On the optimal setting of protected areas

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Abstract

This paper analyses the determinants of the optimal size of protected areas and what conducts neighboring effects. We investigate in which measure the infrastructure effect and the scarcity effect matter. We obtain several results. The size of protected area mainly depends on preferences toward forest, on the firms' production costs and on the relation between municipalities. As far as total deforestation is concerned asymmetric regulation is better than no regulation. The infrastructure effect always leads to smaller protected areas than the scarcity effect. Under the infrastructure effect, centralized decisions do not always work in favor of larger protected areas than decentralized decisions contrary to the scarcity effect. We also show that decentralized decisions can reach the first best under the infrastructure effect without public intervention. A study of protected areas in the Brazilian Legal Amazônia corroborates our theoretical results.

Keywords

Protected areas, Deforestation, Nash equilibrium, Environmental federalism, Brazilian Legal Amazônia.

JEL Codes

Q58, H77.

1 Introduction

Deforestation is the permanent destruction of forests in order to make the land available for other uses: farming, cattle ranching, timber or urbanization. Tropical rainforests are particularly targeted. The causes of deforestation are several. Synthesizing the results of more than 140 economic models, Angelsen and Kaimowitz (1999) concludes that lower wages, more roads and higher agricultural prices generally lead to more deforestation.

Rainforests shelter over half of the world's species of plants and animals. According to Sandler (1993), tropical forests provide a host of local benefits as watersheds, soil erosion protection, timber or non-timber product and global benefits as, for example, carbon storage. Thus as biodiversity preservation gives non excludable benefits, it can be seen as a pure public good whereas timber yielding excludable benefits is a private goods. But some benefits coming from tropical forest are non excludable and non rival only in a country and so have the characteristics of local public goods. As tropical deforestation yields several market failures, there is place to public intervention.

Different types of policies could be used to fight against deforestation. We find policies which the aim is to increase and capture forest rent or, by contrast, to depress agricultural rent, policies that directly regulate land use and cross-sector policies that underpin the first three (Angelsen, 2009). Protected area is an example of the third type. Forest protected areas in IUCN categories 1 to 6 make up 13.5% of the world's forests (Schmitt et al. 2009), the share being significantly higher (20.8%) in rainforests.

Analysis about protected areas seek to know if protected areas enable effectively to fight against deforestation. Indeed protected areas are often located in remote areas with less pressure on forest (Bruner et al. 2001; DeFries et al. 2005) and once established, deforestation activities shift from inside to outside the protected areas. Analyzing these spillover effects or what is called neighboring leakage, Andam et al. (2008) find 10% of protected forests would have been deforested if they have not been protected in Costa Rica whereas Gaveau et al. (2009) find that protected areas reduced deforestation by 24% from 1990 to 2000 in Sumatra. Without taking into account the non-random location of protected areas, results would be overestimated. For example, a naïve (i.e. simple mean differences) comparison of protected areas and adjacent areas would suggest that protected areas reduced deforestation by 59% in Sumatra. Taking into account both the location bias and the spatial spillover effects, Amin et al. (2019) show that integral protected areas and indigenous lands allow for reducing deforestation in the Brazilian Legal Amazônia.

Overall studies about protected areas are mainly empirical. Because the difficulty to estimate benefits or the lack of established property rights, some theoretical analysis underlines that it is difficult to do the usual trade off between benefits and costs coming from protected area. In this case, the socially optimal amount of protected area may not be implemented (Dixon and Sherman (1991), Turner (2002a) and Fisher et al. (1972)). Knowing whether protected areas have to be established in a centralized or in a decentralized way is another important point. According to the Oates decentralization's theorem, we can infer that a decentralized system will be preferred. But spillover effects can arise between local public goods - protected areas - and, in this case, all depends on the assumptions set in the model (Besley and Coate, 2003). Busch (2008) studies cross border effects for transboundary protected areas. Other papers focus on the pricing of protected areas (Alpizar, 2006), the management of multiple activities in national parks (Turner, 2000) or, among others, the optimal provision of services in the parks (Turner 2002b).

Finally, theoretical studies do not analyze the determinants of the optimal size of protected areas, the role of interactions between several jurisdictions and what conducts spillover effects. This is the aim of this paper. Following Oates (2001), it also investigates and compares different implementation levels, *i.e.* decentralized *versus* centralized level. As protected areas are established with two implementation levels in Brazil, we finally take the Brazilian Legal Amazônia as a study case.

We consider that deforestation occurs in a primary forest, covering several municipalities. Forest has several uses. First, it generates benefits to local populations. For example, they enjoy environmental amenities. Second, forest provides inputs to firms in order to produce a private good. This good can be, for example, timber or agriculture foods. As the production of the final good leads to deforestation, a regulator decides to protect forest, providing a local public good. To do that, he uses a command and control policy, establishing a protected area.

