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Climate Actions, Public Investment and Inflationary Effects in a Small Open Economy*

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ABSTRACT

This paper studies the role of public investment and international spillovers in response to climate actions. Using a small-open economy model of a country belonging to a monetary union, it is shown that the inflationary and recessionary effects of a green policy (reduction in emissions or a higher price of fossil energy) can be dampened when the government follows a productive public spending which spurs private sector's productivity and induces a real depreciation. Moreover, the paper documents that when the climate action is followed just by the domestic economy, it is significantly more costly and the foreign counterpart enjoys the benefits of this kind of policy.

JEL Codes: E52, E62, F41, F42, Q50.

Keywords: Monetary Policy, Climate Policy, Business Cycle, Exchange Rate, Fiscal Shocks.

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Executive Summary

The consequences of climate change have sparked extensive debate in both academia and policymaking over recent decades. Fiscal policy is widely regarded as a critical tool for governments to address the harmful effects of greenhouse gas emissions and to combat global warming. This area of policy encompasses government actions related to taxation, public spending, and budgetary measures, all of which can directly impact economic activities and environmental outcomes. This paper develops a small open economy DSGE model with environmental externalities, where the domestic economy is calibrated to Slovak data. The main novelty of the paper is to consider the role of public investments in reducing the cost of climate actions. This is done by assuming that a fraction of government expenditure is directed towards accumulating productive public capital, which in turn enhances private sector labor productivity. By doing so, the financial burden of adopting green policies can be alleviated through the stimulating effects of public investments because they act as a positive technological shock, placing downward pressure on real marginal costs and, in turn improving country's competitiveness through the real exchange rate channel.

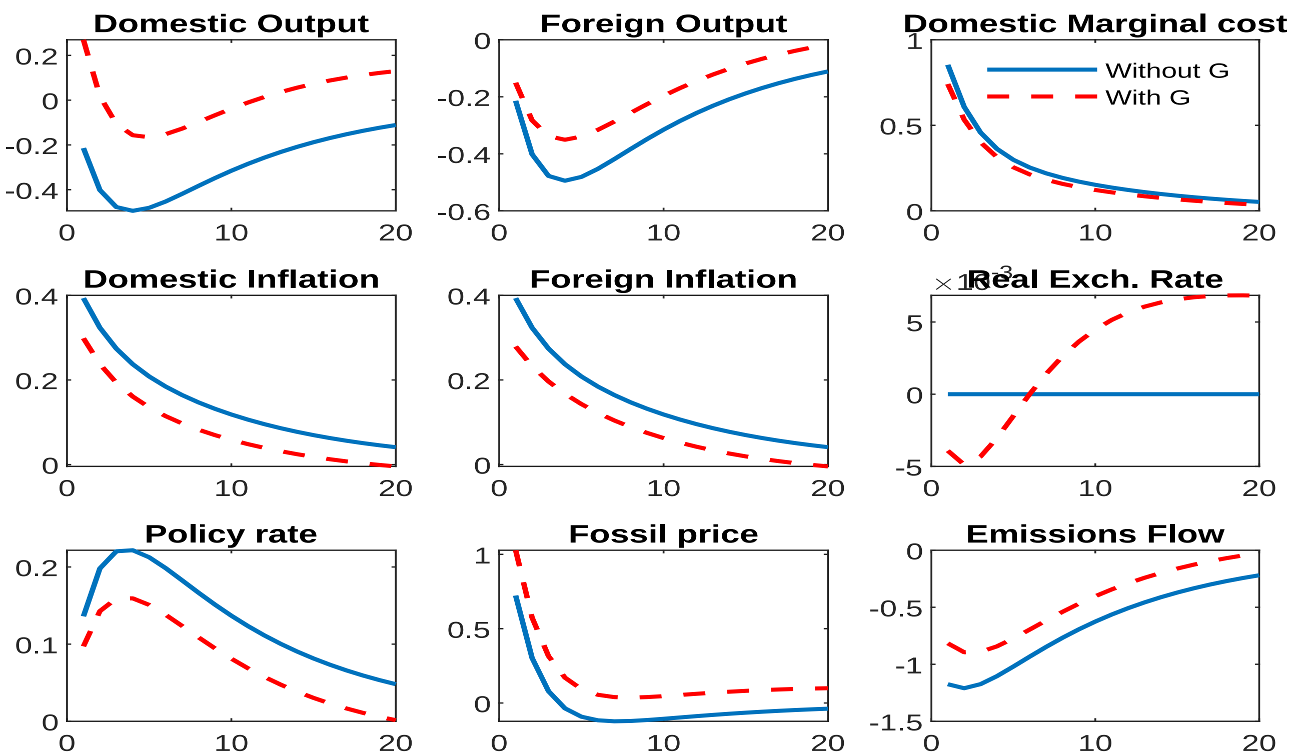

Figure 1: 1 p.p. reduction in emissions without fiscal accommodation (solid blue line) and when it is coupled with half increase in public investment (productive public spending, dashed red line).

In Figure 1 I show the effects of a 1 percentage point reduction in emissions conducted jointly by the two countires without a partial government intervention (solid blue line) and with a fiscal stimulus implemented by the domestic economy (dashed red line). The stimulus is half of the size of the reduction in the emissions and a part of it increases public investment.

The figure highlights that there exsts a trade-off between economic stability and environmental effectiveness when emission reductions are accompanied by public investment, which soften the recessionary and inflationary effects of transitioning to a greener economy, though it comes at the expense of a slower decline in emissions due to higher aggregate demand. Importantly, foreign country suffers a lower recession if domestic country adopts a fiscal stimulus to partially counteract the effect of the reduction in emissions.

The paper also compares the role played by different fiscal stimuli to attenuate the short run cost associated to a reduction in emissions. Public spending is less effective than public investment because it only acts through the demand side. Consequently, the policy message is that, if the fiscal stimulus aims at reducing the cost of the green transition, it is better to make public investments: at its trough, the recession with unproductive public spending is about 60% harder than in the case with public investments. Finally, the paper shows that an uncoordinated reduction in emissions is significantly more expensive for the small domestic economy, with positive spillover effects to the rest of the world.

1 Introduction

The impact of climate change has been largely debated both in academia and in policy-making over the last decades. Fiscal policy is considered to be the most important tool for governments in addressing the adverse effects of greenhouse gas emissions and combating global warming. This policy domain includes government actions related to taxation, spending, and budgetary measures that can directly influence economic activities and environmental outcomes. The ways in which fiscal policy tries to address climate actions are through carbon pricing, subsidies, incentives, green bonds and public investments.

This paper develops a two-country DSGE model with environmental externality where the domestic economy is small and belongs to a monetary union. On the supply side a part of government spending is used to accumulate productive public capital that increases private sector's labor productivity. In this way the cost of adopting green policies can be attenuated through the stimulative effects of public investments. On the one hand, since prices are sticky, higher demand implies upward pressures on real marginal costs which adds to the increase in firms' marginal costs associated to the green transition. On the other hand, an increase in public investment acts as a positive technology shock, thus implying downward pressures on real marginal costs. The effects on the marginal costs and inflation will, in turn, transmit internationally through the real exchange rate: a productive public spending will improve the competitiveness of the country with positive spillovers in terms of output. Therefore, there will be an attenuation in the cost of adopting green policy.

This paper is related to two strands of the literature. The first one is on public spending and fiscal multipliers, pioneered by Aschauer (1989) and Baxter and King (1993), who show that public spending has a significant impact on aggregate productivity and, in turn, on output. Leeper, Walker and Yang (2010) and Bouakez, Guillard and Roulleau-Pasdeloup (2017) consider how time-to-build affects the size of the multiplier in a neoclassical model and in a New-Keynesian setup respectively. Both papers prove that time-to-build is a key element in determining the size of fiscal multiplier: the public investment multiplier is monotonically increasing when the time to build is short or moderate. The intuition behind this result is that, when time-to-build is short, the supply-side effect of public investment produces its effects soon so that the inflationary pressure arising both from the direct increase in aggregate demand and from higher expected wealth fade out rapidly. Additionally, Leeper, Walker and Yang (2010) show that if the government finances the investment with distortionary taxation and public capital is only weakly productive, the stimulus may be contractionary in the long run. A widely accepted result in the literature is that, in a period of liquidity trap, the fiscal multiplier tends to be larger because the increase in the expected inflation brought about by the fiscal stimulus is not counteracted by a restrictive monetary policy. Therefore, the real interest rate lowers and aggregate demand increases. However, Horvath et al. (2020) find that, with a flatter Phillips' curve the multiplier is lower even at the zero lower bound because expected inflation increases less. As to the effects of fiscal stimuli in open economy, Nakamura and Steinsson (2014) and Chodorow-Reich (2019) estimate the open economy relative multiplier, highlighting how it is related to the aggregate one. Nakamura and Steinsson (2014) find that the stance of monetary policy affects significantly the aggregate multiplier, while, being in a monetary union, the relative multiplier is unaffected by the policy implemented by the central bank. On a different side, Di Giorgio, Nisticò and Traficante (2018) show that an increase in domestic public investment induces the exchange rate depreciation, consistently with most of the empirical evidence on the effects of fiscal stimuli on the exchange rate. An exogenous increase in productive public spending has two opposite effects on real marginal costs. Similarly to what found in closed economy by Bouakez, Guillard and Roulleau-Pasdeloup (2017), with sticky prices the increase in domestic public investment induces higher demand and upward pressures on real marginal costs. On the other hand, by improving labor productivity, higher public spending makes domestic firms more competitive, thus implying downward pressures on real marginal costs. Depending on which effect is dominant, the monetary policy response may trigger either an appreciation or a depreciation. Additionally, fiscal regimes contribute to the effect on the exchange rate since in the case of an exogenous tax rule the exchange rate appreciates.

