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Deforestation and environmental policy: A DSGE approach

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**DEFORESTATION AND ENVIRONMENTAL
POLICY: A DSGE APPROACH**

**Rodrigo Mendes Pereira
Geraldo Sandoval Góes**

DISCUSSION PAPER



DEFORESTATION AND ENVIRONMENTAL POLICY: A DSGE APPROACH¹

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DISCUSSION PAPER

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ABSTRACT

This paper proposes an environmental DSGE model with deforestation of a tropical rain forest. The forest can be used to produce goods, but it also affects the well-being of the representative individual. Environmental policy is implemented with the taxation of the deforestation activity. We calibrate the model for the Brazilian economy, and show that it predicts a procyclical deforestation, and that a more stringent policy reduces the volatility of deforestation. Moreover, technological progress decreases the stock of forest, and it does so more intensely with a lenient environmental policy.

Keywords: deforestation; real business cycle; environmental policy; DSGE.

1 INTRODUCTION

The deforestation of tropical rainforests is a major issue in the modern environmental policy debate. They concentrate most of the planet's biodiversity, and unlike other types of forests, their natural rate of regeneration is fairly low. That makes a rainforest an almost non-renewable resource, and deforestation an almost irreversible process. In fact, the evidence shows that it may take up to 80 years for a secondary tropical rainforest to accumulate at least as many species as mature forests (Brown and Lugo, 1990; Finegan, 1996). The best way to design policies that preserve these forests would be to understand what causes deforestation. An extensive empirical literature dedicated to answer that question has been developed through the years by virtue of a good availability of satellite deforestation data in places such as the Brazilian Amazon. A lot less attention, however, has been given to analyzing how economic fluctuations may interact with deforestation in particular, and with environmental variables in general. A booming economy going through technological advancements will most certainly demand more deforestation, considering that the forest provides important inputs to the production of goods. As individuals get richer, they demand more goods but also more leisure time, and more environmental quality. Which in this case means less deforestation. So, it is important to understand how this interaction takes place, and how environmental policy can affect optimal outcomes.

This paper focuses on how business cycles affect the deforestation of tropical rainforests. Essentially, deforestation is carried out in order to enable the productive use of land and/or wood. In both cases, a permanent removal of the trees and bushes gives rise to a production input. We simply name this input as deforestation. It is a flow that, together with a natural regeneration rate of the forest, entails a forest stock loss process. The dynamics is similar to capital build up through investment, except that in this case there is typically a loss of stock rather than an accumulation.

We build a dynamic stochastic general equilibrium model in which the forest is used in the production of goods. It is a Robinson Crusoe economy, so a representative household also owns the representative firm. This individual is happier with more consumption, but also cares about the environment, deriving a direct negative utility whenever deforestation occurs. So, the individual faces these two opposite effects and optimally chooses a deforestation path, in line with the process of choosing optimal

labor supply. What would otherwise be an external effect, in this one-individual economy becomes internalized, since the individual himself suffers the environmental consequences of his own choices. The model assumes a government that has its own idiosyncratic beliefs about the forest, materialized in two fiscal/environmental rules. These rules establish dynamic structures for the taxation of consumption and deforestation, and their parameter values represent the environmental policy. The policy here is not designed to fix market failures, but rather to conform with the government's benevolent beliefs of what is better for the individual. The model is calibrated to the Brazilian economy. It is driven by productivity, preferences and environmental/fiscal policy shocks. It cannot be solved algebraically, so we numerically solve it for the dynamic optimal deforestation, consumption, output, investment, and forest stock, under different environmental/fiscal policies.

The real business cycle (RBC) modelling approach has been widely used in many areas of economic research since its inception in the early 1980's. More recently a number of studies have introduced environmental issues in RBC models. Fischer and Springborn (2011) compare the effects of productivity shocks under different environmental policies towards emissions within an RBC framework. They conclude that intensity targets maintain higher levels of labor, capital and output, and so are more desirable than emission caps, or taxation. Heutel (2012) also introduces emissions and environmental policy in an RBC model. He finds that the optimal paths for tax or quota policies are procyclical. Heutel (2012) shows that a price effect dominates an opposite income effect, rendering procyclical emissions. And this procyclicality would only be higher on an unregulated economy.

Following Fischer and Springborn (2011) and Heutel (2012) pioneer works, a small environmental RBC literature begun to take shape, usually by expanding the basic emissions RBC model in different directions. For example, Annicchiarico and Di Dio (2015) introduce new Keynesian style price rigidities. They show that the optimal environmental policy depends on the degree of price rigidity, as well as on monetary policy. Environmental uncertainty is another important aspect to be considered in this class of models. It was highlighted by Angelopoulos, Economides and Philippopoulos (2013). These authors insert a shock to how emissions relate to output in an RBC framework. They also introduce a government that creates pollution abatement. Vasilev (2018) extends Angelopoulos, Economides and Philippopoulos (2013) by

establishing a more detailed government sector, and then calibrating the model to the Bulgarian economy. Dissou and Karnizova (2016) also introduce pollution into an RBC model. Unlike previous papers, they disaggregate the economy into multiple sectors, with multiple sector-specific productivity shocks. They also compare tax and cap policies, and find that the better policy is dependent upon the source of the shock.

This paper differs from all the previous environmental RBC models in one important aspect. The environmental variable is not greenhouse gas emissions, but rather the level of deforestation. Unlike emissions data, that have to rely on complex estimates,¹ deforestation data is rather precise, gathered through satellite technology, and widely available. Besides, deforestation may be a more pressing environmental issue than emissions in countries endowed with large rain forests. We propose an RBC model with a forest stock, deforestation, and a government that implements environmental policy through taxation. The model is driven by four types of stochastic shocks: Technological, shocks in preferences, and shocks in the taxation of consumption and deforestation. We set up the model with two different types of environmental policy. A stringent policy, in which the tax rate on the deforestation activity is highly sensitive to the level of deforestation. And a loose policy, in which taxes are only slightly adjusted to changes in deforestation. We show that deforestation is procyclical, that the degree of policy stringency reduces the volatility (as well as procyclicality) of deforestation, and that in the presence of constant technological improvements the more stringent policy does a better job in preserving the forest.

