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ABSTRACT

In this paper we examine the international transmission of environmental policy using a New Keynesian model of the global economy. We first consider the case in which the quality of the environment affects utility, but not productivity. This allows us to look at the trade-off between environmental quality and output. We then consider the case in which the quality of the environment increases productivity but does not affect utility. Our main results show that in both cases a unilateral implementation of a more stringent environmental policy by the domestic country raises foreign welfare under a benchmark parameterization. However, since this policy can have a negative impact on domestic utility but a positive one on world utility, an international coordination problem can arise in the implementation of environmental policy: no country will have an incentive to implement environmental reforms if there is a possibility that its trading partners will do so.

JEL Classification: E30, F41, F42, Q50

Keywords: Environmental Economics, Environmental Policy, International Policy Coordination, Open Economy Macroeconomics

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I. INTRODUCTION

In recent decades, global public opinion and world leaders have recognized the importance of environmental issues, both in terms of their impact on human welfare and for their possible economic implications. Important steps to introduce more restrictive environmental policies have been made at least since the 1987 Montreal Treaty, which banned the use of chemical products that damage the ozone layer. Subsequent initiatives included earth summits in Rio de Janeiro in 1992 and in Johannesburg in 2002, as well as the 1997 Kyoto protocol to regulate greenhouse gas emissions. More recently, mitigating the impact of climate change was acknowledged as one of the most pressing policy challenges of our time, attracting unprecedented levels of attention. A summit of world leaders held in December 2009 in Copenhagen recognized that actions should be taken in this direction, although no agreement on binding commitments was reached, while the IMF has proposed the creation of a "Green Fund" aimed at providing the huge sums—which could climb to $100 billion a year in a few years—needed for countries to confront environmental challenges (IMF 2010).

Given the importance of these issues, the economic literature has not shied away from them. While climate scientists have focused on the impact of current levels of energy consumption on the environment, economists have devoted a great deal of attention to the conditions under which environmentally sustainable development is feasible and desirable. Those contributions have typically been made in the context of endogenous growth models, suitably extended to incorporate environmental concerns.

An important strand of the literature studies optimal dynamic environment policies, in which polluters pay the social costs of emissions (see, for example, Smulders 2000; Bretschger 2005; Brock and Taylor 2005; Xepapadeas 2005; Ricci 2007; and Golosov et al. 2009). Some papers—such as Gradus and Smulders (1993), van Marrewijk et al (1993), Musu (1995), and Cazzavillian and Musu (1998)—compute, under different assumptions, the level of emissions and growth consistent with a non-deteriorating environmental quality. Other contributions (for example Porter 1991; Porter and van der Linde 1995; Gans 2009; Acemoglu et al. 2009) have analysed potentially efficiency-enhancing technological adjustments that can be generated by corrective economic policies. Michel and Rotillon (1995), Mohtadi (1996), and Fisher and van Marrewijk (1998) focus on the impact of environmental policy on saving decisions. Nordhaus (1994) adds equations representing emissions and climate change to the neoclassical Ramsey model and studies their impact on traditional economic variables.

This literature introduces environmental concerns in endogenous or neoclassical growth models but abstracts from market imperfections, such as monopolistic competition and short-run price rigidities, which can add important interactions between environmental policy and economic outcomes. In this paper we seek to fill in this gap in the literature, by analyzing the impact of corrective environmental policy in the context of a New Keynesian two-country model incorporating by market imperfections. We believe that this is an important extension, since previous contributions have focused on the impact of environmental policies on long-run growth but have tended to neglect their short-run economic implications. For example, the debate on the short-run effects on output and consumption of corrective environmental policies will be at the forefront of policy discussions as more steps to reduce emissions are introduced, and could indeed even determine, through its impact on public opinion and voters, the success of environmental reforms. Importantly, the open-economy framework also allows us to study the international implications of corrective environmental policy, by analyzing its impact on foreign macroeconomic variables and ultimately on domestic, foreign and global welfare.

The policy exercises that we look at are regulatory shocks, under which one country unilaterally implements a more stringent environmental policy. We start our analysis by abstracting from any productive role of the environment, but assuming that the quality of the environment has a positive effect on private welfare. In this case, the implementation of a more stringent regulatory policy in one country implies both an indirect negative effect on domestic welfare–due to the reduction in domestic consumption—and a direct positive effect due to the fact that reducing pollution improves the quality of the environment. The overall welfare impact depends on specific parameter values. While domestic welfare tends to increase in our benchmark parameterization, a negative impact cannot be ruled out when the direct weight of the environment in private utility is low.

The simulation exercises also show that the impact of the domestic regulatory shock on foreign welfare is unambiguously positive under the benchmark parameterization. In this case there is an indirect negative welfare effect due to the fact that the deterioration of foreign terms of trade implies a reduction in foreign welfare. However, the domestic reduction in pollution also creates a positive international environmental externality. i.e. a reduction in domestic pollution improves the quality of foreign environment. This has a direct positive impact on foreign welfare, which dominates the negative indirect one in the benchmark parameterization.

The results discussed above illustrate the possibility of an international coordination problem point in the implementation of environmental policy when the direct weight of environmental quality is small but the international environmental spillover is sizeable. In this case, the country which introduces a more stringent environmental policy looses in terms of welfare, while both foreign and global welfare are increased. In this situation, no country has an incentive to implement an environmental policy which would be beneficial from the point of view of global welfare. Since the situation is symmetric, no country will introduce more stringent environmental regulations—which would increase global welfare at the expense of domestic welfare—if there is a possibility that such reforms can be implemented abroad. In practice, the world would be caught in a global environmental trap, since no country would reduce emissions.

We then look at the case in which the quality of the environment improves productivity, abstracting from any direct impact of the environment on private utility. Our results suggest that the international coordination problem discussed above may arise also in this case, depending on parameter values. Somewhat paradoxically, this international coordination problem is less severe the smaller the elasticity of output to environmental quality: in this case the foreign country does not gain much from domestic environmental reform.

While our results are consistent with the findings of previous literature, they also offer several new insights. The reduction in domestic output in the case in which the environment does not have any productive role is consistent with the findings of Gradus and Smulders (1993), van Marrewijk et al. (1993), Musu (1995), and Cazzavillan and Musu (1998), who all find that improvements in environmental quality can only be attained at the cost of slowing growth. Unlike in these papers, however, our open economy, New Keynesian setup allows us to analyse the international and global effects of environmental policies and its interaction with traditional macroeconomic transmission channels such as movements in exchange rates. Taking these factors in account, we can show that, despite the reduction in domestic output, environmentally friendly policies can help achieve a global improvement in welfare (i.e. higher global consumption for the same level of labor input) even in this case in which the environment does not increase productivity.