The second strand of the literature is more recent and deals with climate policies in macroeconomics. Nordhaus introduces carbon and more in general climate changes in neoclassical models, as in Nordhaus (2017) and Nordhaus (2018)[1]. I will follow Annicchiarico and Di Dio (2015) and Annicchiarico, Di Dio and Diluiso (2024) in developing a DSGE model with environmental externality. Ferrari Minesso and Pagliari (2023) show that international cooperation is crucial to make climate-related mitigation policies effective. They find that fiscal policy should focus on reducing emissions by levying taxes on polluting production activities, while monetary policy should provide relief to cope with the costs of the environmental transition. Finally, Hasna (2021) and Batini et al. (2022) estimate the local multiplier of spending in green energy in the United States, finding that they are larger than multipliers related to non-green spending. Using an open economy New Keynesian model with public capital, where each US state is an open economy within a fiscal and monetary union, Hasna (2021) argues that most of the difference between the green and non-green multipliers is explained by the fact that the marginal productivity of green investment is higher in the short-run, leading to higher multipliers relative to investment

[1]More in detail, Nordhaus developed the Dynamic Integrated Climate Economy (DICE) model.

in non-green public capital.

The presence of productive public capital highlights a new dimension in which climate externalities can be tackled by the policymaker. If a country counteracts (even partially) the effort in reducing emissions with an increase in productive public spending, the economy will bear a lower cost associated to the climate action. This is due to the stimulative effect in the production side brought about by the public investment which acts also through a reduction in relative prices. Importantly, public investments are not able to avoid the recessionary effects of the climate actions, but they reduce them significantly, compared to the case in which the fiscal stimulus is in terms of purely public consumption. Moreover, the cost of the green policy is higher for the domestic economy in a non cooperative regime, ie when the foreign big economy does not follow the same policy. Also in this regard, the international transmission of the green policy emerges as a key element to consider. Overall, the results of the paper support the role of fiscal policy in the green transition not only in terms of a stimulus to the demand side, but, more importantly, affecting the supply side of the economy.[2]

The paper is organized as follows. Section 2 describes a two-country monetary union DSGE model with environmental externality. Section 3 presents, by means of simulations, the effects of climate policies for different specifications of fiscal policy and cooperation between the two countries on key macroeconomic variables. Finally, Section 4 concludes.

2 The Model

The world economy is composed of two countries, which form a currency union. Both economies are assumed to share identical preferences, technology, and market structure, but may be subject to different shocks. The two countries are indexed by H and F for Home and Foreign respectively. The currency union is populated by a continuum of infinitely lived households of measure one. The population on the segment $[0, n)$ belongs to country H, while the population on the segment $[n, 1]$ belongs to country F. This means that the relative size of country H is n, while the relative size of country F is $1 - n$. This is true for both households and firms. Since domestic economy is small, the size n is much lower than the size of the rest of the monetary union.

[2]The article focuses on the short-run effects of climate actions, without considering the long-run effects, which are a natural dimension in this kind of policies. Diluiso et al. (2021) show that climate actions, while potentially disruptive in the short term, can have significant positive impacts in the long run, particularly concerning macro-financial stability and sustainable economic growth.

2.1 Demand side

Consumers' preferences are over consumption and leisure, since they supply labor services in a domestic competitive labor market and demand consumption goods. Consequently, each domestic household j supplies labor inputs (L) to firms and demands consumption goods C in order to maximize the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C(j)_t^{(1-\sigma)}}{1-\sigma} - \frac{L(j)_t^{(1+\varphi)}}{1+\varphi} \right] \tag{2.1}$$

Households allocate savings among a full set of state-contingent private securities B which pay the interest rate i_t, they earn a nominal wage W, receive dividends D from the ownership of firms, and pay lump sum taxes T

$$P_t C_t(j) + B_t(j) = W_t L_t(j) + (1 + i_{t-1}) B_{t-1}(j) + P_t D_t(j) - P_t T_t(j) \tag{2.2}$$

The consumption index is a CES bundle of domestic and imported goods:

$$C = \left[\kappa^{\frac{1}{\theta}} C_H^{\frac{\theta-1}{\theta}} + (1-\kappa)^{\frac{1}{\theta}} C_F^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{2.3}$$

$$C^* = \left[(1-\kappa^*)^{\frac{1}{\theta}} C_H^{*\frac{\theta-1}{\theta}} + \kappa^{*\frac{1}{\theta}} C_F^{*\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{2.4}$$

with $\theta > 0$ and $\kappa, \kappa^* \in [0,1]$. To introduce endogenous fluctuations in the real exchange rate, there is home bias in consumption setting $\kappa > n$ and $\kappa^* > 1-n$. Moreover, since the foreign economy is much larger than the domestic one and that it consumes a much larger quantity of national goods, $\kappa \neq \kappa^*$, with κ^* almost equal to one (see the subsection on parameterization below). C_H and C_F result from Dixit-Stiglitz aggregation of the consumption goods produced in the two countries:

$$C_H = \left[\int_0^1 C_H(h)^{\frac{\epsilon-1}{\epsilon}} dh \right]^{\frac{\epsilon}{\epsilon-1}} \quad C_F(j) = \left[\int_0^1 C_F(f)^{\frac{\epsilon-1}{\epsilon}} df \right]^{\frac{\epsilon}{\epsilon-1}} \tag{2.5}$$

$$C_H^* = \left[\int_0^1 C_H^*(h)^{\frac{\epsilon-1}{\epsilon}} dh \right]^{\frac{\epsilon}{\epsilon-1}} \quad C_F^* = \left[\int_0^1 C_F^*(f)^{\frac{\epsilon-1}{\epsilon}} df \right]^{\frac{\epsilon}{\epsilon-1}}. \tag{2.6}$$

with ϵ >1. The respective consumer-price indexes (CPI) at Home and abroad are

$$P = \left[\kappa P_H^{1-\theta} + (1-\kappa) P_F^{1-\theta} \right]^{\frac{1}{1-\theta}} \qquad P^* = \left[(1-\kappa^*) {P_H}^{1-\theta} + \kappa^* {P_F}^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{2.7}$$

and the Terms of Trade S_t are defined as the relative price of foreign tradable goods in terms of home tradable goods ($S_t \equiv P_F/P_H$). With home–biased public consumption in both countries, the brand-specific demand for good h, produced in country H is

$$Y_H(h) \equiv C_H(h) + C_H^*(h) + G_H(h) = \\ = \left(\frac{P_H(h)}{P_H}\right)^{-\epsilon} \left[\kappa \left(\frac{P_H}{P}\right)^{-\theta} C + (1-\kappa) \left(\frac{P_H}{P^*}\right)^{-\theta} C^* + G\right], \quad (2.8)$$

while that for good f produced in country F is

$$Y_F^*(f) \equiv C_F(f) + C_F^*(f) + G_F^*(f) = \\ = \left(\frac{P_F(f)}{P_F^*}\right)^{-\epsilon} \left[(1-\kappa^*) \left(\frac{P_F}{P}\right)^{-\theta} C + \kappa^* \left(\frac{P_F}{P^*}\right)^{-\theta} C^* + G^*\right], \quad (2.9)$$

The solution of the optimization problem of domestic and foreign households delivers a set of equilibrium conditions which describe the aggregate labor supply and the dynamic path of aggregate consumption

$$L_t^{\varphi} C_t^{\sigma} = \frac{W_t}{P_t}, \quad (2.10)$$

$$\left(\frac{C_t}{C_t^*}\right)^{\sigma} = RER_t. \quad (2.11)$$

where $RER_t \equiv P_t^*/P_t$ is the real exchange rate.

2.2 Supply side

In each country there is a perfectly competitive final good sector that uses differentiated intermediate goods to produce a single final good Y_t according to a CES technology:

$$Y_t = \left[\int_0^1 Y_{i,t}^{(\chi-1)/\chi} di\right]^{\chi/(\chi-1)} \quad (2.12)$$

where $\chi > 1$ is the elasticity of substitution between intermediate goods and $Y_{i,t}$ is the intermediate good of type i.