The rest of the paper is organized as follows. Section 2 presents a stylized DSGE model of deforestation. Section 3 discusses the fiscal and environmental rules adopted by the government. Section 4 discusses the steady-state equilibrium and calibrates the model for the Brazilian economy. Section 5 presents the main results under our benchmark economy, which has a lenient environmental policy. Section 6 puts in place a pro-environment government, and shows how the model behaves with a more stringent policy. Section 7 concludes the paper.

1. Estimates are based on fossil fuel production and on a stable carbon isotopic signature account (Andres, Boden and Marland, 2017; Doda, 2014).

2 A DSGE MODEL OF DEFORESTATION

We assume an economy that is inhabited by an infinitely lived representative household, who produces and consumes a single final good. The household derives utility from the consumption of the good, C_t , and from his leisure, which is related to the amount of labor supplied to produce the good, N_t . Moreover, the household cares about the environment, and loses utility whenever the stock of forest, F_t , suffers deforestation D_t . We assume a linear functional form for the utility function, which is in line with a large portion of the RBC literature. So, the household maximizes the present value of the following intertemporal flow of utility

$$U = \sum_{t=0}^{\infty} \beta^t \left\{ \frac{[(1-\tau_t^C)C_t]^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\rho}}{1+\rho} - A_{1t} \frac{D_t^{1+\phi}}{1+\phi} \right\} \quad (1)$$

Where β is a time discount factor, σ , ρ and ϕ are parameters, and A_{1t} stands for a stochastic preference term, which essentially captures changes in the household's evaluation of the forest's importance to his well-being. In order to model environmental policy, our framework must include a government. So we assume a government that spends G_t of the final good, and taxes consumption at the rate of τ_t^C and deforestation at the rate of τ_t^D . The government runs a balanced budget at each point in time, so that²

$$G_t = \tau_t^C C_t + \tau_t^D D_t \quad (2)$$

The technology in this economy is a Cobb-Douglass function with constant returns to scale, in which the production of the good depends on the capital stock K_t , on labor hours N_t , and on deforestation D_t . There is also a stochastic technology shock A_{2t} , traditionally an important element to drive RBC models.

$$Y_t = A_{2t} K_t^{\alpha_1} N_t^{\alpha_2} [(1 - \tau_t^D) D_t]^{(1-\alpha_1-\alpha_2)} \quad (3)$$

2. Variables such as deforestation D_t and the forest stock F_t are usually measured in a spacial unit (square kilometers, acres etc). Here they should be thought of in terms of their monetary value. Or, alternatively, in terms of units of the final good, in the absence of a currency.

Where α_1 and α_2 are the shares of capital and labor on the aggregate income, respectively. Government expenditures are simply a necessary waste of resources, since they do not affect the household's utility nor the marginal productivity of inputs in the Cobb-Douglass production function. The resources from deforestation D_t can be interpreted as an intermediate good, used as an input in the production of the final good. We assume that deforestation depletes the forest stock, but it is otherwise costless in terms of labor and capital. So, the forest is there, free for the taking, and it can be harvested with no costs other than the loss of utility due to the deforestation. Hence, the output Y_t of this economy is the total production of the final good, that can be used for consumption, investment, or can be spent by the government.

$$Y_t = C_t + I_t + G_t \quad (4)$$

We consider here a closed economy.³ Consumption in the utility function and deforestation in the production function are discounted of their respective tax rates. The preference and technology terms follow standard AR (1) processes given by

$$A_{1t} = A_{1t-1}^{\gamma_1} \exp(\pi + \varepsilon_{1t}) \quad (5)$$

$$A_{2t} = A_{2t-1}^{\gamma_2} \exp(\varepsilon_{2t}) \quad (6)$$

Where ε_{1t} and ε_{2t} are white noise processes. The positive constant π in the preference process has the role of guaranteeing that the effect of deforestation on the individual's utility is unidirectional, not having its sign changed constantly. The accumulation of capital and forest takes place according to the following equations

$$K_{t+1} = (1 - \delta) K_t + I_t \quad (7)$$

3. Open economy aspects of these types of models have just recently been addressed in the literature. Annicchiarico and Diluiso (2019) propose a two-country environmental Dynamic Stochastic General Equilibrium (DSGE) framework. They analyze the international effect of shocks under different emission regulations.

$$F_{t+1} = (1 + r)F_t - D_t \quad (8)$$

Where δ and r are respectively the depreciation rate of capital, and the regeneration rate of the forest. A few aspects are worth mentioning about these two variables. Capital stock and forest stock are the two predetermined variables in the model. They do not jump instantly to shocks, like every other variable in the model (the jump variables), because their values in, say, time t are already defined by what happened in time $t - 1$. There is however a key difference in the way we are modelling these two variables. Capital stock is intrinsically stable, with a root smaller than one. Forest stock is unstable, with a root higher than one. It is all obvious though that in nature forests do not grow exponentially out of control. If left alone, they expand until eventually they face restrictions of land, soil, climate, etc. So, ideally forest expansion should be modelled with some non-linear difference equation, in which the natural rate of forest expansion would depend on the current size of the forest. In any case, with $1 + r$ higher than one, and the dynamics of F_t explosive, if we use that equation in the model, Blanchard-Khan stability conditions would not be satisfied, and we may have some kind of indeterminacy.

There are two alternatives to analyze a determinate model. One would be to set a negative, but very close to zero value to the parameter r . For all practical purposes, tropical rain forests take so long to regenerate, that a zero r may be an acceptable simplifying assumption. In fact, INPE (*Instituto Nacional de Pesquisas Espaciais*), the institute that gathers the official deforestation data in the Brazilian Amazon, considers a zero forest regeneration rate in their measurements.⁴ The other alternative to analyze a determinate model is simply to exclude the variable forest stock, along with equation (8) from the model. This is possible only in a setup in which F_t does not appear in any other equation of the model other than its own difference equation (8). We then solve the model without F_t , and once an optimal path for D_t is obtained, the optimal path for F_t comes residually from (8), and the definition of an initial value F_0 . We can consider the flow of deforestation and the stock of forest as expressed in units of the final good, as the other variables in the model (see footnote 2). There is no

4. INPE collects annual data of cleared areas in the Amazon forest. Deforestation is then the first difference of this data. Areas that are cleared in a certain year are not even assessed again, they are considered as permanently deforested.

currency or prices, so we can easily assume a unitary relative price between the unit of deforestation, and the unit of the final good.

