The dynamic effects of pollution on growth and inflation: a derivation of the new keynesian environmental canonic model

The article constructs a three-equation model, in which it relates ecological variables with traditional macroeconomic variables, assuming that economic agents decide to look ahead. In the so-called New Keynesian Environmental Canonic Model, environmental preservation is a condition for economic growth with price stability, in this model, pollution shocks cause inflation and fall in the aggregate product of the economy due to the scarcity of environmental assets.

Palavras-chave: Environment; Macroeconomics; Canonic Model; New Keynesian; Scarcity.

Os efeitos dinâmicos da poluição no crescimento e na inflação: uma derivação do novo modelo canônico ambiental keynesiano

O artigo constrói um modelo de três equações, no qual relaciona variáveis ??ecológicas com variáveis ??macroeconômicas tradicionais, assumindo que os agentes econômicos decidam olhar para o futuro. No chamado Novo Modelo Canônico Ambiental Keynesiano, a preservação ambiental é uma condição para o crescimento econômico com estabilidade de preços. Nesse modelo, os choques de poluição causam inflação e caem no produto agregado da economia devido à escassez de ativos ambientais.

Keywords: Meio Ambiente; Macroeconomia; Modelo canônico; Novo Keynesiano; Escassez.

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INTRODUCTION

The theme of sustainability has been growing in relevance over the past 30 years. If, on the one hand, economic growth has had its virtuous effects on employment and income, on the other hand, the scale of human activities has gained dimensions never seen before on the planet (STEFFEN et al., 2007; MCNAILL, 2001), which certainly causes doubts and fears surrounding the sustainability of natural resources throughout the planet's history. Will we be able to preserve natural resources essential to human life for future generations? Or are we exhausting the availability of these resources, and thereby limiting the access to these generations?

When it comes to economy and the environment, the future is too uncertain, and the evidences are dubious. Issues such as the rising of the planet's temperature, changes in the rain cycle, desertification of some areas and rising sea levels are realities of the present time, and the contemporary scientific agenda predominantly points out that such climatic changes are due to human activities, which means, of anthropic origin.

This article's objective is to derive a model of three equations according to the known macroeconomics and the usual relations of supply and demand, according to Clarida et al. (2000)[1]. Assuming that firms and families decide to look forward (forward looking), the authors made this effort to derive a model composed of three equations, from the derivation of a New Keynesian Phillips Curve, an IS Curve and an optimal rule from monetary policy to random shocks of the Central Bank, which seek to stabilize the price level. This model became known in literature as Canonic.

Using the same macroeconomic and microeconomic assumptions and the same methodology, the article aims to derive a New Keynesian Environmental Canonic Model, in which supply relationships are derived by a Calvo (1983), the demand represented by the interface of the IS curve and the Taylor forward looking rule. Finally, a third curve of environmental equilibrium was derived from the contribution of Heyes (2000). Differently from this author, the environmental equilibrium curve here is provided according to technological progress, which in turn depends on competitive conditions in the goods market and public investments in low-pollution innovations. Unlike Heyes (2000), environmental policy has its function to guarantee growth and low inflation[2].

The article is divided into four sessions from this brief introduction. In the first section a brief chronological review of the literature on the environmental problem will be made. Classical authors like Malthus, Walras and Georgescu-Roegen are revisited to deal with the problem of scarcity. In the second session the conditions of economic equilibrium with environmental preservation will be derived, the curves EE, CPh-NK and IS-MR will be shown. The third session will present the New Keynesian Environmental Canonic Model. The fourth session will discuss the implications of this model in the face of pollution shocks and

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[1] There is a set of authors who have developed macroeconomic models from micro fundamentals, with different purposes (CALVO, 1983; LEVY, 1997; MANKIW et al., 2002).

[2] Environmental policy must play an active role in the capitalist economy, for the preservation of environmental goods will guarantee its availability over time, thereby avoiding the rising of prices. Environmental policy can be carried out in two ways: 1st via regulation and 2nd by economic instruments.

innovation shocks about inflation, growth and both real and nominal interest rates. Lastly, the final considerations will be presented in session five.

THEORETICAL REVIEW

The planet's physical basis is limited, as well as the material conditions by which the physical production of goods and services is set. This finding is not new in economics, and Malthus (1996) has immortalized himself in the history of economic thought from his prophecy about scarcity[3]. Evidently, at Malthus's time, the irrelevance of the economic activities' scale treated the problem of the planet's physical limits as something remote. It is clear, since the publication of the Essay on Population in 1798, that economic relations grew in scale and became complex, new economic problems overlapped with reality, many even related to the physical limits of global productive expansion.

