Attitudes Toward Climate Policies in a Macrodynamic Model of the Economy*

Marwil J. Dávila-Fernández and Serena Sordi

University of Siena

Abstract

In a recent article published in this journal, Guarini and Porcile (2016) expanded the Balance-of-Payments Constraint (BoPC) growth model suggesting a way to make it possible to address some of the challenges posed by greenhouse gas emissions. Building on their set up, we formalise into the model a mechanism that explains how people with different environmental attitudes or sentiments influence each other and contribute to the design of environmental policies. We detail the concept of transition probabilities for the agent's switching from pro- to anti-environmental positions and vice-versa and discuss the macroeconomic results that follow. Numerical simulations allow us to investigate in more detail the implications of the validity of Porter's hypothesis as well as to discuss the feasibility of decoupling conditions. A policy implication of our analysis is that we should encourage the dissemination of pro-environmental attitudes among the public because this could lead to a more desirable equilibrium. As important as enhancing public knowledge of climate change is keeping alive the debate at the collective level, influencing the probability of switching sides.

1 Introduction

Given its related effects, which are very likely to be extensive and potentially devastating, it is no exaggeration to say that climate change is the principal challenge of our generation (IPCC, 2013; 2014). From a macroeconomic perspective, there is a fundamental contradiction between the way we currently organise production and the goal of environmental sustainability. On the one hand, we have the well documented positive correlation between the rate of growth of output and greenhouse gas (GHG) emissions (e.g. Itkonen, 2012; Tapia-Granados et al., 2012; Aşici, 2013; Bassetti et al., 2013). On the other hand, in order to obtain a stable rate of employment, the economy needs to expand at the same rate as the sum of labour productivity and the labour force. This means that, under current production conditions, any attempt to reduce GHG emissions threatens employment while it is not possible to pursue full-employment without increasing the pressure on natural resources.

The aforementioned relationship has received considerable attention in the literature on ecological economics and a range of alternatives have been proposed to overcome this dilemma. For instance, a low-growth or slow-growth regime has been discussed in detail by Victor (2008),

*We are grateful to Chandni Dwarkasing and James Newell for their careful reading and helpful suggestions. The usual caveats apply.

Jackson and Victor (2011), and Jackson (2016). These scholars basically proposed a reduction in working hours and structural shifts towards low productivity growth sectors as a way of breaking the link between employment and economic growth making it possible to build the foundations of a green economy.

Decoupling emerges as an obvious alternative to allow for economic growth without the corresponding increases in environmental pressure. At least some degree of decoupling has been documented in the literature (e.g. Raupach et al., 2007; Brinkley, 2014; Naqvi and Zwickl, 2017). Still, to the extent that there is little evidence in favour of absolute decoupling, a combination of moderate growth and relative decoupling appears as a conciliatory option (for a scenario analysis see, for example, Victor, 2012).

The adoption of environmental friendly policies capable of producing changes in growth regimes has been formalised in recent decades from different theoretical standpoints. Such efforts have made possible a better understanding of the interfaces and interplay between "nature's household" and "humanity's household" or, in other words, the ecosystem and the (macro)economy. Among alternative theories of growth and distribution, the perception of the production process as one in which initial conditions matter – where there is little room for substitution between factors – and the fact that instead of assuming a single rational agent one should recognise the relevance of various social actors have allowed a fruitful convergence with ecological economics (see Kronenberg, 2010; Fontana and Sawyer, 2013; 2016; Rezai et al., 2013; Taylor et al. , 2016; Kemp-Benedict, 2018; Rezai et al., 2018).

One should notice, however, that most existing contributions have been restricted to a closed economy framework. The problem is that real-world economies are open to international trade and for this reason, in several cases, to apply analytical results based on the assumption of a closed economy is simply wrong. This is true in particular with regard to the investigation of growth processes. For instance, a large body of literature has documented that the Balance-of-Payments Constraint (BoPC) stands as a powerful explanation of international growth rate differences. According to Thirlwall's law, in the long-run, countries cannot finance increasing balance-of-payments imbalances, which implies that at some point aggregate demand has to adjust, hence, constraining growth (Thirlwall, 1979; 2011).

A large empirical literature gives support to Thirlwall's law both in its aggregate and multisectoral versions (see, for example, Cimoli et al., 2010; Gouvea and Lima, 2013; Romero and McCombie, 2016; 2018). In a recent article published in this journal, Guarini and Porcile (2016, hereafter G&P) expanded the BoPC growth model suggesting a way to make it possible to address some of the challenges posed by greenhouse gas emissions allowing for the inclusion of environmental variables in the structure of this family of models. Demand and productivity regimes were modified to take into account Porter's hypothesis (PH) according to which environmental regulation can potentially foster competitiveness (Porter, 1991; Porter and van der Linde, 1995).

Even though G&P provided important insights into the interaction between the external constraint on the one hand, and ecological concerns on the other, the dynamic system proposed is extremely simple and incapable of representing the irreversibility and path dependence of economic and policy decisions concerning the environment. Furthermore, the discussion provided on public policy neither considers nor formalises the various actors that interact to form the social conventions which ultimately guide policy itself.

A number of studies have pointed out that one of the major barriers to realising a transition to a low-carbon economy lies in a lack of broad public support (e.g. Pietsch and McAllister, 2010; Wiseman et al., 2013) while it is of vital importance to change individual behaviours and lifestyles in order to make the transition to a sustainable society (see Leiserowitz et al., 2006; Steg and Vlek, 2009). Hence, attitudes or sentiments towards the environment become a crucial component to explain the adoption and effectiveness of climate change policies (Tjernström and Tietenberg, 2008; Hurst et al. 2013; Witt et al. 2014; Ratliff et al. 2017; Aasena and Vatn, 2018).

This article aims to make a contribution to the literature on macrodynamics and ecological economics by expanding G&P in order to incorporate how people with different environmental attitudes or sentiments influence each other and contribute to the design of environmental policies. Useful groundwork for setting up an elementary and rigorous sentiment dynamics can be found in Lux (1995) with applications especially in macroeconomic and stock market interactions (e.g. Franke 2012; Flaschel et al., 2018). The main novelty of our exercise consists in dividing the population between supporters and opponents of environmentally friendly policies with the composition changing endogenously over time.

We allow sentiments towards the environment to determine the stringency of green regulation and ultimately, through PH, to influence export competitiveness and labour productivity. While a deeper discussion on which types of environmental regulation are more effective or desirable goes beyond the scope of this paper, some of the macroeconomic and environmental implications are studied in more detail by means of numerical simulations which further suggest that the system exhibits sensitivity to initial conditions.

Our modelling exercise has a clear message. There are different preferences in society regarding the environment which depend on several political and cultural values that shape the views of citizens. To the extent that there is still a significant degree of asymmetric information regarding climate change, it is important to understand how agents with different attitudes interact. The sum of individual sentiments generates what we refer to as collective opinion, and the latter determines the explicit and implicit rules that influence our own beliefs. Environmental regulation depends on the design of public policies which are ultimately the result of people's attitudes and sentiments towards the environment. Porter's hypothesis corresponds to the channel that links environmental regulation to different macroeconomic outcomes.

$$\text{Sentiments} \Rightarrow \text{Environmental regulation} \Rightarrow \text{PH} \Rightarrow \text{ Macroeconomic outcomes}$$

A policy implication of our analysis is that we should encourage more education, and the greater dissemination of information and pro-environmental attitudes among the public because this could, in turn, lead to a more desirable equilibrium. Our model gives indications of how to "reach" this Pareto-superior point, by means of policies that boost the contagion of pro-environment attitudes. However, as important as enhancing public knowledge of ecology, is keeping alive the debate at the collective level, influencing the probability of switching sides. Given the complexity of the phenomenon, it is not possible to guarantee that a desirable equilibrium will necessarily be reached, but we show that the absence of a vivid and open public debate only results in inaction and the maintenance of the *status quo*.

The remainder of the paper is organized as follows. In the next section we present our theoretical model building on G&P's extension of the BoPC approach. We introduce the concept of transition probabilities for the likelihood of an agent switching from support for, to opposition to, environmentally friendly policies and vice-versa, and discuss the main macroeconomic results. Section 3 considers the analytical properties of the system. In section 4, we present a numerical simulation exercise that allows us to investigate further the implications of Porter's hypothesis as well as decoupling conditions. Some final considerations follow.

2 The model

One of the main contributions of G&P was to modify demand and productivity regimes in the BoPC growth model in order to take into account Porter's hypothesis. In two well-known articles Porter (1991) and Porter and van der Linde (1995) challenged the view that the relationship between environmental goals and industrial competitiveness involves a trade-off between social benefits and private costs. They argued that by stimulating innovation, strict environmental regulations can actually enhance competitiveness. The main principle consists in understanding pollution, and for our purposes GHG emissions, as a manifestation of economic waste that involves inefficient or incomplete utilisation of resources and highlights the opportunity costs of pollution instead of its actual costs.

The PH was initially formulated in rather general terms. As initially pointed out by Jaffe and Palmer (1997, pp. 610-611), a more systematic analysis is hindered by ambiguity as to what exactly the hypothesis is. They proceed by identifying three distinct versions. The "narrow" one states that "*certain types* of environmental regulation stimulate innovation". On the other hand, the "weak" version of the hypothesis indicates that "regulation will stimulate certain kinds of innovation". Finally, according to the "strong" version, "regulation induces innovation whose benefits exceed its costs, making the regulation socially desirable". Empirical studies have mainly found support for the narrow and weak versions of PH while evidence for the strong version is more controversial (for a recent review, see Fabrizi et al. 2018).

In this section we present a macrodynamic model built upon G&P to study the economic-environmental effects of Porter's hypothesis as well as decoupling conditions, in a context in which individuals with different opinions towards the environment interact and ultimately determine environmental policies. While we recognise that the effectiveness of green policies depends to a great extent on the specific characteristics of the instruments used, our exercise allows us to map some important channels that link the endogenous dynamics of environmental preferences to the determination of environmental policies, and finally to some key macroeconomic variables.[1] The model consists of four basic blocks of equations – (i) demand conditions, (ii) supply conditions, (iii) sentiment dynamics, and (iv) remaining behavioural relations – resulting in a three dimensional dynamic system.

