The rich, the poor and the very poor: taxation and environmental policies

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Abstract

Public policies have close connexions, both on income distribution and environmental degradation. In this paper, we asses how redistributive policies and policies to reduce deforestation may be related to each other. We first assess how the two kinds of policies affect the agents' distribution. Second, we analyze how those relationships influence the policy maker's choices, depending on his policy priorities.

Keywords: deforestation, taxes, PES, income distribution, poverty.

JEL codes:

1 Introduction

As the call for developing countries to pursue stronger environmental conservation polices increases, they face a dilemma: how can environmental conservation be reconciled with other policy objectives, in particular economic growth and a fair income distribution? Are governments presented with a win-win menu or do they face trade-offs?

The literature on the economics of deforestation have fallen short to answer this question adequately. Almost two decades ago, Angelsen and Kaimowitz (1999) in the first comprehensive review of deforestation models noted that broader economic trends and policies are more influential than sector specific policies. Yet, the impact of these are working through multiple, context specific channels, making generalized conclusions and policy recommendations difficult. A second challenge is possible conflicts between competing policy objectives. For example, the exchange rate (policies) have had large impacts on deforestation, as have been demonstrated both analytically (Arcand et al. (2008)) and in empirical studies on deforestation in Brazil (Richards et al. (2012)). Yet, central banks are unlikely to pay much attention to the forest impacts when choosing the country's exchange rate regime and making specific decision on, for examples, a devaluation.

The recent pursuit for Green/Sustainable/Low-Carbon Development/Growth attempts exactly to get this integration of environmental impacts into the overall economic policy making, in an attempt to design and implement polices that achieve multiple policy objectives.

We analyse these issues by developing an analytical model with three classes, and explore how environmental and redistributive measures will affect the level of deforestation. Our model has several novel features. First, we analyse how capital constraints, rather than marginal incentives determine the deforestation choices of one group. Second, distribution of income poor into those asset constrained and those "only" income poor is endogenous, and important policy effects arise from the movements between these two groups. Third, we consider how policies are linked through a public budget constraint.

Section 2 presents a simple model of deforestation agents classes, and section 3 investigates the implications of public policies on those classes distribution. Section 4 concludes.

2 The rich, the poor and the very poor: a story of classes of deforestation agents

We consider a country composed of three classes of deforestation agents. [1] Wealthy people (index w) represent a share p of the population, while poor people (index p) represent a share $1-p$. We also split the income poor into two sub-groups, depending on their asset constraints. We discuss two types of policies. First, the policy maker can implement a redistributive scheme, which simply consists of taxing wealthy people, and transferring wealth to poor ones (adapted from Boadway and Keen (2000)). This kind of transfer may be considered as unconditional payment for environmental conservation, or a purely redistributive tool. Second, the policy maker can also implement an explicit environmental policy to reduce deforestation, either in the form of a tax or a Payment for Environmental Services (PES) scheme.

We consider first the land expansion choice of the agents of deforestation. Then we assess how it is impacted by the redistributive and the environmental policies.

2.1 Classes of deforestation agents

Both classes of agents $i = p, w$ maximize their expected income I_i. Households of each type i get their income from agricultural expansion (equivalently deforestation), $Y(D_i)$. The agricultural expansion production function has the usual properties: $Y_i' = \frac{\partial Y_i}{\partial D_i} > 0$; $Y_i'' = \frac{\partial^2 Y_i}{\partial D_i^2} < 0$. Agricultural expansion is likely to first encroach into the most fertile land, as proposed by David Ricardo. Deforestation D_i has a constant unit cost c_i. c_i may be an indicator of land accessibility. Rich households are assumed to have higher marginal profit from deforestation for any level of deforestation: $Y_r' - c_r > Y_p' - c_p$, because of their better access to complementary inputs.

Yet, as suggested by Nielsen et al. (2012), the level of economic inequality is not only determined by agricultural net returns, but also by asset from which agents can invest in their economic activities. poor households have a limited access to credit, which could prevent them from engaging in costly activities (Alix-Garcia (2007)). Consider that households have an initial asset Ω_i. This initial asset limits the amount of money they may engage in land conversion. In this case, even if agricultural expansion may be profitable, households may be constrained by their initial asset: they might not have enough money to invest in profitable agricultural expansion. Ω_i is distributed according to $f(\Omega)$ on the interval $[0, \overline{\Omega}]$.

[1] We focus on deforestation as one important type of environmental degradation related to economic activities, but the analysis holds for most types of environmental degradation.