In the intermediate goods sector there is monopolistic competition: each producer uses labor inputs and a fossil resource Z as a polluting source of energy. As in Annicchiarico and Di Dio (2015) and Annicchiarico, Di Dio and Diluiso (2024), all the producers are subject to a common negative environmental externality Δ_t that hits in the same way domestic and foreign country. The presence of a negative externality highlights that rising temperatures adversely affect production. In Nordhaus (1993) DICE model[3], this is captured through a quadratic damage function, where damages increase (ie productivity declines) more sharply as temperatures rise. The way in which the damage is modeled in this paper follows the approach in Golosov et al. (2014), where the damage is proportional to output: the higher the temperature the lower the output.[4]

In the simulation exercises, I will stress the difference between a joint reduction in emissions and the case in which only the domestic economy reduces the emissions. Moreover, the producer i uses labor inputs $L_{i,t}$ and a fossil resource $Z_{i,t}$ as a polluting source of energy, while the standard production function is modified by assuming that the government affects the private sector productivity of labor by using a share ξ of total spending to accumulate a stock of productive capital Γ

$$Y_{i,t} = \Delta_t \left[\mu Z_{i,t}^{\frac{\varkappa-1}{\varkappa}} + (1-\mu)\Gamma_t^{\psi} L_{i,t}^{\frac{\varkappa-1}{\varkappa}} \right]^{\frac{\varkappa}{\varkappa-1}} \tag{2.13}$$

where $\mu \in (0,1)$ measures the weight of energy in the production function, $\varkappa > 0$ is the elasticity of substitution between energy and labor and ψ is the degree of public capital externality to labor productivity.[5] In particular, following the insights of Aschauer (1989) and Baxter and King (1993) and, more recently of Basu and Kollmann (2013), Bouakez, Guillard and Roulleau-Pasdeloup (2017) and Di Giorgio, Nisticò and Traficante (2018), the government potentially affects the private-sector productivity of labor by using a share ξ of total public spending to accumulate a stock of productive public capital Γ (Γ^* for the foreign country):

$$\Gamma_t = (1-\eta)\Gamma_{t-1} + \xi G_t \qquad \Gamma_t^* = (1-\eta)\Gamma_{t-1}^* + \xi G_t^*,$$

where η is the rate of depreciation of public capital. In the steady state, the above law of motions imply

$$\bar{\Gamma} = \frac{\xi}{\eta}\bar{G} \qquad \bar{\Gamma}^* = \frac{\xi}{\eta}\bar{G}^*.$$

The approach used here follows the insights of Aschauer (1989) and assumes that public capital enters as an input in the production function. Moreover, the meta estimates provided by Bom and Ligthart (2014) point out that the majority of estimates about the elasticity of output with respect to public capital are positive, with a meta-estimate of 0.082 when considering a broad measure of public capital at the national level. This estimate in-

[3]See also Nordhaus (2017).
[4]While the two approaches differ, both highlight the impact of climate change on productivity.
[5]The coefficient ψ determines the steady-state marginal product of public capital.

creases to 0.131 when focusing specifically on core infrastructure, such as airports, railways, roads, and utilities.

Given the flow of emissions Z, the stock of them evolves as

$$M_t = \int_0^1 Z_{i,t} di + (1 - \delta_M) M_{t-1} \tag{2.14}$$

and emissions reduce firms' productivity according to

$$\Delta_t = \exp(-\nu M_t) \quad \nu > 0 \tag{2.15}$$

Therefore, while the negative environmental externality reduces productivity, thanks to productive public spending it is possible to increase labor productivity and reduce marginal costs. Firms choose labor demand in a competitive labor market[6] by minimizing their total real costs subject to the technological constraint. In equilibrium, the real marginal cost is:

$$MC_t = \Delta_t^{-1} \left[\mu^{\varkappa} \left(\frac{P_{z,t}}{P_t} \right)^{1-\varkappa} + (1-\mu)^{\varkappa} \left(\frac{W_t}{\Gamma_t^{\psi} P_t} \right)^{1-\varkappa} \right]^{\frac{1}{1-\varkappa}} \tag{2.16}$$

where $P_{z,t}$ stands for the price of the fossil resource.

Price setting is à la Calvo with each firm facing, each period, a probability ϑ of having to charge last period's price, without re-optimizing. Labeling with $N_{t,t+k}$ the stochastic discount factor and with MC^n is the nominal marginal cost, the problem of the firm is therefore to choose $P^o_{H,t}$ in order to maximize

$$E_t \left\{ \sum_{k=0}^{\infty} \vartheta^k N_{t,t+k} Y_{t+k|t}(h) \left[P^o_{H,t}(i) - MC^n_{t+k}(h) \right] \right\}$$

subject to

$$Y_{t+k|t}(h) = \left(\frac{P^o_{H,t}(h)}{P_{H,t+k}} \right)^{-\epsilon} Y^d_{t+k}$$

where aggregate demand Y^d comes from (2.8). All firms re-optimizing at the same time will choose the same price, according to the following implicit rule:

$$E_t \left\{ \sum_{k=0}^{\infty} \vartheta^k N_{t,t+k} Y_{H,t+k} \left[P^o_{H,t} - \frac{\epsilon}{\epsilon - 1} MC^n_{t+k} \right] \right\} = 0$$

[6] Labor is assumed to be immobile across countries.

which can be solved as

$$P^o_{H,t}(h) = \frac{\epsilon}{\epsilon - 1} \frac{\sum_{k=0}^{\infty} \vartheta^k E_t \left\{ N_{t,t+k} Y_{t,t+k} MC^n_{t+k} \right\}}{\sum_{k=0}^{\infty} \vartheta^k E_t \left\{ N_{t,t+k} Y_{t,t+k} \right\}}. \tag{2.17}$$

Log–linearising the previous expression around the zero–inflation steady state, we get

$$\begin{aligned} p^o_{H,t} &= \mu + (1 - \beta\vartheta) \sum_{k=0}^{\infty} (\beta\vartheta)^k E_t \left[mc^n_{t+k} \right] \quad \mu \equiv \log \left(\frac{\epsilon}{\epsilon - 1} \right) \\ &= (1 - \beta\vartheta) \sum_{k=0}^{\infty} (\beta\vartheta)^k E_t \left[mc^n_{t+k} \right] \end{aligned}$$

$$p^o_{H,t} = (1 - \beta\vartheta) (\mu + mc^n_t) + \beta\vartheta E_t p^o_{H,t+1} \tag{2.18}$$

Notice that in the case of flexible prices ($\vartheta = 0$), firms adjust prices every period according to the pricing rule $p^o_{H,t} = (1 - \beta\vartheta)(\mu + mc^n_t)$. Since only a fraction adjusts prices each period, we have that inflation will be $\pi_{H,t} = (1 - \vartheta) \left(p^o_{H,t} - p_{H,t-1} \right)$, which combined with (2.18) yields Phillips curves respectively for Home and foreign country, where $mc_t \equiv mc^n_t - p_{H,t} + \mu$ labels real marginal cost, in deviation from its steady state level.

2.3 The Linear Model

The model is analyzed using a first-order approximation of the equilibrium conditions around a zero-inflation/zero-deficit steady state. Linearization around the steady state previously defined yields the complete set of linear equations needed to study the Rational-Expectation equilibrium (given stochastic processes for public spending). In the next lines, lower-case variables denote percentage deviations from steady state $x_t \equiv \frac{X_t - X}{X}$ and we will focus mainly on the domestic economy, given the symmetric structure with the foreign counterpart.

Starting with the fiscal bloc, the budget is balanced and a fraction of government spending (completely home biased) is devoted to public investment. Monetary policy is structured in terms of Taylor rule that responds to union-wide inflation and output[7]:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \left(\phi_\pi \pi^U_t + \phi_y y^U_t \right) + u_{m,t} \tag{2.19}$$

with a temporary monetary policy shock $u_{m,t}$. As to the demand side, these are the rela-

[7] They are weighted average of domestic inflation and foreign inflation and weighted average of domestic and foreign output respectively.

tionships about consumption and output in each country

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}\left(i_t - E_t \pi_{t+1}\right) \tag{2.20}$$

$$c_t = c_t^* + \frac{1}{\sigma} rer_t \tag{2.21}$$

$$y_t = \kappa c_t + (1-\kappa) c_t^* + \theta(1-\kappa)\left(\kappa + \kappa^*\right) s_t + g_t \tag{2.22}$$

$$y_t^* = \kappa^* c_t^* + \left(1-\kappa^*\right) c_t - \theta\kappa\left(2 - \kappa - \kappa^*\right) s_t + g_t^* \tag{2.23}$$

where s_t denotes the terms of trade.