One of the established works in this area was published by Georgescu-Roegen (1971), in which the author makes an interdisciplinary effort between economics, mathematics and physics, starting from the laws of thermodynamics, and assuming the planet as a closed system which can be explained as a system whose total energy is composed of the sum of the total internal energy plus the energy supplied by the external environment[4].

Assuming that the planet receives solar energy, in the absence of solar cycles, the energy and consequently the internal heat variation to the system, would occur by the amount of work variation performed internally in this system. In other words, reckoning the planet as a closed system, it is possible that changes in the energy quantity of the planet, and consequently total variations in the amount of heat, are produced by the amount of work inside the system, which can be specified as activities typically human and economic.

Since the publication of Malthus's work in 1978 Malthus (1978), the world's population has grown from approximately 900 million to around 7,5 billion today[5]. In practical terms, Malthus was not wrong about the growth of the world population as a geometric progression. Perhaps it was not possible to predict, in due course, that technological revolutions which have taken place during the succeeding centuries would at least hitherto have been the means of providing subsistence for the world's population up to now. Georgescu-Roegen (1971), was assertive in announcing that the planet's energetic boundaries undergo variations caused by the internal workings of the system, in which human activity would be responsible for the transition of the planet's system from a low-entropy condition, which symbolizes internal energy, to a high entropy condition[6].

In practical terms, assuming that Georgescu-Roegen (1971) was right, the changing of the planet from

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[3] In his book Essays on Population, 1798; Malthus problematizes the planet's physical limits, stemmed from the notion that the physical production of food could only grow at a slower rate than the population itself, and hence demand.

[4] The first law of thermodynamics assumes that the energy variation of a system depends on the amount of heat exchanged with the external environment, plus a quantity of work done internally $\Delta U = Q - \tau$.

[5] Data from ourworlddata.org.

[6] The second law of thermodynamics: the law of entropy, which implies the transfer of heat between bodies, thus the release of heat into the environment in a closed system.

a low entropy system to a high entropy system would be related to the expansion of greenhouse gases such as CO_2, CH_4 among others, which would be related to physical and chemical phenomena that affect the planet, such as average temperature rises, or the melting of polar caps and consequently the rising of sea levels, or the desertification of tropical areas, through changes in the rain cycles, and the very existence of the acid rain.

The pessimism about environmental issues doesn't necessarily happen due to the increase in the energy quantity of the planet, which itself justifies human intervention in order to correct them, but also due to its material limitation, since, by the first law of thermodynamics, given a closed system, it is possible to exchange heat with the external environment, but not matter.

As a result, the conditions of the human species' perpetuity would be condemned, according to Malthus, to scarcity and misery. "The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe" (SOLOW, 1974). The problem of scarcity has been typified by economic theory ever since. It is related, according to Walras (1986), to a rarity of things, which means, for an economic science, rarity consists in characteristics of things, such as heat, or movement[7]. The definition of rarity of things makes itself important in Walras; therefore, the set of rare things will set up a society's social wealth and, consequently, its welfare conditions. There are, however, according to this author, a set of things useful to human life that are not – except in exceptional conditions - rare, and therefore, do not constitute a social wealth, for its non-permutable condition[8].

When observing the planet's history and the evolution of the human species itself, we have a consolidated population of 7,5 million inhabitants; it is exceptional when it comes to the scale of the resources that need to be generated to meet all these needs. Thereafter, the finiteness of natural resources in the face of the new scale of human activities on the planet forces the inclusion of the previously useful, but not rare, natural assets into a new condition of rarity. Then the rising of two new problems is noted, which economic science, as well as its interface with the natural sciences, have not yet been able to solve. In Walras, the rare things that make up social wealth must be limited, interchangeable, and producible (or multipliable). In short, this property of rare things is made necessary by its *appropriability*[9], which can be described as the capacity to become the individual property of man.

We have here a philosophical, normative and operational problem, dealing with purely rare things (those which have been rare since the beginning of industrial and commercial capitalism), things that are producible, interchangeable and available only in a limited quantity for human needs. With respect to things that have become rare due to the new scale of human needs from the mid-twentieth century.

This second group of things may in some cases be producible, multipliable, interchangeable, but

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[7] According to Walras' definition in 1890, for scientific purposes, just as heat is not merely an antonym of cold, and movement is not the opposite of morbidity; rarity is not the opposite of abundance as well, but a property of things. Things are rare, rarer of less rare; and being rare, they are only available in limited quantities thus being subject to trade and fulfill human needs.

