_F} (Q_t)^{\xi_F} C_t^* \right] \quad (60)$$

Aggregates II

- Labour Market equilibrium,
  - Domestic country:

$$H_{D,t} = Y_{D,t}\frac{Disp_{D,t}}{A_{D,t}} \tag{61}$$

$$\text{where, } Disp_{D,t} = \alpha_D\left(\underline{\pi}_{D,t}\right)^{\sigma} Disp_{D,t-1} + (1-\alpha_D)\left(\frac{\underline{\pi}_{D,t}}{\pi_{D,t}}\right)^{-\sigma} \tag{62}$$

  - Foreign country

$$H_{F,t} = Y_{F,t}\frac{Disp_{F,t}}{A_{F,t}} \tag{63}$$

$$\text{where } Disp_{F,t} = \alpha_F\left(\underline{\pi}_{F,t}\right)^{\sigma} Disp_{F,t-1} + (1-\alpha_F)\left(\frac{\underline{\pi}_{F,t}}{\pi^*_{F,t}}\right)^{-\sigma} \tag{64}$$

Net Exports

Net export = Export - Import,
$NX_{D,t}$ and $NX_{F,t}$ are the real net export for domestic country and foreign country respectively.

$$NX_{D,t} = T_{D,t} C^*_{D,t} - T_{F,t} C_{F,t}$$

$$NX_{F,t} = \frac{T_{F,t}}{Q_t} C_{F,t} - \frac{T_{D,t}}{Q_t} C^*_{D,t}$$

Preference shock,

$$\Upsilon_{D,t} = \left(1 - \rho_{\Upsilon_D}\right) \overline{\Upsilon} + \rho_{\Upsilon_D} \Upsilon_{t-1} + v_{D,t} \varpi_{D,t} \quad (65)$$

$$v_{D,t} = \left(1 - \rho_{\sigma_{\Upsilon_D}}\right) \overline{\Upsilon} + \rho_{\sigma_{\Upsilon_D}} v_{D,t-1} + \varkappa_{\Upsilon_D} \xi_{D,t} \quad (66)$$

$$\Upsilon_{F,t} = \left(1 - \rho_{\Upsilon_F}\right) \overline{\Upsilon} + \rho_{\Upsilon_F} \Upsilon_{t-1} + v_{F,t} \varpi_{F,t} \quad (67)$$

$$v_{F,t} = \left(1 - \rho_{\sigma_{\Upsilon_F}}\right) \overline{\Upsilon} + \rho_{\sigma_{\Upsilon_F}} v_{F,t-1} + \varkappa_{\Upsilon_F} \xi_{F,t} \quad (68)$$

Interest rate rule

- Domestic country

$$R_{D,t} = \left(\frac{1}{\beta}\right)\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi}\left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{\phi_y} - 1 \tag{69}$$

- Foreign country

$$R_{F,t} = \left(\frac{1}{\beta}\right)\left(\frac{\pi_t^*}{\overline{\pi}^*}\right)^{\phi_\pi}\left(\frac{Y_{F,t}}{Y_{F,t}^{fp}}\right)^{\phi_y} - 1 \tag{70}$$

- Welfare

$$Welfare_{D,t} = U(C_t, H_{D,t}) + \beta Welfare_{D,t+1} \tag{71}$$

$$Welfare_{F,t} = U(C_t^*, H_{F,t}) + \beta Welfare_{F,t+1} \tag{72}$$

$U_{D,t}$ and $U_{F,t}$ are (1) and (4) respectively.

Autarky: Degree of openness is zero

Under autarky $\chi = 0$, when no trade of goods is possible following conditions hold,

- $C_{F,t} = 0$ and $C^*_{D,t} = 0$, implying $C_{D,t} = C_t$ and $C^*_{F,t} = C^*_t$,since

$$\mu_F = 1 \text{ and } \mu_F = 0$$

- $T_{D,t} = 1$, $T_{F,t} = T_t$ (Terms of trade) $= Q_t$ (Real exchange rate)

Steady state

- For $\chi \neq 0$: The steady state is solved numerically for the variables (in MATLAB), $C_t, C_t^*, Y_{D,t}, Y_{F,t}, T_t, T_{D,t}, T_{F,t}, Q_t, \lambda_t, \lambda_t^*, b_t, b_t^*$, the rest have analytical solution
- For $\chi = 0$ there exist analytical solution of the steady state.

Third order approximation for volatility shocks

- First order cannot capture the dynamics due to volatility shocks as the policy functions would only depend on level shocks.
- The second order only captures the partial effects of the volatility shocks through interactions with other shocks.
- Third order approximation of the model will fully capture the effect of rise in volatility
- See Basu and Bundick (2017) , Fernández-Villaverde et al. (2011), Benigno et al. (2013), Grohe and Uribe (2004).

Solution

Very difficult to solve it analytically therefore we need to solve it numerically in MATLAB

AUTARKY

Uncertain productivity shock

Variable	Sticky price						Flexible prices					
	Mean	SS	SSS	%Δ ss	%Δ sss	Std. Dev.	Mean	SS	SSS	% Δ ss	% Δ sss	Std. Dev.
Consumption	0.359708	0.999846	0.994234	-64.023674	-63.820596	7.6850162	0.99888	0.99985	0.9998465	-0.09644901	-0.09644901	0.22192667
Labour	0.999588	0.999846	0.994234	-0.0258528	0.5384787	0.0526038	0.99985	0.99985	0.9998465	1.4855E-05	1.48554E-05	1.22E-06
Nominal Interest rate	0.622633	0.010101	-0.07272	6064.06907	-956.19805	8.1449698	-0.02436	0.0101	-0.076824	-341.145591	-68.2937152	0.21901507
Wages	0.353667	0.85755	-3.96079	-58.758408	-108.92921	43.155282	0.85672	0.85755	0.8575499	-0.09643521	-0.09643521	0.1903433
Welfare	-20081.2	-20000.1	-20078.7	-0.4052831	-0.0123658	42.020664	-20003.3	-20000	-20003.23	-0.01577457	-0.00013986	0.40339025
Output	0.359708	0.999846	0.994234	-64.023674	-63.820596	7.6850162	0.99888	0.99985	0.9998465	-0.09644901	-0.09644901	0.22192667
Inflation	1.613188	1	0.947209	61.3188352	70.309706	7.9605425	0.97285	1	0.9426293	-2.71450394	3.206529331	0.13938097