On the supply side, Calvo price setting implies the new Keynesian curve of the usual kind

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \lambda mc_t \quad \lambda \equiv \frac{(1-\vartheta)(1-\beta\vartheta)}{\vartheta} \tag{2.24}$$

$$\pi_{F,t} = \beta E_t \pi_{F,t+1} + \lambda mc_t^* \tag{2.25}$$

and the real equilibrium marginal costs follow:

$$mc_t = \varphi y_t + \sigma c_t - \psi(1+\varphi)\gamma_t - \delta_t - z_t \tag{2.26}$$

$$mc_t^* = \varphi y_t^* + \sigma c_t^* - \psi(1+\varphi)\gamma_t^* - \delta_t - z_t \tag{2.27}$$

With respect to the environmental part of the model, emissions, pollution stock, fossil prices and environmental damage follow this path respectively

$$z_t = \varkappa mc_t + (\varkappa - 1)\delta_t + y_t - \varkappa p_{z,t} + q_t \tag{2.28}$$

$$m_t = \left(1 - \delta_M\right) m_{t-1} + \delta_M z_t \tag{2.29}$$

$$p_{z,t} = mc_t + \delta_t - (1 - \varkappa)\left(z_t - n_t\right) + \eta_{pz,t} \tag{2.30}$$

$$\delta_t = -\nu m_t \tag{2.31}$$

where $\eta_{pz,t}$ represents a shock to the fossil price. In terms of the law of motion of productive public capital

$$\gamma_t = (1-\eta)\gamma_{t-1} + \xi g_t \tag{2.32}$$

$$\gamma_t^* = (1-\eta)\gamma_{t-1}^* + \xi g_t^* \tag{2.33}$$

where public spending follows an autoregressive process

$$g_t = \rho_g g_{t-1} + \varepsilon_{g,t} \tag{2.34}$$

$$g_t^* = \rho_g g_{t-1}^* + \varepsilon_{g,t}^*. \tag{2.35}$$

Finally, the emissions process and the shock to fossil price follow an autoregressive process

$$q_t = \rho_q q_{t-1} + \varepsilon_{q,t} \tag{2.36}$$

$$\eta_{pz,t} = \rho_{pz} \eta_{pz,t-1} + \varepsilon_{pz,t} \tag{2.37}$$

In the simulations, different specifications are considered with respect to the environmental policy, in terms of a reduction in emissions or an increase in the price of energy. This exercise is conducted by assuming different coordination regimes, where one or both countries implement the green policy and/or the fiscal instrument is used to alleviate the costs associated with the green policy. More in detail, the environmental shock will be analyzed in the case of *i)* a policy followed by the two countries in the monetary union, *ii)* a policy followed just by the domestic small economy, *iii)* when productive fiscal policy is used together with the environmental policy with the aim of reducing the cost induced by the green policy.

2.4 Parameterization

The model is calibrated on a quarterly frequency, following previous studies and convention. Specifically, the intertemporal discount factor β is set at 0.99, implying a long-run real annualized interest rate of 4% for both countries. The degree of monopolistic competition is taken from Rotemberg and Woodford (1997), ϵ =7.66, which implies an average markup of 15%, while I set the Calvo parameter at 0.75, implying that prices are revised on average once a year. As to the steady-state Frisch elasticity of labor supply, $1/\varphi$, there is wide controversy about the value that should be assigned to this parameter. The empirical microeconomic literature suggests values for φ ranging from 0.1 to 0.5 (see Card (1994) for a survey), while business cycle literature mostly uses values greater than 1 (see e.g. Cooley, Hansen and Prescott (1995)). I choose a baseline value of φ =0.5, consistently with the microevidence. The elasticity of substitution between Home and Foreign goods was set equal to $\theta = 1.5$, which implies that home and foreign goods are substitutes in the utility function of consumers. As to the dimension of the Home country, I calibrate it to Slovakia: following Senaj, Výškrabka and Zeman (2010), $n = 0.01$, while home bias in private consumption is introduced by assuming $\kappa = 0.6$ and $\kappa^* = 0.997$. The latter assumption reflects the fact that the domestic economy is much smaller than the foreign one and, therefore, it is natural to assume that the share of domestic goods in the consumption bundle is much larger.

With respect to the calibration of the supply side, I follow Bouakez, Guillard and Roulleau-Pasdeloup (2017), with public capital productivity $\psi = 0.08$ and the share of public investment over total expenditure $\xi = 0.23$. Moreover, public capital depreciates at a rate of $\eta = 2\%$ and fiscal shocks exhibit a persistence $\rho_g = 0.7$. The calibration of the environmental side of the model follows Annicchiarico and Di Dio (2015) and Annicchiarico, Di Dio and Diluiso (2024). In particular, the elasticity of substitution between energy and labor inputs $\mu = 0.3$, emissions wash out at a rate $\delta_M = 0.0021$ and the impact damage coefficient $\nu = 0.0263$. As to the environmental policies, I assume a very persistent effort to reduce emissions and/or increase the price of fossil energy. Consistently with that, $\rho_q = \rho_{pz} = 0.9$. Finally, the Taylor rule is modeled according to Nakamura and Steinsson (2014) and Senaj, Výškrabka and Zeman (2010), with $\rho_i = 0.8$, $\phi_y = 0.5$ and $\phi_\pi = 2$.

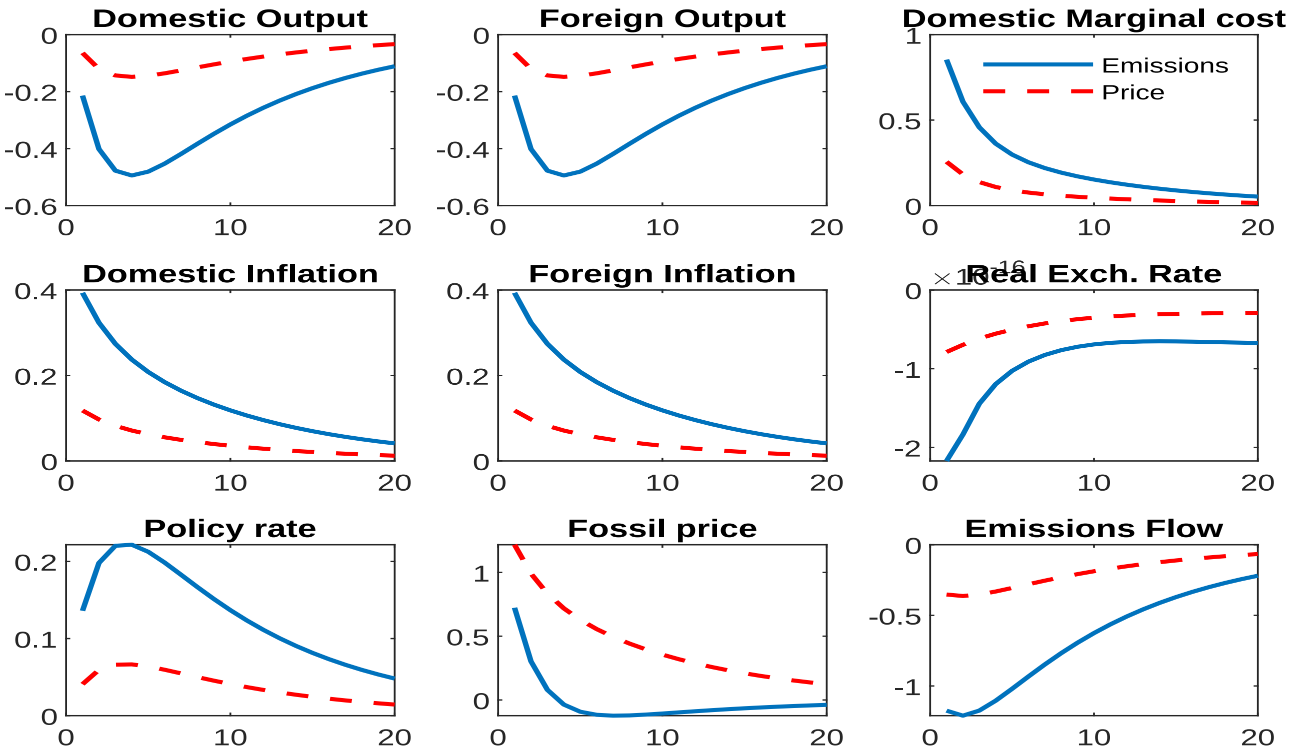

Figure 1: 1 p.p. reduction in emissions (solid blue line) and 1 p.p. increase in fossil price (dashed red line).

3 Policy Experiments

This section evaluates the dynamic effects of a wide set of environmental shocks, comparing the consequences of following a different policy mix in the implementation. As anticipated in the theoretical setup, the analysis is on transition risk and not on physical risk, which is captured by the damage function in (2.13) and (2.15). In other words, we will focus on the short-run effects of a reduction in emissions (hence on inflationary and recessionary consequences) for a given level of long-run physical risk.