[8] By referring to non-rare things, Walras exemplifies those as a collection of utilities available from a stock of natural riches, such as air, sunshine and water itself. However, he considers that in situations rated as exceptional, those things can become rare in the course of history and begin to compose social wealth. This argument converges with the Ecological Economy thinking scarcity's pattern isn't watertight, but dynamic. What was considered abundant may become scarce. It is the transition from empty world to full world which we discussed in the 2012 article (DAILY, 2005)

[9] Appropriability can be read as the asset's aptness of becoming property.

cannot be appropriated individually, such as the desalination of sea water, rare for some peoples, cannot prevent other peoples from using this same water for their individual purposes. In other words, because of its *appropriability*, the social distribution of essentially rare things is due to the optimal allocation of the market, which would occur in a Walrasian world, by the automatic mechanism of price and quantity adjustment, balancing supply relations and demand.

In this way, things that are essentially rare, given their limited availability in the market, presume restrictions on the access of people to their consumption, and consequently, the usefulness that this generates. The principle of *appropriability* means that the consumption of a rare good's unit by a consumer makes the consumption of the same unit unfeasible by another consumer, and there is a rivalry in the consumption of these goods.

The same cannot be said about the things that have become rare, in function of infeasibility of all type: Infeasibility of moral nature, given the fact that the set of non-rare things are essential to human life, the due scarcity of those goods, restricting its use to populations, then creates a moral problem related to the lack of access and its consequences, in terms of human degradation by virtue of this fact; Infeasibility of normative nature, that is, the countries' legal framework doesn't generally foresee the individual appropriation of natural resources such as water and air. These goods are available in nature for the unrestricted use and satisfaction of human needs. We can name those as common goods[10] and with that; the access limitations are unfeasible from the normative point of view.

Infeasibility of operational nature, since things that have become rare are not appropriable, they don't have an exchange value metric, a natural characteristic of essentially rare goods, making it difficult for economic agents to identify scarcity. The unfeasibility of a moral nature ends up being a consequence of the normative and operational problems of the limiting common things issue, but useful to human life. Economic science, aided by the natural sciences, has sought metrics in the sense of measuring, in monetary units, assets of a common nature.

These are all subject to problems and criticisms, applicable to situations, but they do not fail to translate into efforts to quantify the scarcity of commons. If common things are useful, they have demand, as environmental services do not go through the Walrasian price system, Bateman et al. (1992), develop a technique of demand's estimation curves from several criteria, thus estimating the agents' willingness to pay for environmental services[11]. Pearce (1993) uses another criterion to estimate the price of environmental services; it is the method of replacement costs, which means that at limit, the price of an environmental service or a common good is equal to the cost in case of this resource's collapse. From these metrics[12], the problem of scarcity quantification is not solved, but is mitigated.

In other words, the absence of a market does not solve, or even complicates, the problem of scarcity. How to deal with the moral consequences of this problem? Also, how to reconcile the solution of this

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[10] This nomenclature was used by Hardin (1968) to refer to this same set of goods considered by the author as being in common use.
[11] Technique that became known as contingent value method (CVM)
[12] Nogueira et al. (2000) catalogs several environmental valuation methodologies and their respective uses.

problem, along with the solution of many other contemporary problems as unemployment? Inflation? Povery? Hunger? Among countless others. Of course, this article does not provide an answer to each of those problems; however, it is an initial effort to provide a dynamic, organized view of the macroeconomic effects of environmental pollution, which exacerbates the scarcity of things' effect common to society. The article seeks to answer questions such as: would economic growth be detrimental to the environment? Is there dynamic compatibility between economic growth, low employment levels and controlled inflation? What is the role of technological development in this world?

Environment, well fare and macroeconomics

A set of authors has been endeavoring in relating the environmental aspects to the macroeconomics, from different methodologies. A first effort was made from the work of Heyes (2000), interested in the construction of a model for textbooks of macroeconomics that contemplated the environmental problem. Dafermos et al. (2017) uses the stock-flow-consistent methodology to relate physical and biological variables to monetary variables[13]. The theme also gained prominence with the election of the work of Northaus (2008) to the Nobel Prize in Economics in the year 2018. There is also a set of authors that link the environmental aspects with the post-Keynesian theory (REZAI et al., 2013; FONTANA et al., 2013; TAYLOR et al., 2016).