The rest of the paper is organized as follows: Section II introduces the model; Section III discusses our chosen parameterization; Section IV focuses on the trade-off between the quality of the environment and output; while Section V considers the case of external effects of the quality of the environment on productivity; Section VI concludes.

II. THE MODEL

We use a New-Keynesian open-economy model characterized by imperfect competition and nominal rigidities. The main innovation of our modeling strategy is to incorporate environmental concerns in such a framework. In particular, we take into account the polluting effects of production and the impact of environmental quality on productivity and utility. Except for the introduction of the environment, our model is a rather standard one, similar to those developed in the NOEM literature by Tille (2001) and Pierdzioch (2006).[1]

We assume the existence of two countries in the world. The world size is normalized to 1. The size of the domestic country is denoted by n and that of the foreign country by $1-n$. Firms and households populate both countries and are indexed by $z \in [0,1]$. Therefore, the fraction of domestic (foreign) firms and household is $n\,(1-n)$. We introduce below the various sectors of the economy and we discuss the model's equations. In the cases in which the equations are symmetric across countries we only discuss domestic ones.

A. Households

Household utility is a function of their consumption, real money balances, leisure and the quality of the environment. Accordingly, the intertemporal utility function of the representative domestic household can be written as:

[1] Compared to Tille (2001), there is one main difference: in our model nominal rigidities take the form of staggered price setting as in Calvo (1983), rather than one-period fixed prices.

$$U_t = \sum_{s=t}^{\infty} \beta^{s-t} [\log C_s + \frac{\chi}{1-\varepsilon} (\frac{M_s}{P_s})^{1-\varepsilon} - \frac{(l_s(z))^2}{2} + \omega \log E_s] \qquad (1)$$

where C_s denotes private consumption—which takes the form of a composite consumption basket described in more detail below— and P_s is its consumption price index; M_s denotes nominal money balances held by the household; $l_s(z)$ is the household's supply of labor, which negatively affects utility due to the loss of leisure; E_s is the stock of the country's environmental quality; $0 < \beta < 1$ is the intertemporal discount factor ; $\varepsilon > 0$ is the inverse of the consumption elasticity of money demand; χ and ω are positive parameters, respectively denoting the relative weight in private utility of money balances and of the quality of the environment.

We follow Tille (2001) in assuming that there are two types of goods in the world economy and that each country specializes in the production of one type. For simplicity, we call the two types of goods domestic and foreign goods. In addition, goods are also differentiated within each country. Within-country differentiation can be thought of as representing different brands of the same good.

This implies that the composite consumption basket which enters the utility function takes the following form

$$C_t = \left[n^{\frac{1}{\rho}} (C_t^h)^{\frac{\rho-1}{\rho}} + (1-n)^{\frac{1}{\rho}} (C_t^f)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \qquad (2)$$

where C_t^h and C_t^f respectively denote the consumption of home and foreign goods of the representative domestic household. Final consumption C_t is a Constant Elasticity of Substitution (CES) aggregate of domestic and foreign goods, with an elasticity of substitution equal to ρ. Following Tille (2001), we refer to ρ as the cross-country substitutability.

Consumption of domestic and foreign goods C_t^h and C_t^f are in turn CES aggregates of the different brands of domestic and foreign goods:

$$C_t^h = [n^{-\frac{1}{\theta}} \int_0^n (c_t^h(z))^{\frac{\theta-1}{\theta}} dz]^{\frac{\theta}{\theta-1}}, \quad C_t^f = [(1-n)^{-\frac{1}{\theta}} \int_n^1 (c_t^f(z))^{\frac{\theta-1}{\theta}} dz]^{\frac{\theta}{\theta-1}}$$

where $c_t^h(z)$ is consumption of the differentiated domestic brand *z* by the representative domestic households; $c_t^f(z)$ consumption of the differentiated foreign brand *z* by the same household; and θ > 1 is the elasticity of substitution between brands produced in the same country. Using again the terminology followed by Tille (2001), we refer to θ as the within-country substitutability.

Given the consumption indexes discussed above, households allocate their consumption optimally according to the following demand functions:

$$c_t^h(z) = \left[\frac{p_t^h(z)}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} C_t \ , c_t^f(z) = \left[\frac{p_t^f(z)}{P_t^f}\right]^{-\theta}\left[\frac{P_t^f}{P_t}\right]^{-\rho} C_t$$

$$c_t^{*h}(z) = \left[\frac{p_t^{*h}(z)}{P_t^{*h}}\right]^{-\theta}\left[\frac{P_t^{*h}}{P_t^*}\right]^{-\rho} C_t^* \ , c_t^{*f}(z) = \left[\frac{p_t^{*f}(z)}{P_t^{*f}}\right]^{-\theta}\left[\frac{P_t^{*f}}{P_t^*}\right]^{-\rho} C_t^*$$

where asterisks indicate consumption by the representative foreign households. This means that $c_t^{*h}(z)$ $(c_t^{*f}(z))$ denotes consumption of the differentiated domestic (foreign) brand by the representative foreign household.

The demand functions presented above express the fact that in a first stage domestic households allocate their total consumption C_t between the domestic and foreign baskets C_t^h and C_t^f according to relative prices and to the cross-country elasticity of substitution ρ. Subsequently, domestic households allocate their chosen level of consumption of domestic and foreign goods across differentiated brands according to relative prices and to the within-country elasticity of substitution θ.

The domestic currency price of a domestic and foreign brand are denoted by $p_t^h(z)$ and $p_t^f(z)$ respectively. P_t^h and P_t^f are respectively the price indexes corresponding to domestic and foreign aggregate consumption baskets C_t^h and C_t^f. All these price indexes are expressed in domestic currency terms. Corresponding foreign currency price indexes are denoted by an asterisk. For instance, $p_t^{*h}(z)$ is the foreign currency price of a differentiated domestic brand.

P_t^h and P_t^f are defined as

$$P_t^h = [n^{-1}\int_0^n (p_t^h(z))^{1-\theta} dz]^{\frac{1}{1-\theta}} \ , \ P_t^f = [(1-n)^{-1}\int_0^n (p_t^f(z))^{1-\theta} dz]^{\frac{1}{1-\theta}}$$

and they are aggregated to define the overall domestic price index as follows

$$P_t = \left[n(P_t^h)^{1-\rho} + (1-n)(P_t^f)^{1-\rho}\right]^{\frac{1}{1-\rho}}.$$

The corresponding foreign indexes are defined in an analogous way.

We assume that the law of one price holds for each brand: $p_t^h(z) = S_t p_t^{*h}(z)$, where S_t is the nominal exchange rate (how many units of domestic currency are needed to buy one unit of foreign currency). This implies that the purchasing power parity holds: $P_t = S_t P_t^*$.