In order to take into account some causes of deforestation, we retain two alternative assumptions: the *infrastructure effect* and the *scarcity effect*. The infrastructure effect designs the fact that according to several empirical analysis, roads or railroad lead to a greater access to forest and accelerates deforestation.[1] On the contrary, a little primary forest area will increase the costs as new land is less easily available, that is the scarcity effect. Whereas the scarcity effect raises the deforestation cost, the infrastructure effect reduces them. In this article, we investigate whether both cost effects matter in the design of the size of the protected area.[2]

Our way to consider the infrastructure and the scarcity effects differs from Angelsen (2001). The author analyses the deforestation process coming from "a game" between a state and a local community seeking to appropriate tropical forestland. He sets a marginal cost to expand available land, which depends on the total forest and the land appropriate by the State. As the State provides infrastructures, this marginal cost diminishes with State land appropriation (corresponding to the infrastructure effect) and with forest cover as new land is more easily available (i.e. the scarcity effect). In this paper, we theoretically

[1] See, among others, Ludeke et al. (1990) for Honduras, Nelson and Hellerstein (1997) for Mexico, Liu et al. (1993) for the Philipines, Mertens and Lambin (1997) for Cameroon, Chomitz and Gray (1996) for Belize, Sader and Joyce (1988) and Rosero-Bixby and Palloni (1998) for Costa Rica, Cropper et al. (2001) for North Thailand.

[2] In a more generally way, we design in this paper the infrastructure effect (the scarcity effect) several factors reducing (increasing) the cost of deforestation.

reformulate both concepts in another context. We consider a production cost function exhibiting the infrastructure effect or the scarcity effect.

We consider and compare different scenarios. We first assume that each municipality establishes a protected area, deriving a symmetric Nash equilibrium. Then, when only one regulator provides the local public good, we obtain an asymmetric Nash equilibrium. Finally, we retain a central regulator setting protected areas for each municipality. We obtain several results. In all cases, we find that the infrastructure effect always leads to smaller protected area than the scarcity effect. When only one regulator provides the local public good, in spite of having spillover effects, global deforestation is always reduced: asymmetric regulation is so better than no regulation for forest protection. It appears that the centralized provision of protected areas does not always work in favor of forest protection under the infrastructure effect contrary to under the scarcity effect. Finally we show that under the infrastructure effect decentralized decisions can reach the first best without cooperation between regulators. We complete our analysis with a study of the Brazilian protected areas. It corroborates our theoretical results while removing theoretical indetermination, and suggests that the infrastructure effect can be important in the Brazilian Legal Amazônia.

The article is organized as follow. In Section 2 we present the assumptions of our model and the benchmark, *i.e.* the equilibrium of the economy without protected areas. Decentralized regulation is presented in Section 3 whereas centralized regulation in Section 4. Section 5 details our results depending on the infrastructure or the scarcity effect. In Section 6, we study protected areas in Brazil. A conclusion is given in Section 7.

2 Assumptions and the benchmark

We first present the assumptions of the model and then the benchmark.

2.1 Assumptions

We assume that primary forest cover is a public good, and that forest is cut in order to produce a private good. A regulator decides to protect forest localized in her municipality.[3] To do that she determines the optimal area of forest and implements it by means of a protected area. As we will see results will depend on the strategy pursues by the regulator in each municipality.

We consider two municipalities (or two countries) i, $i = 1, 2$. In each municipality, we denote by T_i the forest cover before any regulation (with $T_i = T_{-i} = T$). We assume a representative consumer in each municipality. Her preferences are represented by the following quasi-linear utility function: $U(x_i, g_i, g_{-i}, M) = B(x_i) + \lambda[kJ(g_i) + (1-k)(J(g_{-i})] + M \; \forall i = 1, 2$, where x_i is the private good sold at price p_i, g_i a local public good of which quantity is measured by the forest cover and M the available revenue. Preferences for

[3] In this article, we neglect the lack of property rights and assume perfect information.

private good and local public goods are respectively given by the increasing and concave functions $B(x_i)$ and $J(g_i)$. For example, consumers enjoy forest due to their preferences towards nature, biodiversity or recreational activities. The parameter $k \in [1/2, 1]$ indexes the degree of spillover: $k = 1$ means that citizens care only about the public good in their own municipality while $k = 1/2$ means that they care equally about public goods in both municipality (Besley and Coate 2003). The parameter λ is a weight representing preferences for forest in general ($\lambda > 1$).

The quantity x_i of final good is produced by a representative and competitive firm in Municipality i. Producing x_i units of final good requires x_i units of cover forest and costs $C_i(x_i, x_j)$ with $C_{ix_i} > 0$; $C_{ix_ix_i} = 0$. We will hereafter alternatively take into account the following assumptions $C_{ix_ix_j} < 0$ or $C_{ix_ix_j} > 0$ in order to investigate how the cost of production matters in the protected area setting. To take into account both effects, we assume that the marginal cost of production of a firm in a municipality depends positively or negatively on the production level in another municipality. If the level of production increases in Municipality j, forest is more (less) accessible and the marginal cost of production in i diminishes (increases), representing the "infrastructure effect" (the "scarcity effect").