Uncertain demand shock

Variable	Sticky price						Flexible prices					
	Mean	SS	SSS	%Δ ss	%Δ sss	Std. Dev.	Mean	SS	SSS	% Δ ss	% Δ sss	Std. Dev.
Consumption	0.213337	0.999846	0.994561	-78.662988	-78.549597	7.1391	0.99982	0.99985	0.9998465	-0.00296818	-0.00296818	0.00024466
Labour	0.999281	0.999846	0.994561	-0.0565812	0.4745464	0.0475144	0.99982	0.99985	0.9998465	-0.00296818	-0.00296818	0.00024466
Nominal Interest rate	0.770456	0.010101	-0.01242	7527.51764	-6301.4498	7.4814547	-0.02356	0.0101	-0.016214	-333.229173	45.30162629	0.18379031
Wages	-0.03859	0.85755	-3.68018	-104.49945	-98.951544	39.313279	0.85755	0.85755	0.8575499	-1.1652E-13	0	9.27E-14
Welfare	-20077.6	-20000.1	-20074.7	-0.38767	-0.0147375	38.673641	-20000.1	-20000	-20000.1	-1.5674E-05	-1.3225E-07	0.00010487
Output	0.213337	0.999846	0.994561	-78.662988	-78.549597	7.1391	0.99982	0.99985	0.9998465	-0.00296818	-0.00296818	0.00024466
Inflation	1.759765	1	0.986896	75.9764794	78.313152	7.3185982	0.97351	1	0.9826324	-2.64880214	-0.92816338	0.12582656

FREE TRADE

Uncertain productivity shock

Variable	Both Flexible prices			Both Sticky price			Foreign flex +			Foreign sticky +		
	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.
Consumption	-0.05469	-0.05469	0.110997	-123.991	-124.346	40.02615	-15.0193	-14.9121	1.22773	-15.8614	-15.7765	1.48651
Labour	0.000767	0.000767	0.000114	-0.18991	2.569518	0.458124	-0.03233	0.218567	0.016156	0.010155	0.051991	0.00404
Nominal Interest rate	-84.4085	-113.463	0.097077	24976.95	261.0162	67.68529	2939.637	347.6537	2.104478	1144.573	-1537.52	1.453334
Wages	3.5E-13	3.5E-13	1.64E-13	-3.34188	-103.729	406.4844	-25.6733	-149.393	14.67511	-6.14244	61.58745	2.2916
Consumption_dom	0.000767	0.000767	5.69E-05	-231.644	-235.284	39.2124	-29.2476	-29.07	1.159027	-13.4552	-13.419	0.970511
Consumption_for	-0.09577	-0.09577	0.111016	-16.3252	-16.1324	0.827638	-0.77679	-0.77495	0.115266	-18.2538	-18.1229	0.58952
Welfare	-0.00399	-3.7E-05	0.189374	-0.82579	-0.02433	216.1296	-0.09171	-0.00286	6.438767	-0.08364	-0.0022	4.90994
Output	0.000767	0.000767	0.000114	0	-235.284	78.42479	-29.2476	-29.07	2.318054	-13.4552	-13.419	1.941023
Inflation	-0.67116	0.77879	0.063387	243.6204	134.4921	70.68274	29.23793	24.33472	2.153586	12.01207	13.40687	1.604341
Nominal Exchange Rate change	-2E-13	-1E-13	1.9E-13	240.5116	75.96118	61.13	29.86129	17.46084	1.834858	-6.35443	-6.61437	0.548807
Terms of trade	0.03006	0.03006	0.002456	-2.12391	-2.09982	0.767409	-0.25554	-0.25306	0.021786	0.077253	0.076071	0.011249
Real Exchange Rate	0	0	1.07E-13	0	0	1.16E-13	0	0	1.13E-13	0	0	1.1E-13
Marginal Costs	3.5E-13	3.5E-13	1.73E-13	-3.34188	-103.729	406.4844	-25.6733	-149.393	14.67511	-6.14244	61.58745	2.2916
Inflation_dom_good	-0.6761	0.773771	0.06254	273.38	6558.969	104.2811	29.73456	27.51699	2.278655	88.50565	100.016	8.577964
Net Exports	8.61E+14	1.46E+15	0.109971	-1.9E+18	8651.172	38.0133	-2.5E+17	11356.8	1.086951	4.28E+16	3964.638	0.601584