2.1 Demand conditions

In an open economy with a central government, the expenditure identity is given by:

$$Y = C + I + G + X - M$$

where Y is output, C stands for consumption, I is investment, G corresponds to government expenditures, X are exports, and M represents imports. Abstracting from any price considerations, the real exchange rate is assumed to be equal to one and held constant. It is also assumed, for simplicity, that all trade consists in the exchange of final goods.

Define $A = C + I + G$ as domestic absorption. Hence, we can rewrite the expenditures identity as:

$$Y = A + X - M \tag{1}$$

[1] Different policy measures are very likely to have different impacts on competitiveness. There is a large body of literature which discusses different attributes of regulation, going from stringency to depth, incidence, flexibility, and stability vectors. For a comprehensive discussion, see Johnstone et al. (2010).

Behavioural relations constitute a single block of equations, but for expositional purposes it is useful to introduce the following traditional function for imports:

$$M = M(Y),\ M_Y > 0 \tag{2}$$

Substituting Eq. (2) in (1), taking logarithms and time derivatives, we obtain:[2]

$$\frac{\dot{Y}}{Y} = \frac{\alpha \dot{A}/A + \beta_1 \dot{X}/X}{1 + \beta_2 \pi} \tag{3}$$

where, following G&P notation, $\alpha = A/Y$ is the share of domestic absorption on income, $\beta_1 = X/Y$ corresponds to the share of exports, $\beta_2 = M/Y$ is the share of imports, and $\pi = (\partial M/\partial Y)(Y/M)$ is the income elasticity of imports which for simplicity is assumed to be constant. The expression above separates the growth rate of output into two demand components, a domestic and a foreign one.

2.2 Supply conditions

Consider the following Leontief production function:

$$Y = \min\{E/\vartheta; qNe\}$$

where recognising the biophysical basis of economic activity, E stands for energy, ϑ corresponds to the energy-output ratio, q is labour productivity, N is total labour force, and e is the employment rate. The employment rate is given by $e = L/N$, where L is the level of employment. Finally, labour productivity is defined as $q = Y/L$. We briefly depart from G&P since we explicitly include energy in the production function instead of the level of GHG emissions. The reason for this is that firms when producing use a certain amount of energy as an input while emissions are actually a secondary output.[3]

Notice that this function is in a sense an accounting identity because $Y = E\,(Y/E) = (Y/L)\,N\,(L/N)$. For a constant energy-output ratio, the Leontief dynamic efficiency condition states that:

$$\frac{\dot{Y}}{Y} = \frac{\dot{E}}{E} = \frac{\dot{q}}{q} + \frac{\dot{N}}{N} + \frac{\dot{e}}{e} \tag{4}$$

Suppose, as a simplifying hypothesis, that the size of the labour force is constant. The supply-side of the economy adjusts to the demand-side determined growth rate of output through E and e. Hence, it follows that:

$$\frac{\dot{E}}{E} = \frac{\dot{Y}}{Y} \tag{5}$$

$$\frac{\dot{e}}{e} = \frac{\dot{Y}}{Y} - \frac{\dot{q}}{q} \tag{6}$$

Energy consumption strictly follows output's growth rate, which in the model is determined by aggregate demand. The reason for this is that firms adjust their energy needs in order to match the expansion of demand. On the other hand, employment rates fundamentally depend on the difference between the growth rate of output and labour productivity. That is, if

[2] For any generic variable x, $\dot{x}$ indicates its time derivative $(\mathrm{d}x/\mathrm{d}t)$, while $\dot{x}/x$ indicates its growth rate.

[3] G&P justify the inclusion of pollutant emissions as a production factor making reference to the fact that they are "directly proportional to energy consumption, whose proportion is, for simplicity, 1:1" (p. 19).

output grows faster than the increase in the productivity of workers, employment will expand. However, if labour productivity growth rates are above the rate of growth of output, then employment will be reduced.

Even though we do not explicitly include the environment in the production function, this does not mean that no treatment of greenhouse gas emissions is provided. GHG emissions, P, are a subproduct of production and here are treated as such. Define Z as a measure of environmental efficiency. The higher Z is, the lower are emissions per unit of energy such that $P = E/Z$. Taking logarithms and time derivatives:

$$\frac{\dot{P}}{P} = \frac{\dot{E}}{E} - \frac{\dot{Z}}{Z} \tag{7}$$

which by means of Eq. (5) is equivalent to:

$$\frac{\dot{P}}{P} = \frac{\dot{Y}}{Y} - \frac{\dot{Z}}{Z} \tag{8}$$

In this way, we correctly recover G&P expression for the relation between the growth rates of pollutant emissions, output, and environmental efficiency. We will come to this last expression later to evaluate decoupled conditions.

2.3 Sentiment dynamics

Lux (1995) formalised a mechanism of mutual mimetic contagion in speculative markets that has been intensively used to assess macroeconomic and stock market interactions (e.g. Franke, 2012; Flaschel et al., 2018). The main idea is that traders who do not have access to information about the fundamentals of the economy necessarily have to rely on what can be observed in the markets to take decisions concerning their actions. Without entering into the issue of what kinds of behaviour can be designated as rational, he considers that following others' opinions is not necessarily irrational. For example, a speculator will be more willing to sell if s/he sees most traders selling. On the other hand, with a high proportion of optimistic traders, it will be very probable that the few remaining pessimistic ones will change their attitude and buy.

A similar reasoning can be applied to ecological thinking. As briefly discussed in the introduction to this paper, one of the major barriers to realising the transition to a low-carbon economy lies in a lack of broad public support (see Pietsch and McAllister, 2010; Wiseman et al., 2013). People disagree on their degree of support for environmental policies for different reasons. An immediate one could simply be the fact that changes in consolidated individual or collective behaviours and lifestyles are not an easy task. This is particularly threatening given that a transition to a sustainable society depends on these changes (Leiserowitz et al., 2006; Steg and Vlek, 2009).

The literature on environmental psychology has documented the existence of a relationship between environmental behaviours or attitudes and materialistic values (e.g. Kaiser and Byrka, 2011; Kasser, 2011; Hurst et al., 2013). Individuals pursuing intrinsic goals such as community well-being and close family relationships have been found to be more likely to engage in less harmful environmental behaviour in contrast with those who pursue fame or financial success. Attitudes towards the environment probably depend as much on education, access to information, and specific interests of firms in certain industries as on cultural values related to materialism or solidarity. Whether or not preferences depend on society being more or less materialistic, there is considerable evidence pointing to the influence of political views on environmentally friendly attitudes and sentiments (Drews and van der Bergh, 2016; McCright et al. , 2016; Aasena and Vatn, 2018) which ultimately impact the adoption of climate change policies as shown by Tjernström and Tietenberg (2008).

To the extent that there is still a significant degree of asymmetric information regarding climate change and people have different views about the environment, it is important to understand how they interact. The sum of individual sentiments and attitudes generates what we refer to as collective opinion, and the latter determines the explicit and implicit rules that influence our own beliefs. It is reasonable to suppose that with a high proportion of people with pro-environment attitudes or sentiments, those with the opposing attitudes or sentiments will be likely to change their views. A simple domestic example, though not directly related to GHG, is selective waste collection. If everybody in the neighbourhood does it, new tenants are more likely to do so. On the other hand, a high proportion of people with materialist values make it more likely that those who are initially pro-environment change their positions or at least start to adopt less environmentally-friendly attitudes.

Suppose the population equals the labour force and is divided between those who have environmentally friendly, N^+, and non-environmentally friendly, N^-, attitudes:

$$N = N^+ + N^-$$

while the difference between these two groups, n, can be written as:

$$n = N^+ - N^-$$

Defining:

$$\Phi = \frac{n}{N} = \frac{N^+ - N^-}{N^+ + N^-} \tag{9}$$

we have that $\Phi \in [-1, 1]$ is an index describing the average sentiment of the population towards environmental issues. If all citizens of this society are pro-environment, then $\Phi = 1$. At the other extreme, a complete prevalence of materialistic values delivers $\Phi = -1$. For an equal division of the population between these two groups we have $\Phi = 0$.

Recall that as a simplifying hypothesis we are assuming that the labour force and population do not change over time, i.e. $\dot{N}/N = 0$. Taking time derivatives of Eq. (9) and making use of the respective definitions, we have that:

$$\dot{\Phi} = \frac{\dot{n}}{N} = \frac{\dot{N}^+ - \dot{N}^-}{N^+ + N^-} \tag{10}$$

For a constant N, changes in the sentiments index fundamentally depend on the difference between variations in the two groups that form the population. Hence, we need to specify the behaviour of $\dot{N}^+$ and $\dot{N}^-$ taking into account that people might change their own views on the topic. In mathematical terms we write:

$$\dot{N}^+ = N^- p^{-+} - N^+ p^{+-} \tag{11}$$

$$\dot{N}^- = N^+ p^{+-} - N^- p^{-+} \tag{12}$$

where p^{-+} is the probability of someone who is opposed to environmentally-friendly policies changing their mind and p^{+-} stands for the probability of the opposite case.

Following the discussion provided in the beginning of this subsection, p^{-+} and p^{+-} depend on the distribution of the population between the two groups. The higher the share of pro-environment citizens in the economy the higher the probability of someone with the opposing attitudes changing her/his views. Similar reasoning in the opposite direction applies. Therefore, consider:

$$p^{-+} = v^{+}(\Phi),\ v^{+}_{\Phi} > 0 \tag{13}$$

$$p^{+-} = v^{-}(\Phi),\ v^{-}_{\Phi} < 0 \tag{14}$$

with $v^{+}(\cdot)$ and $v^{-}(\cdot)$ standing as the probability functions of an agent coming to favour or to oppose environmental friendly policies, respectively.