2.2 The benchmark

As a benchmark, we define the market equilibrium in both municipalities without regulation for protecting forest. We first find the demand for the private good. The representative consumer maximizes her utility. If R is the revenue before any spending, we have $M = R - p_i x_i$. We obtain:

$$\text{Max}_{x_i}\ U(x_i, g_i, g_{-i}) = B(x_i) + \lambda[kJ(g_i) + (1-k)(J(g_{-i})] + R - p_i x_i$$

From the first-order conditions, we find:

$$B'(x_i) = p_i\ \forall i = 1,2 \tag{1}$$

$$\lambda k J'(g_i) = 0\ \forall i = 1,2 \tag{2}$$

$$\lambda(1-k)J'(g_{-i}) = 0\ \forall i = 1,2 \tag{3}$$

The representative consumer chooses the private good quantity. From Equation (1), this quantity is such that the marginal benefit from consumption is equal to the good's price. This equation gives us the inverse demand function. Local public goods are consumed such as the marginal benefit is null (see Eq. (2) and (3)[4].

[4]Without public intervention the consumer does not consider that consuming the final good reduces his utility coming from environmental amenities. So first-order conditions are independent.

The representative firm maximizes its profit, *i.e.*:

$$\text{Max}_{x_i}\ \pi_i(x_i, x_j) = p_i x_i - C_i(x_i, x_j)$$

The first-order condition gives:

$$p_i - C_{ix_i}(x_i, x_j) = 0 \tag{4}$$

As the marginal cost is constant in x_i, the offer function $x_i(p, x_j)$ defined by Eq. (4) is a step function. If the output price is lower than the marginal cost, the production level is null and indeterminate if the price is equal to the marginal cost. We have:

$$x_i(p_i, x_j) = \begin{cases} 0 \text{ if } p_i < C_i(p, x_j) \\ \left[0, C_{ix_i}^{-1}(p_i, x_j)\right] \text{ else} \end{cases}$$

From (1) and (4), the market equilibrium condition is given by:

$$B'(x_i) - C_{ix_i}(x_i, x_j) = 0 \tag{5}$$

If the Inada conditions are satisfied for the function $B(x_i)$, the price is positive and the equilibrium quantity of output is determined and set at $\bar{x}_i$. As the quantity produced in one municipality depends on the quantity produced in the other municipality we find from (5) the best response functions. Applying the Implicit Function Theorem on Equation (5), we have $\frac{dx_i}{dx_j} > (<)0$ if $C_{ix_ix_j}(x_i, x_j) < (>)0$. The nature of the strategic interaction between the production and deforestation levels depends on the cost function: under the infrastructure effect (the scarcity effect) deforestation in i increases (decreases) if the level of production increases in j. Hence the levels of deforestation and of production are strategic complements in the first case and strategic substitutes in the second case.

Solving (5) for $i = 1, 2$, we obtain the Nash equilibrium without regulation. Hence the size of the forest is $\bar{G}_i = T - \bar{x}_i\ \forall i = 1, 2$.

Because of several market imperfections, this economy cannot reach the optimum. First, there is a negative externality of consumption: when the consumer defines her demand function for the private good, she does not take into account the fact that her consumption leads to deforestation. Second, as defined above, there are cost interdependencies induced by the infrastructure effect or by the scarcity effect and, third, local public goods represented by forest in each municipality.

3 A decentralized regulation

A regulator in one municipality decides to provide the local public good, *i.e.* to regulate logging: she chooses to implement an integral protected area in which logging will not be allowed.[5] The regulator determines the optimal level

[5] We neglect, in this article, enforcement costs induced by the establishment of the protected area.

of private good and hence sets the size of the protected area. To do that she maximizes the welfare in this economy:

$$\begin{aligned} \text{Max}_{x_i}\ S(x_i, x_j) &= B(x_i) + \lambda[kJ(g_i) + (1-k)(J(g_{-i}))] - C_i(x_i, x_{-i}) \\ \text{subject to } G_i &= T_i - x_i \geq 0 \end{aligned}$$

The first-order condition is:

$$B'(x_i) - C_{ix_i}(x_i, x_{-i}) - \lambda k J'(g_i) = 0 \qquad (6)$$

Compared to Equation (5) the regulator internalizes the negative externality taking into account the third term in (6). As the optimal level of private good depends on the quantity produced in Municipality j, we also find a reaction function. Applying the Implicit Function Theorem on (6) shows that the quantity x_i also increases (decreases) with x_j if $C_{ix_ix_j}(x_i, x_j) < 0$ (> 0) and decreases now with preferences with nature (λ) and the parameter of free riding k. The more k is important, the more consumers enjoy only forest in their municipality and the free ridding effect disappears. In this case, the negative externality is entirely internalized in Municipality i, therefore reducing further the level of production x_i.