The budget constraint of the domestic representative household is given by

$$M_t + \delta_t D_t = D_{t-1} + M_{t-1} + w_t l_t(z) - P_t C_t + \pi_t + P_t T_t \tag{5}$$

Equation (5) expresses the fact that the households are paid a nominal wage w_t for the labor $l(z)_t$ that they supply in a competitive labor market, receive a share π of profits from firms and real transfers equal to T_t from the government. In addition, households consume and can hold their assets as money or nominal bonds. D denotes the household's holding of nominal bonds, which are denominated in domestic currency and account for international shifts in wealth, δ is the price of a bond (the inverse of one plus the nominal interest rate). Since bonds are denominated in domestic currency, the budget constraint of the foreign representative household is given by

$$M_t^* + \delta_t \frac{D_t^*}{S_t} = \frac{D_{t-1}^*}{S_t} + M_{t-1}^* + w_t^* l_t^*(z) - P_t^* C_t^* + \pi_t^* + P_t^* T_t^* \tag{6}$$

where foreign variables are denoted by asterisks. A global asset-market clearing condition $nD_t + (1-n)D_t^* = 0$ also holds.

Domestic households maximize (1) subject to (5), and an analogous optimization problem holds for foreign households. The optimal behavior of households is governed by the following first-order conditions

$$\delta_t P_{t+1} C_{t+1} = \beta P_t C_t \tag{7}$$

$$\delta_t P_{t+1}^* C_{t+1}^* E_{t+1} = \beta P_t^* C_t^* E_t \tag{8}$$

$$l_t = \frac{w_t}{C_t P_t} \tag{9}$$

$$l_t^* = \frac{w_t^*}{C_t^* P_t^*} \tag{10}$$

$$\frac{M_t}{P_t} = \left(\frac{\chi C_t}{1-\delta_t}\right)^{\frac{1}{\varepsilon}} \tag{11}$$

$$\frac{M_t^*}{P_t^*} = \left(\frac{\chi C_t^*}{1-\frac{\delta_t E_{t+1}}{E_t}}\right)^{\frac{1}{\varepsilon}} \tag{12}$$

The first-order conditions shown above are standard ones. Equations (7) and (8) are the Euler equations for optimal domestic and foreign consumption. They state that private consumption growth is a function of the prices of consumption and bonds and of the discount factor β. Equations (9) and (10) are the domestic and foreign labor-leisure trade-off equations, which equate the leisure utility loss of supplying an extra unit of labor with the marginal utility of the extra private consumption that such additional unit of labor can buy. Finally, equations (11) and (12) show that households' optimal money demand is an increasing function of consumption and a decreasing function of the interest rate.

B. The Environment

Environmental quality evolves according to the following law of motion

$$\hat{E}_t = -\kappa_1 \hat{F}_t - \kappa_2 \hat{F}_t^* \qquad (13)$$

$$\hat{E}_t^* = -\kappa_2 \hat{F}_t - \kappa_1 \hat{F}_t^* \qquad (14)$$

where the hat notation denotes log-deviations from an initial steady state, $\hat{F}_t$ is the change in domestic polluting emissions, κ_1 is a parameter which expresses by how much the domestic (foreign) environmental quality deteriorates due to domestic (foreign) emissions. This implies that $-\kappa_1$ can be interpreted as the *within-country* elasticity of environment quality to pollution. κ_2 is a measure of how much the domestic (foreign) environment deteriorates due to foreign (domestic) pollution, we can therefore refer to $-\kappa_2$ as the *cross-country* elasticity of environmental quality to pollution. A natural way to think about κ_2 is as a parameter which quantifies the size of the international environmental externality due to pollution emissions.

C. The Government

In our framework, the most important role of the government is a regulatory one. Through regulation, the government can change the amount of polluting emissions. In practice, we assume that the flow of emissions follows a stochastic process, given by

$$\hat{F}_t = \phi \hat{F}_{t-1} + \nu_t \qquad (15)$$

where ν_t is an unpredictable shock, which we assume to have zero mean and a positive variance. We model regulatory policy interventions as negative shocks to the stochastic process described above.

In addition to imposing environmental regulation, the government also pays lump sum transfers to agents, financing them through seigniorage according to the budget constraint

$$T_t = \frac{M_t - M_{t-1}}{P_t} \qquad (16)$$

D. The Supply Side: Firms

Technology

All firms produce a differentiated good according to the simple production function

$$y_t(z) = A_t l_t(z) \qquad (17)$$

where $y_t(z)$ is the output of firm z, A_t is the level of technology available to firms and $l_t(z)$ is labor input. The level of technology is defined as

$$A_t = E_t^{\alpha} F_t^{\eta} \qquad (18)$$

Equation (18) expresses the fact that both the quality of the environment and the flow of polluting emissions increase the marginal productivity of labor. The parameter α is the share of environmental quality in the production function, which we can also call the output elasticity to environment quality and η is the share of pollution in the production function, or the output elasticity to pollution.

Several authors have recognized the fact that the quality of the environment positively affects total factor productivity.[2] In this paper, we look at the impact of the environment on both utility ($\omega > 0$) and productivity ($\alpha>0$). However, we do not assume those two effects at the same time: we will first look at the ($\omega > 0$; $\alpha=0$) case and subsequently at the ($\omega = 0$; $\alpha>0$) case. This allows us to address separately two of the main issues on which the environmental literature has focused so far in growth models, namely the so-called (i) trade-off between the quality of the environment and output and (ii) external effects of the quality of the environment on productivity.[3]

Profits

The representative domestic firm maximizes profits

$$\pi_t(z) = p_t(z) y_t(z) - w_t l_t \qquad (19)$$

taking into account the production function (18) and the demand curve for its products

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[2] See, for example, Bovenberg and Smulders (1995), Smulders and Gradus (1996), Rosendhal (1997), and Rubio and Aznar (2000).

[3] See Ricci (2007).

$$y_t^d(z) = \left[\frac{p_t^h(z)}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} C_t^W$$

where C_t^W is world demand ($C_t^W = nC_t + (1-n)C_t^*$). The firm's profits can thus be written as

$$\pi_t(z) = \left[\frac{p_t^h(z)}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} C_t^W\,(p_t^h(z) + MC_t) \tag{20}$$

where MC_t is the nominal marginal cost: $MC_t = w_t / A_t$.