A first attempt to stylize a macroeconomic model; thus, equalizing the environmental problem, was performed by Heyes (2000). The author proposes the development of a textbook macroeconomic model, inspired by Mendell Flaming's three equations model. The Heyes model would be composed of a short-term equilibrium relation in the goods and services market, given by an IS curve, also by a monetary equilibrium relationship, defined by the LM curve, in addition to a third curve called the EE curve[14], whose representation implies equilibrium in the environmental market, in which the amount of pollution emitted *e* would be equal to the resilience capacity of the environmental stock *s.E.* The EE model of Heyes (2000) is described in equation $-\left(\frac{dE}{dt}\right) = e(R, A)Y - s.E.$

The equation 1 of environmental equilibrium consists of a first effort to link physical variables to monetary variables. Since *(R, A) Y* is the aggregate demand component, where *R* is the real interest rate, *A* is an autonomous component of fiscal policy, and *Y* is the aggregate income. The general conclusion of the Heyes model (HEYES, 2000) is that the growth of the product driven by lower interest rates (monetary policy expansion), would cause the drop of pollution levels, which would occur by the exchange of more polluting technology, by less polluting technology. Considering, therefore, the variation of pollution's stocks $-\left(\frac{dE}{dt}\right) = 0$, we can affirm that an expansionary monetary policy would lead to a new balance with the same volume of pollution in *Y*.

Even though this is a first attempt to abridge sophisticated thinking about the impacts of macroeconomics on the environment, the Heyes model (2000) presents a set of operational problems, which

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[13] Methodology also used by Berg et. al. (2015), Naqvi (2015), Fontana et al. (2016)
[14] Environmental Equilibrium

need to be punctuated and advanced. Firstly, according to this approach, it is enough that the economy grows so that the agents pollute less[15]; therefore, the model does not contemplate the negative externalities of the own economic growth on the pollution. In addition, static macroeconomic analysis focuses little on the interactions between flow and inventories, relevant to the understanding of intertemporal environmental impacts. We also have that the model conditions the environmental balance to the traditional macroeconomic policy conditions (monetary and fiscal), which is an imprecision, since the model does not contemplate any institutional factor of environmental policy[16].

It is also seen that Heyes (2000) disregards the endogenous characteristics of technological innovations[17]; according to this model, the exchange of more polluting technology for less polluting if the fall is not referred to the capital. Finally, this is his analysis report on the real of economy, neglecting its nominal. Risks are factual, and the consequence of their scale is a progressive change. Is it not possible that environmental degradation, and its consequent influence on scarcity, is not possible for environmental shocks to be transmitted by price?

The conditions of intemporal environmental balance

The first step is to analyze the environmental equilibrium according to Heyes model (2000). Regarding equilibrium, the pollution level must be equal to the resilience capacity of the existing environment $-e(R,A)Y = s.S$. However, sustainability condition of environmental assets for future generations $-\left(dS/dt\right) = 0$ which shows that the optimum environmental asset stock (which guarantees future generations' access) must remain unchanged over time.

Taking discrete time in consideration, the stock of environmental assets in period t is a self-regressing function E_{t-1}, in addition to the difference between resilience capacity of the ecosystems s_t, the level of clean technological advance a_t, which means, sparing environmental resources and less pollution emitted e_t.Thus, the function of intertemporal environmental equilibrium. $S_t = \tau S_{t-1} + \rho[s_t + \gamma a_t - (1-\gamma)e_t(R_t, A_t)Y_t] + \varepsilon_t$. If $\tau = 0$, and the environments resilience capacity s_t is steady, and that, at first, macroeconomic policy does not matter to the pollution level $(R_t, A_t)Y_t = 1$, we can affirm by equation (2) that the intertemporal balance of the environment depends basically on technological progress, pollution level and a random error term ε_t. $S_t = \gamma a_t - (1-\gamma)e_t + \varepsilon_t$.

Being γ the set of firms that innovate and, therefore, reduce their pollutants emission to the environment, and $(1-\gamma)$ the firms that use rudimentary technology; thus, polluting the environment. Considering that the firm aims to maximize profits, $L_t = p.Y_t - (cf_t + cv_t)$, in which the Y_t is the produced quantity, cf_t is the fixed cost and cv_t is the variable cost. For simplification, it is considered that the firm's

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[15] Some papers in the empirical literature corroborate this thesis; articles that estimate the Kuznetz Environmental curve show us that countries display a trend of higher growth in CO2 emissions according to income growth; however, from a certain point, income growth remains as CO2 emissions decrease, as is the case of Grossman et al. (2005), Carvalho et al. (2010). Arraes et. al. (2006) points to a curve in the cubic format, pointing to a cyclical nature of CO2 emissions, and a statistically weak relation with per capita income.