Some scholars have argued that there might be feedback from macroeconomic conditions to public support for environmental measures (see, for example, the literature reviewed by Hurst et al., 2013). In fact, it is reasonable to assume that during an economic crisis, when employment rates are low, people care less about issues such as climate change. Facing more urgent survival decisions, environmental concerns become secondary.[4] There can also be feedback from climate change: a worsening of environmental conditions can influence sentiments in favour of green policies. In any case, we do not tackle these issues here as they go beyond the scope of the paper. If we have managed to convince the reader of the importance of the mechanism so far described, then future research should be done to incorporate additional interaction channels.

Substitute Eqs. (13) and (14) in (11) and (12) so that changes in $\dot{N}^{+}$ and $\dot{N}^{-}$ are a function of the sentiments index. Further inserting the resulting expressions in (10) and making use of the definitions of N and n, we obtain the dynamic relation that governs sentiment dynamics towards the environment:

$$\dot{\Phi} = (1 - \Phi)\, v^{+}(\Phi) - (1 + \Phi)\, v^{-}(\Phi) = \theta\,(\Phi) \tag{15}$$

where $\theta_{\Phi} \gtreqless 0$. Given that the G&P model was formulated under the assumption of a small open economy, the sentiments described in our article refer to the people in the domestic economy. When presenting the remaining behavioural relations, we will show how Φ is related to environmental regulation.

2.4 Remaining behavioural relations

As mentioned several times throughout the article, one of the main contributions of G&P was to modify demand and productivity regimes in the BoPC growth model in order to take into account Porter's hypothesis according to which strict environmental regulations can actually enhance competitiveness by stimulating innovation. Empirical evidence on the topic is ambiguous. There is some evidence of a positive impact of environmental regulation on innovation activity and export performance though the same cannot be said about productivity growth (Lanoie et al., 2011; Costantini and Mazzanti, 2012; Rubashkina et al.,2015; for a review, see Ambec et al., 2013). Empirical studies have found evidence mainly for the "narrow" and "weak" versions of PH while support for the "strong" version is more controversial (e.g. Fabrizi et al. 2018). Still, the literature is far from exhibiting consensus.

In what follows and in line with G&P, we present the remaining behavioural relations necessary to close the model. Even though we recognise the absence of a consensus regarding Porter's hypothesis, we adopt a friendly position towards it.

[4] Such line of argument has some similarities with the so called "basic needs hierarchy" according to which humans only begin to pursue other goals once basic physiological needs, such as physical safety and access to food, have been taken care of. Over the past decade, this assumption has been subject to much debate and not much less criticism (for a discussion, see Tjernström and Tietenberg, 2008).

2.4.1 Exports function

Porter's hypothesis is investigated by adopting export and labour productivity growth functions that are non-neutral to environmental regulations. Strictly in accordance with G&P, we consider the following function of exports:

$$X = X(Y^*, Z),\ X_{Y^*} > 0,\ X_Z > 0 \tag{16}$$

where Y^* corresponds to World Gross Domestic Product (GDP).

Taking logarithms and time derivatives, we have:

$$\frac{\dot{X}}{X} = \varepsilon \frac{\dot{Y}^*}{Y^*} + \xi \frac{\dot{Z}}{Z} \tag{17}$$

where $(\partial X/\partial Y^*)(Y^*/X) = \varepsilon$ is the income elasticity of exports and $(\partial X/\partial Z)(Z/X) = \xi$ stands as a "green elasticity" parameter.

Furthermore, we also make the following assumption about the dynamics of Z:

$$\frac{\dot{Z}}{Z} = F(\lambda),\ F_\lambda \geq 0 \tag{18}$$

with λ standing as a measure or an index of the stringency of environmental regulations. The effect of λ on $\dot{Z}/Z$ is dubious depending on the validity of Porter's hypothesis. While we avoid a deeper discussion on which types of environmental regulation are more effective or desirable, the main idea is that more stringent regulation – or how ambitious is the policy target – the greater the gains in terms of environmental efficiency. In this way, public policy produces changes along curve $F(\cdot)$. The adoption of green practices that enhance competitiveness which do not necessarily derive from environmental regulation leads to shifts in in the curve (for an investigation on "whether it pays to be green" see Antonietti and Marzucchi, 2014; Zeriti et al. , 2014).

It is important to notice that we are introducing an important modification in relation to G&P, who defined λ as the share of environmental spending in public investment. While the original interpretation of this variable has a sound motivation, it does not make clear reference to Porter's hypothesis, which is one of the goals of our article. On the contrary, by describing λ as a measure of stringency, we have a clear channel going from regulations to environmental efficiency, and from there to export competitiveness.

2.4.2 Environmental policy

Considering the empirical evidence revisited by pointing out that environmental policy depends on environmentally friendly attitudes and the sentiments of individuals, consider:

$$\lambda = \lambda(\Phi),\ \lambda_\Phi > 0,\ \lambda(0) = 0 \tag{19}$$

Environmental regulation depends on the design of public policies which are ultimately the result of people's attitudes and sentiments towards the environment. Function $\lambda(\cdot)$ is supposed to represent how sentiments are translated in terms of regulation and more specifically how they are mapped onto our index of stringency regulation.

In reality, this relationship is likely to be highly nonlinear and we are running the risk of oversimplifying a crucial step in our model exercise. For instance, we do not make any differentiation between market-based and more direct forms of regulation. Neither do we go into detail on relevant attributes of regulation, such as predictability, flexibility, incidence, depth, etc. (see Johnstone et al. 2010). This does not mean that we do not acknowledge the importance of these aspects. However, for the purposes of our paper, we propose a simple specification that aims to map attitudes towards the environment into a continuous spectrum of environmental regulation. The latter can be changed only if the composition of the population is no longer the same.

The main idea is the following. If the majority of the population favours environmentally friendly policies, $\Phi > 0$, then policy makers will adopt green policies such that $\lambda > 0$. Still, a society in which 51% of individuals have pro-environmental attitudes does not produce the same set of regulations as one in which 95% do. Hence, it follows that stringency increases in Φ, i.e. $\lambda_\Phi > 0$. On the other hand, if most citizens engage in harmful environmental behaviour, $\Phi < 0$, policy makers will reproduce this characteristic and adopt a regulation framework that reflects the desires of this society, $\lambda < 0$. Since the sentiment index is such that $\Phi \in [-1, 1]$, an equal distribution of citizens between those for and against environmentally friendly policies, $\Phi = 0$, is supposed to produce no environmental policy at all, $\lambda(0) = 0$, because neither group is strong enough to enforce its position.

2.4.3 Aggregate demand adjustment

A balanced current account requires that exports and imports grow at the same rate. Recall that from Eq. (2) we have $\dot{M}/M = \pi\dot{Y}/Y$. Hence, making use of Eqs. (17) and (18), the growth rate of output that guarantees equilibrium in the balance-of-payments, y_{bp}, is given by:

$$y_{bp} = \frac{\varepsilon\dot{Y}^*/Y^* + \xi F(\lambda)}{\pi} \tag{20}$$

that is, an extended environmental version of Thirlwall's law. For developing economies, convergence strongly depends on the ratio between income elasticities, ε/π, which in turn depends on the patterns of specialisation of the productive structure (see Thirlwall, 2011; Dávila-Fernández et al., 2018).

According to G&P, the growth rate of output adjusts to the external constraint through expansionary-contractionary fiscal policy which curbs domestic absorption towards the BoPC rate of growth. We proceed by adopting the same behavioural rule. When there is a current account deficit because the economy is growing too fast, i.e. $\dot{Y}/Y > y_{bp}$, the government adopts contractionary fiscal policy to correct the external deficit. The reason for this is that there is a perception that a crisis will occur at some point in the near future if the government fails to reduce the growth of imports. G&P make reference to outflows of foreign capital and instability in the currency markets that go hand in hand with this perception. Furthermore, given the existence of crowding in effects, a reduction in government expenditures, it is argued, may also induce a similar reduction of private expenditure. Conversely, for $\dot{Y}/Y < y_{bp}$, a current account surplus permits the government to adopt a more expansionary fiscal policy.

In order to simplify notation, define $a = \dot{A}/A$ as the growth rate of domestic absorption. Therefore, the adjustment of aggregate demand follows:

$$\dot{a} = \psi\left(y_{bp} - \frac{\dot{Y}}{Y}\right) \tag{21}$$

where $\psi > 0$ is a parameter that captures the speed of adjustment of output to the external constraint.

Substituting Eq. (18) in (17), and the result in (3) we obtain the rate of growth of output as a function of domestic absorption and changes in environmental regulation:

$$\frac{\dot{Y}}{Y} = \frac{\alpha a + \beta_1 \left[\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda)\right]}{1 + \beta_2 \pi} \tag{22}$$

A quick look at the macroeconomic data shows that in general $\beta_1 \approx \beta_2$ (e.g. Razmi, 2016). Hence, substituting Eqs. (20) and (22) in Eq. (21), and assuming as a simplification hypothesis that $\beta_1 = \beta_2$, we have that:

$$\dot{a} = \psi \left[\frac{\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda) - \alpha \pi a}{\pi \left(1 + \beta_2 \pi\right)}\right] \tag{23}$$

Through PH, stronger environmental regulation reduces emissions per unit of energy increasing the competitiveness of exports and, therefore, the BoPC growth rate. This is turn leaves space for a higher growth rate of domestic absorption without incurring current account deficits.

2.4.4 Labour productivity growth

We allow environmental regulation to affect $\dot{q}/q$. Furthermore, alternative theories of growth and distribution have extensively explored the relationship between factor productivity growth and cost-shares. For instance, the wage-share of income is a measure of the cost of labour weighted by its productivity and, as such, can potentially affect the growth rate of labour productivity. This is because firms facing higher labour costs have incentives to adopt labour saving production techniques (Hicks, 1932; Duménil and Levy, 1995; Acemoglu, 2003; Hein and Tarassow, 2010).