Price Setting

In the absence of price rigidities, the optimal price charged by the firm for the brand that it produces would be given by a simple mark-up over the marginal cost, according to the formula

$$p_t(z) = \frac{\theta}{\theta - 1} MC_t \tag{21}$$

However, following Calvo (1983), we introduce nominal rigidities by assuming that each firm resets its price with a probability $1-\gamma$ in each period, independently of other firms and independently of the time passed since the last change in prices. Each firm has to take into account, when setting its profit-maximizing price, that in every subsequent period there is a probability $0 < \gamma < 1$ that it will not be able to change it again.

When setting a new price in period t, each firm seeks to maximize the present value of profits. In doing this, the firm weights future profits by the probability that the price will still be effective in that period. Thus the representative home firm seeks to maximize

$$\max_{p_t^h(z)} V_t(z) = \sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} \pi_s(z) \tag{22}$$

where $\zeta_{t,s}$ is the stochastic discount factor for nominal payoffs in period t.

The firm's optimization problem results in the following pricing rule

$$p_t(z) = \left(\frac{\theta}{\theta-1}\right) \frac{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} (C_s^W)\left(\frac{1}{P_s}\right)^{-\theta}\left(\frac{P_s^h}{P_s}\right)^{-\rho} MC_t}{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} (C_s^W)\left(\frac{1}{P_s}\right)^{-\theta}\left(\frac{P_s^h}{P_s}\right)^{-\rho}} \tag{23}$$

The log-linear version of equation (23) can be written as

$$\hat{p}_t^h(z) = \beta\gamma\hat{p}_{t+1}^h(z) + (1-\beta\gamma)M\hat{C}_t$$

so that the optimal price is simply the weighted average of the current and future marginal costs.

E. The Symmetric Steady State

In the following sections we carry out some policy exercises. In doing so, we use a log-linearized version of the model around an initial symmetric steady state in which initial net foreign assets are zero ($D_0 = 0$) and the initial level of technology is normalized to one. Under this assumption the following relationship holds

$$y_0 = C_0 = \left(\frac{\theta-1}{\theta}\right)^{\frac{1}{2}} \tag{24}$$

where we have used the zero subscript to denote the initial steady state.

Since all firms in a country are symmetric, every firm that decides to change its price in any given period chooses the same price and output consistently with (23). The structure of price setting implies that each period a fraction of $1-\gamma$ of firms sets a new price and the remaining fraction keeps their price unchanged.

The consolidated budget constraint of the home country can be derived using equation (5), (16) and (19) as[4]

$$P_t C_t = p_t^h(z) y_t(z) + D_{t-1} - \delta_t D_t$$

Equilibrium is defined as sequences of variables that clear the labor, goods and money markets in each country in each period and satisfy intertemporal budget constraints.

III. The Choice of Parameter Values

Our parameterization is quite standard. The subjective discount factor β is set at 0.99. The countries are assumed to be of equal size, implying n=0.5. The consumption elasticity of money demand is set at ε=1. The price rigidity parameter is assumed to be γ=0.5, implying the average time until a new price is reset is two periods. Following Rotemberg and Woodford (1992) and Tille (2001), we chose a within-country elasticity of substitution of θ=6, which implies a 20% markup. Since we believe that the most realistic case is the one in

[4] The corresponding foreign equation is $P_t^* C_t^* = p_t^{*f}(z) y_t^*(z) - \frac{n}{1-n}\frac{D_{t-1}}{S_t} + \frac{n}{1-n}\delta_t \frac{D_t}{S_t}$.

which the substitutability between brands of the same good is higher than the substitutability between different (domestic vs. foreign) goods, we set the cross-country substitutability parameter to be smaller than the within country one, specifically ρ=3

We now move to discuss the parameters related to the modelling of the environment. The share of environmental quality in the production function, which we have also called above the output elasticity to environmental quality, is set at a low value: α=0.05. This choice can be justified by the argument that an improvement in environmental quality is likely to have only a marginal direct impact on aggregate production (see, for example, Ricci 2007). We similarly choose the share of pollution in the production function, which we also called the elasticity of output to pollution, to be η=0.05. The choice of a low η is made to model relatively inefficient "dirty" technologies, which pollute the environment without creating a large productivity gain. As it will become clear below, when η= α the values taken by the *within-country* and *cross- country* elasticities of environmental quality to pollution are crucial for the results. We therefore consider a range of values for κ_1 and κ_2, in addition to the benchmark values κ_1=0.5 and κ_2=0.3, to assess the sensitivity of our results to those parameters.

We assume that the utility derived from the stock of environmental quality is low compared to that provided by consumption. We therefore set ω= 0.1 in the benchmark parameterization. This implies that a 1% increase in consumption increases utility ten times more than a one percent increase in the stock of environmental quality. We also look at the impact of changing the value if this parameter. In all exercises, we consider a permanent one percent reduction in the flow of domestic polluting emissions due to regulatory changes ($\phi = 1, v_t = -1$). The numerical simulations are derived ne using the algorithm developed by Klein (2000) and McCallum (2001).

IV. THE TRADE-OFF BETWEEN THE QUALITY OF THE ENVIRONMENT AND OUTPUT

As stressed by Ricci (2007), environmental regulation, i.e. a policy aimed at reducing the flow of pollution and improving environmental quality, has a negative impact on economic growth due to the additional costs that it imposes on the production sector. In order to focus on the costs, in terms of output, consumption and welfare, of such a policy, in this section we abstract from any productive role of the environment. At the same time, we assume that the quality of the environment has a positive effect on private welfare. We also assume that the environmental regulatory change is implemented unilaterally by the domestic country, while there is no regulatory change in the foreign country.

In our framework, the cost of environmental regulation under these assumptions can be evaluated by looking at the effects of a permanent one percent reduction in the flow of domestic polluting emissions due to regulatory changes (a negative 1% shock to equation (15) with $\phi = 1, v_t = -1$) in the case in which α=0 and $\omega = 0.1$. Figure 1 and Table 1 present the results of this policy exercise. In Figure 1, the vertical axes show percentage deviations from the initial steady state.[5]

As expected on the basis of the representative domestic firm's production function and available technology (equations (17) and (18)), a permanent reduction in the flow of polluting emissions permanently reduces domestic output by reducing the marginal productivity of the labor input. This effect is shown in Figure 1(a). Our parameterization of the elasticity of output to pollution (η=0.05) and the fact that the regulatory shock is a 1 percent reduction in emissions imply a long-run reduction in domestic output of about 0.05 percent. The fall in domestic output implies a reduction in disposable income of domestic households, who therefore reduce their consumption, as shown in Figure 1(b).