Therefore, the poor category is split between what we call income poor (ip) and asset poor (ep), noting that the latter are also income poor, and possibly more so than the "only" income poor. Income-poor agents are the one in which the asset constraint is not binding: they can make their optimal choices regardless of their initial asset position. Asset poor are bonded in their choices by their asset constraint. [2] We label the last asset poor as the ones with asset holdings below a threshold: $\tilde{\Omega}$. Agents from $[0, \tilde{\Omega}]$ are then asset poor, while the ones from $[\tilde{\Omega}, \overline{\Omega}]$ are income poor.

The agents maximize their income, choosing how much land to convert to agriculture- i.e. how much forest to be cleared, given their asset constraint. The first-order condition gives their equilibrium levels of deforestation D_i^*.

Total deforestation thus takes the form[3]: $DD = pD_w + (1-p)(\int_0^{\tilde{\Omega}} D_{ep} f(\Omega) d\Omega + \int_{\tilde{\Omega}}^{\overline{\Omega}} D_{ip} f(\Omega) d\Omega)$, and total income takes the form: $II = pI_w + (1-p)(\int_0^{\tilde{\Omega}} I_{ep} f(\Omega) d\Omega + \int_{\tilde{\Omega}}^{\overline{\Omega}} I_{ip} f(\Omega) d\Omega)$.

2.2 Redistributive and environmental policies

The policy maker implements a redistributive policy as well as an environmental policy. The redistributive policy consists of taxing the wealthiest agents at a tax rate t and to give an unconditional payment L to poor agents.

The environmental policy aims to decrease deforestation. We consider two options (e_j, $j = t, r$). The first one is to set an environmental tax (e_t) for every unit of deforestation. It can also be interpreted to represent the expected fine from illegal deforestation. The tax paid by agent i is thus: $e_t D_i$. The second policy takes the form of a Payment for Environmental Services (PES). Agents are rewarded for their efforts to reduce deforestation compared to a business-as-usual (BAU) scenario: $e_r(D_i^{BAU} - D_i)$. Note here that the two policies are opposites in terms of property rights: under the environmental tax, deforestation agents are expected to buy their deforestation rights from the government at price e_t; under PES implementation, agents can sell their rights to deforest at price e_r (for a maximum supply of D_i^{BAU}). It follows that e_t and e_r can be compared as they both describe the non-use forest value, e.g., in terms of sequestering and storing carbon.

The policy maker's budget constraint is, in the case of an environmental tax: $tpY_w + e_t DD \geq (1-p)L$. It follows that, in terms of public revenue, there is perfect substitutability between the environmental tax and the income tax, and complementarity between the environmental tax and the unconditional payment. In the PES case, one can assume that PES is in part financed by an

[2] Note that asset poor are also by definition income poor.

[3] All text long, variables with two caps (DDs and IIs) describe aggregated variables, while variable with single cap (D and I) describe individual variables.

international donor or carbon markets. In that case, the policy maker sells the PES credit at a price p_c, which can be considered as the forest-adjusted carbon price, i.e., carbon price times the tons of carbon per unit forest land (the emission factor in IPCC terminology). The budget constraint is the following: $tpY_w \geq (1-p)L + (e_r - p_c)(D^{BAU} - D)$. As shown by Delacote et al. (2014), the objective of the policy maker has an impact on the price given to agents, the one received from the international transfer can be considered exogenous. If the PES level is set at the international carbon price ($e_r = p_c$), then the PES program is self-funded. If the PES level is set lower than the international carbon price ($e_r < p_c$), then the policy maker makes some benefit on the PES funding. Finally, if the PES level is set higher than the international carbon price ($e_r > p_c$), then the policy maker has to fund part of the PES policy from his own budget. In any case, in terms of public funding, there is substitutability between the PES payment and the unconditional payment, while there is complementarity between the PES payment and the income tax.

2.3 Deforestation agents optimal choices

2.3.1 Wealthiest agents

The policy maker taxes a share t of the wealthy people's income. They are also impacted by the environmental policy (tax or PES). The program of those agents is to maximize their income I_w:[4]

$$\max_{D_w} I_w = (1-t)(Y_w(D_w)) - c_w D_w \begin{cases} -e_t D_w \\ +e_r(D_w^{BAU} - D_w) \end{cases} \quad (1)$$

The optimal deforestation of wealthy people $D_w^*(t, e_j)$ is thus implicitly defined by the first-order condition (the same for the two policies):

$$(1-t_w)Y_w'(D_w^*) = c_w + e_j \quad (2)$$

Note here that the tax level has the distortive effect of reducing wealthy people deforestation level: $\frac{\partial D_w^*}{\partial t} < 0$. It is also straightforward that the environmental policy unambiguously reduces their level of deforestation: $\frac{\partial D_w^*}{\partial e_j} < 0$. Consequently, income of those agents ($I_w(D_w^*(t, e_j)) = I_w^*(t, e_j)$) decreases with the tax rate, decreases with the environmental tax, and increases with the PES policy: $\frac{\partial I_w^*}{\partial t} < 0$, $\frac{\partial I_w^*}{\partial e_t} < 0$, $\frac{\partial I_w^*}{\partial e_r} > 0$.