3 FISCAL/ENVIRONMENTAL RULES

Fiscal rules are a standard feature of DSGE models with government. For the most part they model tax rates and government expenditures as processes with autoregressive components, stochastic shocks, and some additional features that replicate some public finance stylized facts. For example, a tax rate fiscal rule may include a measure of debt/Gross Domestic Product – GDP ratio (Bi and Traum, 2012), capturing an implicit effort from governments to raise revenue whenever their indebtedness increase, guaranteeing fiscal sustainability. An expenditure fiscal rule may include lagged GDP, capturing a countercyclical fiscal policy, or even a procyclical one, which is a more prevalent feature of less developed economies (Alesina, Tabellini and Campante, 2008; Bi, Shen and Yang, 2016).

With the government running balanced budgets at all times, our focus is not the government solvency, sovereign debt defaults, or any other fiscal policy issues. Indeed what would otherwise be a pure fiscal rule, in our model can be interpreted as an environmental rule. By that means, the government adjusts environmental taxes to changes in the level of deforestation. The parameter capturing how intense is the adjustment is the essence of the environmental policy. With a stringent policy, adopted by a government that values the environment, a slight increase in deforestation spurs a large tax raise. An anti-environment government, on the other hand, would choose a loose environmental policy, in which increases in the deforestation would have a very mild response in terms of tax increases.

In this one-individual economy there is no externality associated with deforestation, so resources would be allocated efficiently without any government intervention, and the equilibrium would be optimal. The government, however, can change the optimal paths of all the key variables through taxation of consumption and deforestation. The reason as to why the government would change an allocation that is already optimal has to do with its own idiosyncratic beliefs, which are embedded in the fiscal and environmental rules.

We assume two rules for the the two tax rates in the economy, τ^D and τ^C . They all have an autoregressive component, and a stochastic shock. We assume that the deforestation tax depends on the deforestation, and that the consumption tax depends on the consumption. The idea is that an environmentally-coscious government feels uncomfortable whenever deforestation increases. The response then is to increase taxation. How uncomfortable the government feels determines the magnitude of the response, and the degree of policy stringency. Similarly, if deforestation falls, the government reduces taxation. A similar mechanism happens with the taxes on consumption, and the consumption level. So, the two rules are given by

$$\tau_t^D = (\tau_{t-1}^D)^\theta (D_t)^\lambda \exp(\Omega + \varepsilon_{3t}) \quad (9)$$

$$\tau_t^C = (\tau_{t-1}^C)^\mu (C_t)^\nu \exp(\varepsilon_{4t}) \quad (10)$$

Where ε_{3t} and ε_{4t} are white noise shocks. They are stochastic disturbances to idiosyncratic rules set by the government. Fiscal rules similar to equations (9) and (10) are standard features of DSGE models with government (see, for example, Bi, Shen e Yang, 2016; Pereira, 2019). Fiscal rules usually define tax rate paths that depend on government expenditures, and guarantee fiscal sustainability in models in which the government can run deficits. In our case, with permanent balanced budgets, the fiscal rules are better interpreted as simply environmental rules. Essentially if parameters λ and ν are positive, the government raises deforestation and consumption tax rates as a response to increases in deforestation and consumption levels, respectively. So, environmental policy in this model is related to the magnitudes of parameters λ and ν . λ captures how stringent is the tax response to an undesirable level of deforestation. ν has a similar interpretation, but for consumption.

The representative individual in this economy maximizes the present value of his expected flow of utilities (1), subject to the government budget (2), the technology (3), the resouces constraint (4), and the capital accumulation rule (7). We have a dynamic structure with non-linear equations that cannot be solved algebraically. Following the standard practice in DSGE models, we define a steady-state for the model, and

provided it satisfies Blanchard-Khan condition for stability, we log-linearize it around this steady-state. After that we solve it numerically, analyzing impulse responses to the four types of shocks present in the model.

4 CALIBRATION AND THE STEADY STATE

In this section we define a suitable steady state equilibrium around which the model will be log-linearized. In defining this steady-state we also calibrate some parameters of the model to the Brazilian economy. Ideally we would obtain a steady state by solving a system of 10 non-linear equations and 10 steady-state variables ($\bar{K}; \bar{Y}; \bar{C}; \bar{N}; \bar{D}; \bar{G}; \bar{I}; \bar{\tau}^C; \bar{\tau}^D \bar{F}$). That strategy has a drawback. The non-linearities tend to generate equilibriums with complex numbers that are hard to interpret.⁵ So we exogenously defined steady-state values for some variables that we know would be consistent with a long-run equilibrium for the Brazilian economy. And then we obtained some parameter values endogenously.

The parameter values used for calibration are summarized in table 1. The discount factor β is set at 0.92, consistent with a quarterly interest rate of 2.1 percent (8.7 percent per year), which is very close to the recent historical average of real interest rates practiced in the Brazilian economy. This is also in line with the values used by other authors in DSGE models calibrated to Brazil (Castro *et al.*, 2015). Capital is a lot more expensive and labor is a lot cheaper in Brazil, as compared to developed economies. Hence, the usual split of aggregate income of 30 percent accruing to capital and 70 percent is not realistic. A higher share for capital is a more plausible assumption in this case. In our model there is an additional share of the income that goes to the deforestation activity.⁶ We set an economy with capital and labor shares with the values of 0.425 and 0.525 respectively. With constant returns to scale, a share of 0.05 goes to deforestation.

5. We tried to solve the system with several combinations of parameter values using matlab's "fsolve" command, and in all the attempts we obtained complex numbers as part of the solution.

6. We assume that deforestation is free of production costs, but in this Robinson Crusoe economy it is associated with other types of costs. It negatively affects the individual's utility. And it is nearly a non-renewable resource. All of that prevents the existence of an equilibrium with total instant use of the forest stock.