In this model, we are abstracting from income distribution considerations but we can still take into account the aforementioned relationship through employment rates. The reason for this is that as the labour market tightens and the labour shortage becomes clearer, there is an increase in the bargaining power of workers which allows them to obtain higher real wages, finally leading profit maximising firms to adopt production techniques that are more labour-saving (see, for example, Sasaki, 2013; for a review of the literature, see Tavani and Zamparelli, 2017).

Hence, we make:

$$\frac{\dot{q}}{q} = G(\lambda, e), \; G_\lambda \gtreqless 0, \; G_e > 0 \tag{24}$$

where it is assumed that λ may or may not affect the growth rate of labour productivity.

In G&P, the growth of labour productivity was supposed to depend negatively on λ because in their model this variable stood as the share of environmental spending in public investment. Given that an increase in λ would imply that fewer public resources are devoted to labour-saving technical change, they make $G_\lambda < 0$. In our model, on the contrary, the impact of environmental regulations on labour productivity is not clear. On the one hand, one could argue that if more stringent environmental regulations increase firms' competitiveness overall, at some point this should also be reflected in labour productivity. On the other hand, the reader might wonder if it would be possible that a strong emphasis on reducing GHG emissions could actually reduce the rate of innovation aimed at increasing labour productivity, while fostering energy-saving innovations, for example.

Given the lack of a consensus in the empirical literature on how productivity responds to more stringent environmental regulation, we allow $G_\lambda \gtreqless 0$. We will return to this point when investigating the existence of multiple equilibrium points and the stability properties of the model.

2.5 Dynamic system

Our dynamic system consists of three differential equations in the employment rate, domestic absorption, and sentiments or attitudes towards the environment. Substituting Eqs. (19), (22), and (24) in (6), we obtain the behaviour of employment rates. The dynamic equations for domestic absorption and sentiment towards the environment were already reported in (23) and (15), respectively, and are rewritten here.

$$\begin{aligned} \frac{\dot{e}}{e} &= \frac{\alpha a + \beta_1 \left[\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda(\Phi))\right]}{1+\beta_2 \pi} - G\left(\lambda(\Phi), e\right) \\ \dot{a} &= \psi \left[\frac{\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda(\Phi)) - \alpha \pi a}{\pi\left(1+\beta_2\pi\right)}\right] \\ \dot{\Phi} &= \theta\left(\Phi\right) \end{aligned} \tag{25}$$

Notice that function $\theta(\cdot)$ is highly non-linear which leaves the door open to the existence of multiple non-trivial equilibria. This is particularly interesting for the literature on ecological economics because it indicates the complexity of ecological problems and the possibility of path dependence. In order to provide a more concrete view of its structure and properties, we define functional forms for p^{-+} and p^{+-} following Lux (1995) and Franke (2012). The properties of the resulting expression for sentiment dynamics have been extensively studied and provide solid ground on which to stand. Hence, suppose:

$$p^{-+} = \zeta \exp\left(\mu\Phi\right) \tag{26}$$

$$p^{+-} = \zeta \exp\left(-\mu\Phi\right) \tag{27}$$

where $\zeta > 0$ captures the speed of change, and $\mu > 0$ is a measure of the "strength of infection" or "herd behaviour". This last parameter is particularly important for the existence of a unique equilibrium value or multiple equilibria values as we will show in the next section.

It is important to emphasise the economic content behind μ. As previously discussed, several studies have suggested that one of the major barriers to the adoption of a green policy agenda lies in a lack of broad public support. Parameter μ captures, in a way, how strongly climate change has been debated at the collective level, influencing the probability of switching sides. In the next section, we will demonstrate that a low μ leads to a consensus of inaction. Infection of a certain minimum strenght is necessary in order to move on and adopt a policy agenda regarding climate change, an agenda that might or might not be a pro-environmental one.

Substituting Eqs. (26) and (27) in (15) we can rewrite the dynamic system (25) as:

$$\begin{aligned}
\frac{\dot{e}}{e} &= \frac{\alpha a + \beta_1 \left[\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda(\Phi))\right]}{1+\beta_2 \pi} - G\left(\lambda(\Phi), e\right) \\
\dot{a} &= \psi \left[\frac{\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda(\Phi)) - \alpha \pi a}{\pi\left(1+\beta_2 \pi\right)}\right] \\
\dot{\Phi} &= \zeta \left[(1-\Phi)\exp\left(\mu\Phi\right) - (1+\Phi)\exp\left(-\mu\Phi\right)\right]
\end{aligned} \tag{28}$$

The system depicts the dynamics of environmental sentiments which interact with the macroeconomy through employment rates and domestic absorption.

3 Local stability analysis

In steady-state $\dot{e}/e = \dot{a} = \dot{\Phi} = 0$. This gives us the following equilibrium conditions:

$$\begin{aligned}
\frac{\alpha a + \beta_1 \left[\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda(\Phi))\right]}{1+\beta_2 \pi} &= G\left(\lambda(\Phi), e\right) \\
\varepsilon \frac{\dot{Y}^*}{Y^*} + \xi F(\lambda(\Phi)) &= \alpha \pi a \\
(1-\Phi)\exp\left(\mu\Phi\right) &= (1+\Phi)\exp\left(-\mu\Phi\right)
\end{aligned} \tag{29}$$

The growth rate of aggregate demand – given by the rate of growth of domestic absorption and exports – must equal the natural rate of growth – which in this case is simple labour productivity growth – to deliver a stable employment rate. Furthermore, GDP growth rates follow the external constraint which requires that the growth rate of domestic absorption weighted by the income elasticity of imports equals the rate of growth of exports. Finally, the sentiment index towards the environment can only stabilise when the probabilities of changing between groups equilibrate.

Given the equilibrium conditions (29), we can state and prove the following propositions regarding the existence and uniqueness of an internal equilibrium.

Proposition 1 *If the "strength of infection" regarding sentiments towards the environment is weak enough, i.e.* $\mu \leq 1$*, the dynamic system has a unique non-trivial equilibrium solution that satisfies:*

$$\begin{aligned}
y_{bp}^E &= G\left(0, e^E\right) \\
a^E &= \frac{y_{bp}^E}{\alpha} \\
\Phi^E &= 0
\end{aligned}$$

where for any variable x*,* x^E *indicates its equilibrium value and* $y_{bp}^E = \left[\varepsilon \dot{Y}^*/Y^* + \xi F\left(\lambda(\Phi^E)\right)\right]/\pi$ *corresponds to the steady-state "green version" of Thirlwall's law.*

Proof. See Mathematical Appendix. ■

That is, if there is little interaction among citizens and the individual's opinions about the environment do not depend on what most people think about the subject, $\mu \leq 1$, we should expect an equal distribution between those who support environmentally friendly policies and those who do not. In this context, it makes little sense to refer to Porter's hypothesis, at least as far as the determination of equilibrium values is concerned. This is because an equal distribution between N^+ and N^- produces no response in terms of environmental policy, $\lambda(0) = 0$. We are addressing Porter's hypothesis by looking at the impact of environmental policy on (i) export competitiveness through GHG emissions efficiency, F_λ and (ii) through the direct impact on labour productivity, G_λ. However, for the determination of equilibrium, it does not matter if F_λ or G_λ have values other than zero because society is not able to produce any kind of environmental policy in the first place.

The determination of equilibrium follows a sequence that goes from sentiments to the macroeconomy. Once the distribution of the population between those for and against environmentally friendly policies is determined, the growth rate of exports stabilises. This allows the government to adjust fiscal policy in order to make the growth rate of domestic absorption, a, match the external constraint. Finally, the employment rate adjusts so as to guarantee that (Harrod's) natural growth rate equalises Thirlwall's law.

$$\Phi^E \Rightarrow a^E \Rightarrow e^E$$

When collective sentiments do matter for how the individual feels and behaves in relation to the environment, there is a qualitative change in the nature of the system that now exhibits multiple equilibria, as stated in the following proposition.

Proposition 2 *If the "strength of infection" regarding sentiments towards the environment is strong enough, i.e.* $\mu > 1$*, the dynamic system has two additional non-trivial equilibrium solutions,* $\Phi^{E_1} > 0$ *and* $\Phi^{E_2} < 0$*, that satisfy:*

$$\begin{aligned} y_{bp}^E &= G\left(\lambda(\Phi^{E_i}), e^{E_i}\right) \\ a^{E_i} &= \frac{y_{bp}^{E_i}}{\alpha} \\ \left(1 - \Phi^{E_i}\right)\exp(\mu\Phi^{E_i}) &= \left(1 + \Phi^{E_i}\right)\exp(-\mu\Phi^{E_i}) \end{aligned}$$

where $i = [1, 2]$ *stands for each additional equilibrium solution.*

Proof. See Mathematical Appendix. ■

In the case in which the individual's position is strongly influenced by the social context, there is a stronger interaction between macroeconomic variables and environmental attitudes that can lead the economy to new equilibrium situations. For each of them it makes sense to refer to Porter's hypothesis since $\Phi \neq 0$ implies $\lambda \neq 0$. Three main macroeconomic variables are affected by environmental regulation, namely, the growth rate of output, the growth rate of labour productivity, and the employment rate. With regard to the first two, the effects are straightforward given that there is a positive relationship between the "green version" of Thirlwall's law, labour productivity and $\lambda(\Phi)$. In simple terms, $\Phi^{E_1} > 0$ corresponds to the equilibrium with higher output and productivity growth.

Looking to equilibrium employment rates, however, the final effect is undetermined. This is already obvious from Eq. (6) from which we have $\dot{e}/e = \dot{Y}/Y - \dot{q}/q$. It will pay to be green also in terms of employment if and only if $\partial y_{bp}/\partial\Phi > \partial\left(\dot{q}/q\right)/\partial\Phi$. If we assume higher environmental regulation is associated with higher labour productivity growth, $G_\lambda > 0$, then technical change is creating unemployment. Hence, we will have higher employment only if the same regulation is capable of increasing external competitiveness in a such a way that increases in the rate of growth of output more than compensates the first effect. On the other hand, if a strong emphasis on reducing GHG emissions actually reduces the rate of innovation aimed at increasing labour productivity, $G_\lambda < 0$, we will obtain an unequivocally higher equilibrium rate of employment. This tells us something about the nature of technical change and how regulations can affect the choice of production technique by the firm.