[4]When brackets are given in the equation, the first term refers to the environmental tax, while the later refers to the PES program.

Total income of and total deforestation from wealthy agents can be written: $II_w^*(t, e_j) = pI_w^*(t, e_j)$ and $DD_w^*(t, e_j) = pD_w^*(t, e_j)$.

2.4 Poor households

Poor people receive an unconditional payment L and are also impacted by the environmental policy. As noticed before, poor households are bounded by their initial asset for investing in deforestation activities. We consider here that the unconditional payment and the environmental tax are received and payed ex ante, such that they integrate the asset constraint. In contrast, the income from PES comes ex-post, once the deforestation choices can be observed (hence the PES payment cannot be integrated in the asset constraint).

In this case, poor people income I_p maximization is:

$$\max_{D_p} I_L = Y_p(D_p) - c_p D_p + L \begin{cases} -e_t D_p \\ +e_r(D_p^{BAU} - D_p) \end{cases} \tag{3}$$
$$s.t \begin{cases} \Omega_i + L \geq (c_p + e_t) D_p \\ \Omega_i + L \geq c_p D_p \end{cases}$$

As mentioned above, poor agents can be decomposed between income poor (no binding asset constraint), who have the following implicit deforestation level $D_{ip}^*(e_j)$:

$$Y'_{ip}(D_{ip}^*) \quad = \quad c_p + e_j \quad \forall \quad \Omega_i \in [\tilde{\Omega}, \overline{\Omega}] \tag{4}$$

and the asset poor (with binding asset constraint), who have deforestation $D_{ep}^*(L, e_j)$:

$$\begin{cases} D_{ep}^* = \frac{\Omega_i + L}{c_p + e_t} \\ D_{ep}^* = \frac{\Omega_i + L}{c_p} \end{cases} \quad \forall \quad \Omega_i \in [0, \tilde{\Omega}] \tag{5}$$

It is critical for the later analysis to note that the cut-off asset level is endogenous to the policies: $\tilde{\Omega} = \tilde{\Omega}(L, e_j)$. Total income and deforestation from poor agents are noted:

$$II_{ip}^* \quad = \quad (1-p) \int_{\tilde{\Omega}(L,e_j)}^{\overline{\Omega}} I_{ip}^*(L, e_j) f(\Omega) d\Omega \tag{6}$$

$$DD_{ip}^* \quad = \quad (1-p) \int_{\tilde{\Omega}(L,e_j)}^{\overline{\Omega}} D_{ip}^*(e_j) f(\Omega) d\Omega \tag{7}$$

$$II_{ep}^* \quad = \quad (1-p) \int_{0}^{\tilde{\Omega}(L,e_j)} I_{ep}^*(L, e_j) f(\Omega) d\Omega \tag{8}$$

$$DD_{ep}^* \quad = \quad (1-p) \int_{0}^{\tilde{\Omega}(L,e_j)} D_{ep}^*(L, e_j) f(\Omega) d\Omega \tag{9}$$

2.4.1 Policies impact on poor-agents deforestation

The level of the unconditional payment L has no influence on the income-poor deforestation, while it positively impacts the asset-poor's deforestation: $\frac{\partial D^*_{ip}}{\partial L} = 0$; $\frac{\partial D^*_{ep}}{\partial L} > 0$. Indeed, the unconditional payment represents a way to relax the asset constraint for the agents. It is also easy to see that the environmental policy decreases the income-poor deforestation in the same manner as for the wealthiest-agents deforestation: $\frac{\partial D^*_{ip}}{\partial e_j} < 0$. In contrast, only the environmental tax decreases the asset-poor deforestation, as it tightens even more those agents' investment constrains since it is paid ex ante: $\frac{\partial D^*_{ep}}{\partial e_t} < 0$. The impact of the PES on asset poor agents may be twofold: if the payment is larger than the full opportunity cost of those agents, they completely stop deforesting: $D^*_{ep} = 0$ if $e_r D^{BAU}_{ep} \geq I_{ep}(D^{BAU}_{ep})$; if not, they will not engage in the PES: $\frac{\partial D^*_{ep}}{\partial e_r} = 0$ if $e_r D^{BAU}_{ep} < I_{ep}(D^{BAU}_{ep})$. This result come from the fact that asset poor agents do not make their decisions based on first-order conditions, but deforestation is determined by their asset constraint.