In this paper the time unit considered is the year. That is because we have Amazon deforestation data as a reference, which always consists of annual observations. The presence of clouds in rainy seasons render higher frequency satellite observations unusable. So, capital stock depreciation is set at 0.1., and forest's regeneration rate is set at 0.0087. With that number one unit of forest becomes approximately two in 100 years. Parameters σ , ρ , and ϕ , which capture the inverse of the intertemporal elasticity of substitution of consumption, labor and deforestation, respectively, are set to 0.85, 1, and 1. Brazil's tax burden ranges around 32 percent of GDP. So, the steady-state tax rate of consumption and deforestation are set to 0.32. The steady-state consumption/output ratio is set to 0.57, which is consistent with the share in Brazil.

This way of defining the steady-state makes some parameter values endogenously linked with others. So they cannot be freely set up, and only certain combinations of parameters produce acceptable steady-states. Specifically, on the consumption tax rate rule, once we set the AR coefficient, μ , we have a unique possible value for the policy parameter ν , that captures how the taxes on consumption vary with the consumption/output ratio. In fact the relation exists between the mean of the AR process (which depends on the AR parameter) and the policy parameter. The same happens in the environmental rule. Since the environmental policy is one of the key elements of our analysis, it would not make sense to let it be endogenously determined. So, in order to avoid that we introduce a constant parameter Ω . The idea is to free both the AR coefficient θ and the policy parameter λ to be set exogenously in the steady-state. So now we can set θ to a regular 0.9, and still analyze the effects of different environmental policies. The constant Ω would then be adjusted endogenously. First we assume a very loose policy, in which the government raises deforestation taxes very mildly in response to an increase in deforestation. That is captured by a value of 0.05 for parameter λ . We name the government that adopts this policy an anti-environment government. In contrast, we later choose a high value for λ , a policy likely to be implemented by a more environmentally-driven government. Then we compare how the model behaves under each of these two opposing environmental policies.

TABLE 1
Calibrated parameters and steady-state relations

| Parameter | Meaning | Value |
|---------------------------------|-----------------------------|--------|
| α_1 | Capital share | 0.425 |
| α_2 | Labor share | 0.525 |
| β | Time disc. factor | 0.92 |
| δ | Depreciation rate | 0.1 |
| σ | Intert. elast. subst. cons. | 0.85 |
| ρ | Intert. elast. subst. labor | 1 |
| ϕ | Intert. elast. subst. def. | 1 |
| θ | Def. tax rule AR coef. | 0.9 |
| λ | Env. policy parameter | 0.05 |
| μ | Cons. tax rule AR coef. | 0.9 |
| ρ | Forest regeneration rate | 0.0087 |
| $s_c = \frac{\bar{C}}{\bar{Y}}$ | S.s. cons. output ratio | 0.57 |
| $\bar{\tau}^D$ | S.s. def. tax | 0.32 |
| $\bar{\tau}^C$ | S.s. cons. tax | 0.32 |

Elaborated by the authors.

Once the values of table 1 are inserted in the model, we get the values of parameters and steady-state relations that are endogenously defined. They also need to be consistent with the values observed in the real economy. The values are presented in table 2.

TABLE 2
Values of endogenously defined parameters

| Parameter | Meaning | Value |
|---------------------------------|-----------------------------|--------|
| $s_k = \frac{\bar{K}}{\bar{Y}}$ | S.s. cap./output ratio | 2.27 |
| $s_i = \frac{\bar{I}}{\bar{Y}}$ | S.s. inv./output ratio | 0.227 |
| $s_g = \frac{\bar{G}}{\bar{Y}}$ | S.s. gov. exp./output ratio | 0.203 |
| $s_D = \frac{\bar{D}}{\bar{Y}}$ | S.s. def./output ratio | 0.063 |
| $s_F = \frac{\bar{F}}{\bar{Y}}$ | S.s. forest/output ratio | 7.28 |
| ν | Cons. tax policy parameter | 0.2027 |
| Ω | Env. rule constant | 0.024 |

Elaborated by the authors.

5 RESULTS FOR THE BENCHMARK ECONOMY

This section analyzes how the model performs in terms of the moments of the key macroeconomic variables, and also in terms of responses to shocks.

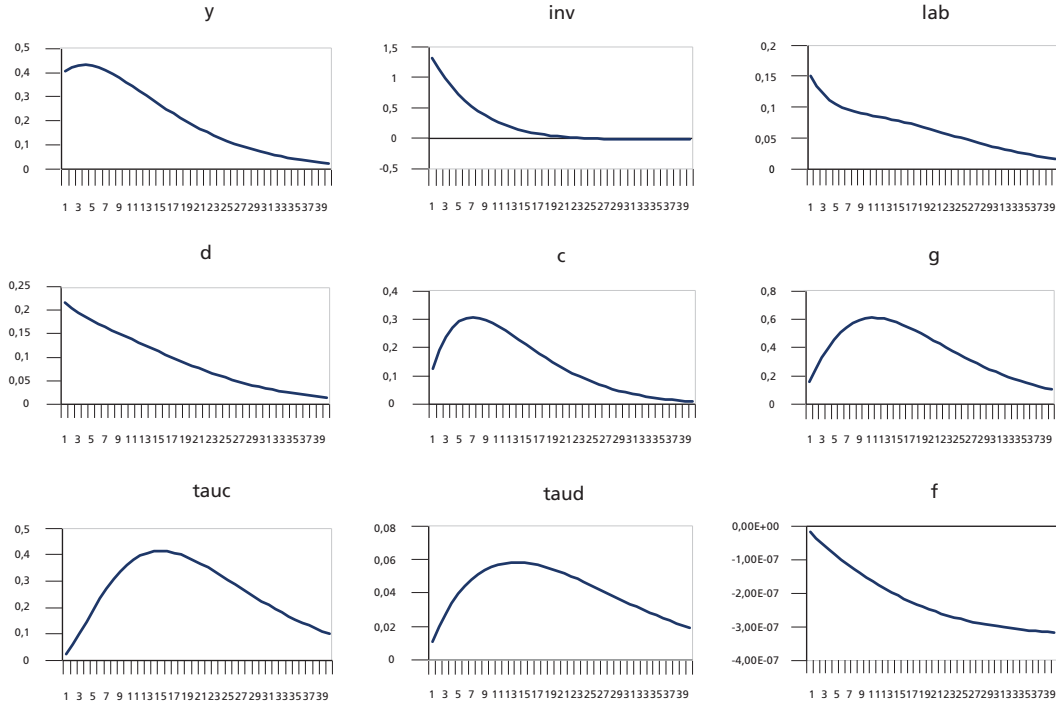
First we present the Impulse Response Functions (IRF) for our benchmark economy, in which the government's environmental policy is weak. The policy parameter λ is set to 0.05. Figure 1 presents the model's impulse responses to a one time technology shock with the magnitude of one standard deviation. Goods are now produced more effortlessly, so there is the traditional instantaneous jump in output. Also, it is worth sacrificing a little more of leisure time, and of the forest stock to produce more goods. There is then instantaneous jumps in labor hours, investment and deforestation. More output means more availability of resources not only for investment, but also for consumption. So we observe a well-known jump in consumption followed by a hump-shaped trajectory. There is only a small increase in the deforestation tax, due to the loose environmental policy implemented by the government. As such, that policy is not enough to curb deforestation, and what we observe is a relatively large jump in deforestation, and a higher drop of the forest stock.

