CONSERVATION BY LENDING

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Abstract

This project analyses two political economics benefits of "conservation by lending" relative to other environmental instruments (such as PES and REDD+). A donor or compensator K can offer a loan to a country's policymaker P, where the future repayment (or interest rate) is contingent on the amount of resource extraction (e.g., deforestation level, or remaining forest cover).

The first benefit is that the loan helps P to solve its time inconsistency problem: P prefers that future policies are sustainable, but is tempted to exploit the resource right now. The more frequent is the rotation of policymakers, the larger is this time inconsistency problem, and the larger is the benefit (and the smaller is the cost) of the contingent loan.

The second benefit is that the loan can exploit the existence of the private credit market. If P can borrow privately, but creditors are worried about default, then P can borrow more if P exploits the resource, because exploitation enables P to serve a larger amount of debt. Thus, the existence of the credit market motivates P to exploit more. However, if K requests a high interest rate from its loan if P exploits the resource, P will need to default on its debt if P exploits. This linkage raises P' s cost from exploitation, and K can induce P to conserve at a lower cost.

Keywords: Rotation of political power, time inconsistency, environmental conservation, sovereign debt, sustainability-linked bonds, default.

JEL codes: D72, C73, Q57, O13.

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I. Introduction

This paper first presents a tractable dynamic game of resource exploitation between consecutive governments. The model is employed to illustrate how the conflicts between governments can be taken advantage of by a principal who prefers conservation, or by a principal who prefers exploitation, and the fundamental difference between the two.

The model can be applied to several situations. For example, it is applicable to recent deforestation in the tropics. As I will explain in Section II, the deforestation rate in the Brazilian Amazon is pretty much determined by governmental policies. When the forest is cleared, the land is converted to agriculture. Thus, deforestation is valuable to the agricultural industry, which spends large resources on lobbying the government. On the other side, developed countries have offered payments in return for conservation through the United Nations program Reduced Emission from Deforestation and Forest Degradation (REDD+). Over time, the stakes have increased in the agricultural sector thanks to new trade agreements that enlarge the markets.[1] Simultaneously, the threat of climate change, the emergence of global climate policies, and biodiversity losses have made the world community more willing to pay for conservation than before. Franklin and Pindyck (2018) estimate that the average marginal social cost of deforestation in the Brazilian Amazon increases from $9,000 to $35,000 per hectare when deforestation rates return to the high levels of the early 2000s. (See also Strand et al., 2018.) The estimates vastly exceed the cost of conservation (Stern, 2008; Busch et al., 2012; Edenhofer et al., 2014). Nevertheless, deforestation levels have increased the last few years.[2]

These developments raise positive and normative questions. When can high exploitation rates be the outcome of the game between governments? What are the roles of polarization, political stability, institutions, and the policymakers' discretion? These and other questions were explored in Harstad (2023, JPE).

This project analyzes and derives the benefits of conservation-linked sovereign bonds. With this, we search for the donor's or a "principal's" optimal contract in a dynamic game in which the sovereign South ("agent") extracts an exhaustible resource, which the North prefers to conserve. The resource in question can be a tropical forest, and the principal

[1] Burgess et al. (2019) observe a "growing political power of the agriculture producers" (p. 8).
[2] https://data.worldbank.org/indicator/AG.LND.FRST.K2?locations=BR

can be the UN, the World Bank, or an individual donor country, such as Norway. (Norway has spent billions on tropical forest conservation through the UN program REDD+).

Traditionally, the REDD+ contracts take the following form: If the deforestation level ("x") is below some threshold, then the principal, P, will pay the government in the South, S. The amount of payment is linear in the distance between x and the threshold. One purpose of this analysis is to show when P can do better with more clever sovereign debt contracts, where the contract specifies that the loan must be repaid (at a high interest rate) if and only if the forest cover falls. Forest cover is verifiable by satellites, and if the forest is conserved, the contract can specify that there is no interest and/or no repayment due. This type of policy instrument is not completely novel, because it is similar by the so-called sustainability-linked bonds issued by the governments of Uruguay and Chile in 2022. Our main contribution, therefore, is to shed light on two major benefits of this policy instrument relative to the traditional instruments that have been used to encourage nature conservation in other countries (such as REDD+).