As suggested above, both the unconditional payment and the environmental policy shift the agent's distribution between income poor and asset poor. In our setting, this is represented by the position of the cut-off agent that separates the poor population in two, which depends on the two policies characteristics: $\tilde{\Omega} = \tilde{\Omega}(L, e_j)$. The intuition behind the result is simple: when the unconditional payment increases, the asset constraint becomes less binding, and some agents thus pass from the asset-poor category, to the income-poor category: $\frac{\partial \tilde{\Omega}}{\partial L} < 0$. The case of the environmental tax is identical: when e_t increases, the asset constraint becomes tighter, and some income poor switch to the asset-poor class: $\frac{\partial \tilde{\Omega}}{\partial e_t} > 0$.

The mechanism is different when it comes to the PES policy. PES has no influence on the asset constraint. Yet, the distribution of agents is still modified. PES decreases the optimal deforestation level from the income-poor agents. When this payment increases, some asset poor close to the cut-off asset level will not be constrained anymore. Indeed, increasing the PES level reduces the income loss of being asset constrained. Thus when the PES payment increases, some agents switch from the asset-poor category to the income-poor category: $\frac{\partial \tilde{\Omega}}{\partial e_r} < 0$.

Overall, increasing the unconditional payment has the following impact on the total asset-poor deforestation:

$$\left\{ \frac{\partial DD^*_{ep}(L,e_r)}{\partial L} = (1-p)\left(\frac{F(\tilde{\Omega}(L,e_r))}{c_p} + \frac{\Omega_i + L}{c_p} f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial L}\right) \lesseqgtr 0 \right. \tag{10}$$

The net impact is undetermined and depends on the distribution of the initial assets: on the one hand, unconditional payment increases individual deforestation from asset poor agents; on the other hand, it decreases the number of asset-poor. Nevertheless, those agents switch from the *ep*

category to the *ip* category. For this category, the impact of increasing the unconditional payment is the following:

$$\frac{\partial DD^*_{ip}(L,e_j)}{\partial L} = -(1-p)D^*_{ip}(e_j)f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial L} > 0 \tag{11}$$

Concerning the income-poor agents, unconditional payment does not increase their individual level of deforestation, but it influences the number of income-poor agents. It follows that this increases total deforestation from income-poor agents. Note here that $D^*_{ep} < D^*_{ip}$ by definition (if not, *ep* agents are not constrained). It follows that when an agent switches from the *ep* category to the *ip* category, its deforestation increases. Logically, then, deforestation from (both income and asset) poor increases when $\tilde{\Omega}$ increases. When taking the whole set of (both asset- and income-) poor agents, higher unconditional payment unambiguously increases their deforestation: $\frac{\partial DD^*_p(L,e_j)}{\partial L} = \frac{\partial DD^*_{ep}(L,e_j)}{\partial L} + \frac{\partial DD^*_{ip}(L,e_j)}{\partial L} > 0$.

Turning to the environmental policy, the environmental tax and the PES payment do not have the same impact when it comes to asset-poor agents:

$$\begin{cases} \frac{\partial DD^*_{ep}(L,e_t)}{\partial e_t} = (1-p)(-\frac{\Omega_i+L}{(c_p+e_t)^2}F(\tilde{\Omega}(L,e_t)) + \frac{\Omega_i+L}{c_p+e_t}f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial e_t}) \lesseqgtr 0 \\ \frac{\partial DD^*_{ep}(L,e_r)}{\partial e_r} = (1-p)(\frac{\Omega_i+L}{c_p}f(\tilde{\Omega}(L,e_r))\frac{\partial \tilde{\Omega}}{\partial L}) < 0 \end{cases} \tag{12}$$

The environmental tax decreases individual deforestation from asset-poor agents, but it also increases the number of those types of agents. In contrast, increasing the PES payment has no direct influence of the asset-poor agents individual deforestation levels, but it shifts a part of this population into the income-poor category. The *ep* deforestation thus unambiguously decreases.

The impact of the environmental policy on the income-poor deforestation is the following:

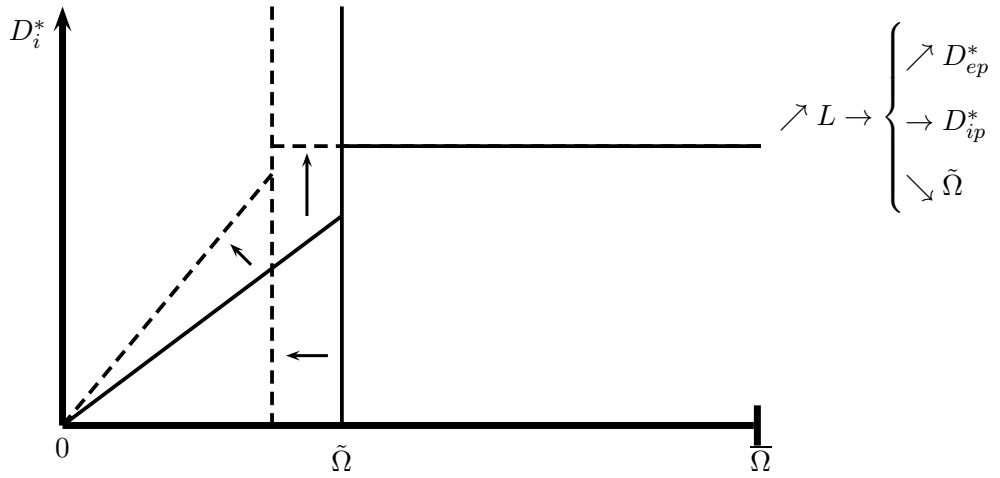
$$\begin{cases} \frac{\partial DD^*_{ip}(L,e_t)}{\partial e_t} = (1-p)(\frac{\partial D^*_{ip}(L,e_t)}{\partial e_t}(F(\overline{\Omega}) - F(\tilde{\Omega}(L,e_t))) - D^*_{ip}(L,e_t)f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial e_t}) < 0 \\ \frac{\partial DD^*_{ip}(L,e_r)}{\partial e_r} = (1-p)(\frac{\partial D^*_{ip}(L,e_r)}{\partial e_r}(F(\overline{\Omega}) - F(\tilde{\Omega}(L,e_r))) - D^*_{ip}(L,e_r)f(\tilde{\Omega}(L,e_r))\frac{\partial \tilde{\Omega}}{\partial e_r}) \lesseqgtr 0 \end{cases} \tag{13}$$

Increasing the environmental tax (i) decreases the individual level of deforestation from income-poor agents, and (ii) decreases the number of income-poor agents (switching to the asset-poor category). The net effect is thus unambiguously negative. In contrast, higher PES decreases the individual level of deforestation, but it also increase the number of income poor (moving from the asset-poor category).

Total deforestation can then be expressed as follows:

$$DD^*(t,L,e_j) = DD^*_w(t,e_j) + DD^*_{ep}(L,e_j) + DD^*_{ip}(L,e_j) \tag{14}$$

Figure 1: **Impact of increasing the unconditional payment L on poor households deforestation**



From our previous results, it follows that total deforestation is decreasing in the income tax, increasing in the unconditional payment, and decreasing in the environmental policy: $\frac{\partial DD^*}{\partial t} < 0$, $\frac{\partial DD^*}{\partial L} > 0$, $\frac{\partial DD^*}{\partial e_j} < 0$.

Figure 2: **Impact of increasing the environmental tax e_t on poor agents deforestation**

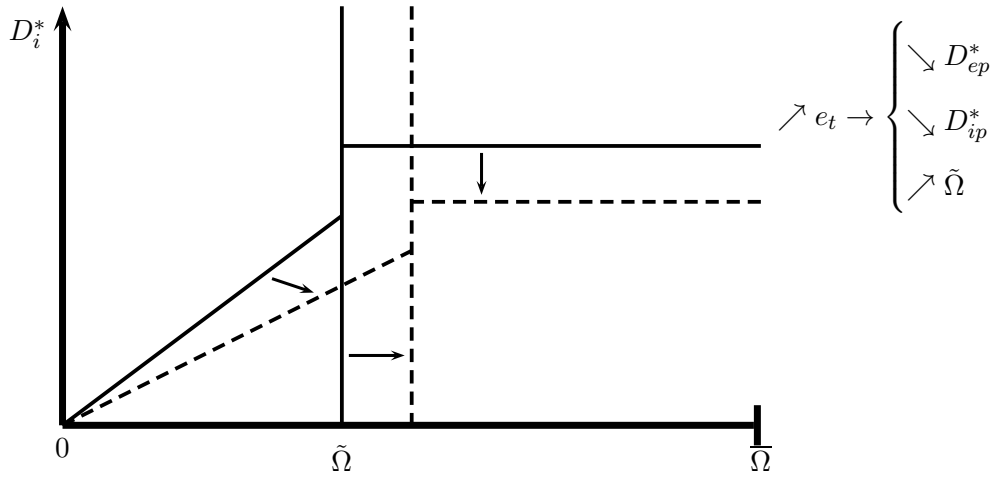


Figure 3: **Impact of increasing the PES e_r on poor agents deforestation**
Case 1: high PES $e_r D_{ep}^{BAU} \geq I_{ep}(D_{ep}^{BAU})$