Concentrating on the dynamic equation of environmental sentiments it is easy to see that for $\mu \leq 1$ then $\theta_\Phi(0, e^E) < 0$. On the other hand, for $\mu > 1$ we have (i) $\theta_\Phi(0, e^E) > 0$ while (ii) $\theta_\Phi(\Phi^{E_i}, e^{E_i}) < 0$. Hence, we are able to state and prove the following propositions regarding the local stability of equilibria.

Proposition 3 *When the "strength of infection" regarding sentiments towards the environment is weak enough, i.e.* $\mu \leq 1$*, the unique internal equilibrium point of the dynamic system is locally stable.*

Proof. See Mathematical Appendix. ■

In a situation in which the interaction between citizens with different opinions on environmental policy is low, there is a balance between the two population groups that results in no environmental regulations at all. This equilibrium is always stable and society basically ignores climate change because it is unable to produce environmental policies in the first place. Things will continue the way they are and the economy will be negatively affected by the ecosystem degradation caused by the accumulation of GHG emissions. The story changes if there is sufficient interaction between environmental sentiments and attitudes.

Proposition 4 *When the "strength of infection" regarding sentiments towards the environment is strong enough, i.e.* $\mu > 1$*, the internal equilibrium solution with an equal distribution between sentiments for and against environmentally-friendly policies is locally unstable.*

Proof. See Mathematical Appendix. ■

Proposition 5 *When the "strength of infection" regarding sentiments towards the environment is strong enough, i.e.* $\mu > 1$*, the two additional non-trivial equilibrium solutions with* $\Phi^{E_1} > 0$ *and* $\Phi^{E_2} < 0$ *are locally stable.*

Proof. See Mathematical Appendix. ■

These last two propositions indicate that, for $\mu > 1$, being indifferent towards the environment is not an option anymore. The intensity of interactions is such that society converges either to a situation in which the majority of the population adopts environmentally-friendly attitudes or becomes openly hostile to them. Both cases are stable and initial conditions become crucial for understanding different trajectories. One could think of the United States as a textbook example of a more materialistic society with a more aggressive posture towards the environment while Europe has historically lead international pro-environment efforts. While attitudes towards the environment are very likely to depend on other variables beyond the materialistic story, the main point is that, once we allow preferences to be influenced by collective behaviour, our model is capable of generating different levels of polarisation.

At this point it is important to notice that $G_\lambda \gtreqless 0$ is not crucial for the local stability properties of the model. Hence, for $G_\lambda < 0$, propositions 3-5 remain the same. As previously pointed out, the only difference concerns the determination of equilibrium employment rates. Since for $G_\lambda < 0$ we have $\partial\left(\dot{q}/q\right)/\partial\Phi < 0$, in that case, environmental regulation always delivers higher steady-state employment. In other words, it always pays to be green.

4 Numerical simulations

We are ready to perform a numerical exercise to evaluate some of the possible macroeconomic effects of Porter's hypothesis. For this purpose, we need to define functional forms for $F(\cdot)$, $G(\cdot)$, and $\lambda(\cdot)$. Our chosen specifications are linear so as to keep the exercise as simple as possible and to emphasise that the dynamics obtained do not rely on specific non-linearities in the behavioural relations, with the exception of the very natural non-linearity in the switching process already introduced.

$$\begin{aligned} F(\lambda) &= f\lambda \\ G(\lambda, \varpi) &= g_1\lambda + g_2 e \\ \lambda(\Phi) &= \Phi \end{aligned} \tag{30}$$

where f , g_1, and g_2 are positive structural parameters. Also notice that environmental regulation simply reflects attitudes or sentiments of the population towards the environment.

The main result presented in the analytical part of this paper was that depending on the "strength of infection" regarding sentiments towards the environment, we might have a unique stable equilibrium in which the population is equally divided between those for and against environmentally friendly policies, or multiple equilibria with the majority of the population supporting environmental regulation or opposing this kind of intervention. In this section, we further investigate the properties of this outcome.

In order to choose plausible parameter values, we have considered the evidence provided in a number of empirical studies and well-known macroeconomic regularities. Our representative economy is significantly open to international trade while maintaining a certain equilibrium between exports and imports, such that $\alpha = 1$ and $\beta_1 + \beta_2 = 1$. These numbers are reasonable if we consider that in 2018, according to the Organisation for Economic Co-operation and Development (OECD), the ratio of total trade to GDP was around 0.6 in France, Spain, and United Kingdom; 0.85 in Germany; 1 in Denmark and Sweden; getting closer to 2 in Hungary, Belgium and Slovak Republic. Our estimates of foreign trade income elasticities, ε and π, come from Dávila-Fernández and Sordi (2018) which also provide data on $\dot{Y}^*/Y^*$. The response of labour productivity to changes in employment rates follows the magnitudes estimated by Hein and Tarassow (2010). Finally, with regard to the remaining parameters, given the absence of a consensus in the literature regarding the validity of PH, we adopted sufficiently low values so as to provide trajectories with economic meaning (for a recent estimation of different versions of Porter's hypothesis, see Fabrizi et al. 2018).

$$\begin{aligned} \alpha &= 1,\ \beta_1 = 0.5,\ \beta_2 = 0.5,\ \varepsilon = 1.25,\ \dot{Y}^*/Y^* = 0.03,\ \xi = 0.15 \\ \pi &= 1.5,\ \psi = 0.5,\ \zeta = 0.1,\ f = 0.1,\ g_1 = 0.0075,\ g_2 = 0.0275 \end{aligned}$$

The crucial parameter μ is supposed to capture the "strength of infection" of the switching process between environmental sentiments or attitudes. For $\mu \leq 1$ we have simple convergence to the unique equilibrium solution. This equilibrium is stable and society ignores climate change because it is unable to produce environmental policies in the first place. Setting $\mu > 1$ corresponds to the case with multiple equilibria and is more interesting for several reasons. First, because it corresponds to a representation of the statement "history matters". Different initial conditions can potentially lead to very different equilibrium points. Secondly, because a sufficiently high μ indicates that people do care about other people's opinions on environmental issues and there is an interaction between individual and collective beliefs with one influencing the other. Last but not least, we have that environmental sentiments and attitudes have important macroeconomic implications that may or may not be desirable.

Hence, in what follows we adopt $\mu = 1.1$. Fig. 1 depicts trajectories for different initial conditions that indicate convergence to two different equilibrium points, $(e^{E_1}, a^{E_1}, \Phi^{E_1}) = (0.95, 0.03, 0.5)$ and $(e^{E_2}, a^{E_2}, \Phi^{E_2}) = (0.86, 0.02, -0.5)$, the first one with the majority of the population being in favour of pro-environment governmental intervention (in green), and the other against these kinds of policies (in red). Given that in both cases the macroeconomy is non-neutral to Φ, we also have different equilibrium values for employment rates and output growth. In the scenarios reported it always pays to be green, both in terms of employment and growth.

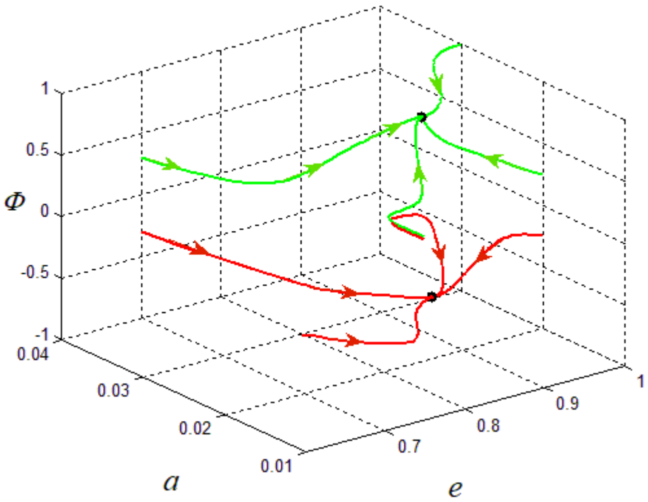


Figure 1: Multiple equilibria when $\mu = 1.1$. Green (red) trajectories indicate convergence to the high (low) growth equilibrium point.

Furthermore, fixing initial conditions of environmental sentiments, $\Phi_0 = 0$, we identify a "corridor of stability" with trajectories converging to $(e^E, a^E, \Phi^E) = (0.91, 0.025, 0)$. We would like to emphasise that any small deviation from $\Phi = 0$ immediately falls into one of the cases previously discussed. The mathematical properties of such corridor are interesting but go beyond the scope of this article. This is mainly because a case in which changes in the micro level are always balanced at the macro level in a 1:1 proportion is extremely unlikely to happen in reality. Still, we report in Fig. 2 the trajectories for a set of different initial conditions with $\Phi_0 = 0$ showing the dynamics briefly discussed.