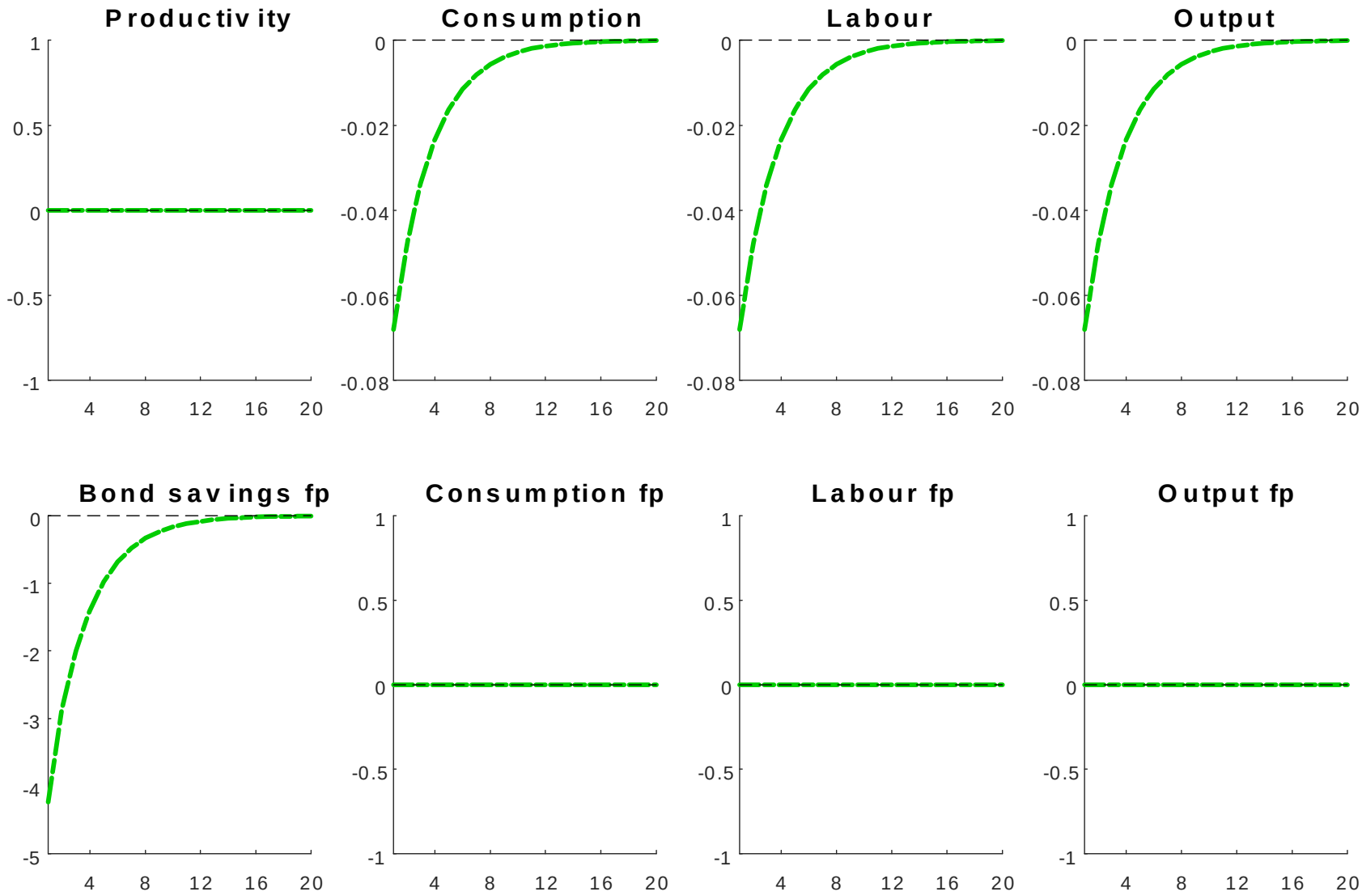
FREE TRADE

Uncertain demand shock

Variable	Both Flexible prices			Both Sticky price			Foreign flex + Domestic sticky			Foreign sticky + Domestic flex		
	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.	% Δ ss	% Δ sss	Std. Dev.
Consumption	-0.00148	-0.00148	0.000122	-451.81	-464.46	146.543283	-5.0522	-5.00798	0.223455	-44.5606	-44.3762	7.4623
Labour	1.48E-06	1.48E-06	1.22E-07	-0.7093	5.89099	1.66549712	-0.0122	0.074297	0.003348	0.001371	0.105358	0.01842
Nominal Interest rate	-0.00161	0.147309	0.000102	77110.8	421.838	243.451464	760.278	368.7216	0.355177	1874.115	-414.404	6.10901
Wages	1.98E-12	1.98E-12	4.97E-13	-1262.9	-81.049	1464.35231	-13.756	535.6335	3.089293	-42.9518	-1455.67	9.97674
Consumption_dom	1.48E-06	1.48E-06	6.09E-08	-821.01	-868.94	141.820579	-7.5478	-7.46785	0.198897	-13.0719	-12.9815	4.22792
Consumption_for	-0.00297	-0.00297	0.000122	-82.603	-82.479	4.75945066	-2.5566	-2.55007	0.032016	-76.0492	-75.9145	3.72414
Welfare	-7.8E-06	-7E-08	0.000202	-1.9138	-0.0815	792.207744	-0.0287	-0.00079	1.106008	-0.25869	-0.00743	28.1392
Output	1.48E-06	1.48E-06	1.22E-07	-821.01	-868.94	283.641158	-7.5478	-7.46785	0.397794	-13.0719	-12.9815	8.45584
Inflation	-1.1E-05	0.000981	6.75E-05	787.75	343.763	254.791034	7.58446	6.958	0.36617	16.85153	22.76639	6.8164
Nominal Exchange Rate change	4.37711	2.593517	0.153507	676.181	162.19	217.355208	9.44083	6.423277	0.218616	-51.0005	-46.5245	3.26549
Terms of trade	2.97E-05	2.97E-05	2.45E-06	-7.3842	-7.333	2.74223892	-0.0499	-0.04912	0.003535	0.629776	0.625197	0.05588
Real Exchange Rate	0	0	1.07E-13	0	0	2.1218E-13	0	0	1.06E-13	0	0	1E-13
Marginal Costs	2.45E-12	2.45E-12	5.53E-13	-1262.9	-81.049	1464.35231	-13.756	535.6335	3.089293	-42.9518	-1455.67	9.97674
Inflation_dom_good	-1.1E-05	0.00098	6.67E-05	1179.75	-1555.7	390.959961	9.53252	9.712667	0.455439	274.8359	254.1579	48.3869
Net Exports	2.65E+13	1.96E+12	0.000121	-7E+18	13262.2	135.729385	-4E+16	6165.171	0.174975	5.61E+17	13737.77	2.76546

Autarky

IRFs for one period uncertain world productivity shock I



Autarky

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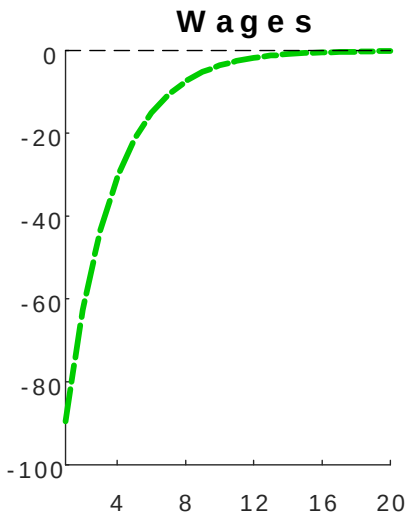
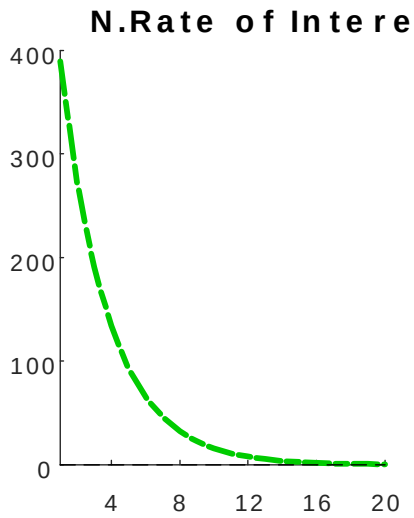
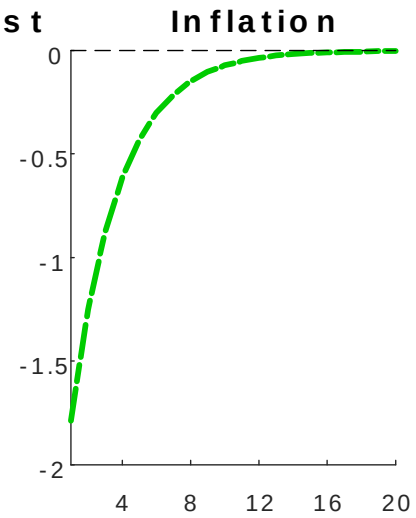
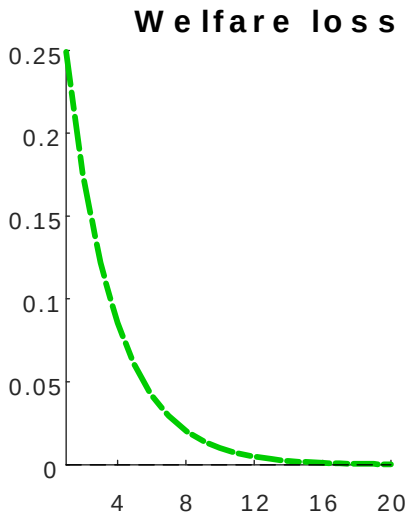
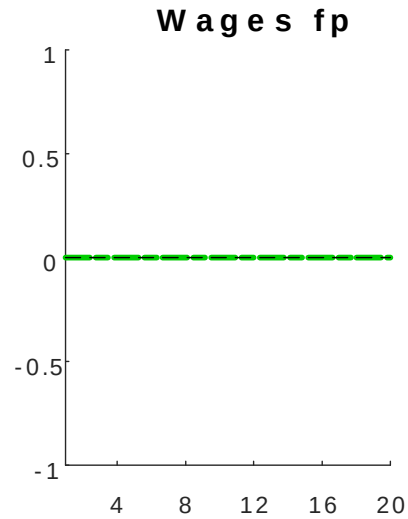
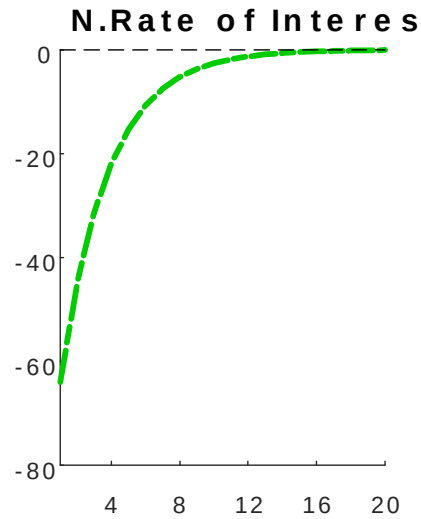