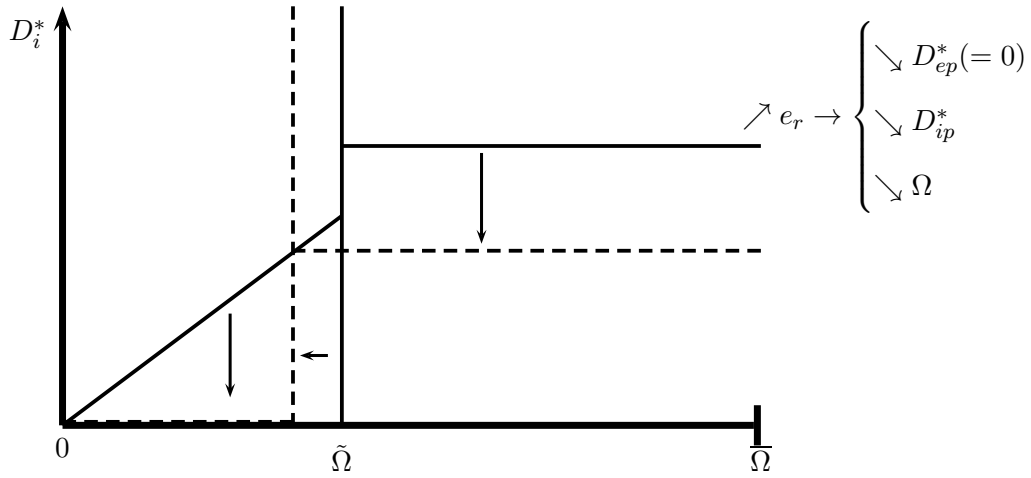
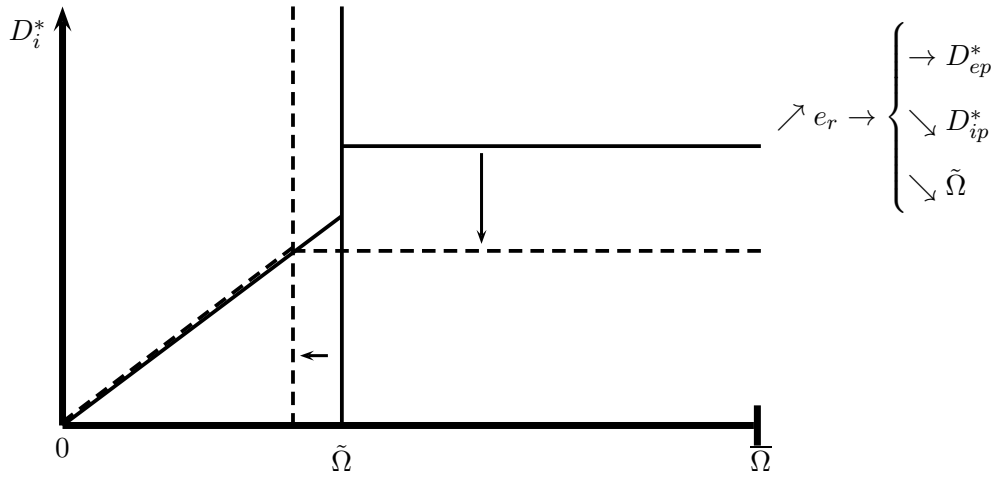


Figure 4: **Impact of increasing the PES e_r on poor agents deforestation**
Case 2: low PES $e_r D_{ep}^{BAU} < I_{ep}(D_{ep}^{BAU})$



2.4.2 Policies impact on poor-agents income

The same type of mechanisms takes place concerning the poor-agents income:

$$\frac{\partial II_{ep}^*(L,e_j)}{\partial L} = (1-p)(\frac{\partial I_{ep}^*(L,e_j)}{\partial L}F(\tilde{\Omega}(L,e_j)) + I_{ep}^*(L,e_j)f(\tilde{\Omega}(L,e_j))\frac{\partial \tilde{\Omega}}{\partial L}) \lesseqgtr 0 \tag{15}$$

$$\frac{\partial II_{ip}^*(L,e_j)}{\partial L} = (1-p)((F(\overline{\Omega}) - F(\tilde{\Omega}(L,e_t))) - I_{ip}^*(L,e_j)f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial L}) > 0 \tag{16}$$

$$\begin{cases} \frac{\partial II_{ep}^*(L,e_t)}{\partial e_t} = (1-p)(\frac{\partial I_{ep}^*(L,e_t)}{\partial e_t}F(\tilde{\Omega}(L,e_t)) + I_{ep}^*(L,e_t)f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial e_t}) \lesseqgtr 0 \\ \frac{\partial II_{ep}^*(L,e_r)}{\partial e_r} = (1-p)(I_{ep}^*(L,e_r)f(\tilde{\Omega}(L,e_r))\frac{\partial \tilde{\Omega}}{\partial e_r}) < 0 \end{cases} \tag{17}$$