The equilibrium depends on the behavior of the regulator in the other municipality. The regulator j can also choose to regulate logging or "laissez faire". We assume that both regulators take their decision simultaneously. The equilibrium of the economy is so given by a Nash equilibrium.

3.1 The Nash symmetric equilibrium

If each municipality implements a protected area, the Nash symmetric equilibrium is obtained solving Eqs (6) for $i = 1, 2$. The quantities of private good are given by x^{ns} and the size of the protected areas (AP) is $AP^{ns} = G^{ns} = T - x^{ns}$.

3.2 The Nash asymmetric equilibrium

At the Nash asymmetric equilibrium Municipality 1 chooses to fight against deforestation whereas the Municipality 2 does not. The equilibrium (x_1^{na} and x_2^{na}) is obtained from reaction functions given by Equations (5) and (6). The size of protected area is $AP_1^{na} = G_1^{na} = T - x_1^{na}$ and the forest cover in Municipality 2 is $G_2^{na} = T - x_2^{na}$.

4 A centralized regulation

Under the decentralized regulation each municipality takes as a given the existence or not of a protected area in the other municipality. This regulation enables to internalize the negative externality coming from consumption. However the regulator in each municipality cannot internalize alone neither positive externality - the "spillover effect" - nor the "cost effect". The spillover effect is represented by the parameter k and comes from the fact that forest is a local public good. The cost effect comes from cost interdependencies represented by the infrastructure effect or the scarcity effect. Hence the equilibrium described in Section 3 cannot be optimal.

These externalities can be taken into account only by a supranational jurisdiction, one say a national or a federal level. In this case the national (federal) regulator establishes the size of protected areas in each municipality (state) maximizing the global welfare. This latter is composed of the sum of welfare in both municipalities:

$$\begin{aligned} \text{Max } W^g(x_i, x_j) &= \sum_{i=1}^{2}[B(x_i) - C_i(x_i, x_{-i})] + \lambda[J(g_i) + J(g_{-i})] \\ \text{subject to } G_i &= T_i - x_i \geq 0,\ i = 1, 2 \end{aligned}$$

The first-order conditions are the following:

$$B'(x_i) - C_{ix_i}(x_i, x_j) - C_{jx_i}(x_i, x_j) - \lambda J'(g_i) = 0,\ i = 1, 2 \tag{7}$$

By solving equations given by (7) we find the cooperative equilibrium denoted by x^c. This time all externalities have been internalized. As in the decentralized regulation, the negative externality has been taken into account. However the centralized equilibrium also internalizes the free riding effect since the levels of production do not depend anymore of the parameter k, as well cost interdependencies. Now it is the "global cost effect" which matters, by the second and third term in Equation (7).

5 Cost functions

To analyze in which measure the nature of the production cost function impacts the size of the protected area and the global level of deforestation, we derive results retaining alternatively both following assumptions: the infrastructure effect and the scarcity effect. In this section we set $B(x_i) = \gamma x_i - \frac{x_i^2}{2}$ and $J(g_i) = \beta g_i - \frac{g_i^2}{2}$.

5.1 The infrastructure effect

We investigate the assumption of "infrastructure effect" and we set $C_i(x_i, x_j) = \alpha x_i(1 - x_j)$ with $\alpha < 1$. The marginal cost of production decreases with the level of production in Municipality j due to the creation of infrastructures such as roads. Without regulation the best response function in Municipality i is given by:

$$x_i = \gamma - \alpha(1 - x_j) \tag{8}$$

The level of production in i increases with the quantity produced in j (strategic complement) and with the benefit parameter to consume good (γ), and decreases with the cost parameter (α). If the regulator decides to implement a protected area, its best response function is:

$$x_i = \frac{\gamma - \alpha(1 - x_j) - \lambda k[\beta - T]}{1 + \lambda k} \tag{9}$$

As in the case without regulation this quantity increases with (x_j) and (γ) and decreases with (α) but also now with preferences for forest (λ), (β), and the free ridding parameter (k). Finally, if a centralized regulator decides to set a protected area in each municipality, we find:

$$x_i = \frac{\gamma - \alpha(1 - 2x_j) - \lambda[\beta - T]}{1 + \lambda} \ \forall i = 1, 2 \tag{10}$$

This function has similar qualitative properties as (9) except that it does not depend anymore on (k).