4.1 A note on decoupling conditions

With these results in mind we can also mention some considerations on decoupling conditions. G&P showed that, once we incorporate Porter's hypothesis into the BoPC framework, a policy that aims at decreasing GHG emissions can be potentially harmful to the environment in a sort of macroeconomic rebound effect. Substitute the extended environmental version of Thirlwall's law, see Eq. (20), and (18) in (8). This gives us:

$$\frac{\dot{P}}{P} = \frac{\varepsilon \dot{Y}^*/Y^* + \xi F(\lambda)}{\pi} - F(\lambda) \tag{31}$$

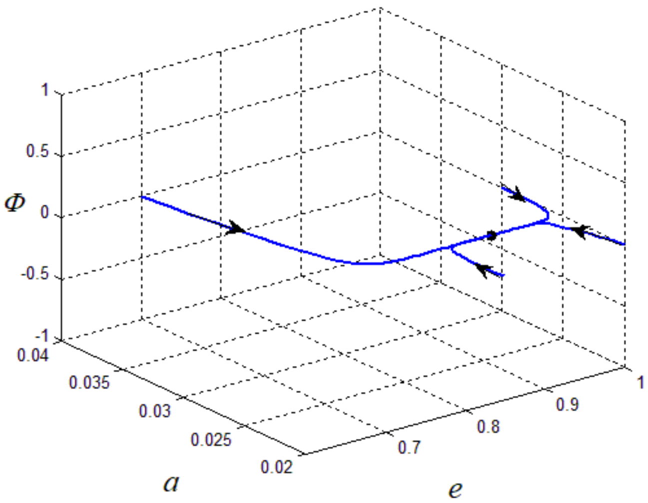


Figure 2: Corridor of stability when $\mu = 1.1$ and $\Phi_0 = 0$. Changes in sentiments at the micro level are balanced at the macro level in a 1:1 proportion.

Derivating (31) with respect to environment regulation, λ, we have that the validity of Porter's hypothesis does not generate a rebound effect as long as:

$$\xi < \pi$$

which is easily satisfied since empirical evidence suggests $\pi > 1$ (see, for example, Romero and McCombie, 2016; Dávila-Fernández and Sordi, 2018) and ξ is relatively close to zero.

This result already discussed in G&P, however, here comes with an extra dimension. Recall that λ is a function of Φ. *Ceteris paribus*, societies that are against environmentally friendly policies, $\Phi < 0$, will present less growth but much lower environmental efficiency. Since $\xi < \pi$ is likely to be satisfied, in this case, the growth rate of emissions will be significantly higher. In the numerical example presented in this section we have that, in steady-state, for $\Phi^{E_1} = 0.5 \Rightarrow \dot{P}/P = -0.02$ while for $\Phi^{E_2} = -0.5 \Rightarrow \dot{P}/P = 0.07$. Therefore, Porter's hypothesis can potentially increase the growth rate of output while reducing the growth rate of GHG emissions.

Fig. 3 plots the differences in trajectories of GHG emission levels and growth rates for the initial conditions $(e_0, a_0, \Phi_0) = (0.85, 0.02, 0.01)$ in green and $(e_0, a_0, \Phi_0) = (0.85, 0.02, -0.01)$ in red. In the first case, diagrams (a) and (c), we have that an initially positive growth rate of GHG emissions leads to an increase in pollution up to a certain point when environmental regulation effectively turns $\dot{P}/P < 0$ resulting in a reduction in P. In the second case, diagrams (b) and (d), society converges to an equilibrium in which the majority of the population is against environmental regulation. Hence, the government actually adopts policies that are harmful to the environment resulting in an acceleration of emissions.

Finally, we can go further and determine the conditions for absolute decoupling, that is, for obtaining $\dot{P}/P < 0$ with $\dot{Y}/Y > 0$. From Eq. (31) we have that this will be the case as long as:

$$\lambda > F^{-1}\left(\frac{\varepsilon \dot{Y}^*/Y^*}{\pi - \xi}\right)$$

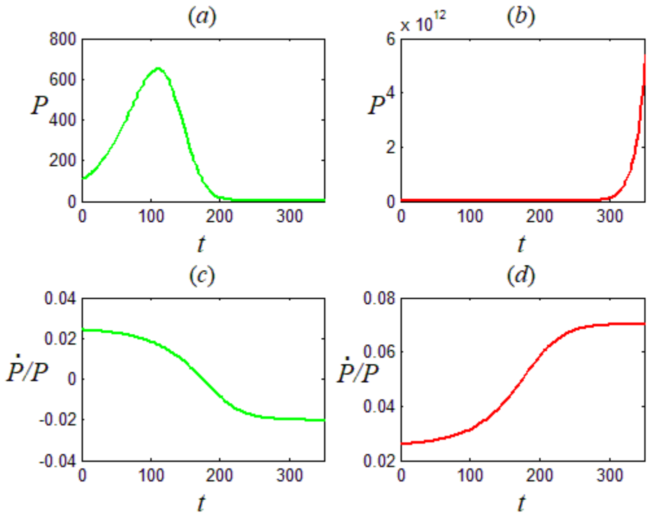


Figure 3: GHG emission levels and growth rates. Green (red) trajectories correspond to the "good" ("bad") equilibrium point.

How likely this inequality is to be satisfied is something to be investigated empirically. At least some degree of decoupling has been documented in the literature (see, for example, Raupach et al. 2007; Brinkey, 2014; Naqvi and Zwickl, 2017). However, there is little evidence pointing to absolute decoupling. Our numerical simulations suggest it is feasible. Still, two important remarks follow.

The first one concerns how much support the "climate change cause" needs in order to result in the adopttion of sufficiently stringent regulations capable of generating absolute decoupling. Recall that $\Phi \in [-1, 1]$. If all citizens are pro-environment, then $\Phi = 1$, while a complete prevalence of anti-environment sentiments delivers $\Phi = -1$. Under the parametrisation proposed in this section, we need that $\Phi > 0.27$ for getting at some point in time $\dot{P}/P < 0$. This means that at least 65% of the population has to support green policies. Further research on the topic is certainly needed, but our numerical simulations give us some insights into the considerable distance we still have to cover, both in terms of education and public debate. A second remark is related to the time necessary until absolute decoupling occurs. If absolute decoupling takes place too late, catastrophic climate change might not be prevented. In our exercise, GHG emissions only started to fall after 100 years, an amount of time that, given the urgency of the challenge, we do not have.

Despite the fact that these observations might seem discouraging, one must recognise two limitations of our model that should be addressed in future research and that could increase the importance of our approach from a policy perspective. The first regards the possibility of feedback from climate change to environmental sentiments. A worsening of environmental conditions could influence sentiments in favour of green policies, though the perception of a problem is not always translated into a willingness to incur the economic costs that environmental protection requires.

We should also bring to the reader's attention the relevance of escaping from the dichotomy between pro- and anti-environment attitudes to a more realistic framework that includes the possibility of neutrality. In real-world societies, a significant share of the population knows little (or nothing) about the environment and simply do not care about the subject. As our exercise indicates, generalised apathy, captured by a lower μ, generates inaction and the maintenance of the *status quo*. Nonetheless, the inclusion of a specific group of "apathetic" people is actually functional in a democratic society given that "it allows flexibility for leaders to make decisions without experiencing an immediate, critical response on every decision made" (Ramsey and Rickson, 1976, p.11).

5 Final Considerations

With related effects likely to be extensive and potentially devastating, it is no exaggeration to say that climate change is the challenge of our generation. In a recent article published in this journal, Guarini and Porcile (2016) expanded the BoPC growth model suggesting a way that allows for the inclusion of environmental variables in the structure of this family of models and makes it possible to address some of the challenges posed by greenhouse gas emissions. Building on their set up, we incorporate the ways in which people with different environmental attitudes or sentiments influence each other and contribute to the design of environmental policies. We detailed the concept of transition probabilities for the agent's switching from pro- to anti-environmentally friendly positions and vice-versa and discussed the macroeconomic results that follow. Numerical simulations allowed us to investigate in more detail the implications of the validity of Porter's hypothesis as well as decoupling conditions.

If we have managed to convince the reader of the importance of the mechanism so far described, then future research should explore the possibility of feedback from the macroeconomy and GHG emissions to environmental sentiments. Another natural extension consists in escaping from the dichotomy between pro- and anti-environmentally friendly attitudes to a more realistic set up that includes the possibility of neutrality.[5] A state of neutrality is not only justified by its greater psychological plausibility. At a micro-level, individuals do not immediately change their political views, and it might be useful for policy makers to have a clear picture of the macroeconomic implications of the transition process. The existence of a corridor of stability suggested by our numerical simulations provided some initial insights in that direction but was still too preliminary.

A policy implication of our analysis is that we should encourage more education, and the dissimination of information and pro-environmental attitudes among the public because this could lead, in turn, to a more desirable equilibrium. Adopting a friendly position towards Porter's hypothesis, our model gives indications of how to "reach" this Pareto-superior point, by means of policies that boost the contagion of pro-environment attitudes. As important as enhancing public knowledge of ecology is keeping alive the debate at the collective level, influencing the probability of switching sides. The complexity of the phenomenon does not guarantee that a desirable equilibrium will necessarily be reached, but the absence of a vivid and open public debate will inevitably result in the maintenance of the *status quo*. This insight was confirmed by the numerical simulations contained in the article.

Several studies have indicated that one of the major barriers to the adoption of an open agenda against climate change lies in a lack of broad public support. In this context, changes in individual behaviours and lifestyles are of crucial importance for achieving a sustainable society. Given that the sum of individual sentiments and attitudes generates what we refer to as collective opinion, and given that the latter determines the explicit and implicit rules that influence our own beliefs, understanding the interaction between sentiments towards the

[5] Franke and Westerhoff (2018) have recently included neutral agents when studying sentiment dynamics in the macroeconomy and is a useful reference in that sense.

environment and the macroeconomy becomes a crucial component for explaining the adoption and effectiveness of climate change policies.

References

[1] Aasena, M. & Vatnb, A. (2018). Public attitudes toward climate policies: the effect of institutional contexts and political values. *Ecological Economics* 146, 106-114.

[2] Acemoglu, D. (2003). Factor prices and technical change: from induced innovation to recent debates. In Aghion, P.; Frydman, R.; Stiglitz, J. and Woodford, M. (eds.) Knowledge, Information, and Expectations in Modern Macroeconomics. Princeton University Press, Princeton.

[3] Ambec, S., Coheny, M., Elgiez, S. & Lanoie, P. (2013). The Porter Hypothesis at 20: can environmental regulation enhance innovation and competitiveness?. *Review of Environmental Economics and Policy* 7(1), p. 2-22.