We chose to use levels of D_t and C_t on the government rules, rather than the more usual shares of output. So, the deforestation tax depends on the deforestation level, instead of the share deforestation/output. This share is usually reduced with a positive shock in technology, because output increases more intensely than deforestation. Results would then be different, had the shares been used. With technological progress, for example, deforestation increases, but the share deforestation/output decreases. That would trigger a reduction rather than an increase in deforestation taxes. And the higher is the value of λ , the more intense is the tax decrease, and the larger is the environmental damage. So it would either be the case that the policy is poorly designed, with a higher stringency causing more deforestation, or that the idea of stringency should be reinterpreted. In order to avoid these issues, we decided to just use the variables in levels.

Similarly, for the consumption rule the tax rate depends on the consumption level, rather than on the share consumption/output. So, with a positive technological shock, the jump in consumption is followed by a jump in consumption taxes. Consumption

becomes less volatile than it would otherwise be. Also, because governments are running balanced budgets, the extra revenues from taxation have to be matched by a higher level of government expenditures. So, G_t is procyclical, and has a hump-shaped pattern similar to consumption.

FIGURE 1
IRF to a technology shock (anti-environment government)

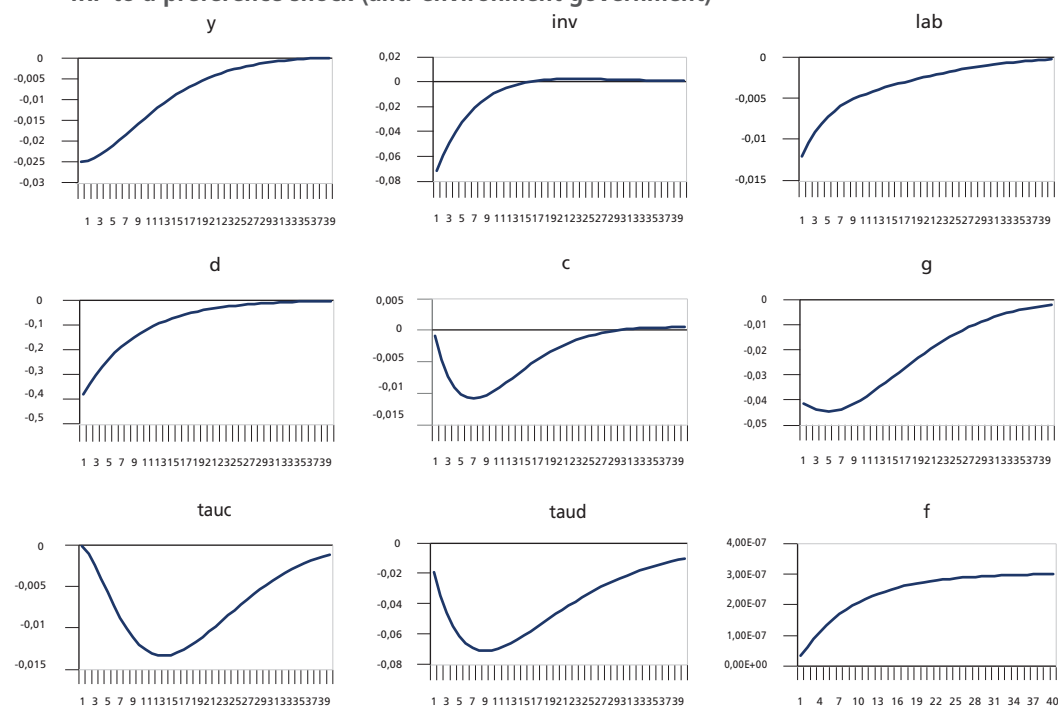


Elaborated by the authors.

Figure 2 presents the model's impulse responses to a one time preference shock with the magnitude of one standard deviation. It is a positive shock that increases the term A_1 in the utility function. So, deforestation affects the individual more intensely. He becomes more unhappy at every level of deforestation, and of course more willing to trade less deforestation for less consumption of goods and/or less leisure time. The shock produces an instantaneous fall in deforestation, with a fall in output, investment, and labor hours. Consumption is also reduced, with an inverse hump-shaped trajectory. With less deforestation the stock of forest begins to increase. The tax rates on consumption and deforestation are reduced. The decrease in revenues forces the government to cut expenditures in order to keep the budget balanced.

With a mild environmental policy, the deforestation tax is only slightly reduced. The loss of revenues are tiny, and so the necessary adjustment in government expenditures to keep the budget balanced is also small. This small drop in G_t releases resources for C_t and I_t , however not enough to compensate for the effects of the fall in output. The positive preference shock towards more environmental quality causes a higher drop in deforestation (and a higher level of convergence of the forest stock) with the loose environmental policy than they would with a more stringent policy.

FIGURE 2
IRF to a preference shock (anti-environment government)



Elaborated by the authors.