In terms of the environmental policies, two cases are considered. In the first one, it is assumed that emissions decrease by one percentage point, while in the second setup the government increases the price of fossil energy by one percentage point. Notice that the two variables are related: in the case of a reduction in emissions, the fossil price adjusts endogenously and it increases. Similarly, if the government decides to increase exogenously the price of fossil energy, this will trigger a reduction in emissions.[8] Figure 1 compares the reduction in emissions (solid blue line) and the increase in fossil price (dashed red line). In both cases, the size of the shock is one percentage point.[9] The graph shows that in the short run a green policy produces costs and it is recessionary. By comparing the two instruments, a policy that reduces the emissions is more effective in reducing the pollution stock, it also induces a higher inflation, which calls for a more aggressive increase in the policy rate. As a consequence, the real exchange rate remains persistenlty appreciated and the economy experiences a long recession.

The key result shown above is that, whatever the instrument chosen, a climate action is very costly in terms of inflation and output. In the following analysis, there will be a discussion about the mechanisms to attenuate the cost of the climate action. In Figure 2 I show the effects of a 1 percentage point reduction in emissions with or without a partial government support, defined as a fiscal stimulus with half of the size of the reduction in the emissions.[10] When the government does not intervene with a partial accommodation through a productive public spending (solid blue line), the green transition entails more persistent inflationary and recessionary consequences in both economies. Whenever the decrease in the emissions is coupled with a productive public spending (dashed red line), on impact output increases and then the economy enters in a recession that lasts less than in the case without productive public spending. Similarly, inflation increases less than in the case in which public spending moves: This is due to the increase in productivity triggered by public investment which, in addition, induces a real exchange rate depreciation after some quarters. Moreover, the impact on the aggregate demand spurred by public investment affects also the emissions flow which decrease less than in the case without public investment. Hence, the graph shows that combining the reduction in emissions with productive public spending reduces the economic impact of it at the cost of a relatively larger environmental damages. As to the effects on the foreign counterpart, it can be observed

[8]See equations 2.28–2.30.

[9]The response of the variables are qualitatively the same also in the case in which the shock is built to produce a specific deterministic path followed by emissions. Results are available on request.

[10]Therefore, the increase in public spending will be 0.5 percentage points.

that foreign output decreases less also in the case in which the green policy is partially accommodated by an increase in domestic public spending. Ferrari Minesso and Pagliari (2023) show the role of international cooperation and of monetary policy to accommodate the green transition. However, they do not consider deviations from the commitment to target the emissions. In this setup the common monetary policy across the two countries aims at stabilizing prices and we consider the possibility that a country does not adopt a green policy. In such a setup, fiscal policy plays a dual role in driving the economic transition towards a greener economy and to make it less costly.

The evidence of the latter figure points out that fiscal policy can play a relevant role in attenuating the impact of emissions. A similar result is documented in Forni and Kiarsi (2023), who show that the presence of carbon taxation policy reduces the fall in output if emissions decrease. However, their analysis is based on optimal Ramsey policy and there is not a persistent supply effect brought about by public investment. With the objective to evaluate the supply-side effect, Figure 3 considers again the policy experiment of a reduction in the emissions coupled with the partial increase in productive public spending (blue solid line) with the case in which public spending is completely wasteful ($\psi = 0$). The figure shows that with a productive public spending the recessionary and inflationary effects are lower since a purely wasteful fiscal shock does not improve the productivity and stimulates less the economy through the exchange rate channel. As a consequence, if the fiscal stimulus aims at reducing the cost of the green transition, it is better to make public investments: at its trough, the recession with unproductive public spending is about 60% harder than in the case with public investments.

The capacity to attenuate the short-run costs associated with green transition can be increased whenever public investment targets a green sector. In Figure 4 I compare the case of a generic public investment (dashed line) already considered in the previous analysis, with a green public investment (solid line). To differentiate green versus non green public investments, I follow Hasna (2021) and I modify the production function (2.13) by assuming that the government allocates a share $\xi^g \neq \xi$ of total spending to accumulate a stock of productive green public capital Γ^g:

$$Y_{i,t} = \Delta_t \left[\mu Z_{i,t}^{\frac{\varkappa-1}{\varkappa}} + (1-\mu) \Gamma_t^{g^{\psi}} L_{i,t}^{\frac{\varkappa-1}{\varkappa}} \right]^{\frac{\varkappa}{\varkappa-1}} \tag{3.1}$$

The green public investment differs from the non-green for the following features: *i)* the green shock is less persistent (0.56 versus 0.8): *ii)* the share of green public investment to total public spending is also much lower than in the case of a non green public investment

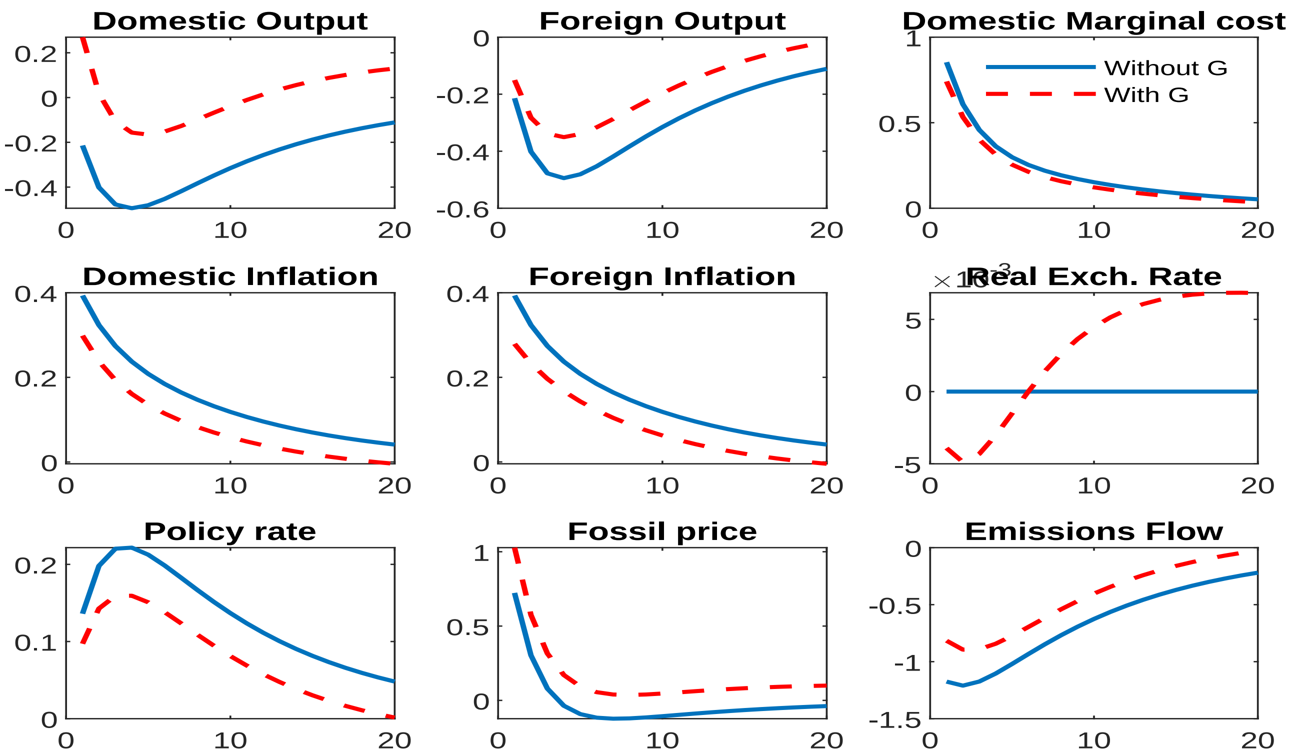

Figure 2: 1 p.p. reduction in emissions without fiscal accommodation (solid blue line) and when it is coupled with half increase in public investment (productive public spending, dashed red line).