$$\begin{cases} \frac{\partial II_{ip}^*(L,e_t)}{\partial e_t} = (1-p)(\frac{\partial I_{ip}^*(L,e_t)}{\partial e_t}(F(\overline{\Omega}) - F(\tilde{\Omega}(L,e_t))) - I_{ip}^*(L,e_t)f(\tilde{\Omega}(L,e_t))\frac{\partial \tilde{\Omega}}{\partial e_t}) \lesseqgtr 0 \\ \frac{\partial II_{ip}^*(L,e_r)}{\partial e_r} = (1-p)(\frac{\partial I_{ip}^*(L,e_r)}{\partial e_r}(F(\overline{\Omega}) - F(\tilde{\Omega}(L,e_r))) - I_{ip}^*(L,e_r)f(\tilde{\Omega}(L,e_r))\frac{\partial \tilde{\Omega}}{\partial e_r}) > 0 \end{cases} \tag{18}$$

We summarize the results as follows:

- increasing the unconditional payment (L)
  - increases income from both income and asset-poor agents;
  - decreases the number of asset poor and increases the number of income poor;
  - increases total income to poor agents;
- increasing the environmental tax (e_t)
  - decreases income from both income and asset-poor agents;

  - increases the number of asset-poor and decreases the number of income poor;
  - decreases total income to poor agents

- increasing the PES payment (e_r)
  - increases the income of income poor but not the one of asset-poor agents;
  - decreases the number of asset poor and increases the number of income poor;
  - increases total income to poor agents.

An interesting result is that the impact of a policy on a particular category is not always straightforward, is it depends also on the distribution of agents between the income poor and asset poor categories. Both policies do not only modify the behavior of agents within a particular category, but also move some agents from one category to another. Such "distributional impacts" thus need to be considered when analyzing policy impacts. For instance, the PES policy, as opposed to the environmental tax, makes some households get out the asset-poor category.

3 A political economy model of redistributive policy and its impact on deforestation

We know consider the Policy Maker's choice to implement both policies. Our aim is to analyze possible synergies and trade offs of the policies, depending on the policy maker's priorities.

3.1 Policy implementation

The policy maker cares about economic welfare and the environment. He sets the redistributive and the environmental policy so that it maximizes a weighted sum of income (to the different groups) and environmental protection, under the budget constraint described above:

$$\begin{aligned} \max_{t,L,e_j} \quad & \delta[(1-\alpha)(II^*_{ep}(L,e_j)+II^*_{ip}(L,e_j))+\alpha II_w(t,e_j)]-(1-\delta)C(DD(t,L,e_j)) \\ s.t. \quad & \begin{cases} tpY_w + e_t D \geq (1-p)L \\ tpY_w \geq (1-p)L + (e_r - p_c)(D^{BAU} - D) \end{cases} \end{aligned} \tag{19}$$

δ is the weight given to the economic objective, while $(1-\delta)$ is the weight given to environmental degradation. $C(DD)$ is the public cost of deforestation. Finally, α and $(1-\alpha)$ are the weights given to wealthy and poor agents in the PM objective. These weight can differ from the actual

shares of the population, p and $(1-p)$. In particular, higher income to the poor might be given more weight than to the rich ($\alpha > p$.

The budget constraint allows us to reduce the policy choice to two arguments:

$$\begin{cases} t = \frac{(1-p)L - e_t DD}{pY_w} \\ t = \frac{(1-p)L + (e_r - p_c)(DD^{BAU} - DD)}{pY_w} \end{cases}$$

It follows that the complementarity between the income tax and the unconditional payment is given by: $\frac{\partial t}{\partial L} = \frac{(1-p)}{pY_w} > 0$. It is financially easier to increase the income tax if wealthy people represent an important share of the population, and if they are richer. In contrast, there is substitution between increasing income tax and increasing the environmental policy only in the case of the environmental tax: $\frac{\partial t}{\partial e_t} = \frac{-DD}{pY_w} < 0$. It if financially easier to replace income taxes by an environmental tax if deforestation is important, if there are few rich agents, and if their wealth is not smaller. Finally, in the PES case, the payment and the income tax are complement $\frac{\partial t}{\partial e_r} = \frac{(DD^{BAU} - DD)}{pY_w} > 0$.