Solving each equilibrium enables us to obtain the levels of production and the size of each protected areas or forest. We begin to compare the "laissez faire" equilibrium and the Nash symmetric equilibrium. We find:

$$x^{ns} < \bar{x}$$

Under the symmetric non-cooperative equilibrium regulators only internalize the negative externality coming from consumption in each municipality. They take as a given the "spillover effect" induced by local public goods as well as the "cost effect". If both municipalities internalize the negative externality we find unsurprisingly that production levels are lower than levels without regulation.

Introducing the Nash asymmetric equilibrium, we obtain the following comparisons:

$$x_1^{na} < x_2^{na}$$

and:

$$x^{ns} < x_i^{na} < \bar{x} \ \forall i = 1, 2$$

Under the infrastructure effect, establishing a protected area only in Municipality 1 leads to an increase of the production costs in Municipality 2. Hence the firm located in Municipality 2 has to decrease its production level, bearing the "cost effect". Finally quantities of the produced good at the Nash asymmetric equilibrium are higher than at the symmetric one in both municipalities but lower than the "laissez faire" quantities. Thus establishing a protected area only in one municipality leads to preserve forest in another municipality although this latter does not regulate. Asymmetric regulation is better than no regulation at all for forest preservation.

Under the symmetric or asymmetric equilibrium, the size of the protected area negatively depends on the level of deforestation in the other municipality. This result seems counterintuitive. However the higher the deforestation in Municipality j, the lower the production costs in Municipality i. Hence the usual trade-off between marginal social benefit and marginal social cost given by Equation (6) balances toward an increase in production and so reduces the size of the protected area.

However these non-cooperative equilibria are not optimal because they neither take into account the spillover effect nor cost interdependency. The cooperative equilibrium takes into account all these effects. We find:

$$x^c < \bar{x} \text{ and } x^c \lesseqgtr x^{ns} \text{ or } x^{na}$$

The centralized regulation internalizes first, the negative externality, second, the free rider effect and third, the cost interdependency. The two first effects lead to a decrease in the level of production contrary to the third one. Under the infrastructure effect, implementing a protected area in Municipality i increases the production cost in j leading to less deforestation in j. A way to reduce the global cost is so to increase levels of production. Hence, if the two first effects are higher than the third effect, the centralized equilibrium protects more forest than the Nash symmetric equilibrium. On the contrary, if the cost effect is enough important, the protected area sizes at the centralized equilibrium are lower than the Nash symmetric equilibrium. Thus the good equilibrium for the economy - the centralized one - is not the best equilibrium for forest preservation.

In the case where $x^{ns} > x^c$ if $k = \frac{1}{2}$, as $x^c > x^{ns}$ if $k = 1$ and $\frac{dx^{ns}}{dk} < 0$ we find the following result:

$$\exists k^* \in [\frac{1}{2}, 1]/.\ x_i^c = x^{ns}$$

This result suggests that the centralized equilibrium can be reached without cooperation if preferences are such as $k = k^*$ (see Figure 1). This point is interesting because it is difficult to obtain cooperation in a real world. Of course this case can occur by chance. As k is the free ridding parameter it would be difficult to change it by a public policy. However, λ represents preferences toward nature. We can think that an active education policy can help to change λ in order to have $x^{ns}(\lambda^*) = x^c$, if $\lambda < \lambda^*$. However this kind of policy would have effects only in the medium or long term and the impact on deforestation could be to late.

5.2 The scarcity effect

In this section, we set $C_i(x_i, x_j) = \alpha x_i(1 + x_j)$ with $\alpha < 1$ in order to take into account the "scarcity effect". The best response functions are the following

$$x_i = \gamma - \alpha(1 + x_j) \tag{11}$$

without any regulation,

$$x_i = \frac{\gamma - \alpha(1 + x_j) - k\lambda[\beta - T]}{1 + \lambda k} \tag{12}$$

under a Nash equilibrium, and

$$x_i = \frac{\gamma - \alpha(1 + 2x_j) - \lambda[\beta - T]}{1 + \lambda} \tag{13}$$

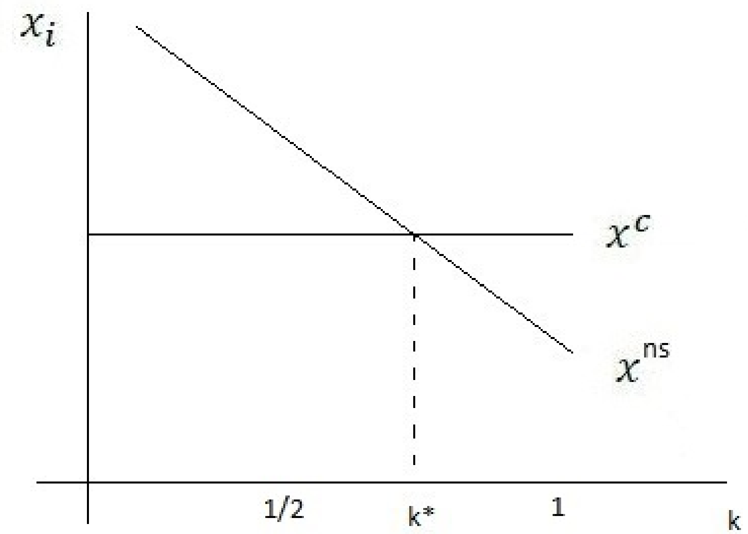


Figure 1: Centralized and Nash symmetric equilibria depending on the parameter k

under a centralized regulation. Compared with Section 5.1, we find similar qualitative properties for γ, α, λ and k. However under the scarcity effect the level of production in i always decreases if the level of production increases in j. After solving each equilibrium we obtain the following results:

$$\begin{aligned} x_1^{na} &< x^{ns} < \bar{x}_1 \\ x^{ns} &< \bar{x}_2 < x_2^{na} \end{aligned}$$

with

$$x_1^{na} < x_2^{na}$$

In conformity with intuition the levels of production are lower than the levels without regulation if both municipalities internalize the negative externality. Establishing a protected area only in Municipality 1 leads to a decrease in the production cost in Municipality 2. Hence firms located in this municipality can increase their production levels with respect to the unconstrained production level ($\bar{x}_i$). Two effects appear in Municipality 1 working towards a reduction in the level of production: the negative externality and the cost effect. Contrary to the negative externality, the cost effect cannot be internalized by a local regulator. A higher level of production in Municipality 2 increases the production cost in Municipality 1. Finally the quantity at the Nash asymmetric equilibrium is lower than the Nash symmetric one in Municipality 1.

As far as forest preservation is concerned we find:

$$\sum_{i=1}^{2} g_i^{ns} > \sum_{i=1}^{2} g_i^{na} > \sum_{i=1}^{2} \bar{g}_i$$

Establishing a protected area only in Municipality 1 leads to an increase of deforestation in Municipality 2. But the net effect leads to forest protection. Implementing alone a protected area leads to globally preserve forest: asymmetric regulation is better than no regulation at all.

Deriving the centralized equilibrium, we find the following results:

$$x^c < \bar{x} \text{ and } x^c < x^{ns}$$

As under the infrastructure effect, internalizing the negative externality and the spillover effects leads to a decrease in the levels of production. Under the scarcity effect, establishing a protected area in Municipality i leads to decrease the production cost in j. So a way to reduce global production costs is to reduce the levels of production. As the three effects work in the same sense, the centralized regulation always protects more forest than the Nash symmetric equilibrium.

5.3 Results

In this section, we compare results in Sections 5.1 and 5.2. First, the equilibrium quantities of private good are always higher under the infrastructure effect than under the scarcity effect. Others results obtained in this paper are summed up in the following Propositions:

Proposition 1 *As far as total deforestation is concerned asymmetric regulation is better than no regulation.*

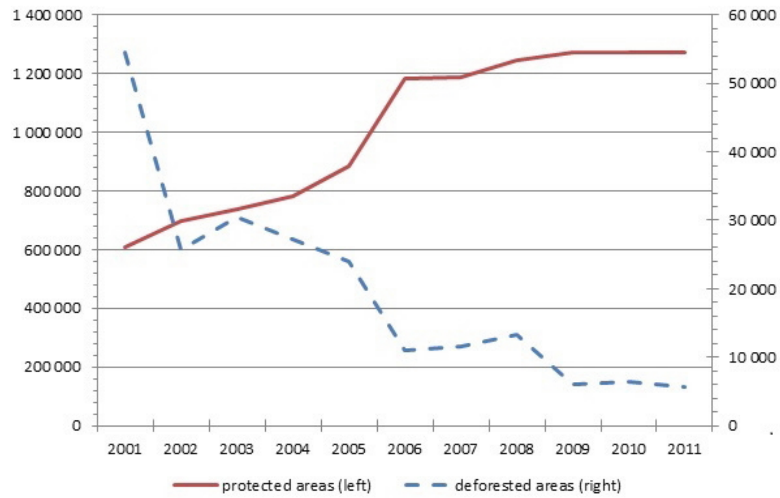
Proposition 2 *Under the infrastructure effect a centralized policy does not always work in favor of larger protected area than a decentralized policy contrary to the scarcity effect.*

Proposition 3 *The infrastructure effect always leads to smaller protected area than the scarcity effect.*

Corollary 4 *The infrastructure effect always leads to more deforestation than the scarcity effect.*

Proposition 5 *Under the infrastructure effect the decentralized equilibrium can reach the first best.*

1



2.jpg

Figure 2: Evolution of protected areas and deforestation in the Brazilian Legal Amazon, square kilometers. *Source : INPE, authors' calculations. Note that protected areas are from federal and state entities but indigenous lands are not included.*

6 A study case: The Brazilian Legal Amazônia

Deforestation in the Brazilian Legal Amazônia has been greatly studied in the literature because of the extent of the phenomenon and its adverse effects on biodiversity, the ecological system of the region and climate. From 54,534.2 km2 in 2001, deforestation in the Brazilian Legal Amazônia rainforest declined to 27,136 square kilometers in 2004 and about 5,800 square kilometers in 2014 according to INPE. The decline of deforestation in Brazil is explained not only by the 2008-2009 financial crisis (Nepstad et al. 2009) but especially by the hardening of conservation policies (Assunção et al. 2012; Hargrave and Kis-Katos 2012; Nolte et al. 2013; Palmer and Di Falco 2012 among others).