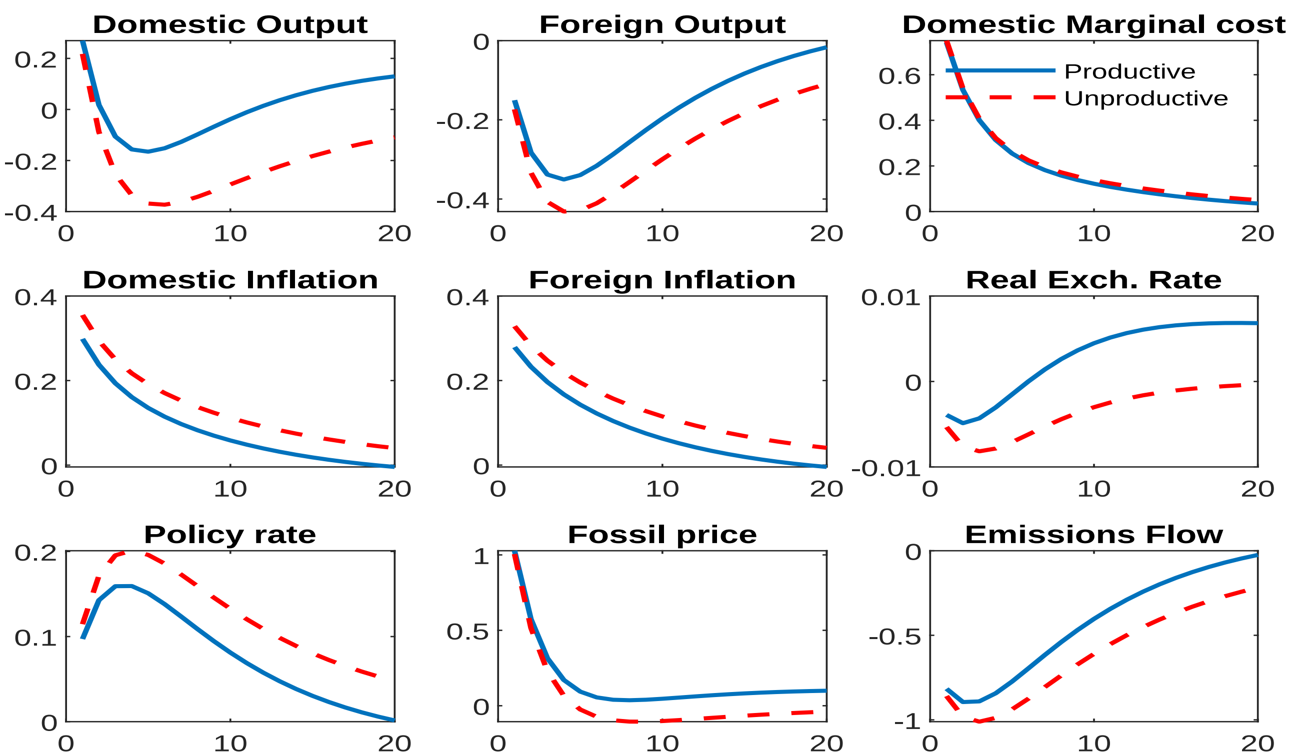

Figure 3: 1 p.p. reduction in emissions coupled with half increase in public investment (productive, solid blue line) and public spending (unproductive, dashed red line).

(0.05 versus 0.23)[11]. The figure shows that a green public investment is more succesful in coping with the costs of green transition. In terms of the effect on output, it turns out that there is a positive and a persistent multiplier in the short run. This effect is consistent with the theoretical and empirical evidence for the USA found by Hasna (2021) and it is explained by the *shovel-ready* nature of green projects compared to other public investments (eg public infrastructure projects). Clearly, to draw quantitative policy conclusions on the role of green public investments, data on Slovak green public investments would be more suitable. However, the analysis shown here will hold in qualitative terms to evaluate which public investments to implement in a process of green transition.

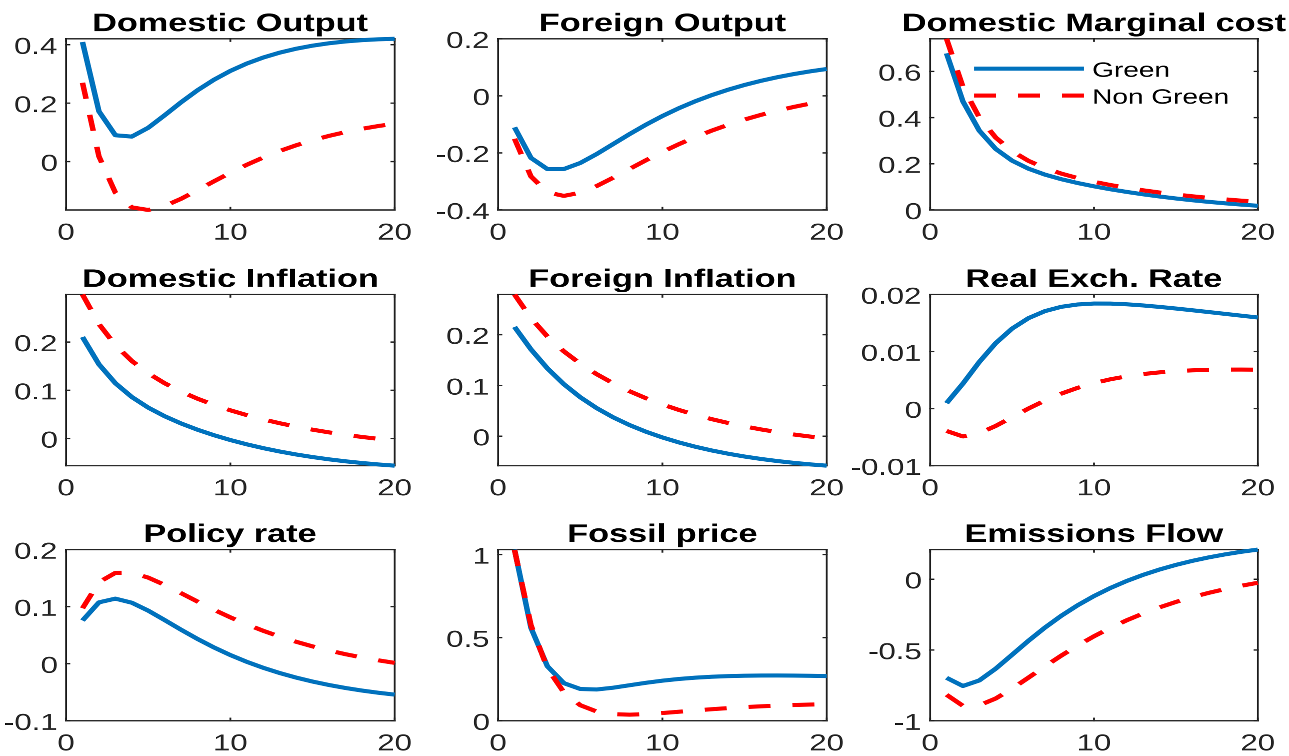

Figure 4: 1 p.p. reduction in emissions coupled with half increase in green public investment (solid blue line) and non-green public investment (dashed red line).

Given the open economy dimension of the model, it is interesting to evaluate what happens if only one country conducts a green policy. Figure 5 offers a comparison of the case in which both countries reduce emissions by one percentage point (cooperation, blue solid line) and when only domestic country follows this policy (no cooperation, dashed red line). Under the perspective of the domestic economy, a non cooperative regime is more costly since the recession is largely more persistent. On the contrary, for the foreign economy inflation rises slightly just on impact and there is a short-run expansion in output. This

[11] In addition, Hasna (2021) assumes a one-year time-to-build for non green public capital, while for the green public capital there is no time-to-build, based on micro data for the US. I simulate the model also by varying time-to-build, but the results shown in the paper do not vary significantly.

result seems to suggest that green policies follow a *beggar thy neighbor* logic with respect to its real consequences. Interestingly, emissions flow decreases more in the non cooperative scenario, but this result seems to be driven by the more recessionary impact of the policy without coordination rather than by a real greener policy. Therefore, when policymakers discuss on how to structure policies that aim at reducing emissions should take into account the international transmission that works through relative prices, as shown by the dynamic response of the real exchange rate. In the cooperative regime the real exchange response is almost muted, while a no cooperative regime induces an appreciation which is accompanied by a significant recession at home.