First, we show that loans for conservation exploit the government's time inconsistency problem. The government would like to ensure that future governments act sustainably, but right now it is tempting to extract the resource. It is, generally, difficult to commit and influence what later governments will do, but a loan, that must be repaid by the next government if it extracts, enables the current government to "tie the hands" of the next government. The current government values this commitment, especially when the rotation of power is frequent in country S, and thus S accepts more conservation at a lower price for P. We show that the more myopic S is (e.g., because the government may, with some probability, lose power), the more P benefits from offering a debt contract, instead.

Second, we show that loans for conservation enable the donor to take advantage of the private sector's punishment if S ends up defaulting. In fact, the existence of a foreign credit market leads to more deforestation in the absence of a principal (/donor), because by extracting more, one can take on more sovereign debt (because it is able to repay more in the future, without being tempted to default). In contrast, if a donor exists, it can take advantage of the credit market (and the possibility to default) in order to obtain more conservation at a lower cost. By requesting a high repayment if the resource is extracted,

S will not face the opportunity to deforest without defaulting, because deforestation will force S to default. This temptation is less attractive to S, because the cost of default is especially high if S determines to extract the resource (for export or agric production that can be used to export). Thus, by combining the temptation to deforest with forced default, the donor can achieve more conservation at a lower cost by using conservation by lending.

Literature.—The literature review is yet to be written. Clearly, we draw on the seminal work of Bulow and Rogoff (1989) and Bolton and Jeanne (2009) when we model sovereign debt, the incentives to default, and the importance of seniority. The time inconconsistency of Laibson (1997) follows naturally when we add political rotation, as in Amador (2003), Chatterjee and Eyigungor (2016), and Harstad (2020). This leads to strong incentives to extract natural resources and benefits from tying the hands of future governments (Harstad, 2023). Our "conservation by lending" approach is clearly different from the traditional green bonds, and the associated literature (Mok et al., 2020).

Dynamic games between successive governments have been studied extensively. It is well known that political turnover leads to less investments in state capacity (Besley and Persson, 2009; 2010), more redistribution and depletion of capital (Tornell and Lane, 1999), less stabilization (Alesina and Drazen, 1991) and debt repayment (Amador, 2003), or the accumulation of debt (Persson and Svensson, 1989; Alesina and Tabellini, 1990; Tabellini, 1991; Battaglini and Coate, 2008). Harstad (2020) connects with the hyperbolic discounting literature and show that political rotation motivates investments in commitment technologies.

Similar results appear in resource economics. Extraction rates are shown to be larger if one fears nationalization (Long, 1975) or future over-exploitation (Kremer and Morcom, 2000), if there are multiple dynasties (Nowak, 2006), or if the resource fuels conflicts (van der Ploeg and Rohner, 2012). More specifically, Robinson et al. (2006) show that an incumbent extracts more if he is unlikely to be reelected. Their two-period model is extended by Ryszka (2013) and van der Ploeg (2018), who investigate how a higher probability of being removed from office leads to more rapacious depletion.[3]

[3]There is a theoretical literature on dynamic contribution games (see Bagnoli and Lipman, 1989; Marx and Matthews, 2000, Battaglini et al., 2014, and subsequent papers), but the present game is different since every player fears that later players will end the game (by exploiting the resource). In

Outline.—For the interested reader, the next section discusses available empirical evidence and explains why the model is consistent with deforestation in the Brazilian Amazon. Section III presents the positive theory with rotations of political power and derives the multiplier. These two secions are copy-pasted from Harstad (2023). The new material starts in Section IV, which derives the benefit from conservation by lending when the policymaker is time inconsistent. Section V derives another benefit from conservation by lending which allows the donor to draw on the existence of the private credit market, and the associated cost of default. The Appendix contains the proofs.