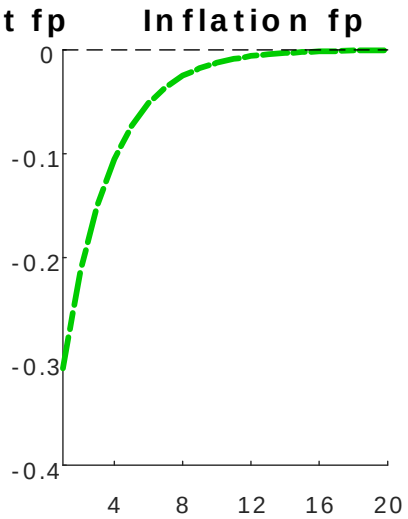


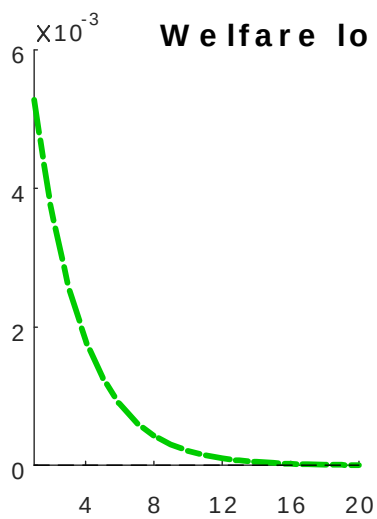






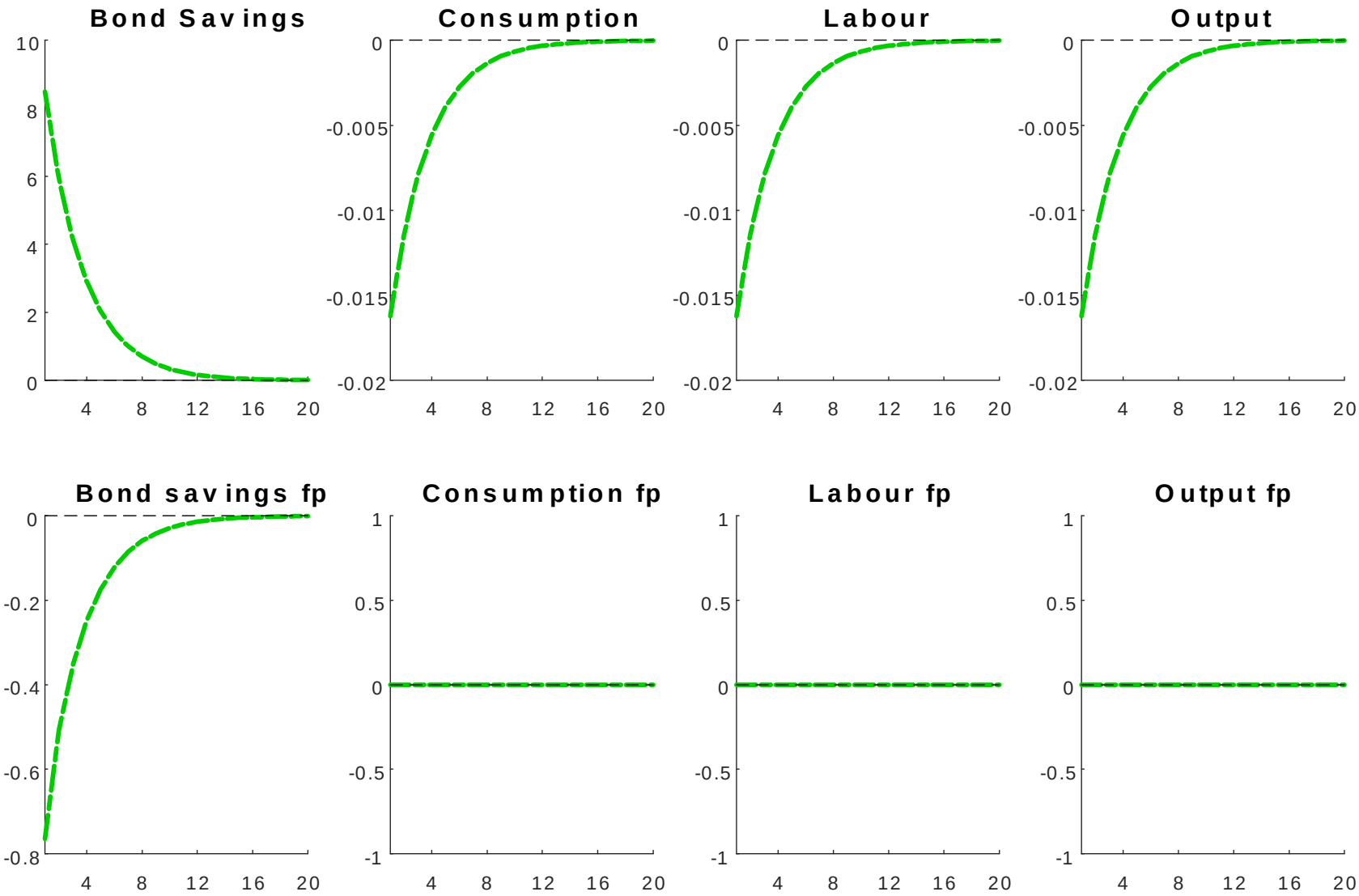






Autarky