[16] There is a broad literature on institutional factors oriented towards the environment's preservation, the polluter-pays principle is an example (CÁNEPA et al., 1999).

[17] There are some examples that demonstrate the character of the technological transformation process, for example, Romer (1990; 1993).

only variable cost is with innovations, which can be described as, $cv_t = a_t$. If the firm's goal is to maximize profit, *ceteris paribus*, its cost will be minimum when $cv_t = a_t = 0$, in this case there wouldn't be, in the absence of other factors, incentives for innovation.

Regarding the macro environment in which this representative firm is emerged, let's consider μ this firm's market structure, in a way that $(0 < \mu \le 1)$, so that if $\mu \to 0$ is a market in conditions closer to perfect competition, or if $\mu \to 1$, there is a greater market concentration. It is therefore assumed that in monopolized markets, depending on the firm's discretionary power on prices, there is no incentive to spend on innovations, so the total innovations to reduce pollutants in that economy will be as high as the market's competitive edge[18]. There is also the possibility that innovations in the direction of a pollution-sparing technology take place exogenously, i.e. through direct government spending on P & D, in favor of innovation through the *spillovers* effects on firms. In this case, the innovation in period t is given by equation $a_t = A_{t-1} + \theta\mu + (1-\theta)G + u_t$.

The conclusions we get on equation 4 show that the technological advance a_t depends on an initial stage of available technology A_{t-1}, in addition, pollution-sparing innovations can only happen by the conjunction of two factors, be it the market's opening μ or public investments for this purpose G. The existence of some collinearity between the variables μ and G can be understood, due to the government's efforts to invest in innovation being limited in its effect's *spillovers* in firms, in case of a highly concentrated market structure. Hence, (4) can be joined in (3) to find the fundamental equation of intertemporal environmental equilibrium. $S_t = \gamma[A_{t-1} + \theta\mu + (1-\theta)G] - (1-\gamma)e_t + \varepsilon_t + u_t$, if we consider $\varepsilon_t + u_t = \epsilon_t$, equation can be rewritten as: $S_t = \gamma[A_{t-1} + \theta\mu + (1-\theta)G] - (1-\gamma)e_t + \epsilon_t$.

Equation consists of the intertemporal environmental equilibrium equation. It advances in relation to first equation of Heyes (2000) in the following ways: Here, microeconomic policy, either to increase competition in the goods market or in the strictly environmental meaning in the form of public investments, has an active role in environmental stock sustainability for future generations. Here, it is also possible that innovations, omitted from the Heyes (2000), play an important role in preserving the environment; Lastly, the dynamic analysis from the discrete time, shows that if in a given period t, the pollution level exceeds the environment's resilience capacity $-e(R,A)Y > s.E$, there is deterioration of the environmental stock. The government acts then, promoting reforms and investments, in order to elevate technological innovation a_t.

The supply sides

The effects of environmental shocks on the economy's nominal side depend, at first, on the shape of the Phillips Curve[19]. Assuming that firms have an objective of intertemporal profit maximization, and that the firm's fraction $\alpha(0 < \alpha \le 1)$ use inputs available in the environment, and that these firms readjust their prices over the period $t = n$ in a stochastic manner according to a *Poisson Process*, through n periods, the

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[18] If there is more competition, firms are price takers, the only way to obtain Market Share and increase their profits is by organizing their cost structure and / or creating new and better products.

[19] In this article, we chose to derive a Phillips Curve in the Calvo (1983) format; however, it is possible to obtain results from the hypothesis of rational expectations in a CPh Lucas (1976) format.

firms' probability of adjusting their prices is the same for each period unit. Thus, for each t period, the set of firms that readjust their prices regarding a supply shock on the stock of environmental assets E_t, in a random way is α, while companies that do not readjust their prices, therefore bearing their menu costs(readjusting their prices in the following period) are $(1 - \alpha)$. In such a way, prices level in t is given by the equation $p_t = \alpha x_t + (1 - \alpha)p_{t-1}$.

In which x_t is the price of the set of firms that readjusted their prices in t, while p_{t-1} is the price of firms that have adjusted their prices in an earlier period, and therefore pay the menu cost of price readjustment, in the face of an E_t shock. Bearing that in mind, it is possible to observe that inflation, which means, the price variation from one period to the next, is due to the price adjustments of firms that do it in t period, which is given by equation $\pi_t = \alpha(x_t - p_{t-1})$. Considering that firms are profit-maximizing, the decision to readjust their prices in the face of an E_t cost shock, is demonstrated in equation $x_t = \sum_{j=0}^{\infty} \frac{\beta^j q_j}{\sum_{k=0}^{\infty} \beta^k q_k} E_t p_{t+j}^*$.