II. Supporting and Motivating Evidence

A. Empirical Investigations

Among other things, the below positive theory relies on the assumption that the party in power obtains an additional benefit (Δ) from extracting the resource, compared to the benefits obtained by the parties not in power. The theory predicts that (i) the larger this additional benefit is, the larger the equilibrium extraction rate is, (ii) the lower the probability (p) for staying in power is, the more one extracts, and (iii) the the pro-exploitation lobby will be more influential than the pro-conservation donor.

The assumption is natural, given that governmental revenues can be used for party perks, and not only for public goods that benefit everyone. The assumption is also in line with empirical evidence. Caselli and Michaels (2013:230–31) find that "some of the revenues from oil [in Brazil] disappear before turning into the real goods and services they are supposed to be used for" and "the evidence leads us to conclude that the missing money result is explained by a combination of patronage spending/rent sharing and embezzlement." More recently, Andersen et al. (2017:857) estimate that "around 15% of the windfall gains accruing to petroleum-rich countries with autocratic rulers is diverted to secret accounts in havens." They continue: "This finding provides empirical support for the theoretical argument that rulers and political elites in countries with weak political constraints and lack of competitive elections transform petroleum rents into political rents."

much of the contribution games literature, in contrast, each player fears that subsequent players will not contribute, i.e., that the game will continue for a long time.

In the model, Δ can be large because of disagreements, weak institutions, or corruption. In line with prediction (i), weaker institutions, and more corruption, seem to be associated with faster resource exploitation. Barbier et al. (2005:294) confirm that "corruption appears to be associated with cumulative land expansion in tropical developing economies." More specifically, they find: "The direct effect of greater control of corruption appears to be a reduction in cumulative agricultural land expansion of between 0.11% and 0.22%" (p. 292).

There is more empirical evidence regarding prediction (ii). Recently, Sanford (2021:11) documents that "political competition may fuel exploitation of natural resource[s]." More specifically, he studies the effects on deforestation and finds that "competitive elections were associated with increased deforestation" (p. 1). Sanford argues that the democratic transition (with more competition between parties) leads to a reduction in forest cover.

Oil is extracted by private companies, but policymakers may still prefer faster extraction if they don't expect to stay in power for long. Collier (2010:1124) found that "ministers in the transitional government in the Democratic Republic of Congo (DRC) knew that they only had around three years in office. During this period many contracts were signed with resource extraction companies conceding very generous terms in return for signature bonuses that cashed in the value of the natural assets to the society."

More generally, Bohn and Deacon (2000:543) compare different types of resources and find that: "Higher risk implies heavier discounting of future returns, tending to hasten production in the short run, but lowers the capital intensity of oil production, tending to slow production in the long run." That is, they find that "forest stocks are reduced by ownership risk" (p. 547), but a resource like oil, which requires up-front investments before it can be exploited, is not necessarily exploited faster.

Combined, (i) and (ii) suggest that resources are better managed if p is large, while Δ is small. This finding is consistent with the empirical evidence of Collier and Hoeffler (2009:305), who find that: "electoral competition on the resource-rich societies appears to be particularly inappropriate unless, it is complemented by checks and balances." They also write: "our results suggest that the form of democratic polity best-suited to resource-rich countries is one with checks and balances that are strong relative to electoral competition. This is indeed the form of democracy in the most striking exception to

generally adverse combination of democracy and resource rents, namely Botswana. Electoral competition is in practice quite limited: The government has never been defeated at the polls. Yet, perhaps because the democracy has been continuous since independence, the legal and bureaucratic procedures that constitute checks and balances have been maintained."

Future research must test other predictions of the model, including (iii) the stronger influence of pro-exploitation lobbies compared with that of pro-conservation stakeholders. Sure, lobby groups are active, as argued below. Harding et al. (2022:1) study lobby groups in Columbia and argue that "given the benefits to be had from forest clearance, campaign donations are used to buy regulatory non-enforcement of [conservation laws], as mayors choose not to sanction illegal deforestation in return for campaign contributions." At the same time, we have more than a decade of experience with REDD+. Despite the large conservation benefits referred to in the Introduction, relative to the costs, IPBES (2019: 54) reports that "the literature is currently mixed on the success rates of forest carbon projects". Despite Brazil's being the largest recipient of REDD+ funds, its policymakers have tolerated deforestation levels that have increased.