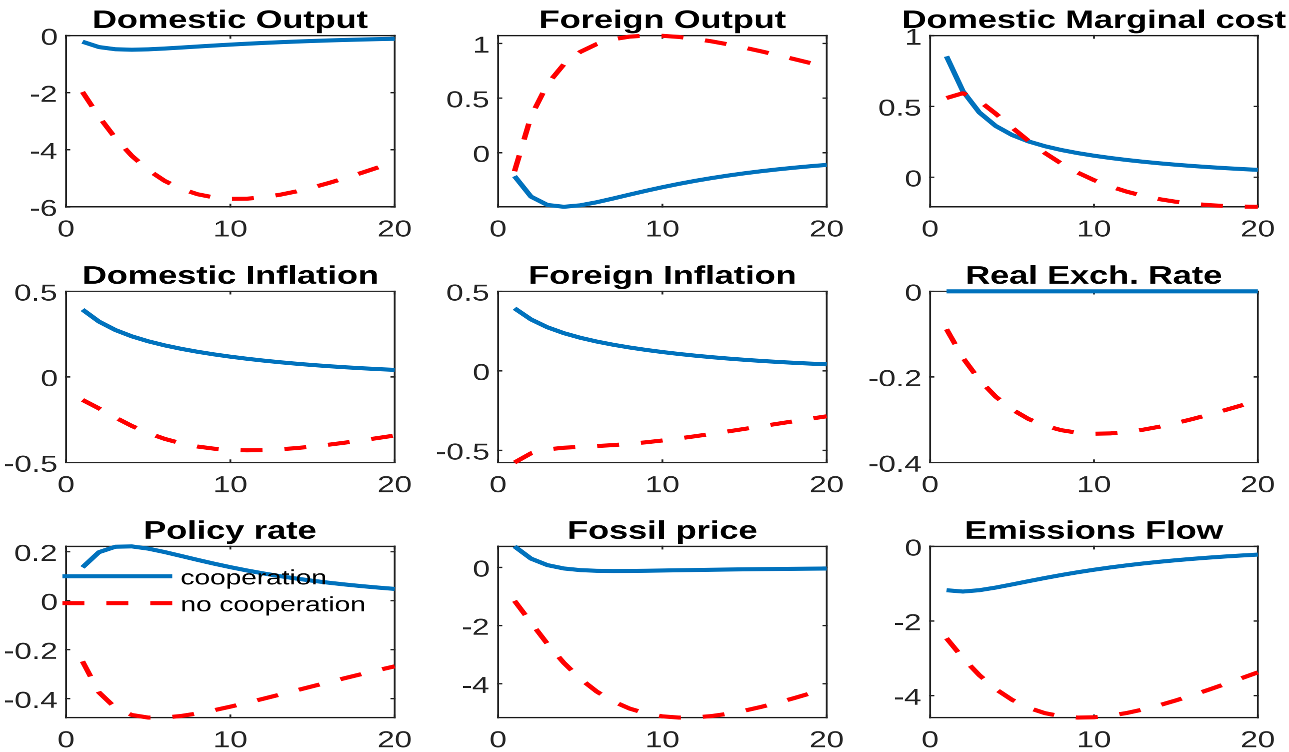

Figure 5: 1 p.p. reduction in emissions followed by all the monetary union (cooperation, solid line) and when the policy is implemented only by the domestic country (dashed red line).

3.1 The Role of Monetary Policy and Taxation

This section explores the role of monetary and fiscal policy in shaping the economy's response to climate policy, starting by assessing how the transmission of the climate shock varies in response to different values of the coefficients of interest rate inertia ρ_i and the response to inflation ϕ_π in the Taylor rule (2.19). The results are shown in Figure 6, where the solid blue line corresponds to the scenario of a 1 p.p. reduction in emissions described in Figure 1, the dashed red line corresponds to the setup without interest rate inertia and, finally, the dashed-dotted green line shows the case where monetary policy exhibits no inertia and a more aggressive response to inflation. A higher reactivity of the interest rate to inflation strongly reduces the size of the increase in inflation and output in both countries. Interestingly, this aggressive policy stance allows to reduce the emissions on impact more than what is done in the other regimes. The intuition for this result is that a significant effort of the central bank to stabilize inflation reduces more the aggregate demand and, in turn, also the emissions. Since the emissions are lower, it is not necessary to increase the price of fossil energy, which actually decreases on impact. Therefore, there is not a trade off between inflation stabilization and the climate target. Furthermore, simply eliminating the interest rate inertia with the same level of response to inflation does not alter significantly the response of the economy, even if for an increasing value of ρ_i the Taylor rule becomes less reactive to current variations of the output gap and inflation. Despite this, this policy regime induces a larger response on impact of output and fossil price.

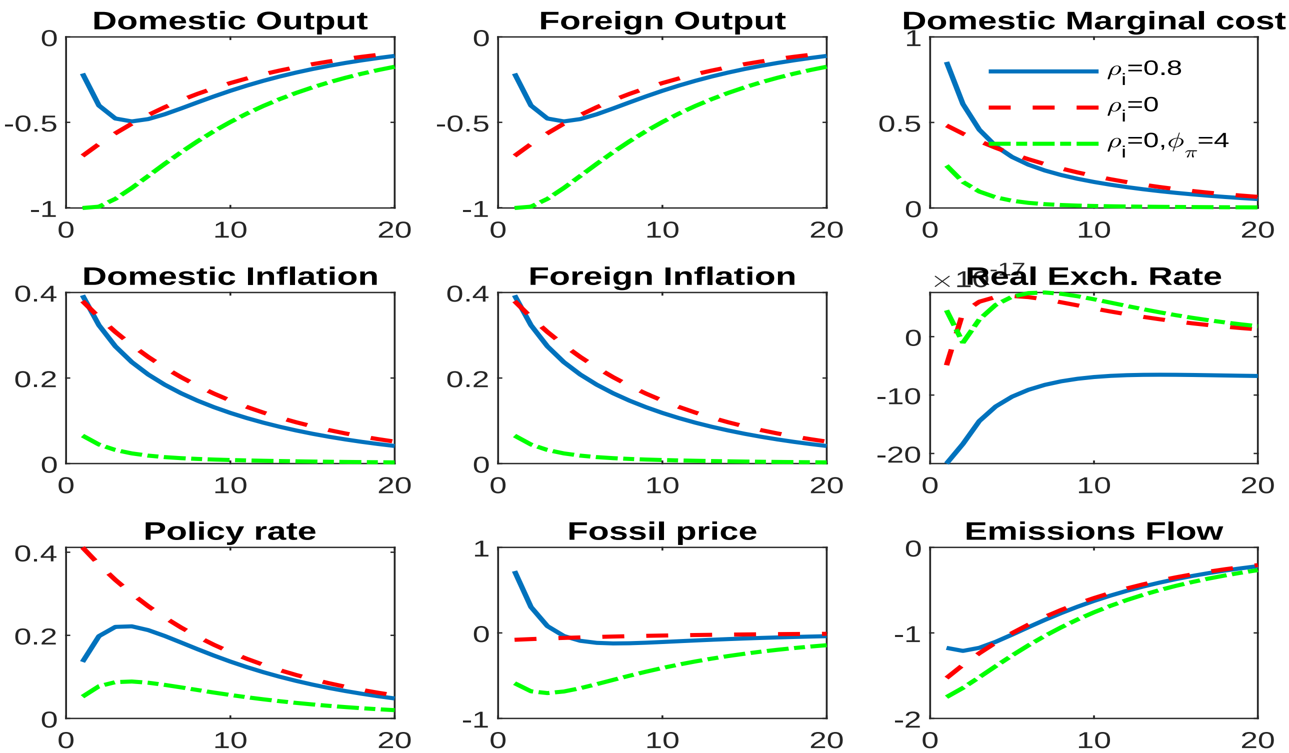

Figure 6: 1 p.p. reduction in emissions in the baseline scenario ($\rho_i = 0.8$, $\phi_\pi = 2$, solid blue line), without interest rate inertia ($\rho_i = 0$, $\phi_\pi = 2$, dashed red line), without interest rate inertia and more aggressive monetary policy (dashed-dotted green line).

In the analysis conducted above taxation is lump sum, hence taxation does not alter the choices of the private sector. Here I consider how the presence of a distortionary taxation affects the transmission mechanism of a reduction in the emissions. In Figure 7 I show the scenario with lump sum taxation (already illustrated above, solid blue line) with the scenario in which the budget is balanced with a distortionary taxation (dashed red line). More in detail, in a setup where both countries implement the green policy, the taxation is structured in the following way (in log-linear terms):

$$\tau_t = n \times g_t + (1-n)g_t^* - n \times w_t - (1-n)w_t^* - n \times l_t - (1-n)l_t^* \tag{3.2}$$

Therefore, the rule (3.2) can be seen as a joint taxation program set by the two countries to balance the budget. By looking at the figure, it turns out that, when taxation is distortionary, inflation is higher in both countries; this induces the central bank to respond more aggressively and, in turn, recession is larger in both countries.