These policies consisted mainly in the establishment of protected areas, monitoring of deforestation and hardening legislation via the Action Plan for the Prevention and Control of Deforestation in the Legal Amazônia (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal , PPCDAm). Protected areas represented 42% of the area of the Brazilian Amazônia in 2009, about 2 million square kilometers.

By Law No. 9.985 of 18 July 2000, Brazil created a formal, unified system for federal, state and municipal parks, allowing classifying protected areas in three categories: integral protection areas, sustainable use areas, and indigenous lands. Integral areas define the fully protected areas. They are intended to maintain the natural ecosystem without human interference and can be classified in the most restrictive categories of the International Union for Conservation of Nature (IUCN) classification (categories I, II and III). In 2009 they accounted 19% of the protected surface areas. Sustainable use areas, which represented for 32% in 2009, aim for sustainable use of renewable environmental resources, maintain biodiversity and other ecological attributes. They are equivalent to categories IV, V, and VI of the IUCN classification. Indigenous lands are lands traditionally occupy by indigenous peoples. The Brazilian constitution recognizes their inalienable right on these lands and confers them permanent possession of these lands after a formal process of demarcation. Indigenous lands are devoted to the protection of the living space of indigenous peoples.[6]

Integral protection areas are managed by federal units and sustainable protected areas by municipalities. So the study of Brazilian protected areas can illustrate our theoretical model because we find two implementation levels, one say, a centralized and a decentralized level. To conduct our study, we use data on forest cover and protected areas in the Brazilian Legal Amazônia for the period 2001-2009 available from the PRODES System of the Instituto Nacional de Pesquisa Espacial-INPE (National Institute Space Research Center).

As shown in Figure 2, the implementation of the regulation through protected areas contributed to reduce drastically deforestation. However there is no a protected area in each municipality. Even if spillover effects with deforestation displacement may occur, deforestation is globally reduced in Brazil. That supports Proposition 1 of our theoretical model.

We aggregate the municipal data into the 248 Minimum Comparable Areas (MCAs) located in the Brazilian Legal Amazônia.[7] To isolate protected areas in zones where the scarcity or infrastructure effect occurs, we take the distribution of protected areas according to the remaining forest area in Minimum Comparable Areas. The first quartile corresponds at a forest cover rate less than 5.2%, the second one at a forest cover between 5.2% and 25,43%, the third one at a forest cover between 25.43% and 61.82% and finally in the fourth one forest cover is superior to 61.82%. In Figure 3, we represent the average size of protected areas with respect to the total deforestation in the quartile. Following Angelsen (2001), we consider that the infrastructure effect decreases relative to the scarcity effect as deforestation increases. We are so able to classify protected areas in which the scarcity (infrastructure) effect predominates. The scarcity effects should occurs in protected areas located in the first quartile and the infrastructure effect in the last quartile.

Globally, Figure 3 shows that protected areas are higher under the scarcity effect than under the infrastructure effect, satisfying our Proposition 3. We consider that integral (partial) protection areas correspond to centralized (decentralized) protected areas. Hence, we observe whatever the cost effect driving de-

[6] In this study case, we do not take into account indigenous land because they are mostly created before the period 2001-2009. Moreover the aim of indigenous lands is different to that integral or sustainable protected areas.

[7] Using MCA data allows comparison (because the number and size of municipalities may change through time). The list of MCAs is available from the Brazilian Institute of Applied Economic Research (IPEA - Instituto de Pesquisa Econômica Aplicada).