B. Deforestation in the Amazon

Even though deforestation is influenced by many factors, it is mostly influenced by the government. Burgess et al. (2019:3) analyze satellite data and conclude that they "demonstrate the remarkable reach of the Brazilian state to exploit or conserve its natural resources."[4] The authors also find "concrete evidence that the Brazilian state is now favoring exploitation over conservation" (p. 2).

The high deforestation levels under President Jair Bolsonaro are consistent with the theory. After the election in 2018, *The Economist* wrote that "most analysts had thought that the rightwinger would eventually lose to someone less divisive" and "his own Social Liberal Party, until now a tiny group, will have 52 seats in the 513-member lower house, up from eight in the outgoing congress."[5] Low approval rates suggest that the probability

[4] In particular, the high deforestation rates in the early 2000s were "associated with Brazilian policies to develop the Amazon," they write (p. 2) but "this policy stance was sharply reversed in the 2006–2013 period with laws to protect the Amazon rainforest being introduced and enforced" (p. 3).

[5] https://www.economist.com/the- americas/2018/10/13/jair-bolsonaro-is-poised-to-winbrazils-pr

of staying in power must have appeared limited.

Nevertheless, "Brazil's powerful farm lobby endorses far-right presidential candidate Bolsonaro" – according to Reuters.[6] The agricultural sector has for decades supported, and lobbied for, a policy that permits extensive deforestation.[7] Transparency International reports that the Brazilian agriculture business "donated close to US$100 million to politicians in the 2014 elections".[8] Some pay illegal bribes, and the police have "crack[ed] down on an alleged massive land grab by an agribusiness collective in western Bahia, one of Brazil's largest soy producing regions."[9]

Evidently, the pro-exploitation lobby does not attempt to earmark the donations for public goods.

Pro-conservation donors, in contrast, may benefit from earmarking the compensation for public goods, according to my theory. In the period 2005–2012, the Brazilian government proved that deforestation can be reduced dramatically when there is a political will. Norway, the biggest contributor to the REDD+ program, paid Brazil $1.2 billion in return. The REDD+ funds are, in part, earmarked, but the debate regarding earmarks is intense. In 2019, the governments of Brazil and Norway disagreed on how much discretion the Brazilian government should have and, as a result, the funding was suspended.[10] The conflict has nurtured a debate regarding alternative targets. Angelsen et al. (2018) find that a donor might benefit from cooperating with farmers and agricultural associations instead of with governments, exactly as my theory predicts.

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[6] https://www.reuters.com/article/us-brazil-election-agriculture-idUSKCN1MC21M

[7] See Barbier et al. (2005) and, more recently, *The Washington Post*: https://www.washingtonpost.com/world/the_americas/why-brazilian-farmers-are-burning-the-rainforest–and-why-its-difficult-for-bolsonaro-to-stop-them/2019/09/05/3be5fb92-ca72-11e9-9615-8f1a32962e04_story.html.

[8] https://www.jstor.org/stable/pdf/resrep24899.pdf

[9] https://news.mongabay.com/2019/11/brazil-investigates-agribusiness-bribes-to-judges-for-favorable-land-rulings/

[10] Reuters reports: "The aid that Brazil receives depends on the results of work to curb deforestation and for 2018 the funding would amount to about 300 million Norwegian crowns ($33.27 million), but Norway will not proceed with the payment, a ministry spokeswoman confirmed to Reuters." In particular: "Norway has suspended donations supporting projects to curb deforestation in Brazil after the country's right-wing government blocked operations of a fund receiving the aid." See:
https://www.reuters.com/article/us-brazil-environment-norway-idUSKCN1V52C9

III. The Dynamics of Conservation and Extraction

A. An Extraction Game

The following is from Harstad (JPE, 2023).