Figures 1(a) and 1(b) also show that the fall in foreign output following the unilateral domestic regulatory shock is small and temporary, while foreign consumption is permanently (but only marginally) reduced. The negative impact of domestic regulatory changes on foreign variables is due to the fact that, in a globalized economy, a reduction in domestic output and consumption implies a reduction of demand for foreign goods. However, since the cross-country substitutability between the domestic and foreign good is smaller than the within-country substitutability between brands ($\rho=3< \theta=6$) of the same good, this negative impact on foreign output (and consumption) is small.

The fact that domestic consumption drops more than foreign drives the dynamics of the exchange rate. Subtracting the log-linearized version of the foreign money demand equation (eq. 12) from the domestic one (eq. 11) and taking into account that the PPP holds in our model, it is possible to show that, following a regulatory shock, the domestic exchange rate immediately jumps to its new long-run value given by

$$\hat{S}_t = -\frac{1}{\varepsilon}(\hat{C}_t - \hat{C}_t^*)$$

where an increase in S is a depreciation.[6]

The depreciation of the domestic nominal exchange rate creates an expenditure switching effect, i.e. it tends to make the foreign good more expensive compared to the domestic one. This is another factor, in addition to the reduction in domestic demand discussed above, behind the fall of foreign output. However, as it is evident from Figure 1(a), the impact of such expenditure switching effect on foreign output is quantitatively small and short lived. This expenditure switching effect also tends to increase domestic output, but this effect is

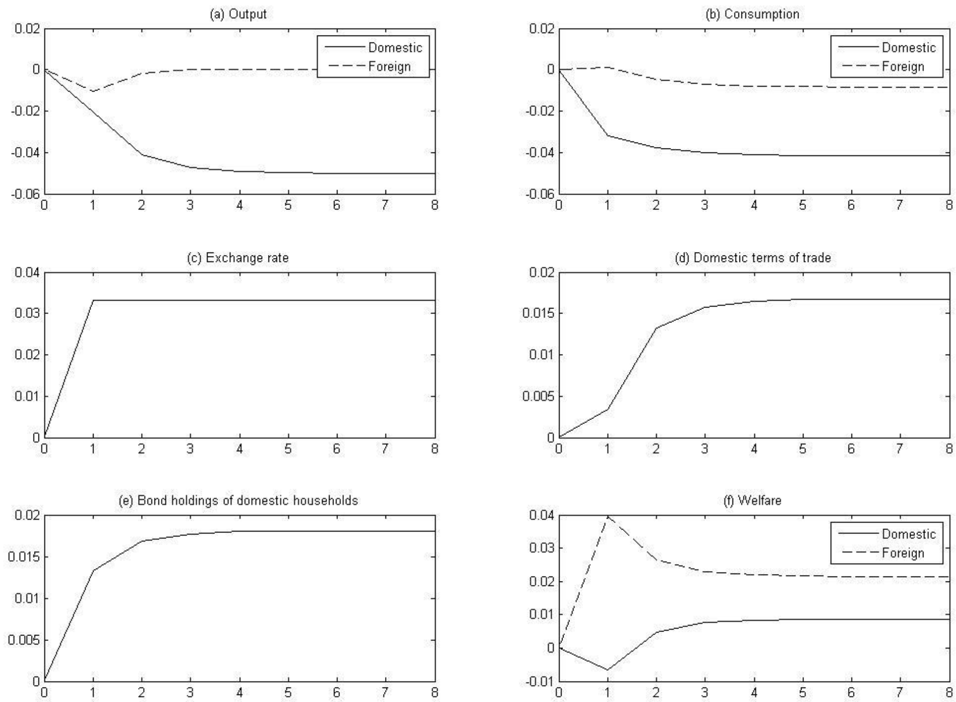
[5] For variables whose initial steady-state value is zero (e.g. bond holdings), deviations are expressed in relation to initial output.

[6] The result that a decrease (increase) in relative domestic consumption implies a depreciation (appreciation) of the domestic exchange rate without overshooting is standard in the NOEM framework (see, for example, Obstfeld and Rogoff 1995, 1996).

weaker that the negative effect on domestic production caused by the reduction in polluting emissions.

Figure 1(d) also shows that the domestic terms of trade, defined as the relative price of domestic exports in terms of its imports, improve following a unilateral domestic regulatory shock. This result is due to the fact that the fall in relative (domestic compared to foreign output) output increases its relative price. The fact that in the short run the fall in domestic output is larger than the fall in domestic consumption also implies an accumulation of bond holdings by the domestic country (Figure 1(e)).

Figure 1. Macroeconomic Effects of a Domestic Regulatory Shock When α=0



We now shift our analysis to welfare, by looking at the combined impact of the changes in individual macroeconomic variables on private utility. We first study the change in period-by-period utility. Then we calculate the Present Discounted Value (PDV) of these changes.

Formally, the change in domestic utility in period *t* is given by

$$dU_t = \hat{C}_t - l_0^2 \hat{l}_t + \omega \hat{E}_t \tag{25}$$

while an analogous expression holds for foreign utility.[7] Figure 1 illustrates the response of domestic period-by-period utility (dU_t). The PDV value of the change in utility is calculated on the basis of the following equation[8]

$$dU_{DPV} = \sum_{s=t}^{\infty} \beta^{s-t} dU_s \tag{26}$$

with an equivalent expression holding for the foreign country. Given (25) and (26), the change in global (world) utility can be defined as the population weighted average of the change in domestic and foreign utility as follows

$$dU_{DPV}^{W} = ndU_{DPV} + (1-n)dU_{DPV}^{*}$$

Table 1 shows the PDV of welfare for the benchmark parameterization (with $\omega = 0.1$), as well as a higher and lower value ω.

Table 1. PDV of Changes in Utility Following a Domestic Regulatory Shock

Parameterization	dU_{DPV}	dU_{DPV}^{*}	dU_{DPV}^{W}
ω=0.05	-1.7	0.67	-0.49
ω=0.07	-0.67	1.3	0.30
ω=0.1	0.83	2.2	1.5
ω=0.15	3.3	3.7	3.5

Following the implementation of a more stringent regulatory policy in the domestic country, two effects are at work on domestic welfare: an indirect negative effect due to the reduction in domestic consumption and a direct positive effect due to the fact that reducing pollution improves the quality of the environment.

Figure 1(f) shows that, for the benchmark parameterization ($\omega = 0.1$), the negative indirect effect dominates in the short run, while the positive direct effect dominates in the medium and long run. In terms of PDV, the medium and long run dominates the short run, so that the overall welfare impact on domestic residents is positive (Table 1, row $\omega = 0.1$). Only in the case in which the weight of environmental quality in domestic utility is very low (Table 1, row $\omega = 0.05$) the indirect effect due to lower consumption dominates and the overall implication of the regulatory shock is to reduce domestic welfare.