In which β is a discount factor, which for simplicity is considered equal to 1, q_j consists in the probability of the price being readjusted over the $t + j$ period. Assuming that this readjustment probability obeys a *Poisson Process*, then $q_j = (1 - \alpha)^j$, equation can be rewritten as: $x_t = [1 - \beta(1 - \alpha)]\sum_{j=0}^{\infty} \beta^j (1 - \alpha)^j E_t p_{t+j}^*$. The process by which firms decide to adjust their prices during the period $t + j$, was carried out so far following the Calvo (1983) approach[20]. The term $E_t p_{t+j}^*$ shows that firms readjust their prices looking ahead, which means the price adjustment in t, depends on the general price level expected for the period $t + j$. In such a way, the decision to readjust the firms' prices can be rewritten in the following format. $x_t = [1 - \beta(1 - \alpha)]p_t^* + \beta(1 - \alpha)E_t X_{t+1}$.

The difference in this article, in relation to Calvo's original model (CALVO, 1983), is that here the parameter α represents the set of firms that have environmental assets in their production function, and so, the decision to readjust prices, or change its product's level isn't due to a monetary shock, but rather an environmental shock in E_t. Considering now the price difference of firms that readjust their prices, in relation to those who do not readjust their prices $x_t - p_t = (x_t - p_{t-1}) - (p_t - p_{t-1})$, it can be rewritten: $(x_t - p_{t-1}) - (p_t - p_{t-1}) = [1 - \beta(1 - \alpha)](p_t^* - p_t) + \beta(1 - \alpha)(E_t x_{t-1} - p_t)$.

Considering the inflation presented in equation (8), and that the non-adjustment of prices in t period, leads to a change in the production of firms of φY magnitude, in which the parameter φ shows how much of an environmental shock is transmitted to companies' products. The equation is rewritten: $(\pi_t/\alpha) - \pi_t = [1 - \beta(1 - \alpha)] \varphi Y + \beta(1 - \alpha)(E_t \pi_{t+1}/\alpha)$. Rearranging the expression, we have: $\pi_t = \frac{\alpha}{1 - \alpha}[1 - \beta(1 - \alpha)]\varphi Y + \beta E_t \pi_{t+1}$. Finally considering $k \equiv \frac{\alpha[1 - (1 - \alpha)\beta]\varphi}{1 - \alpha}$, we have the Calvo's model (1983) Phillips Curve, as described by equation $\pi_t = kY_t + \beta E_t \pi_{t+1}$.

It can be seen from equation 10 that environmental shocks captured in parameter k can have effects on both the real side and the nominal side of the economy. The effects of these shocks on production and

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[20] Details on the mathematical process can be studied in Romer (2012).

prices are not very different from the already known effects of monetary shocks studied by the New Keynesian Phillips Curve of Calvo (1983). A more detailed study of environmental shocks is now of interest. Greater details will be presented further on. However, the described logic in equation (15), is that once an α number of firms produce using inputs from the environment, a pollution shock would mean an increase in firms' costs, a set of firms acts increasing their prices in the period t, another set of firms act to reduce their production to suit their new cost structure.

The demand sides

Once the intertemporal environmental equilibrium curve has been described, it has been found that adverse pollution shocks have an impact on production decisions and prices on the firm. In other words, it has an effect on the economy's real side and monetary side. Now, the understanding of the effects of an environmental shock on the demand side, remains; especially its effects on the nominal rate, the real rate and the investment. In such wise, assuming that consumption and investment decisions are given by families and firms that look ahead, consider the following IS curve forward looking[21]: $Y_t = E_t[Y_{t+1}] - \frac{1}{\sigma} r_t$.

Where $\sigma > 0$. Implications of the IS Curve based on equation, imply that the aggregate product's displacements Y_t may be due to expectation shocks about future income $E_t[Y_{t+1}]$, or even by changes in the real interest rates r_t. For reasons of simplification, the effects of fiscal policy, and even the multiplier effects of environmental tax expenditures G, provided in equation (7). Now consider a Taylor forward looking rule for the interest rate, according to the following format[22]: $r_t = \phi_\pi E_t[\pi_{t+1}] + \phi_y E_t[Y_{t+1}]$.