[4] Antonietti, R. & Marzucchi, A. (2014). Green tangible investment strategies and export performance: a firm-level investigation. *Ecological Economics* 108, 150-161.

[5] Aşici, A. (2013). Economic growth and its impact on environment: a panel data analysis. *Ecological Indicators* 24, 324-333.

[6] Bassetti, T., Benos, N. & Karagiannis, S. (2013). CO_2 emissions and income dynamics: what does the global evidence tell us?. *Environmental and Resource Economics* 54(1), 101-125.

[7] Brinkley, C. (2014). Decoupled: successful planning policies in countries that have reduced per capita greenhouse gas emissions with continued economic growth. *Environment and Planning C: Politics and Space* 32(6), 1083 - 1099.

[8] Cimoli, M., Porcile, G. & Rovira, S. (2010). Structural change and the BOP-constraint: why did Latin America fail to converge? *Cambridge Journal of Economics* 34, 389–411.

[9] Costantini, V. & Mazzanti, M. (2012). On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. *Research Policy* 41, 132-153.

[10] Dávila-Fernández, M. & Sordi, S. (2018). Distributive cycles and endogenous technical change in a BoPC growth model. *Economic Modelling.* https://doi.org/10.1016/j.econmod.2018.09.002.

[11] Dávila-Fernández, M., Oreiro, J. & Dávila, M. (2018). Endogenizing non-price competitiveness in a BoPC growth model with capital accumulation. *Structural Change and Economic Dynamics* 44, 77-87.

[12] Drews, S. & van den Bergh, J. (2016). What explains public support for climate policies? A review of empirical and experimental studies. *Climate Policy* 16(7), 855-876.

[13] Duménil, G. & Levy, D. (1995). A stochastic model of technical change: an application to the US economy (1869-1989). *Metroeconomica* 46(3), 213-245.

[14] Fabrizi, A., Guarini, G. & Meliciani, V. (2018). Green patents, regulatory policies and research network policies. *Research Policy* 47, 1018-1031.

[15] Flaschel, P., Charpe, M., Galanis, G., Proaño, C. & Veneziani, R. (2018). Macroeconomic and stock market interactions with endogenous aggregate sentiment dynamics. *Journal of Economic Dynamics & Control* 91, 237-256.

[16] Fontana, G. & Sawyer, M. (2013). Post-Keynesian and Kaleckian thoughts on ecological macroeconomics. *European Journal of Economics and Economic Policies: Intervention* 10(2), 256–267.

[17] Fontana, G. & Sawyer, M. (2016). Towards post-Keynesian ecological macroeconomics. *Ecological Economics* 121, 186-195.

[18] Franke, R. (2012). Microfounded animal spirits in the new macroeconomic consensus. *Studies in Nonlinear Dynamics & Econometrics* 16(4).

[19] Franke, R. & Westerhoff, F. (2018). Different compositions of aggregate sentiment and their impact on macroeconomic stability. *Economic Modelling.* https://doi.org/10.1016/j.econmod.2018.07.022

[20] Gouvea, R., Lima, G. (2013). Balance of payments constrained growth in a multisectoral framework: a panel data investigation. *Journal of Economic Studies* 40(2), 240-254.

[21] Guarini, G. & Porcile, G. (2016). Sustainability in a post-Keynesian growth model for an open economy. *Ecological Economics* 126, 14-22.

[22] Hein, E. & Tarassow, A. (2010). Distribution, aggregate demand and productivity growth: theory and empirical results for six OECD countries based on a post-Kaleckian model. *Cambridge Journal of Economics* 34(4), 727-754.

[23] Hicks, J. (1932). *The Theory of Wages.* London: Macmillan.

[24] Hurst, M., Dittmar, H., Bond, R. & Kasser, T. (2013). The relationship between materialistic values and environmental attitudes and behaviors: A meta-analysis. *Journal of Environmental Psychology* 36, 257-269.

[25] IPCC. (2013). Climate change 2013: the physical science basis. In: Stocker, T.F., Q., D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[26] IPCC. (2014). Summary for policymakers. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge/New York, pp. 1–32.

[27] Itkonen, J. (2012). Problems estimating the carbon Kuznets curve. *Energy* 39(1), 274-280.

[28] Jackson, T. (2016). *Prosperity without Growth: Foundations for the Economy of Tomorrow.* 2nd edition. Routledge.

[29] Jackson, T. & Victor, P. (2011). Productivity and work in the 'green economy' Some theoretical reflections and empirical tests. *Environmental Innovation and Societal Transitions* 1, 101-108.

[30] Jaffe, A. & Palmer, K. (1997). Environmental regulation and innovation: a panel data study. *Review of Economics and Statistics* 79, 610-619.

[31] Johnstone, N., Haščič, I. & Kalamova, M. (2010). Environmental policy characteristics and technological innovation. *Economia Politica* 27(2), 275-299.

[32] Kaiser, F. & Byrka, K. (2011). Environmentalism as a trait: gauging people's prosocial personality in terms of environmental engagement. *International Journal of Psychology* 46, 71-79.

[33] Kasser, T. (2011). Cultural values and the well-being of future generations: a crossnational study. *Journal of Cross-Cultural Psychology* 42, 206-215.

[34] Kemp-Benedict, E. (2018). Dematerialization, decoupling, and productivity change. *Ecological Economics* 150, 204-216.

[35] Kronenberg, Y. (2010). Finding common grounds between ecological economics and post-Keynesian economics. *Ecological Economics* 69, 1488–1494.

[36] Lanoie, P., Lucchetti, J., Johnstone, N. & Ambec, S. (2011). Environmental policy, innovation and performance: new insights on the Porter Hypothesis. *Journal of Economics and Management Strategy* 20, 803–42.

[37] Leiserowitz, A., Kates, R. & Parris, T. (2006). Sustainability values, attitudes, and behaviors: a review of multinational and global trends. *Annual Review of Environment and Resources* 31, 413-444.

[38] Lux, T. (1995). Herd behaviour, bubbles and crashes. *Economic Journal* 105(431), 881-896.

[39] McCright, A., Dunlap, R. & Marquart-Pyatt, S. (2016). Political ideology and views about climate change in the European Union, *Environmental Politics*, 25(2), 338-358.

[40] Naqvi, A. & Zwickl, K. (2017). Fifty shades of green: revisiting decoupling by economic sectors and air pollutants. *Ecological Economics* 133, 111-126.

[41] Pietsch, J. & McAllister, I. (2010). 'A diabolical challenge': public opinion and climate change policy in Australia. *Environmental Politics* 19(2), 217-236.

[42] Porter, M. (1991). America's green strategy. *Scientific American* 264(4), 168-168.

[43] Porter, M. & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives* 9(4), 97-118.

[44] Ramsey, C. & Rickson, R. (1976). Environmental knowledge and attitudes. *Journal of Environmental Education* 8(1), 10-18.

[45] Ratliff, K., Howell, J. & Redford, L. (2017). Attitudes toward the prototypical environmentalist predict environmentally friendly behavior. *Journal of Environmental Psychology* 51, 132-140.

[46] Raupach, M., Marland, G., Ciais, P., Le Quéré, C., Canadell, J., Klepper, G. & Field, C. (2007). Global and regional drivers of accelerating CO_2 emissions. *PNAS* 104(24), 10288–10293.

[47] Razmi, A. (2016). Correctly analysing the balance-of-payments constraint on growth. *Cambridge Journal of Economics* 40(6), 1581-1608.

[48] Rezai, A., Taylor, L. & Mechler, R. (2013). Ecological macroeconomics: an application to climate change. *Ecological Economics* 85, 69–76.

[49] Rezai, A., Taylor, L. & Foley, D. (2018). Economic growth, income distribution, and climate change. *Ecological Economics* 146, 164–172.

[50] Romero, J. & McCombie, J. (2016). The multi-sectoral Thirlwall's law: evidence from 14 developed european countries using product-level panel data. *International Review of Applied Economics*, 30(3): 301-325.

[51] Romero, J. & McCombie, J. (2018). Thirlwall's law and the specification of export and import functions. *Metroeconomica*. https://doi.org/10.1111/meca.12185.

[52] Rubashkina, Y., Galeotti, M. & Verdolini, E. (2015). Environmental regulation and competitiveness: empirical evidence on the Porter Hypothesis from European manufacturing sectors. *Energy Policy* 83, 288–300.

[53] Sasaki, H. (2013). Cyclical growth in a Goodwin–Kalecki–Marx model. *Journal of Economics* 108, 145-171.

[54] Steg, L. and Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology* 29(3), 309-317.

[55] Tapia-Granados, J., Ionides, E. & Carpintero, O. (2012). Climate change and the world economy: short-run determinants of atmospheric CO_2. *Environmental Science & Policy* 21, 50-62.

[56] Tavani, D. & Zamparelli, L. (2017). Endogenous technical change in alternative theories of growth and distribution. *Journal of Economic Surveys* 31(5), 1272–1303.

[57] Taylor, L., Rezai, A. & Foley, D. (2016). An integrated approach to climate change, income distribution, employment, and economic growth. *Ecological Economics* 121, 196–205

[58] Thirlwall, A. (1979). The balance of payments constraint as an explanation of international growth rate differences. *BNL Quarterly Review* 32(128), 45-53.

[59] Thirlwall, A. (2011). Balance of payments constrained growth models: history and overview. *PSL Quarterly Review* 64(259), 307-351.

[60] Tjernström, E. & Tietenberg, T. (2008). Do differences in attitudes explain differences in national climate change policies?. *Ecological Economics* 65, 315-324.

[61] Victor, P. (2008). *Managing Without Growth – Slower by Design not Disaster*. Edward Elgar, Cheltenham.

[62] Victor, P. (2012). Growth, degrowth and climate change: a scenario analysis. *Ecological Economics* 84, 206–212.

[63] Wiseman, J., Edwards, T. & Luckinsc, K. (2013). Post carbon pathways: a meta-analysis of 18 large-scale post carbon economy transition strategies. *Environmental Innovation and Societal Transitions* 8, 76-93.