Consider a natural resource that is being depleted over time. The resource can be a standard exhaustible resource, such as oil or coal. In practice, even a biodiverse tropical forest is exhaustible: once the forest is logged, and once the land is converted to agriculture, it will not return anytime soon. To fix ideas, I thus refer to the stock as tropical forests.

Time is discrete and there is a infinite number of periods. At time t, the size of the stock is S_t. When the extracted fraction is $x_t \in [0,1]$, $S_{t+1} = (1-x_t)\,S_t$.

Players.—Variable x_t is decided on by the party in power at time t, P_t. This party may or may not be in power in the future. Let $p \in [0,1]$ measure the probability that the party is in office in any later period. If $p = 1$, there is no rotation of political power. If there are n identical parties, we may have $p = 1/n$. For simplicity, I abstract from autocorrelation: whether P_t is in power at some time t' does not influence P_t's chance of being in power later.[11] For now, the parties are identical and p is exogenous, but Section VI discusses how both assumptions can be relaxed.

From the next section, we also emphasize the importance of the donor, or compensator, K, who benefits f every period for each unit of the forest that is conserved.

Benefits.—The resource can be beneficial whether it is extracted or conserved. Deforestation implies land-use change so that agricultural products can be produced. If the per-period marginal agricultural value be lowercase a_1, the present-discounted value of each extracted unit is uppercase $A_1 = a_1/(1-\delta)$, where δ the discount factor. I let the present-discounted value A_1 also include the value of the timber (or of the oil or coal, if the model is applied to fossil fuel extraction).

To allow for a conflict of interest, $A_1 > 0$ is the extraction benefit for the party in power, while $A_0 \geq 0$ is the benefit for a party not in power. I assume that $\Delta \equiv A_1 - A_0 \geq 0$, meaning that any P_t benefits more if it exploits the resource, than if

[11] With incumbency advantage, P_t's probability of staying in office is higher at $t+1$ than at $t+2$, and so on. This autocorrelation leads to a time inconsistency problem that is less tractable (Harstad, 2020).

another party exploits the resource. This assumption is natural, since the party in power can spend (parts of) the revenues on perks (see Section II). With this interpretation, it seems reasonable that Δ is correlated with the amount of corruption in the country. In other applications, as when each government would prefer to postpone the repayment of debt, $\Delta < 0$ can be natural.

There may also be a benefit from conservation. The per-period benefit from each conserved unit is lowercase $b > 0$. Thus, the benefit from conserving a unit indefinitely is uppercase $B = b/(1-\delta)$. For the most part, it will be assumed that the optimal extraction level is strictly positive (i.e., $A_0 > B$). (The Appendix permits disagreements over the conservation benefit.)

The extraction cost.—The extraction cost function is:

$$\frac{c}{2}x_t^2 S_t. \tag{1}$$

Intuitively, one view is that the extraction cost should increase in the fraction that is extracted, x_t, and also with the total stock S_t, for a given x_t, because the effort associated with extracting the fraction x_t from an average unit must be repeated for the number of units. An alternative viewpoint is that it seems reasonable to let the extraction cost be increasing and convex in the extracted quantity ($x_t S_t$) but possibly decreasing in the size of the remaining stock (for a given extracted quantity), because a larger stock makes it possible to distribute the extraction intensity over multiple remaining units. The cost function (1) is in line with both views, because we can write $cx_t^2 S_t/2 = c\left(x_t S_t\right)^2/2S_t$.

A micro-foundation.—Because (1) is in line with the both views discussed above, it is not difficult to provide a supporting micro-foundation. Suppose that to successfully log a typical unit of S_t, one must offer a payment $\omega \geq 0$ that is larger than the input cost, θ. For example, a local worker or supplier may need to be hired. When each local input cost is unknown, and uniformly distributed as $\theta \sim U\left[0, \overline{\theta}\right]$, a take-it-or-leave-it offer ω implies that the unit is logged with probability $\omega/\overline{\theta}$, and the fraction of units that is logged is $x = \omega/\overline{\theta}$. The total cost of this extraction is $\omega \cdot \left(\omega/\overline{\theta}\right) \cdot S_t$, written as (1) when $c \equiv 2\overline{\theta}$.[12]

[12]If the local workers' surplus (which is expected to be $(\omega/2) \cdot \left(\omega/\overline{\theta}\right) \cdot S_t$) is internalized, the net extraction cost is (1) with $c \equiv \overline{\theta}$.