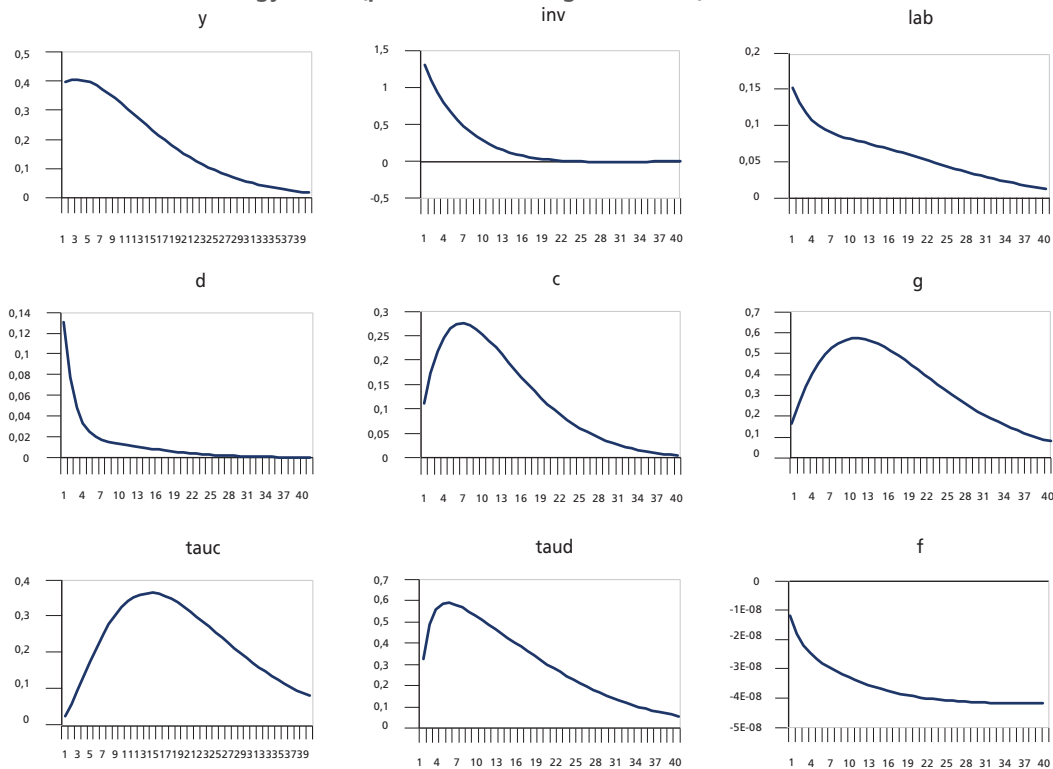
6 A PRO-ENVIRONMENT GOVERNMENT

A pro-environment government has a high concern with the deforestation, and then adopts a stringent environmental policy. That policy is carried out by setting a high value for parameter λ . So, whenever deforestation goes up, the government increases the deforestation tax by a large magnitude, making it a relatively more expensive input in the production function, encouraging its substitution for labor and capital. We make

$\lambda = 2.5$, way above the 0.05 of the previous exercise. That has an impact of raising the mean of the autoregressive process defining the path of τ^D . That mean depends on the constant Ω and on the AR parameter θ . Since θ is fixed at 0.9, the parameter Ω is endogenously changed from the value of 0.024 in the previous exercise with an anti-environment government to a new value of 6.783.

The impulse response functions for this experiment are presented in figure 3. Once again, there is a one time jump in the technological shock with a magnitude of one standard deviation. The initial jump in deforestation is now half of what it was with a loose environmental policy. And the decay process is much faster. Another striking difference between figures 3 and 1 is the jump in deforestation tax, that is about ten times more intense with the stringent environmental policy. Not surprisingly, the more stringent policy is capable of saving quite a lot of forest, if compared to the loose policy of figure 1. As displayed on the forest stock graph, the convergence occurs now on a higher level of forest.

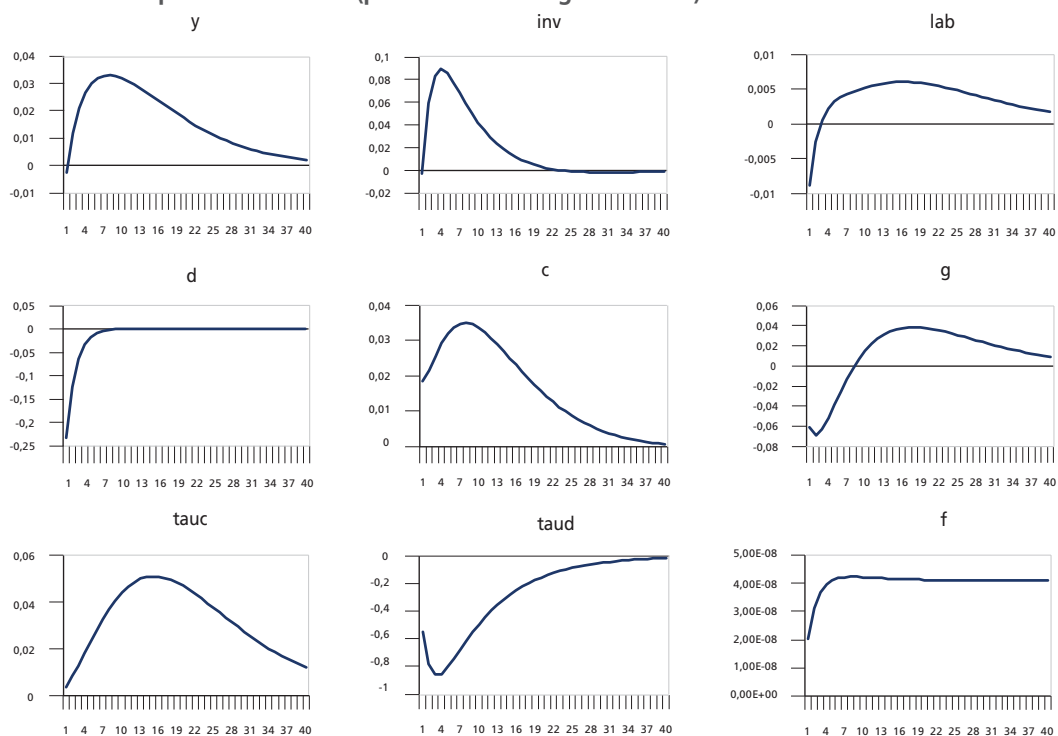
FIGURE 3
IRF to a technology shock (pro-environment government)



Elaborated by the authors.