The policy maker program then becomes:

$$\max_{L, e_j} \delta[(1-\alpha)(II^*_{ep}(L, e_j) + II^*_{ip}(L, e_j)) + \alpha II_w(L, e_j)] - (1-\delta)C(DD^*(L, e_j)) \tag{20}$$

The policy maker has the two first-order conditions which implicitly describe the policy mix (t^*, L^*, e_j^*):

$$\delta[\alpha(\frac{\partial II^*_{ep}}{\partial L} + \frac{\partial II^*_{ip}}{\partial L}) + (1-\alpha)\frac{\partial II^*_w}{\partial t}\frac{\partial t}{\partial L}] - (1-\delta)C'[\frac{\partial DD^*}{\partial L} + \frac{\partial DD^*}{\partial t}\frac{\partial t}{\partial L}] = 0 \tag{21}$$

$$\delta[\alpha(\frac{\partial II^*_{ep}}{\partial e_j} + \frac{\partial II^*_{ip}}{\partial e_j}) + (1-\alpha)(\frac{\partial II^*_w}{\partial e_j} + \frac{\partial II^*_w}{\partial t}\frac{\partial t}{\partial e_j})] - (1-\delta)C'[\frac{\partial DD^*}{\partial e_j} + \frac{\partial DD^*}{\partial t}\frac{\partial t}{\partial e_j}] = 0 \tag{22}$$

Equations 21 and 22 take into account both direct impacts of the policies on income and deforestation, but also indirect impacts through public finance funds. In both cases, the policy maker is confronted to a double trade off: the first one concerns the trade off between income impacts and deforestation impacts; the second one concerns poor agents versus wealthy agents.

3.2 Unconditional payment

The policy maker will choose a higher unconditional payment when he gives a higher importance to poor income, and if increasing L has an major impact on the poor income (related to higher sensitivity of $\tilde{\Omega}$ to L). In contrast, because of the indirect impact of the unconditional payment on taxes, the unconditional payment will be lower if the impact on wealthy agents is large, and if the policy maker puts higher weight on those agents. From the environmental perspective, the unconditional payment will be higher if the indirect negative impact on the wealthy agents'

deforestation is important, while it will be lower if the direct impact on the asset-poor deforestation is larger.

3.3 Environmental tax

On the economic side, the environmental tax has the direct impact of reducing the agents' income. It also allows some substitution in public funding by reducing the income tax (or increase the unconditional payment). It follows that the environmental tax will be higher if it allows larger substitution with the income tax. This is the case when the level of deforestation is larger, and when the wealthy's income is lower.

On the environmental side, the tax directly reduces overall deforestation, as expected. However, it also has the indirect effect of increasing deforestation from the wealthy agents, due to the indirect effects on income taxation (the tax is lower due to the substitution effect in public funding).

Overall, the effect of the public funding substitution on the choice of the environmental tax depends on the weight given to the two objectives. If the policy maker puts high importance on the development (income) objective, the environmental tax will be higher if the public funding substitution effect is important. If the policy maker puts high importance to the environment, the environmental tax will be lower if this effect is more important.

3.4 PES

The mechanism is different with PES+, mainly because the indirect impact on public funding is the opposite: increasing the PES+ payment implies to increase the income tax rate (or decrease the unconditional payment). From the development perspective, the PES level directly increases income from both poor and wealthy agents. Yet the indirect effect on public spending is to be taken into account: higher payment implies higher income tax rate, which hurts the wealthy agents' income (or decrease the unconditional payment, which decreases the poor agents' income). The indirect effect on deforestation brings about the following mechanisms. Deforestation is reduced directly by PES. Further, the payment indirectly reduces the deforestation from wealthy agents because of the public funding substitution effect (or reduces deforestation from the poor agents if it leads to decrease the unconditional payment).

4 Discussion and conclusions

The behaviour of our three groups of deforesting agents follow standard microeconomic incentives, where the relative profitability determines the overall level of deforestation by our representative agents. We have added three features that enrich our understanding of deforestation processes.

First, for one group of agents ñ the asset poor ñ the level of deforestation is determined by their asset constraints, rather than marginal incentives. For this groups changes in the asset position is the key mechanism through which policies affect deforestation.

Second, the distribution of the poor population between the (only) income poor and the asset poor is endogenous. Both the redistributive and the environmental policy modify this distribution and this have effects on the overall level of deforestation.

Third, indirect effects are important. The two policy instruments may be used by the policy maker strategically. For example, the redistributive policy may be used to indirectly influence deforestation. This is especially true if the distortion of wealthy agents' behavior is important. Similarly, the environmental taxation can be used to raise funding for redistribution without raising income taxes. Finally, PES allows to spread the development policy instead of focusing it on redistribution.

Those indirect effects are important when choosing between an environmental tax and PES. Indeed, if the policy maker puts more weight on development, he may prefer the environmental tax, as it benefits from a positive public funding substitution effect. It can allow the policy maker to increase the unconditional payment if he puts more weight on poor people income, or to decrease taxes if he puts more weight on wealthy agents income. In contrast, if the policy maker has strong preference for the environment, he may prefer the PES system, as it brings the benefit of reducing deforestation through the public funding substitution effect.

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