B. Strategies and Equilibrium Concept

Given the large set of equilibria in dynamic games, it is common to restrict attention to stationary Markov-perfect equilibria (MPEs). A Markov strategy cannot depend on payoff-irrelevant aspects of the history. That is, if P_t does not strictly benefit from conditioning its strategy on the stock – in a situation in which the *other* parties do not condition their strategies on the stock – then P_t's Markov-perfect strategy does *not* depend on the stock.[13] Here, a Markov-perfect x_t must be independent from S_t.

Lemma 1. *There is a unique MPE. The MPE requires x_t to be invariant in S_t. Continuation values are linear in S_t.*

The lemma follows because, given x_t, all benefits and costs are proportional to S_t. With alternative functional forms, x_t may decline or increase with S_t, but these changes would make the results emphasized in this paper less transparent and the analysis would also be less tractable.

C. The First Best

Let A_* be the social planner's value of each extracted unit. (E.g., A_* may be a weighted average of A_0 and A_1.)

Consider, first, a planner at t, taking as given $x_\tau = x_s$, $\tau > t$. The planner's continuation value at $t+1$, $v_*(x_s)$, is given by (9) if we replace A_p with A_*. Given $v_*(x_s)$, the first-best x_t follows from (10) if A_* replaces A_1, and if the benefit from conservation, b, is replaced by the planner's benefit (potentially different), b_*.

$$x_t = \frac{A_* - b_* - \delta v_*(x_s)}{c} = \frac{A_* - b_*}{c} - \frac{\delta}{c}\frac{x_s A_* + (1 - x_s) b_* - x_s^2 c/2}{1 - \delta(1 - x_s)}. \tag{2}$$

Because $v_*(x_s)$ is concave in x_s, x_t is convex in x_s. Because $v_*(\cdot)$ is maximized at

[13] Or, as Maskin and Tirole (2001:202) write: "Markov strategies are the simplest strategies (i.e., the strategies measurable with respect to the coarsest partition and hence dependent on the fewest variables) that are consistent with rationality in the sense that, if the other players make their strategies measurable with respect to some [even] coarser partition [of the history] it would *not* always be optimal for a player to make his or her choice between any two given continuation strategies measurable with respect to [that partition]."

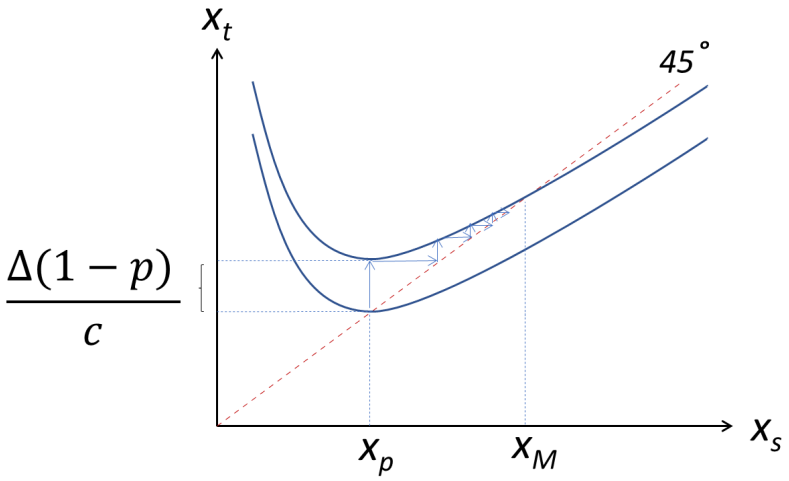


Figure 1: *If* Δ *increases a little,* x_M *can increase by a lot – thanks to the multiplier.*

$$x_* = \arg\max v_*(x) = \max\left\{0, \sqrt{\left(\frac{1-\delta}{\delta}\right)^2 + 2\left(\frac{1-\delta}{\delta}\right)\frac{A_* - B_*}{c}} - \frac{1-\delta}{\delta}\right\}, \tag{3}$$

the optimal x_t, given x_s, is minimized when $x_s = x_*$. When $x_s = x_*$, the planner's preferred x_t maximizes the same continuation value as does x_s, so $x_t = x_*$.[14]