Figure 4 showcases the impulse response functions of a one time preference shock, with one standard deviation. The comparison of figures 4 and 2 reveals how the two opposing policies can generate different transitional dynamics. Here, the balanced budget plays an important role. With the stringent policy of figure 4, the tax rate is highly sensitive to the level of deforestation. Deforestation falls as the individual suddenly becomes more upset about it, with an exogenous change in tastes. The tax rate receives a big cut (about ten times more intense than with a loose policy). The revenue reduction forces an initial drop in government expenditures such that the budget is kept balanced. A lower G_t sets free resources for higher levels of consumption and investment. So, unlike the previous case of a loose policy, now consumption and investment increase, in the event of a positive preference shock. Labor hours have an initial drop, but quickly move up, as output goes up to match the higher levels of consumption and investment. The fall in deforestation is less intense and the forest stock converges to a lower level, as compared to the previous case with a loose environmental policy. With any kind of shock, a faster response of taxation clearly reduces the volatility of deforestation.

FIGURE 4
IRF to a preference shock (pro-environment government)



Elaborated by the authors.

7 CONCLUSION

The deforestation of tropical rain forests is a major concern in a number of countries endowed with such biomes. Once a rain forest is depleted, it cannot be easily regenerated due to the loss of biodiversity.

In this paper we investigated how economic fluctuations may interact with this type of deforestation. We modeled it within the framework of a widely used macroeconomic tool: a dynamic stochastic general equilibrium model. We outlined an economy in which deforestation is used to produce goods, but also leaves the environmentally-conscious representative individual unhappy. It is a Robinson Crusoe type of economy in which this individual is also the producer, consumer and deforester. By maximizing his utility he chooses an optimal path of deforestation.

What sets our work apart from the previous environmental macro literature is that we use deforestation rather than greenhouse gas emissions as our fundamental variable. Greenhouse gas emissions are essentially indissociable from the concept of externality and market failure. Our underlying idea, nonetheless, is based on the depletion of an (almost) non-renewable resource, which we believe is a better description of the deforestation issue, as compared to the traditional externality approach.

The economy has a government that designs an environmental policy with taxes on the deforestation activity. By taxing the economy the government changes resource allocation based on its own idiosyncratic beliefs of what is optimal for the individual (the government knows better). The degree of policy stringency is captured by how intensely taxes are adjusted to changes in the level of deforestation.

The model was calibrated for the Brazilian economy. It predicts a procyclical deforestation. In the presence of continued technological progress the forest stock is repeatedly shortened. Deforestation in this case is higher with a more lenient environmental policy. In the presence of a repeated change in tastes towards more environmental quality, deforestation is reduced and the forest stock converges to a higher level. However, in this case the intensity of the reduction in deforestation and increase in forest stock vary inversely with the degree of policy stringency. So a loose policy would actually do better for the environment. All of these scenarios are based on the finding that a more stringent policy reduces the volatility of deforestation.

REFERENCES

- ALESINA, A.; TABELLINI, G.; CAMPANTE, F. Why is fiscal policy often procyclical? **Journal of the European Economic Association**, v. 6, n. 5, p. 1006-1036, 2008.
- ANDRES, R. J.; BODEN, T. A.; MARLAND, G. Annual fossil-fuel CO₂ emissions: global stable carbon isotopic signature. **Carbon Dioxide Information Analysis Center**, 2017.
- ANGELOPOULOS, K.; ECONOMIDES, G.; PHILIPPOPOULOS, A. First-and second-best allocations under economic and environmental uncertainty. **International Tax and Public Finance**, v. 20, n. 3, p. 360-380, June 2013.
- ANNICCHIARICO, B.; Di Dio, F. Environmental policy and macroeconomic dynamics in a new Keynesian model. **Journal of Environmental Economics and Management**, v. 69, p. 1-21, Jan. 2015.
- ANNICCHIARICO, B.; DILUISO, F. International transmission of the business cycle and environmental policy. **Resource and Energy Economics**, v. 58, Nov. 2019.
- BI, H.; SHEN, W.; YANG, S. S. Fiscal limits in developing countries: a DSGE approach. **Journal of Macroeconomics**, v. 49, p. 119-130, 2016.
- BI, H.; TRAUM, N. Empirical approaches to sovereign debt default and monetary-fiscal interactions: estimating sovereign default risk. **American Economic Review: Papers and Proceedings**, v. 103, n. 2, p. 161-166, 2012.
- BROWN, S.; LUGO, A. E. Tropical secondary forests. **Journal of Tropical Ecology**, v. 6, n. 1, p. 1-32, 1990.
- CASTRO, M. R. de. *et al.* SAMBA: Stochastic Analytical Model with a Bayesian Approach. **Brazilian Review of Econometrics**, v. 35, n. 2, 2015.
- DISSOU, Y.; KARNIZOVA, L. Emissions cap or emissions tax? A multi-sector business cycle analysis. **Journal of Environmental Economics and Management**, v. 79, p. 169-188, 2016.
- DODA, B. Evidence on business cycles and CO₂ emissions. **Journal of Macroeconomics**, v. 40, p. 214-227, 2014.
- FINEGAN, B. Pattern and process in neotropical secondary rain forests: the first 100 years of succession. **Trends in Ecology and Evolution**, v. 11, n. 3, p. 119-224, 1996.
- FISCHER, C.; SPRINGBORN, M. Emissions targets and the real business cycle: intensity targets versus caps on taxes. **Journal of Environmental Economics and Management**, v. 62, n. 3, p. 352-366, 2011.
- HEUTEL, G. How should environmental policy respond to business cycle? Optimal policy under persistent productivity shocks. **Review of Economic Dynamics**, v. 15, n. 2, p. 244-264, 2012.

PEREIRA, R. **Estimating a simple fiscal policy DSGE model for Brazil**. Brasília: Ipea, 2019.

VASILEV, A. A real-business-cycle model with pollution and environmental taxation: the case of Bulgaria. **Journal of Environmental Economics and Policy**, v. 7, n. 4, p. 441-451, 2018.

COMPLEMENTARY BIBLIOGRAPHY

CHANG, J. *et al.* Optimal tax policy, market imperfections, and environmental externalities in a dynamic optimizing macro model. **Journal of Public Economic Theory**, v. 11, n. 4, p. 623-651, 2009.

FISCHER, C.; HEUTEL, G. Environmental macroeconomics: environmental policy, business cycles, and directed technical change. **Annual Review of Resource Economics**, v. 5, n. 1, p. 197-210, 2013.