IRFs for one period uncertain world demand shock I



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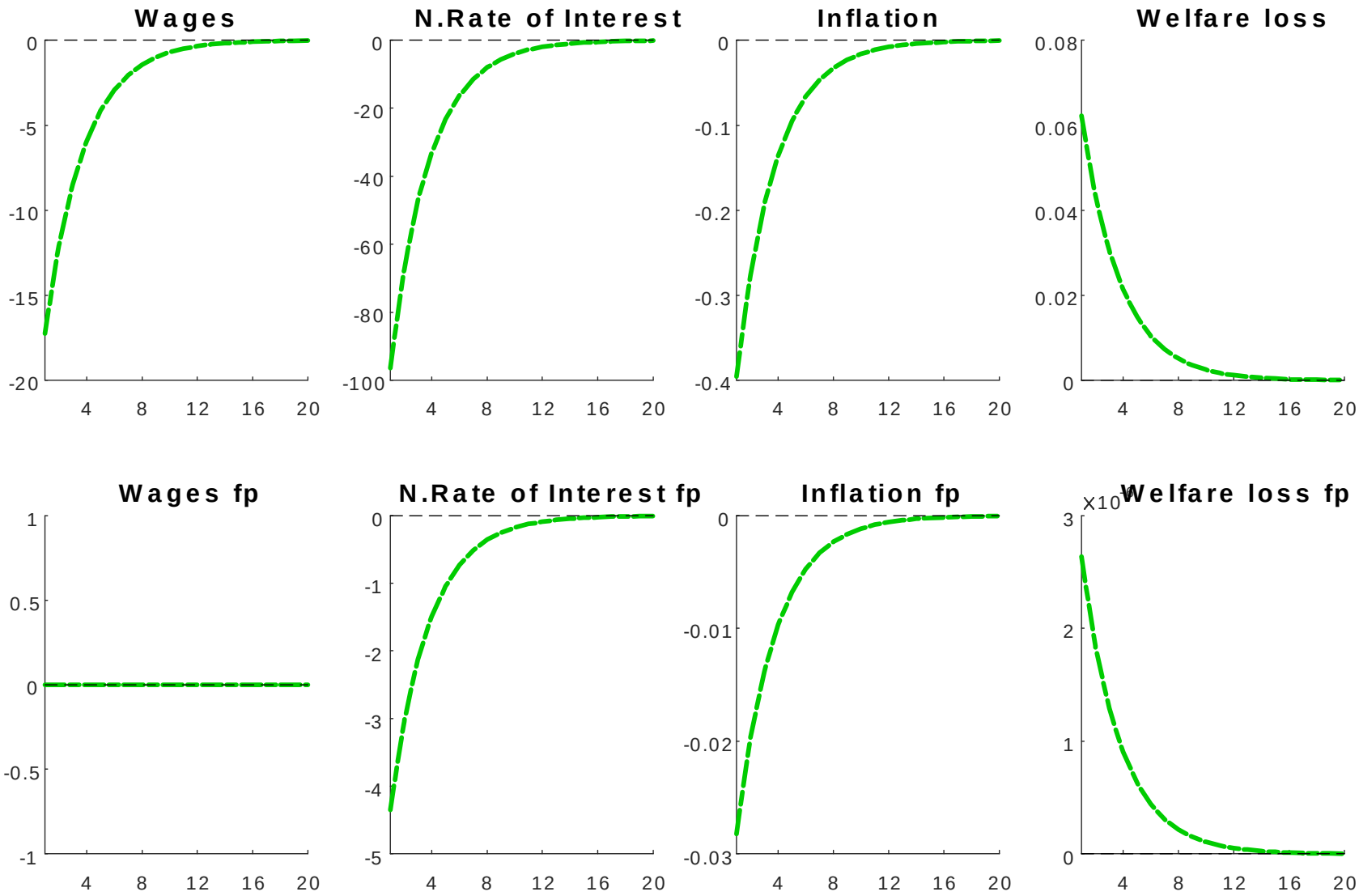
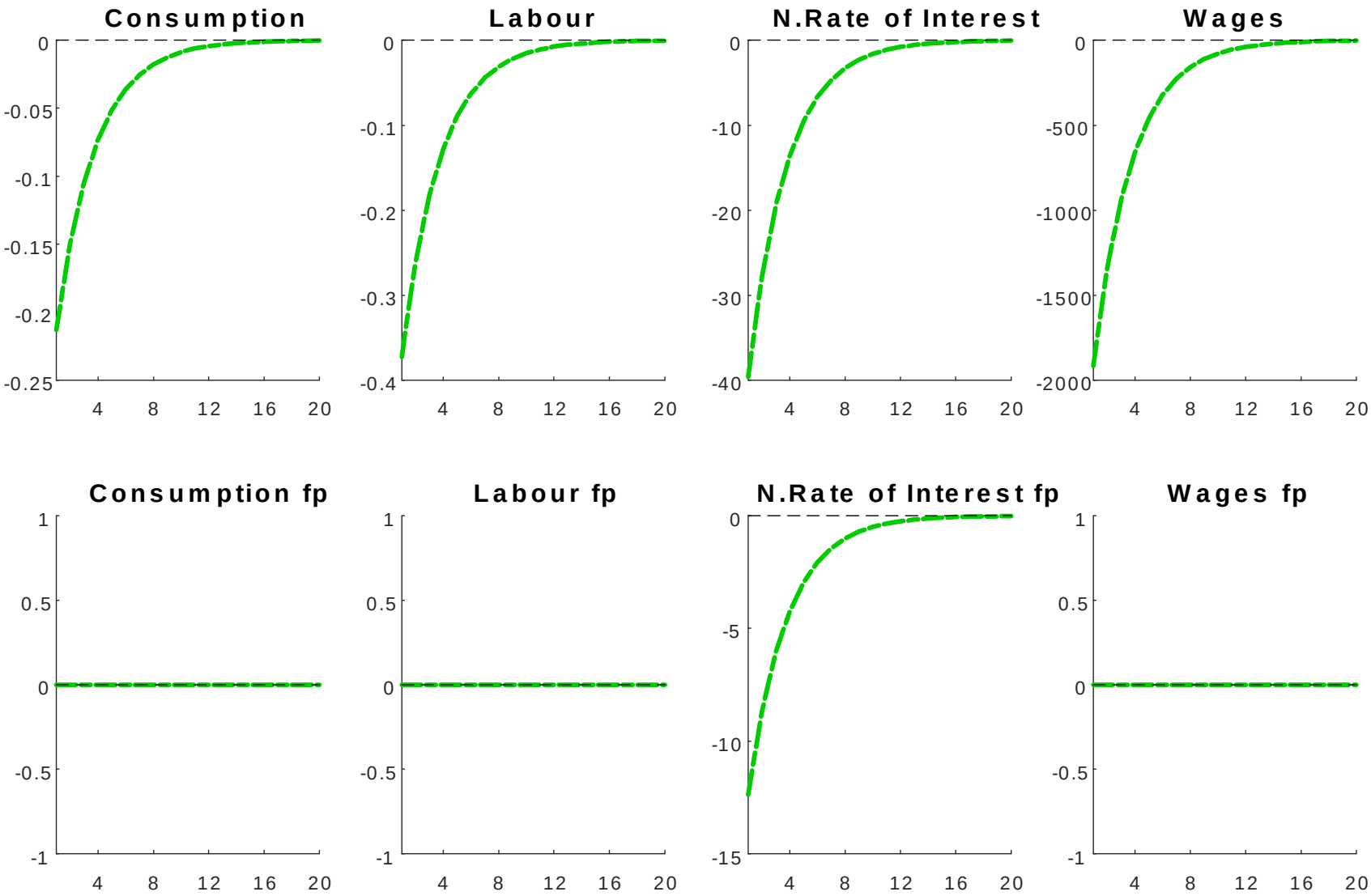