D. The Equilibrium Outcome

In general, P_t's preferred x_t will depend on the expected future stationary x_s. To see how, note that P_t's problem is given by (10), and the first-order condition (f.o.c.) becomes:

$$x_t = \frac{A_1 - b - \delta v_p(x_s)}{c} \tag{4}$$

Analogously to the first best, because $v_p(x_s)$ is concave in x_s, x_t will be convex in x_s (see Figure 1). Because $v_p(x_s)$ is maximized at x_p, x_t is minimized at x_p, where:

$$x_p \equiv \arg\max v_p(x) = \max\left\{0, \sqrt{\left(\frac{1-\delta}{\delta}\right)^2 + 2\left(\frac{1-\delta}{\delta}\right)\frac{A_p - B}{c}} - \frac{1-\delta}{\delta}\right\}. \tag{5}$$

In contrast to the first best, however, $x_t > x_p$ even if $x_s = x_p$, when $(1-p)\Delta > 0$:

[14] To ensure $x_* \in (0,1)$, assume $\sqrt{\left(\frac{1-\delta}{\delta}\right)^2 + 2\frac{A_*}{c}\left(\frac{1-\delta}{\delta}\right) - 2\frac{b_*}{c}} - \frac{1-\delta}{\delta} \in (0,1)$.

$$x_t = x_p + \frac{A_1 - A_p}{c} = x_p + \frac{(1-p)\,\Delta}{c}.$$

In equilibrium, we have that extraction is larger than x_p not only at time t, but at *all* future dates. When extraction is larger, the resource will be exploited faster in the future, and the value of contemporary conservation is reduced. The lower continuation value motivates P_t to extract even more. This iterative domino process, illustrated in Figure 1, converges to the fixed point $x_t = x_s = x_M$:

Proposition 0. *In equilibrium,*

$$x_M = \frac{A_1 - b - \delta v_p\left(x_M\right)}{c} \Rightarrow$$
$$x_M = \sqrt{\left(\frac{(1-p)\,\Delta}{c} - \frac{1-\delta}{\delta}\right)^2 + 2\left(\frac{1-\delta}{\delta}\right)\frac{A_1 - B}{c}} + \left(\frac{(1-p)\,\Delta}{c} - \frac{1-\delta}{\delta}\right). \quad (6)$$

The Markov-perfect extraction level is stationary and increasing in $(1-p)\,\Delta$, as shown in the Appendix. Thus, x_M declines in p. In contrast, x_p increases in p. That is, when P_t is less likely to be in power later, P_t's preferred future x_p is smaller, but P_t's actual x_t is larger. For every $p < 1$, $x_M > x_1$, where $x_1 = \max_p x_p$.[15]

IV. Conservation by Lending

Here, we highight two inefficiencies in the model above. One inefficiency is that the policymaker cannot commit, and thus future exploitaton levels are higher than what the current policymaker would have liked to commit to. Thus, P_t would be willing to pay in order to be able to commit.

A second inefficiency arises when the compensator K experiences harm $F = f/(1-\delta)$ when a forest unit is lost forever. Even if P_t could commit, this inefficiency is not taken into account. It appears that the two inefficiencies are independent from one another.