In which $\phi_\pi > 0$ and $\phi_y \geq 0$. Equation seventeen shows that Central Bank moves the interest by looking at the expected future inflation and also the expected output gap over the natural product. Therefore, it is a Central Bank with a double mandate, whose parameters ϕ_π and ϕ_y show respectively the weight given by monetary authority, economic growth and inflation.

Let's now suppose that the Central Bank adopts an inflation target π_t^T, in this case, every movement of the real interest rate must take place in order to guide this inflation towards the target. Hence, all the matter given by the monetary authority relies on inflation expectations and $\phi_y = 0$. In this case, equation seventeen is rewritten: $r_t = \phi_\pi [E_t[\pi_{t+1}] - \pi_t^T]$.

The monetary rule described by equation (18) indicates that the Central Bank acts by shifting the interest rate when there is an expected inflation shift in relation to the imposed target $E_t[\pi_{t+1}] \neq \pi_t^T$. Substituting, in this way, equation (18) in equation (16) where the IS curve is described, we have: $Y_t = E_t[Y_{t+1}] - \frac{1}{\sigma} \phi_\pi [E_t[\pi_{t+1}] - \pi_t^T]$. By considering $\frac{1}{\sigma} \phi_\pi = b$ equation 20 can be rewritten as: $Y_t = E_t[Y_{t+1}] - b[E_t[\pi_{t+1}] - \pi_t^T]$.

Equation shows the relation of aggregate demand for forward looking, it concludes that the spending decisions in t, are given through the expected income in $t + 1$, as well as the expected changes in general

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[21] IS Curve format as used by Clarida, Galí and Gertler (2000) when proposing the New Keynesian Canonic Model, forward looking.
[22] Format of a New Keynesian Taylor forward looking Rule used, again, by Clarida et al. (2000).

price level in relation to the goal assigned by the Central Bank. If Central Bank was fully credible $E_t[\pi_{t+1}] = \pi_t^T$, in this case expenditures in t would be an exclusive function of expected income in $t + 1$, $Y_t = E_t[Y_{t+1}]$. However, for the time being, the hypothesis of Central Bank's full credibility is disregarded.

The New Keynesyan Environmental Canonic Model

It has been seen that there is no novelty in the deductions made about the forward-looking New Keynesian supply and demand curves; both are already stylized facts of the literature in macroeconomics. Even if the intertemporal environmental equilibrium curve is deduced, this one being this article's great novelty, it is now up to briefly organize the New Keynesian Canonic Model from a system of three equations: $Y_t = E_t[Y_{t+1}] - b[E_t[\pi_{t+1}] - \pi_t^T] + u_t^{IS}$; $\pi_t = kY_t + \beta E_t\pi_{t+1} + u_t^{\pi}$; and $S_t = \gamma[A_{t-1} + \theta\mu + (1 - \theta)G] - (1 - \gamma)e_t + \epsilon_t + u_t^{EE}$. In which the inclusion of the terms u_t^{IS}, u_t^{π} e u_t^{EE} are self-regressive random shocks that can be defined as: $u_t^{IS} = \rho_{IS}u_{t-1}^{IS} + \varepsilon_t^{IS}$; $u_t^{\pi} = \rho_{\pi}u_{t-1}^{\pi} + \varepsilon_t^{\pi}$; and $u_t^{EE} = \rho_{EE}u_{t-1}^{EE} + \varepsilon_t^{EE}$. In which the terms $\varepsilon_t^{IS}, \varepsilon_t^{\pi}$ e ε_t^{EE} are respectively uncorrelated white noise.

The real challenge is to combine physical variables with monetary variables. For a given stock of natural assets S_t, were found to correlate with the general price level by parameter k; since it was noted that this parameter brings together the set of price-fixing firms from the usage of environmental inputs α, as well as the discount factor bearing the present value of these factors' expected price level β. Therefore, adverse shocks in S_t affects the overall price level π_t and also the firms' production Y_t on the supply side. Affecting the price level, agents understand that inflation must shift from the goal $E_t[\pi_{t+1}] \neq \pi_t^T$, On that account, Central Bank should act by moving the interest rate to make it $E_t[\pi_{t+1}] = \pi_t^T$ again. The effects of changes in the stock of natural assets will be seen in greater detail.