Turning to the impact of the domestic regulatory shock on foreign welfare, we can see from Figure 1(f) and Table 1 that this is unambiguously positive under the benchmark parameterization. This result is robust to changes in the weight of the environment in private

[7] As customary in this literature, we neglect the utility derived from real balances.

[8] We approximate the infinite-time horizon by including a large number of periods (3,000) in Equation (26).

utility. In this case there is an indirect negative welfare effect due to the fact that the deterioration of foreign terms of trade (Figure 1(d)) implies a reduction in foreign welfare. However, since in the benchmark parameterization the *cross-country* elasticity of environment quality to pollution is non-zero (κ_2 =0.3), a domestic reduction in pollution creates a positive international environmental externality. i.e. a reduction in domestic pollution improves the quality of foreign environment. Since the quality of the environment enters foreign private utility ($\omega = 0.1$), the improvement in the environment has a direct positive impact on foreign welfare, which dominates the negative indirect one in the benchmark parameterization. This result is robust to changes in the weight of the environment in private utility. However, as shown in Table 2 below, if the international environmental externality was small or zero (for example if we set $\kappa_2 = 0.1$), the impact on foreign welfare would be negative.

Table 2. PDV of Changes in Foreign Utility for Various Values of κ_2 and ω

Parameterization	ω=0.05	ω=0.1	ω=0.15
$\kappa_2 = 0.1$	-0.78	-0.73	-0.67
$\kappa_2 = 0.2$	0.17	1.17	2.17
$\kappa_2 = 0.3$	0.67	2.2	3.7

Table 3 below presents some plausible combinations of parameters for which an international coordination problem may arise in the implementation of environmental policy when the direct weight of environmental quality in utility is small (low ω) but the international environmental spillover is sizeable (high κ_2). As shown in Table 3, when $\omega = 0.07$ the country which introduces a more stringent environmental policy looses in terms of welfare, while foreign and global welfare increases. This means that countries would have no incentive to implement environmentally friendly reforms if there is a possibility that such reforms can be implemented abroad: if a country increases environmental regulation, it would improve foreign and global welfare at the expense of its own citizens, while if it waits for the foreign country to do so, it could increase domestic welfare by free-riding on the foreign reforms.[9] In practice, the world would be caught in a global environmental trap, since no country would reduce emissions.

Table 3. PDV of Changes in Utility Following a Domestic Regulatory Shock: the Possibility of an International Coordination Problem

Parameterization	dU_{DPV}	dU^*_{DPV}	dU^W_{DPV}
ω=0.07, $\kappa_2 = 0.3$	-0.67	1.3	0.30
ω=0.07, $\kappa_2 = 0.4$	-0.67	2.0	0.65

[9] Given the symmetry of the model, the effects of a foreign regulatory shocks would be symmetric to those presented in Table 3 for the case of a domestic shock.

As shown in Table 3, when the size of the international environmental externality is reduced (when κ_2 becomes smaller), the severity of this coordination problem is also reduced, because in this case each country would gain less from environmental reforms abroad. Since κ_2 is likely to be smaller for countries which are geographically more distant, another implication of our analysis is that globalization (defined as increased trade with country which are geographically far) can reduce the likelihood of the opportunistic behavior that we have described above, and facilitate the implementation of environmental reforms.

V. External Effects of the Quality of the Environment on Productivity

In this Section we analyze the case in which the quality of the environment improves productivity (α>0). This assumption has received significant attention in the growth literature (see, for example, Michel (1993); Smulders (1995); Bovenberg and Smulders (1995); Smulders and Gradus (1996); Rosendalh (1997); and Rubio and Aznar (2000)). As stressed by Ricci (2007)—who provides an excellent survey of the literature which incorporates environmental issues in growth models—this assumption is particularly relevant for economies relying heavily on the exploitation of natural resources. While it might seem less relevant for industrialized economies, the case α>0 can also been thought of as a reduced-form way of modeling the negative impact of pollution on human capital, and therefore on growth.[10] In order to focus on the impact of the environmental quality on productivity, we abstract in this Section from any direct impact of the environment on private utility, by assuming $\omega = 0$.

A. The Basic Analytics

Before presenting our simulations, it is useful to focus on some basic analytics of the model in this case, which will be useful for the interpretation of the quantitative results. Equation (13) and the log-linear version of equation (18) imply that the change in the level of domestic "technology" can be expressed as a function of foreign and domestic pollution emissions and of parameters of the model as

$$\hat{A}_t = (\eta - \alpha\kappa_1)\hat{F}_t - \alpha\kappa_2\hat{F}_t^* \qquad (27)$$

Equation (27) shows that, since domestic emissions $\hat{F}_t$ have both a positive direct impact and a negative indirect impact (through domestic environmental deterioration) on the level of domestic productivity, their net impact on domestic technology depends on the interplay of : the elasticity of output to environmental quality α ; the elasticity of output to the pollution η ; and the *within-country* elasticity of environment quality to pollution - κ_1. Equation (27) also expresses the fact that the level of domestic technology is reduced when foreign emissions

[10] Uzawa (1965) and Lucas (1988) have stressed the role of human capital in explaining growth. Kany and Ragot (1998) and van Ewijk and van Winbergen (1995) develop growth models in which pollution reduces productivity by damaging human capital.

$\hat{F}_t^*$ are increased, because an increase in foreign emissions reduces the quality of the domestic environment without any positive impact on domestic productivity. The latter effect is stronger for larger values of α and of the international environmental externality κ_2. An analogous expression, with a symmetric interpretation, can be derived for the level of foreign technology

$$\hat{A}_t^* = -\alpha\kappa_2\hat{F}_t + (\eta - \alpha\kappa_1)\hat{F}_t^* \tag{28}$$

Equations (27) and (28) imply that the change in world technology $\hat{A}_t^W = n\hat{A}_t + (1-n)\hat{A}_t^*$ in the case in which $\hat{F}_t \neq 0$, $\hat{F}_t^* = 0$ and $n = 0.5$ can be expressed as

$$\hat{A}_t^W = \frac{1}{2}[\eta - \alpha(\kappa_1 + \kappa_2)]\hat{F}_t \tag{29}$$

From equation (29) it is evident that the policy experiment that we are focusing on, a reduction in the flow of domestic pollution emissions ($\hat{F}_t < 0$), has a positive impact on world technology ($\hat{A}_t^W > 0$) if and only if

$$\alpha(\kappa_1 + \kappa_2) > \eta \tag{30}$$

The left-hand side of the above inequality measures the positive indirect effect on world technology of the improved environmental quality following a reduction in emissions, while the right-hand side shows the direct negative effect caused by the reduction in polluting emissions.