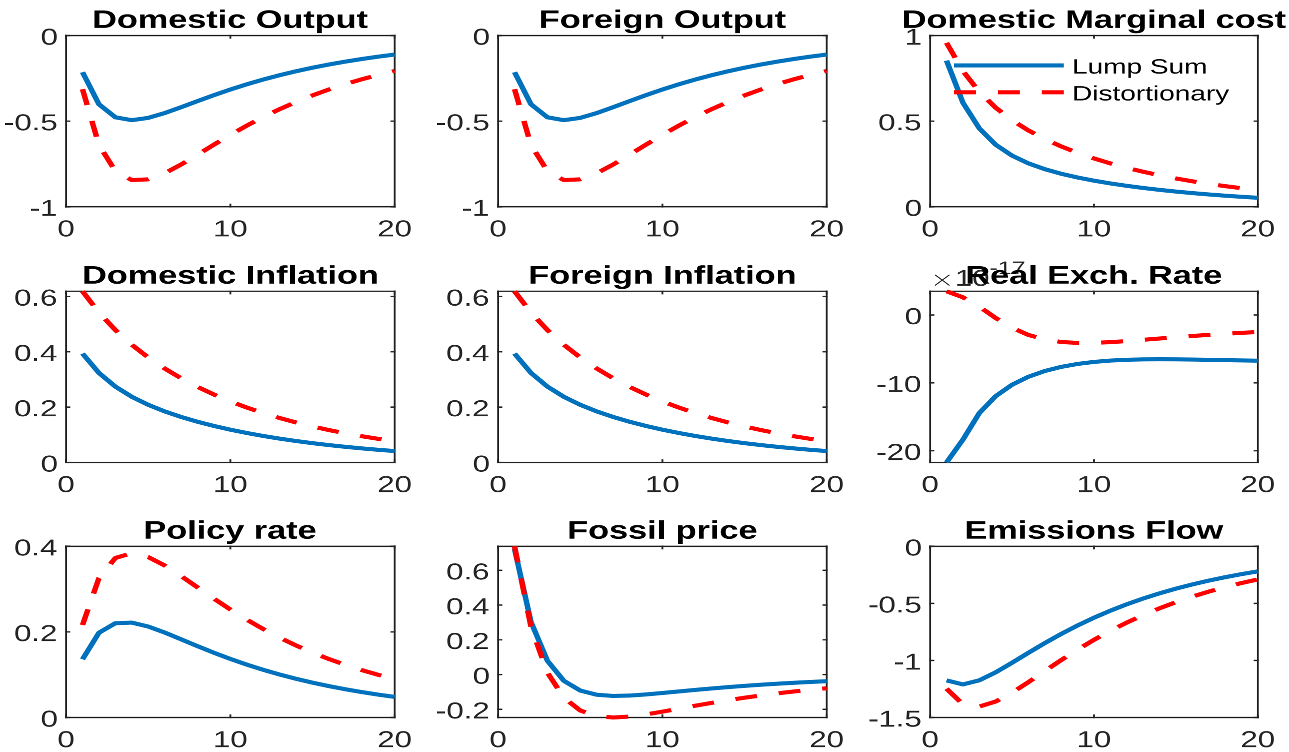

Figure 7: 1 p.p. reduction in emissions financed with a lump sum tax (solid blue line) and with a union-based distortionary taxation (dashed red line).

Section 3 shows that the cost of the green transition is larger for the domestic small open economy in a non cooperative setup. A natural question to assess is if the result depends on which type of taxation is present in the economy. Figure 8 compares the case in which distortionary taxation is applied in a cooperative setup (solid blue line) and when only the home country reduces emissions (dashed red line). Similarly to what discussed in the case of lump-sum taxation, in a non cooperative regime the domestic economy experiences a deeper recession which can reduce emissions more. Differently to the case with lump-sum taxation, in a non cooperative regime domestic inflation increases less. Overall, under a non cooperative regime there is an asymmetric response between domestic and foreign economy with respect to output and inflation, which is another proof of the relevance of the international transmission of green policies. The simulation suggests that international cooperation helps substantially in climate actions provided that both countries belong to a monetary union and policy rates are set in terms of the union-wide inflation objective. The role of international cooperation was also discussed by Ferrari Minesso and Pagliari (2023), but their analysis is more on the effectiveness of climate actions rather than on international spillovers.

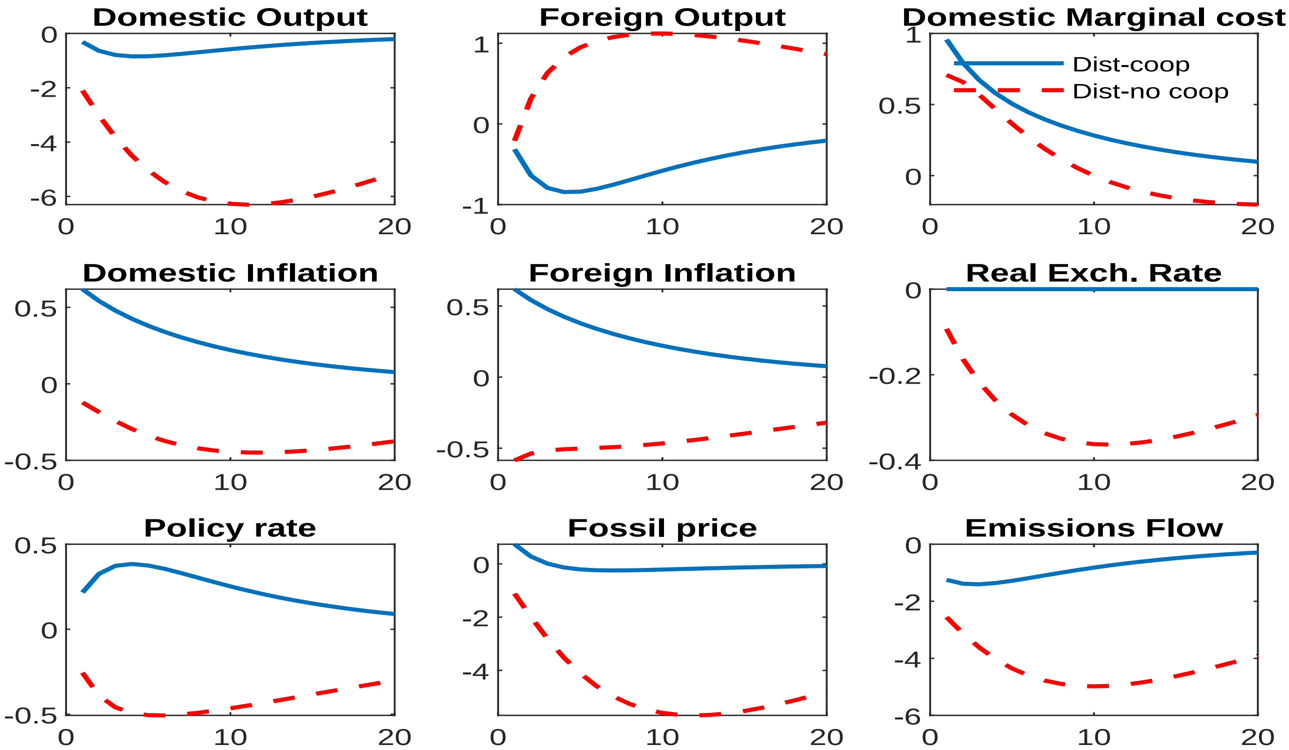

Figure 8: 1 p.p. reduction in emissions followed by all the monetary union and financed with distortionary taxation in both countries (solid blue line) and when the policy is implemented just at home and financed with domestic distortionary taxation (dashed red line).

4 Concluding Comments

This paper contributes to the theoretical literature about the macroeconomic effects of climate change considerations by showing how they are related to fiscal policy, monetary policy and the coordination across countries. The analysis is carried out in a DSGE model under the perspective of a small open economy like Slovakia belonging to a monetary union. Emissions enter as an input in the production function but they also affect productivity in a negative way. Moreover part of government spending contributes to the creation of productive public capital which affects private sector's labor productivity. The climate policies are evaluated with or without fiscal support, when they are followed by just domestic country and varying some features of the economy in terms of monetary policy and taxation. Therefore, the paper offers an evaluation on how different policy schemes affect the transmission of the climate policies.

First, a climate action (a reduction in emissions or an increase in the fossil price) is costly since it induces persistent inflationary and recessionary effects in the short run. An expansionary fiscal policy helps attenuating this cost especially if it is productive because it improves private sector's productivity, triggering a depreciation of the real exchange rate and, in turn, positive spillovers to output.

Second, for the domestic small economy, implementing a climate action exacerbates the recession when the foreign counterpart does not follow this policy. In fact, the big economy in the monetary union is insulated from the effort to adopt green policies and it enjoys the benefit of a lower level of emissions. Also in this case relative prices play a relevant role in the transmission of the policy, since the recession in the domestic economy mimics the dynamics of the real exchange rate.

Third, a more aggressive monetary policy rule induces a larger decrease in the emissions because it reduces more the aggregate demand. Furthermore, the cost of the climate action is larger when taxation is distortionary than when it is lump sum.

The paper focuses on the short-run effects of climate policies abstracting from the long-term effects of emissions. Enlarging the time horizon of the analysis will probably show that the short-run costs associated with climate actions could be overcome by the durable benefit in terms of lower stock of emissions and lower losses due to physical risks. To that extent, it would be interesting to include climate considerations in the conduct of monetary policy, consistently with the ECB climate agenda. Moreover, introducing debt-financed fiscal policies would add another twist in the model in terms of interactions between fiscal sustainability and climate policies. Finally, the cost of the climate actions can vary substantially if there heterogeneity across agents. These extensions are left for future work.

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