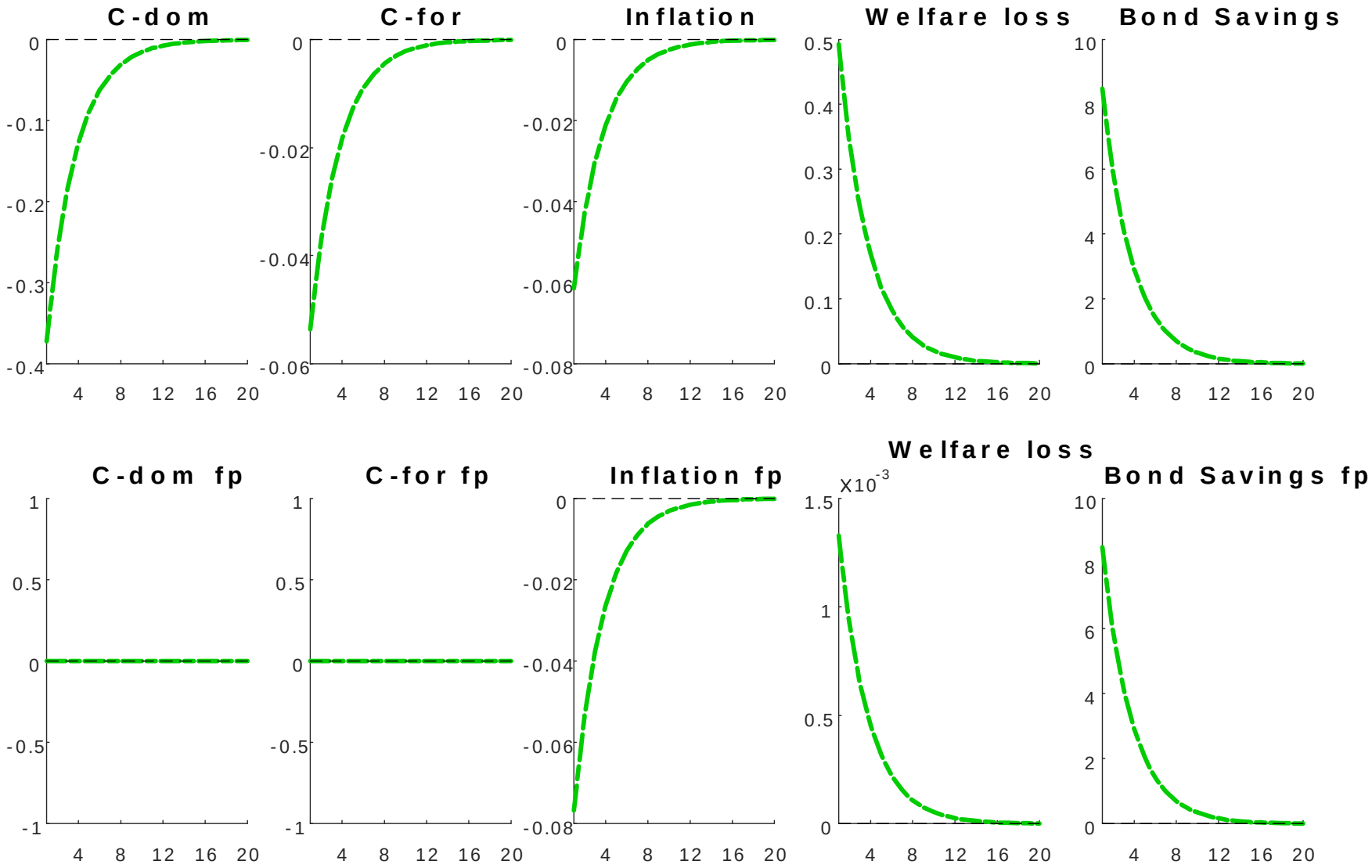
Free Trade

IRFs for one period uncertain world productivity shock I



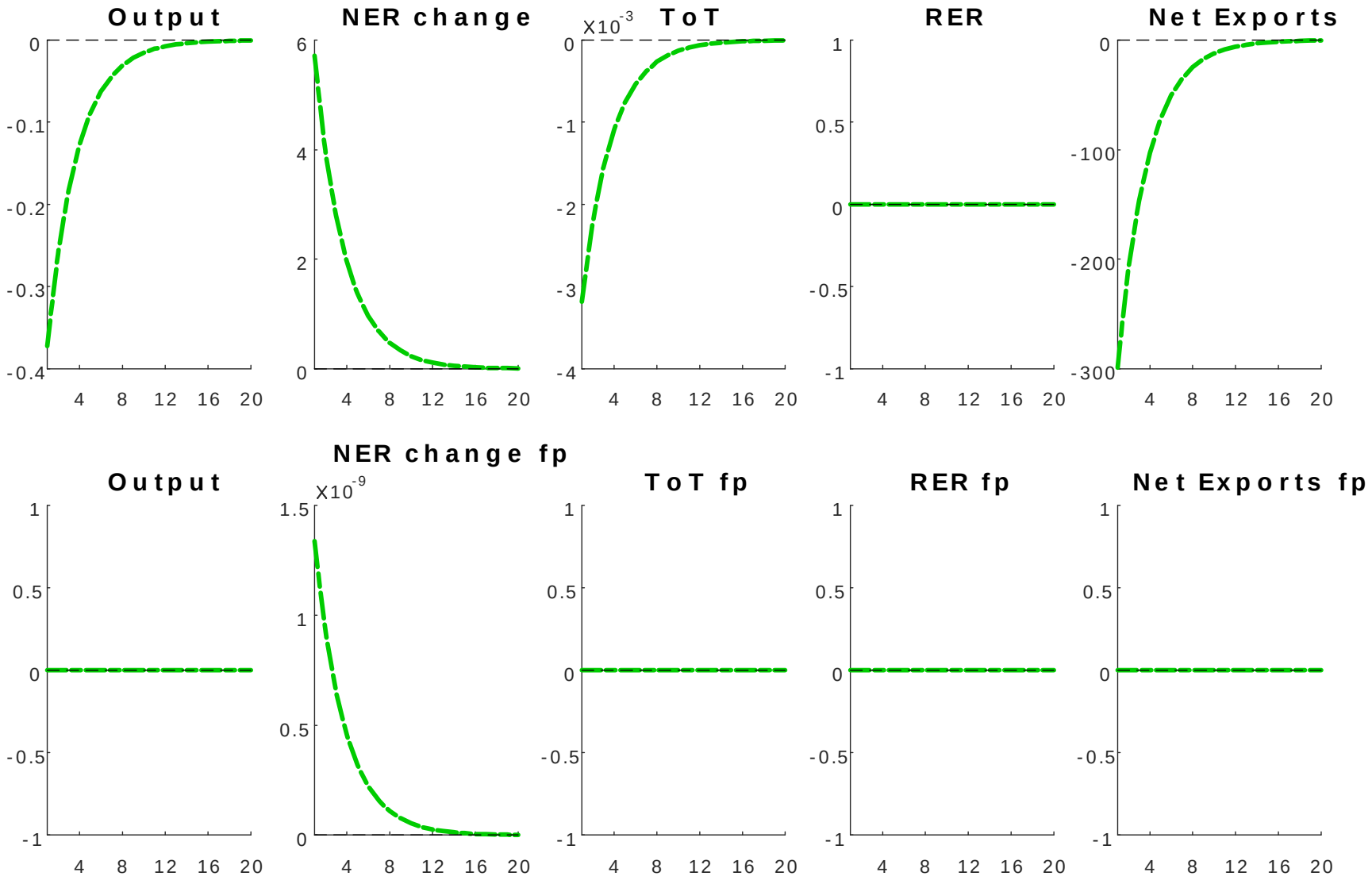
Free Trade

IRFs for one period uncertain world productivity shock II



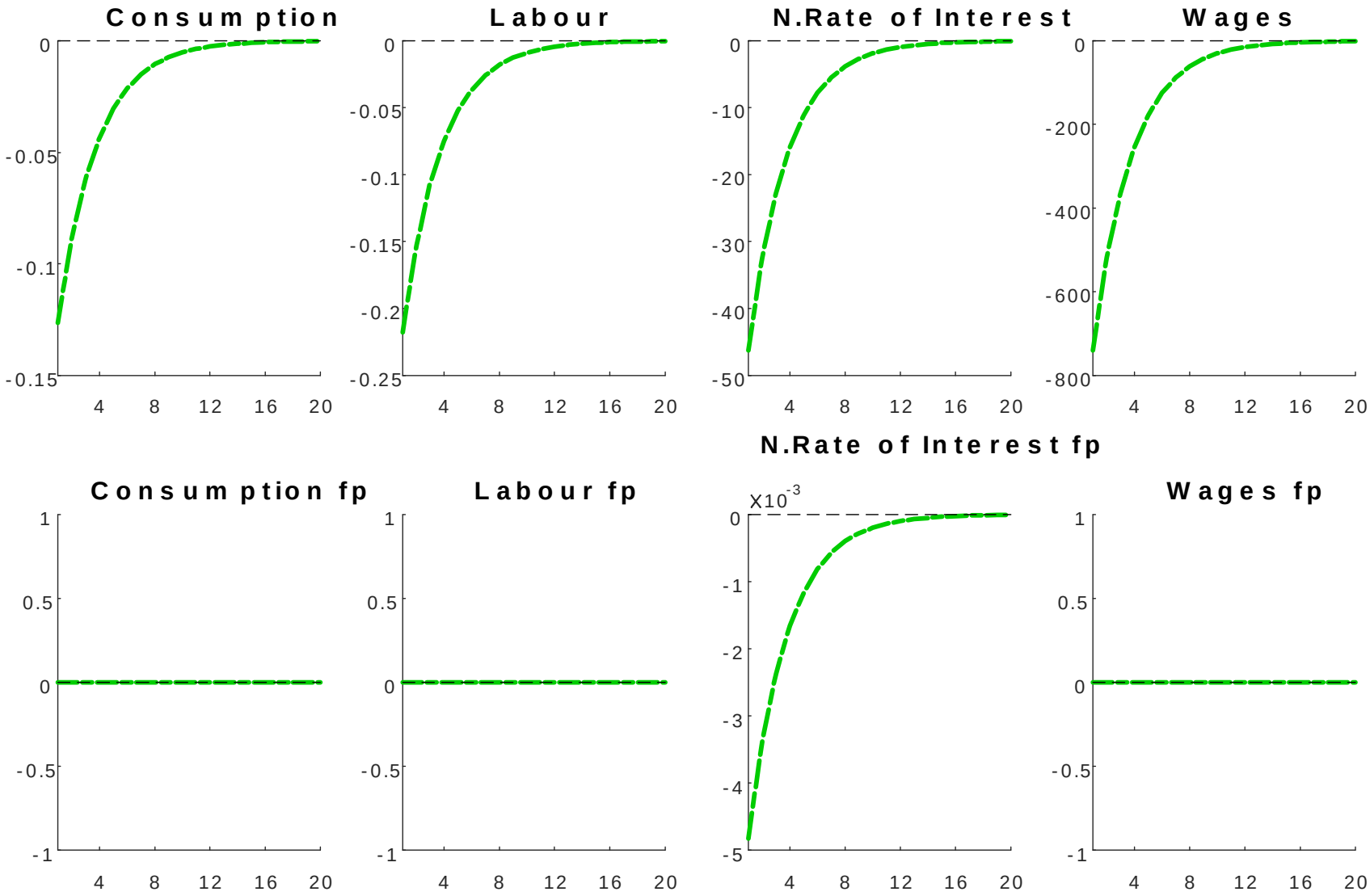
Free Trade

IRFs for one period uncertain world productivity shock III



Free Trade

IRFs for one period uncertain world demand shock I



Free Trade

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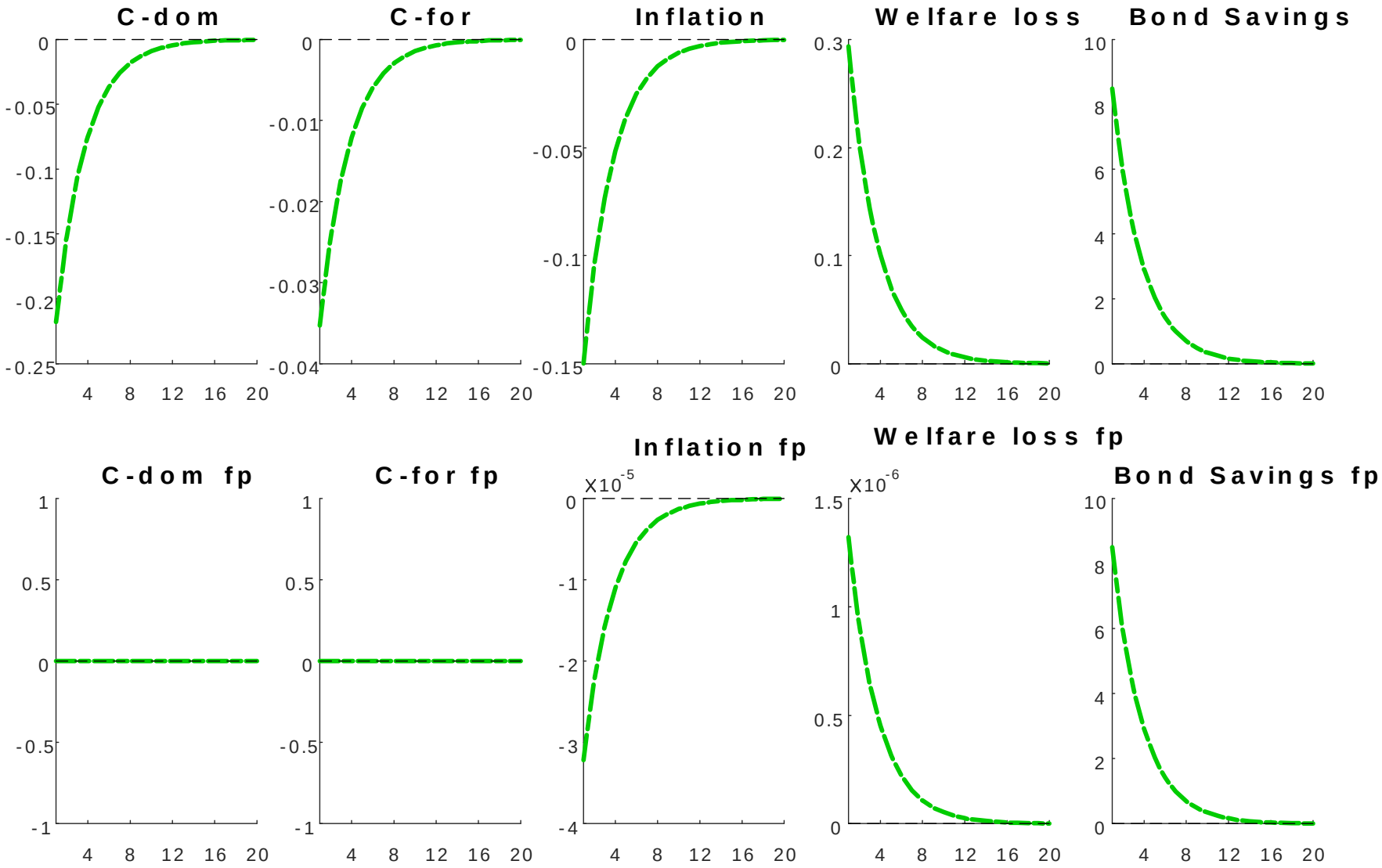

Free Trade

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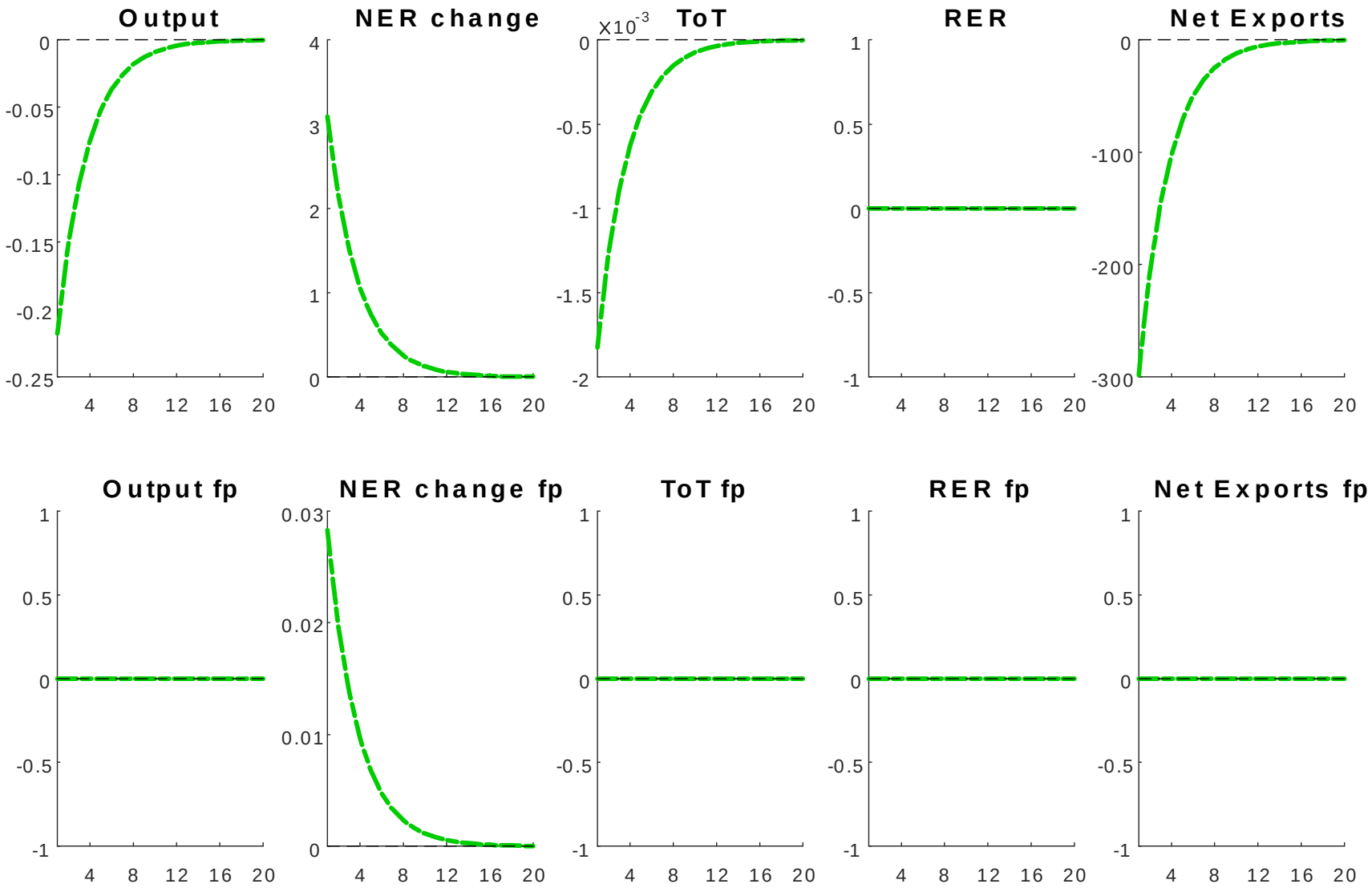

Results

- Uncertainty shock external to the country does affect the level of the macroeconomic variables under free trade in the long run as well as the short run as the domestic economy opens up its trade.
- One of the most important feature that determines whether the real variables of the domestic economy get affected is the flexibility of prices.
- Using the baseline model we observe that the real variables do not get affected when the prices are completely flexible as all nominal variables adjust completely here.
- When the prices are sticky the real variables adjusts and the welfare losses are higher.

Work in Progress

- A model version where domestic producers are not price makers but price takers as assumed here.
- Assuming that the foreign country has a zero lower bound on the interest rates, does this changes the response of domestic monetary policy?
- Does the role of monetary policy vary with the change of exchange rate determination from floating to fixed exchange rate regime?
- We are also trying to understand the role of important parameters like coefficient of risk version and elasticity of demand on the welfare results.