The welfare benefits to the domestic country of a unilateral reduction in pollution depend on the change in domestic technology, because in an imperfectly competitive economy the initial level of output is suboptimal and therefore all policies that bring output closer to its efficient level, such as an increase in technology, must be welfare-improving. Furthermore, a more productive technology would also improve domestic welfare by allowing domestic residents to achieve a higher level of consumption with the same labor effort. Equation (27) implies that, under the policy we are considering ($\hat{F}_t < 0$ and $\hat{F}_t^* = 0$)

$$\hat{A}_t = (\eta - \alpha\kappa_1)\hat{F}_t \tag{31}$$

thus, a necessary and sufficient condition for a unilateral domestic regulatory shock ($\hat{F}_t < 0$) to increase domestic technology ($\hat{A}_t > 0$) and domestic welfare is

$$\alpha\kappa_1 > \eta \tag{32}$$

Equations (29), (30), (31) and (32) show that in the case in which $\alpha\kappa_1 < \eta$, the domestic country does not have an incentive for unilateral reduction in pollution, even if the international environmental spillover is so strong that world technology (and therefore welfare) would improve (if $\alpha(\kappa_1 + \kappa_2) > \eta$).

B. Simulation Results

The analytical results derived above are consistent with our quantitative simulations. The impact of a domestic regulatory shock on macroeconomic variables and on welfare under this assumption is shown in Figure 2 and Table 4. The parameterization is the same as the benchmark one in the previous section, except for the fact that here we set α=0.05 and $\omega = 0$. In order to show the impact of assuming that the quality of the environment increases productivity, we also include for comparison the case α=0.

Figure 2. Macroeconomic Effects of a Domestic Regulatory Shock When α≥0 and $\omega = 0$

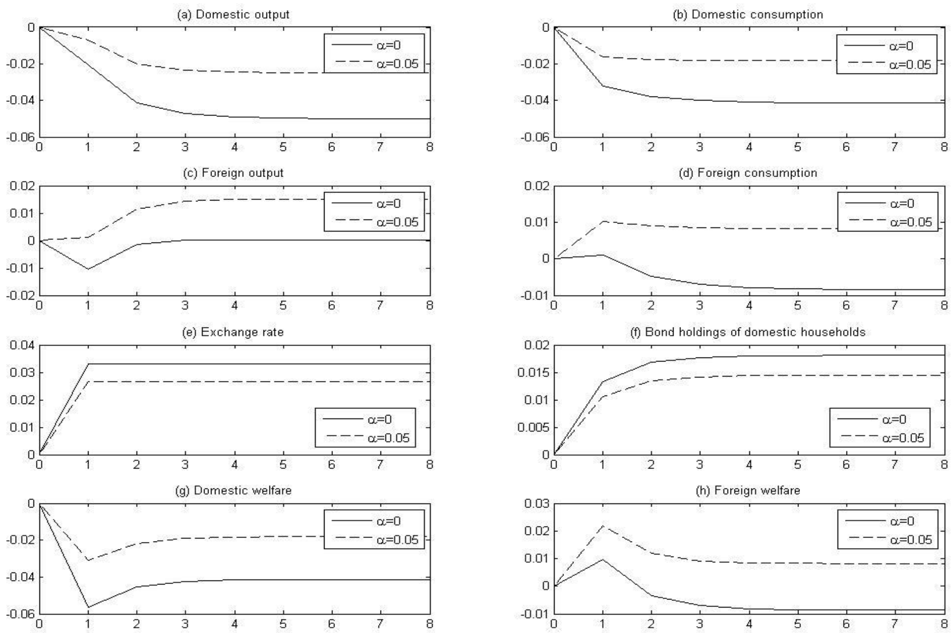


Table 4. PDV of Changes in Utility Following a Domestic Regulatory Shock When α≥0 and $\omega = 0$

Parameterization	dU_{DPV}	dU^*_{DPV}	dU^W_{DPV}
$\kappa_1 = 0.5, \kappa_2 = 0.3, \alpha = 0.00$	-4.2	-0.83	-2.5
$\kappa_1 = 0.5, \kappa_2 = 0.3, \alpha = 0.05$	-1.8	0.83	-0.50

Figure 2(a) shows that a reduction in the flow of polluting emission reduces domestic output. This is because, as evident from Equation (27), a reduction in pollution represents a negative shock to the level of domestic technology. Since under our parameterization this negative effect is only partially offset by the positive effect caused by the improved quality of the environment, the net effect is a fall in output. Figure 2(a) also shows that the fall in output is lower when α=0.05 compared to the case α=0, because in the latter case there is no positive effect of the quality of the environment on productivity.

Figures 2(c) and 2(d) show that in the case α=0.05 foreign output and consumption increase following a domestic regulatory shock. Even in this case, the intuition is straightforward and consistent with the basic analytics of the model discussed above: as shown in Equation (28), a reduction in the flow of domestic polluting emission is a positive technology shock for the foreign economy, because less domestic pollution implies, through the international environmental externality, an improvement in the quality of the foreign environment, and therefore higher foreign productivity. The latter effect is obviously at work only when α>0. In the α=0 case, the reduction in domestic emissions, and the attendant improvement in the quality of foreign environment, do not generate any productivity gain for the foreign country. The fall in foreign output and consumption in the α=0 case (shown in Figures 2(c) and 2(d)) is therefore completely driven by "traditional" international macroeconomic spillover channels, such as the reduction in global demand (domestic output falls) and an expenditure switching effect. The latter is due to the fact that the fall in relative domestic consumption depreciates the domestic exchange rate (see Figure 1(e)), thus making the domestic good relatively cheaper. The fact that foreign output and consumption increase instead of falling when α=0.05 is due to both the positive international environmental externality (discussed above) in that case and to a reduced expenditure switching effect (the domestic exchange rate depreciates less when α=0.05, because the fall in domestic consumption relative to foreign is smaller).

As shown in Figures 2(g) and in Table 4, in the case α=0.05 both period-by-period utility and the PDV of domestic welfare falls following a domestic regulatory shock. This is consistent with the basic analytics discussed above, since in this case inequality (32) is not satisfied (under our parameterization $\alpha\kappa_1 = .03 < \eta = .05$). Table (3) also shows that in this case the PDV of foreign welfare is increased.

Another interesting factor to consider is the impact of a higher κ_1. We report the results for this case in Figure 3 and Table 5, in which we have set $\kappa_1 = 0.8$ and $\kappa_2 = 0.3$. As it can be seen from Figure 3(h) and Table 5, in the $\kappa_1 = 0.8$ case the positive impact on foreign welfare of a domestic increase in environmental regulation is even stronger than in the previous case ($\kappa_1 = 0.5$). In addition, the reduction in domestic welfare is smaller than in the basic case. These effects of a higher κ_1 are so strong, in fact, that the PDV of world welfare now increases, rather than decreasing as it did in the $\kappa_1 = 0.5$ case. Unfortunately, as shown in Table 5, the country that implements environmentally friendly reforms looses, so that no country will have an incentive to embark in such policies even in they would increase world welfare.