HOFER, R. A.; MIKHAIL, O. Beyond backyard environmentalism: a stochastic dynamic general equilibrium approach to environmental quality. **University of Central Florida**, 2002. Mimeografado.

APPENDIX

In this appendix we present the model's solution strategy. The representative household maximizes (1) subject to restrictions (2), (3), (4) and (7). The Lagrangean for this constrained utility maximization is given by

$$\begin{aligned} \mathcal{L} = \sum_{t=0}^{\infty} \beta^t \{ & \frac{[(1 - \tau_t^C)C_t]^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\rho}}{1+\rho} - A_{1t} \frac{D_t^{1+\phi}}{1+\phi} - A_t[C_t + K_{t+1} \\ & - (1 - \delta)K_t + \tau_t^C C_t + \tau_t^D D_t - A_{2t}K_t^{\alpha_1} N_t^{\alpha_2} [(1 - \tau_t^D)D_t]^{1-\alpha_1-\alpha_2}] \} \end{aligned} \quad (11)$$

The first order conditions for optimality are given by

$$\Lambda_t = \frac{(1 - \tau_t^C)^{1-\sigma} C_t^{-\sigma}}{1 + \tau_t^C} \quad (12)$$

$$N_t^\rho = \Lambda_t \alpha_2 A_{2t} K_t^{\alpha_1} N_t^{\alpha_2-1} [(1 - \tau_t^D)D_t]^{(1-\alpha_1-\alpha_2)} \quad (13)$$

$$\Lambda_t = \beta E_t \{ \Lambda_{t+1} [(1 - \delta) + \alpha_1 A_{2t+1} K_{t+1}^{\alpha_1-1} N_{t+1}^{\alpha_2} [(1 - \tau_{t+1}^D)D_{t+1}]^{1-\alpha_1-\alpha_2}] \} \quad (14)$$

$$A_{1t} D_t^\rho = \Lambda_t [(1 - \alpha_1 - \alpha_2) A_{2t} K_t^{\alpha_1} N_t^{\alpha_2} [(1 - \tau_t^D)D_t]^{-\alpha_1-\alpha_2} - \tau_t^D] \quad (15)$$

$$\begin{aligned} C_t + K_{t+1} - (1 - \delta)K_t + \tau_t^C C_t + \tau_t^D D_t = \\ A_{2t} K_t^{\alpha_1} N_t^{\alpha_2} [(1 - \tau_t^D)D_t]^{(1-\alpha_1-\alpha_2)} \end{aligned} \quad (16)$$

We calibrate parameter values in order to guarantee that a steady-state exists, and Blanchard-Khan conditions for a saddle path are satisfied (see section 4). Then, the system is log-linearized around this steady-state. The result is a linear system with eleven equations and eleven variables, namely, output \hat{Y} , consumption \hat{C} , investment \hat{I} , capital

stock \hat{K} , labor supply \hat{N} , deforestation \hat{D} , government expenditures \hat{G} , consumption tax $\hat{\tau}^C$, deforestation tax $\hat{\tau}^D$, technology \hat{A}_2 , and environmental preferences \hat{A}_1 . The eleven log-linearized equations are given by:

$$(\rho - \alpha_2 + 1) \hat{N}_t = \Gamma \hat{\tau}_t^C - \sigma \hat{C}_t + \hat{A}_{2t} + \alpha_1 \hat{K}_t + (1 - \alpha_1 - \alpha_2) (\hat{D}_t - \hat{\tau}_t^{D_t} \frac{\bar{\tau}^D}{1 - \bar{\tau}^D}) \quad (17)$$

$$\Gamma \hat{\tau}_t^C - \sigma \hat{C}_t = \Gamma \hat{\tau}_{t+1}^C - \sigma \hat{C}_{t+1} + \eta \hat{A}_{2t+1} + \eta(\alpha_1 - 1) \hat{K}_{t+1} + \eta(1 - \alpha_1 - \alpha_2) (\hat{D}_{t+1} - \hat{\tau}_{t+1}^{D_{t+1}} \frac{\bar{\tau}^D}{1 - \bar{\tau}^D}) \quad (18)$$

$$\hat{A}_{1t} + \varphi \hat{D}_t = \Gamma \hat{\tau}_t^C - \sigma \hat{C}_t + \xi (\hat{Y}_t - \hat{D}_t) + (1 - \xi) \hat{\tau}_t^D \quad (19)$$

$$\hat{Y}_t = \hat{A}_{2t} + \alpha_1 \hat{K}_t + (1 - \alpha_1 - \alpha_2) (\hat{D}_t - \hat{\tau}_t^{D_t} \frac{\bar{\tau}^D}{1 - \bar{\tau}^D}) \quad (20)$$

$$\hat{Y}_t = s_c \hat{C}_t + s_i \hat{I}_t + s_g \hat{G}_t \quad (21)$$

$$\hat{G}_t = \frac{\bar{\tau}^C s_c}{s_g} (\hat{\tau}_t^C + \hat{C}_t) + \frac{\bar{\tau}^D s_d}{s_g} (\hat{\tau}_t^D + \hat{D}_t) \quad (22)$$

$$\hat{\tau}_t^D = \theta \hat{\tau}_{t-1}^D + \lambda (\hat{D}_t) + \varepsilon_{3t} \quad (23)$$

$$\hat{\tau}_t^C = \mu \hat{\tau}_{t-1}^C + \nu (\hat{C}_t) + \varepsilon_{4t} \quad (24)$$

$$\hat{A}_{1t} = \pi + \gamma_1 \hat{A}_{1t-1} + \varepsilon_{1t} \quad (25)$$

$$\hat{A}_{2t} = \gamma_2 \hat{A}_{2t-1} + \varepsilon_{2t} \quad (26)$$

$$\hat{I}_t = \frac{1}{\delta} \hat{K}_{t+1} - \frac{1-\delta}{\delta} \hat{K}_t \quad (27)$$

Once the model is solved, and optimal trajectories are found for every variable, we then obtain the optimal trajectory for the forest stock by log linearizing equation (8) around the steady-state. The resulting equation is given by:

$$\hat{F}_{t+1} = (1+r) \hat{F}_t - r \hat{D}_t \quad (28)$$

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