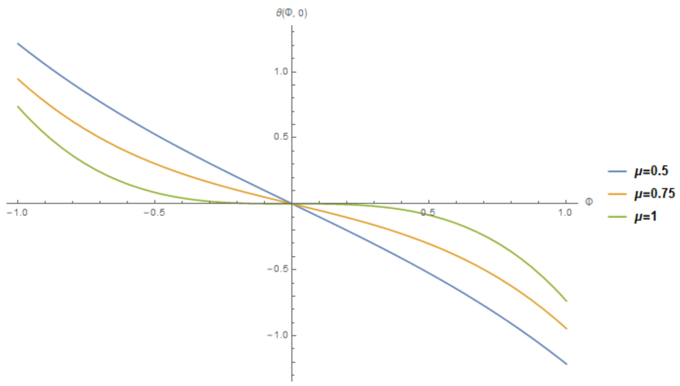
[64] Witt, A.; Boer, J. & Boersema, J. (2014). Exploring inner and outer worlds: a quantitative study of worldviews, environmental attitudes, and sustainable lifestyles. *Journal of Environmental Psychology* 37, 40-54.

[65] Zeriti, A., Robson, M., Spyropoulou, S. & Leonidou, C. (2014). Sustainable export marketing strategy fit and performance. *Journal of International Marketing* 22(4), 44-66.

Mathematical appendix

Proof of Proposition 1

The determination of equilibrium follows a sequence that run from sentiments towards the environment to the macroeconomy. The properties of equation (15) have been extensively discussed in the literature. Lux (1995) showed that for $\mu \leq 1$ this equation has a unique equilibrium given by $\Phi^E = 0$. Since Φ^E is determined independently of the rest of the economy, Lux's demonstration is also valid here. Graphically we have:



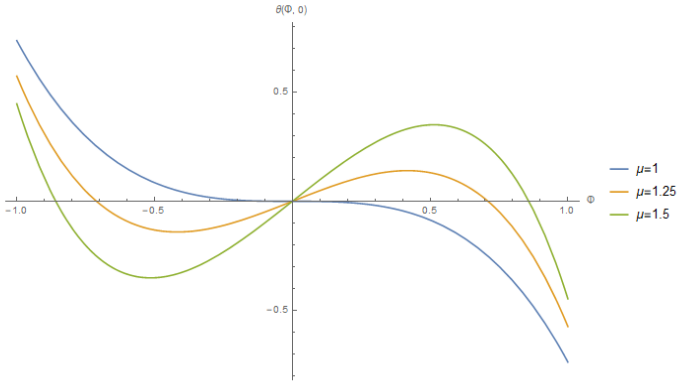
where we set $\zeta = 1$ for purposes of exposition only. Adopting different values of this parameter changes the scale of the vertical axis with no further implications.

From equation (23) we have that in steady state $\varepsilon\dot{Y}^*/Y^* + \xi F(\lambda(\Phi)) = \alpha\pi a$. Recall that $\lambda(0) = 0$. Making use of (19) we can rewrite the expression as $\varepsilon\dot{Y}^*/Y^* + \xi F(0) = \alpha\pi a$. Notice that $\varepsilon\dot{Y}^*/Y^* + \xi F(0)$ corresponds to the equilibrium growth rate of exports. Hence, we have that $\left[\varepsilon\dot{Y}^*/Y^* + \xi F(0)\right]/\pi$ is the equilibrium "green version" of Thirwall's law, y^E_{bp}. This means that the growth rate of domestic absorption is defined and given by $a^E = y^E_{bp}/\alpha$.

Finally, $\dot{e}/e = \left\{\alpha a + \beta_1\left[\varepsilon\dot{Y}^*/Y^* + \xi F(\lambda(\Phi))\right]\right\}/(1+\beta_2\pi) - G(\lambda(\Phi), e)$. Recall that $\Phi^E = 0$ and $a^E = y^E_{bp}/\alpha$. Hence, we have that $(1+\beta_1\pi)y^E_{bp}/(1+\beta_2\pi) = G(0, e)$. By assumption, $\beta_1 = \beta_2$. Therefore, $y^E_{bp} = G(0, \varpi)$. $G : \Re \rightarrow \Re$ is a monotonically increasing function in λ and e. It follows that the unique equilibrium for the employment rate, e^E, exists and is such that $y^E_{bp} = G\left(0, e^E\right)$.

Proof of Proposition 2

To prove Proposition 2 we follow the same sequence of steps as in Proposition 1. Lux (1995) showed that for $\mu > 1$ this equation has two additional equilibria given by $\Phi^{E_1} > 0$ and $\Phi^{E_2} < 0$. Graphically we have:



where once more we set $\zeta = 1$ only for purposes of exposition only. Adopting different values of this parameter changes the scale of the vertical axis with no further implications.

Once Φ^{E_i} is reached, we are able to determine the growth rate of domestic absorption, $a^{E_i} = y_{bp}^{E}/\alpha$. Employment adjusts in order to allow the natural growth rate to equalise the external constraint, i.e. $y_{bp}^{E_i} = G(\cdot)$. Since $G : \Re \to \Re$ is a function monotonically increasing in λ and e, it follows that the unique equilibrium for the employment rate, e^E, exists and is such that $y_{bp}^{E_i} = G\left[\lambda\left(\Phi^{E_i}\right), e^{E_i}\right]$.

Proof of Proposition 3

The Jacobian matrix that corresponds to our dynamic system is such that:

$$J = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ 0 & J_{22} & J_{23} \\ 0 & 0 & J_{33} \end{bmatrix}$$

where the elements are given by:

$$\begin{aligned} J_{11} &= -G_e e^E < 0 \\ J_{12} &= \frac{\alpha e^E}{1+\beta_2\pi} > 0 \\ J_{13} &= \left(\frac{\beta_1 \xi F_\lambda \lambda_\Phi}{1+\beta_2\pi} - G_\lambda \lambda_\Phi\right) e^E \gtreqless 0 \end{aligned}$$

$$\begin{aligned} J_{21} &= 0 \\ J_{22} &= \frac{-\psi\alpha}{(1+\beta_2\pi)} < 0 \\ J_{23} &= \frac{\psi \xi F_\lambda \lambda_\Phi}{\pi\left(1+\beta_2\pi\right)} > 0 \end{aligned}$$

$$\begin{aligned} J_{31} &= 0 \\ J_{32} &= 0 \\ J_{33} &= \theta_\Phi \gtreqless 0 \end{aligned}$$

so that the characteristic equation can be written as:

$$\rho^3 + b_1\rho^2 + b_2\rho + b_3 = 0$$

where the coefficients are given by:

$$b_1 = -\operatorname{tr} J = -\left(J_{11} + J_{22} + J_{33}\right)$$

$$\begin{aligned} b_2 &= \begin{vmatrix} J_{22} & J_{23} \\ 0 & J_{33} \end{vmatrix} + \begin{vmatrix} J_{11} & J_{13} \\ 0 & J_{33} \end{vmatrix} + \begin{vmatrix} J_{11} & J_{12} \\ 0 & J_{22} \end{vmatrix} \\ &= J_{22}J_{33} + J_{11}J_{33} + J_{11}J_{22} \end{aligned}$$

$$b_3 = -\det J = -J_{11}J_{22}J_{33}$$

The necessary and sufficient conditions for the local stability of a given equilibrium point is that all roots of the characteristic equation have negative real parts, which from Routh-Hurwitz conditions, requires:

$$b_1 > 0,\ b_2 > 0,\ b_3 > 0 \text{ and } b_1b_2 - b_3 > 0$$

When $\mu \leqslant 1$ we have already proved that in equilibrium $\Phi = 0$ and $\theta_\Phi < 0$. In this case it is easy to see that:

$$\begin{aligned} b_1 &= G_e e + \frac{\psi\alpha}{(1+\beta_2\pi)} - \theta_\Phi > 0 \\ b_2 &= -\left[\frac{\psi\alpha}{(1+\beta_2\pi)} + G_e e\right]\theta_\Phi + \frac{G_e e\psi\alpha}{(1+\beta_2\pi)} > 0 \\ b_3 &= -\frac{G_e e\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} > 0 \end{aligned}$$

The crucial condition for local stability becomes the last one. Through direct computation we find that:

$$\begin{aligned} b_1b_2 - b_3 &= \left[G_e e + \frac{\psi\alpha}{(1+\beta_2\pi)} - \theta_\Phi\right]\left[\frac{G_e e\psi\alpha}{(1+\beta_2\pi)} - \frac{\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} - G_e e\theta_\Phi\right] + \frac{G_e e\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} \\ &= \underbrace{\left[G_e e + \frac{\psi\alpha}{(1+\beta_2\pi)}\right]}_{>0}\underbrace{\left[\frac{G_e e\psi\alpha}{(1+\beta_2\pi)} - \frac{\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} - G_e e\theta_\Phi\right]}_{>0} \\ &\quad -\theta_\Phi\underbrace{\left[\frac{G_e e\psi\alpha}{(1+\beta_2\pi)} - \frac{\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} - G_e e\theta_\Phi\right]}_{>0} \\ &> 0 \end{aligned}$$

Therefore, the system is locally stable.

Proof of Proposition 4

When $\mu > 1$ is easy to see that for $\Phi = 0$ we have $\theta_\Phi > 0$. It immediately follows that:

$$b_3 = -\frac{G_e e\psi\alpha\theta_\Phi}{(1+\beta_2\pi)} < 0$$

and the system is locally unstable.

Proof of Proposition 5

We have already proved that when $\mu > 1$, there are two additional non-trivial equilibrium solutions, $\Phi^{E_1} > 0$ and $\Phi^{E_2} < 0$. For each of them the partial derivative $\partial\dot{\Phi}/\partial\Phi = \theta_\Phi < 0$. Following the same sequence of steps as in Proposition 3 we have that all Routh-Hurwitz conditions are satisfied and, thus, that the system is locally stable.