Effects of an adverse pollution shock

Considering the New Keynesian Environmental Canonic Model described in equations 22 to 24, a pollution shock e_t, caused, for example, by water contamination[23], would lead to a reduction of environmental assets' stock S_t. Considering that there is a set of α firms which use water as a basic input for their production, water contamination cause firms that fix prices to raise their expectations according to the behavior of the general price level $E_t\pi_{t+1}$ over the period $t + 1$. It was seen by Calvo's New Keynesian supply equation (CALVO, 1983) that, in face of an adverse shock in the future prices' expectations, a set of β firms readjust their prices on t period, while a set of k firms absorbs this costs shock, by simply reducing its production.

The same occurs on the demand side; the agents that decide expenditures observing the expected general level of prices understand from an adverse pollution shock that the general level of prices will be higher than the goal set by the Central Bank $E_t[\pi_{t+1}] > \pi_t^T$; therefore, a b portion of the agents decide to reduce their spending on consumption or investments. Given the fact that the Central Bank decides on

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[23] The water example is quite didactic, since it is a basic input for dozens of productive chains. Water is essential for agricultural production, fish farming, food, beverage, etc.

monetary policy based on the expectation of inflation $E_t\pi_{t+1}$ for the period $t+1$, it acts by raising the real interest rate r_t; an increase in the real interest rate requires, according to Taylor's rule[24] an increase in the nominal interest rate i_t above the rise in the verified inflation. To sum up, the presence of pollution above the ecosystem's resilience capacity, both on the supply side and the demand side, leads the economy, *ceteris paribus*, to a lower level of activity and a higher overall level of prices. The economy converges, at the end of the process, towards a balance of higher nominal and real interest rates.

Effects of a technological shock from institutional changes

Consider now that institutional reforms are put in place in order to encourage the adoption of innovations by companies a_t, and consequently replacing dirty technology with clean technology. This could be due either to market opening in monopolized sectors μ, or to government investment in innovations linked to clean technology G.

As verified, regarding measures of this nature, this would result in an increase in the availability of environmental assets S_t; the energy example can be used here, the substitution of fossil energy by solar or wind energy would lead to an expected fall in the overall energy price. Considering, again, that there is a set of α firms that use energy as a basic input for their production, the diversification of the energy matrix causes price-fixing firms to reduce to reduce their expectations to the general price level's behavior $E_t\pi_{t+1}$ over $t+1$ period. In the view of how this effect on future price expectations β of firms that reduce their prices over the period t, while a set of k firms absorbs this costs shock, simply by raising its production.

As for the demand side, the agents that decide expenditure observing the expected general level of prices understand, from the advance in social technological standard, the energy price will be lower in the future; thus, understanding that the general prices' level will also be lower than the target set by Central Bank $E_t[\pi_{t+1}] < \pi_t^T$; therefore, a portion b of the agents decides to raise their consumption or investment expenditure. Finally, given that the Central Bank decides on monetary policy based on the inflation's expectation $E_t\pi_{t+1}$ for the period $t+1$, it acts reducing the real interest rate r_t; as seen, a real reduction of the interest rate requires, by Taylor's rule, a fall in the nominal interest rate i_t higher than the drop of the verified inflation.

In conclusion, in the presence of institutional factors that encourage innovation, and the exchange of dirty energy for clean energy, we can note that pollutant emissions reduce themselves below the environment's resilience capacity; thus, raising the availability of environmental assets, making them cheaper, leading the economy to a new balance, providing a higher level of economic growth, with stable prices, lower nominal and real interest rates.

FINAL CONSIDERATIONS

The article reached its goal in offering a theoretical model to address the environmental issue, as

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[24] See Taylor (1995).

well as the problem of the environmental assets' scarcity in view of the new scale of economic activities and its influence on society's welfare. The New Keynesian Environmental Canonic Model considers, a dynamic relation of real, nominal and physical variables in its structuring, through three equations that relate the supply side, the demand side and the availability of natural resources existing in the ecosystems. The developed model was based on micro-fundamentals, considering the role of institutional advance through the regulation of market structure and the defense of competition, also through an active public policy, to create and diffuse innovations with the aim of reducing pollution levels.

The New Keynesian Environmental Canonic Model inverts the logic of the IS-LM-EE macroeconomic model of Heyes (2000), if economic growth was a necessary condition for a greater preservation of the environment on Heyes' model; here instead, a greater environmental preservation is a mandatory condition for a balanced growth trajectory with low inflation. It was verified with the deduction of the three equations, that a higher pollution level has undesirable macroeconomic consequences, similar to those of a traditional supply shock on the economy, which is characterized by the reduction of production, rising inflation as well as both real and nominal interest rates. In other words, pollution is inflationary, since it exacerbates the problem of natural resources' scarcity.

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