Figure 3. Macroeconomic Effects of a Domestic Regulatory Shock When α≥0, $\omega = 0$ and $\kappa_1 = 0.8$

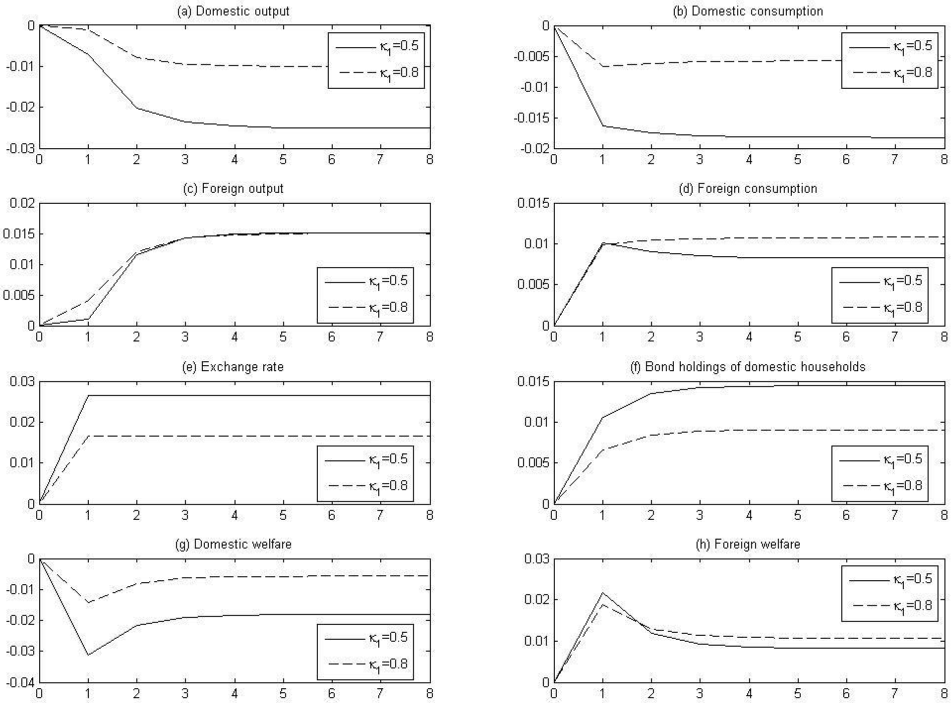


Table 5. PDV of Changes in Utility Following a Domestic Regulatory Shock When α≥0, $\omega = 0$ and $\kappa_1 = 0.8$

Parameterization	dU_{DPV}	dU^*_{DPV}	dU^W_{DPV}
$\kappa_1 = 0.8, \kappa_2 = 0.3, \alpha = 0.05$	-0.59	1.1	0.25

This result suggests that the international coordination problem already discussed in Section IV might arise also in this case for reasonable parameter values: since the country which introduces stricter environmental regulation looses and the other country gains in terms of welfare, no country has an incentive to implement such policy if there is a positive probability that the other country will do so. Comparing Tables 4 and 5 we can see that, somewhat paradoxically, this international coordination problem is less severe the smaller the elasticity of output to environmental quality: when α=0 the foreign country does not gain from domestic environmental reform (the PDV of foreign welfare is reduced and global welfare is strongly reduced), because an improved environmental quality does not increase its productivity. If we recall the possible interpretations of α discussed at the beginning of this Section, this result suggests that the coordination problem is likely to be more sever for countries who rely more heavily on natural resources (such as agriculture) and/or human capital.

VI. CONCLUSIONS

In this paper we incorporate environmental concerns in an open-economy model with imperfect competition and nominal rigidities. Our analysis shows that in this framework the unilateral implementation of a more stringent environmental policy by one country has important positive and welfare implications both domestically and abroad.

In the case in which the environment affects private welfare but not productivity, such a policy has two contrasting effect on domestic welfare: an indirect negative one due to lower consumption and a direct positive one due the improvement in environmental quality. Our simulations show that possibility of welfare losses for domestic residents cannot be ruled out in cases in which the direct weight of environmental quality in private utility is low. Under these assumptions, the impact of the domestic regulatory shock on foreign welfare is unambiguously positive in a benchmark parameterization, due to the international environmental externality created by the implementation of environmentally friendly policies in the domestic country.

We then look at the case in which the quality of the environment improves productivity, abstracting from any direct impact of the environment on private utility. Under these assumptions a more stringent environmental policy reduces domestic output, because a reduction in pollution represents a negative shock to the level of domestic technology, which is only partially offset by the positive impact of an improved environmental quality on productivity. In this case, both foreign output and foreign consumption increase following a domestic regulatory shock, because a reduction in domestic pollution implies, through the international environmental externality, an improvement in the quality of the foreign environment, and therefore higher foreign productivity. The results just discussed imply that, under our benchmark parameterization, domestic welfare falls and foreign welfare increases following a domestic regulatory shock

Our results suggest that an international coordination problem in the implementation of environmental policy might arise for both the cases that we have considered in our paper. When the country which introduces a more stringent environmental policy looses in terms of welfare—while both foreign and global welfare are increased—no country would have an incentive to pursue such policy, but what rather seek to free ride on foreign environmental reforms As a result, the world would be caught in a global environmental trap in which no country would reduce emissions. This international coordination problem can be made less severe by a reduced size of the international environmental externality, because in this case each country would gain less from environmental reforms abroad. Since such externality is likely to be smaller for countries which are geographically more distant, an implication of our analysis is that globalization (defined as increased trade with country which are geographically far) can reduce the likelihood of free-riding on the implementation of environmental reforms abroad. The international coordination problem is also likely to be less severe for smaller values of the elasticity of output to environmental quality. In this case, the foreign country would not gain much from domestic environmental reform, because an improved environmental quality would not increase foreign productivity. One policy implication of our analysis is that, to avoid this global environmental trap, international coordination of environmental policy may be necessary.

An interesting extension of our model for future research could be the introduction of a richer technological menu for production, for example by allowing for relatively "clean" and "dirty" technologies along the lines of Acemoglu et al. (2009). Studying how environmental reforms interact with traditional macroeconomic policies would also be of interest. This could include, for example, an analysis of the implications of tax and spending measures which can be used to mitigate (and/or adapt to) climate change.

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