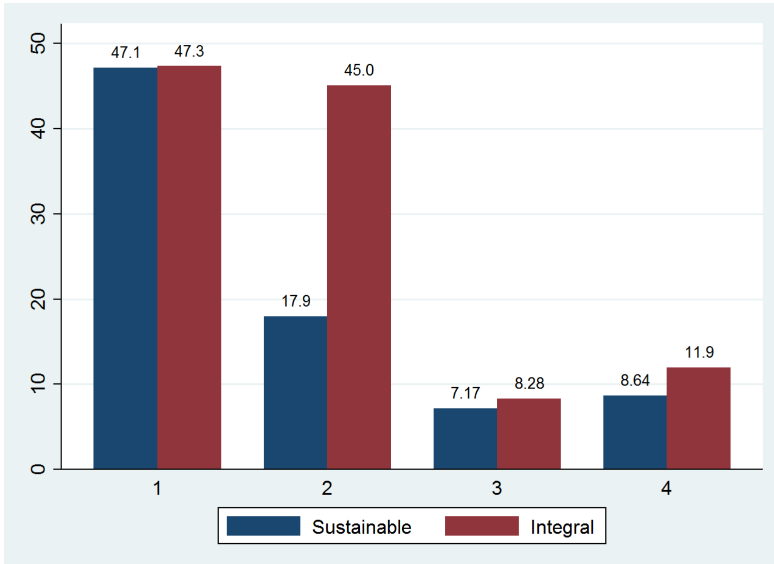


Figure 3: Percent of protected area in terms of forest area by forest area quartile. *Source: INPE, authors' calculations.*

forestation, centralized protected areas are higher than decentralized protected areas. According to Proposition 2, it should be the case under the scarcity effect but the result is undetermined under the infrastructure effect. According to Figure 3, the cost effect seems to be offsetting the negative externality and the free rider effect exposed in our theoretical analysis in the Brazilian Legal Amazônia. Finally, we see on Figure 4 that deforestation increases if the scarcity effect diminishes, as the Corollary of Proposition 3 notes. This study case not only corroborates our theoretical results but also enable to remove theoretical indetermination.

7 Concluding remarks

In this article we highlighted the mechanism leading to set the size of a protected area. We have considered an economy composed of two municipalities. In each one, forest is cut in order to produce a private good. Three kinds of externalities are present: a consumption externality, local public goods and cost interdependencies between firms. We investigated two assumptions about cost functions: the infrastructure effect and the scarcity effect. Finally, we compared the decentralized regulation and the centralized one.

We showed that decisions in other municipality about forest protection do not determine the choice of implementing or not a protected area in a municipality but affect the surface of the protected area. This latter mainly depends

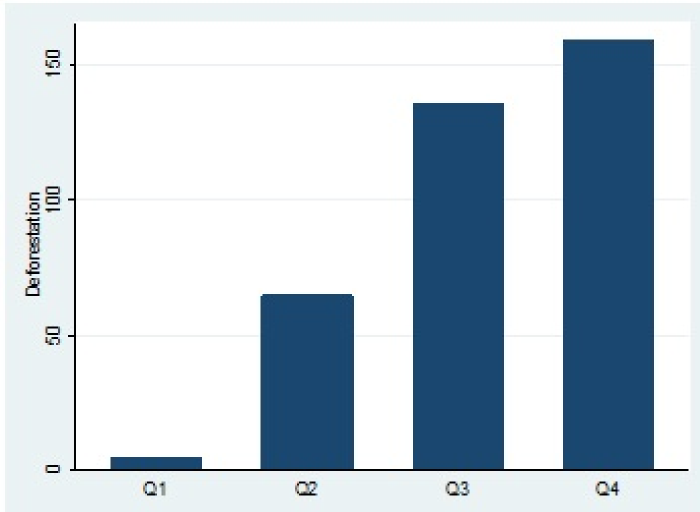


Figure 4: Average surface cleared (deforestation) by forest area quartile. *Source: INPE, authors' calculations.*

on preferences toward forest, on the firms' production costs and on the relation between municipalities. We find an optimistic result. In spite of having neighboring effects, implementing a protected area just in one municipality leads to globally decrease deforestation. Hence, asymmetric regulation is better than no regulation for forest preservation.

Comparison with centralized regulation depends on cost functions. Under the scarcity effect, the centralized regulation always leads to larger protected area than decentralized regulation. Under the infrastructure effect we first show that centralized regulation does not always work toward less deforestation. Then it appears that decentralized decisions can reach, by chance, the first best, i.e. the centralized regulation. This result is important because it is known that cooperation between regulators is difficult to obtain. Otherwise an active educative policy towards environmental protection may help to reach this equilibrium. Finally it appears that whatever the equilibrium considered (centralized or decentralized level) the infrastructure effect leads to smaller protected area than the scarcity effect.

We finally conducted a study case in the Brazilian Legal Amazônia. This analysis not only corroborates our theoretical results but also removes a theoretical indetermination. It suggests that the infrastructure effect matters a lot in the Brazilian Legal Amazônia.

This article underlines the relevance of cost functions in the implementation of protected area and in the assessment of neighboring effects. Of course some assumptions set in this article can seem restrictive. Among others, we assumed perfect information. We know that in a real world regulators do not have complete information about production costs. This assumption is also crucial about the benefit evaluation coming from forest. We have also implicitly considered full property rights and no enforcement cost. These assumptions can be criticized mainly in developing countries. Further research could investigate how taking into account some of these more realist assumptions could challenge our results.

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