With conservation by lending, we allow K to offer a loan to P_t that must be repaid

[15] As before, I restrict attention to parameter values ensuring that x_M is in $(0,1)$, i.e.,

$$\sqrt{\left(\frac{\Delta\,(1-p)}{c} - \frac{1-\delta}{\delta}\right)^2 + 2\frac{(1-\delta)\,A_1 - b}{\delta c}} + \left(\frac{\Delta\,(1-p)}{c} - \frac{1-\delta}{\delta}\right) \in (0,1)\,.$$

by P_{t+1}. The amount of repayment, i.e., the rate of return, is stated in the loan contract. Because forest cover is verifiable by satellites, we allow the interest to be a function of the forest cover in the future. In particular, this allows K to offer a loan that will not need to be repaid unless some future policymaker selects an exploitation level than is different from, say, x_A. If the cost of repaying the loan is sufficiently large, deviating from x_A will not be attractive for future policymakers. The reduction in P_t's continuation value from moving from the stationary equilibrium x_s to x_A must be compensated for by the amount of the loan offered by K, L_K. The more P_t value the commitment and the reduction from x_s, the smaller is the required loan. The required loan can even be negative, unless x_A is much smaller than x_*, because P_t values the reduction in x_s.

Proposition 1. *If K offers an x-contingent loan in return for x_A, its size will be decreasing in $(1-p)\Delta$:*

$$L_K = \delta \frac{(x_s - x_A)^2 c/2 - (x_s - x_A)(1-p)\Delta}{1 - \delta(1 - x_A)}.$$

Loan, given full conservation. Suppose all is conserved, so that $x_A = 0$. We can use the formulae for the equilibrium x_s to show that the loan must be:

$$L \geq L_{all} := c\frac{1-\delta}{\delta} + Z_1 - \frac{\delta b_p}{1-\delta} - (1-p)\Delta - c\sqrt{\left(\frac{1-p}{c}\Delta - \frac{1-\delta}{\delta}\right)^2 + \frac{2}{c}\left(\frac{1-\delta}{\delta}Z_1 - b_p\right)},$$

which decreases in $(1-p)\Delta$.

If $p = 1$, this becomes:

$$L_{all,p=1} = c\frac{1-\delta}{\delta} + Z_p - \frac{\delta b_p}{1-\delta} - \sqrt{\left(c\frac{1-\delta}{\delta}\right)^2 + 2Z_p c\frac{1-\delta}{\delta} - 2cb_p}. \tag{7}$$

Comparative Value of Lending

The traditional way of consvering forests is through the REDD+ program by the United Nation. According to this scheme, P_t is compensated (by, say, k) for conservation per period, and there is no repayment or dynamic linkage between the periods.

Here, we analyze and compare this scheme to the loans, above, assuming that the

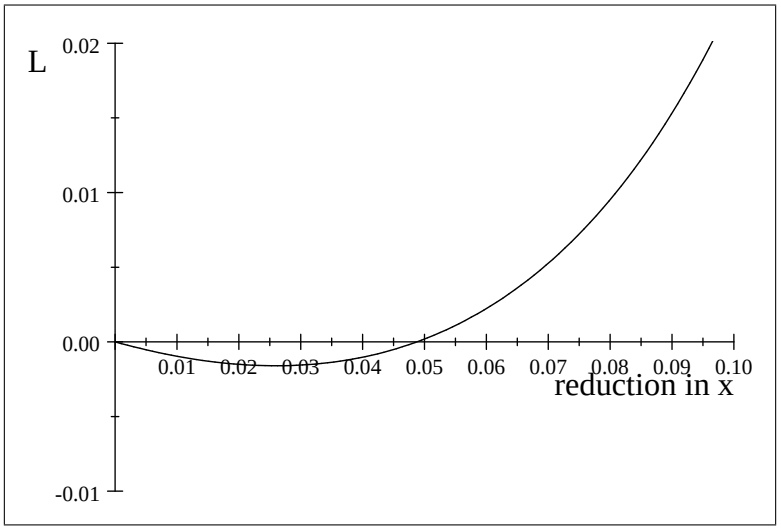


Figure 2: *Because of P_t's time-inconsistency problem, the cost of the loan is small (and can be negative) if the requested reduction in x is small.*

contracts lead to exploitation. To make the schemes comparable, the payments at t are offered for $t+1$. (Relaxing this assumption would have no qualitative effect.) We consider two alternative assumptions. We start with the following assumption, before relaxing it in the next subsection.

REDD now and in the future. We start by imposing Assumption D-1:

Assumption D-1. Whether or not P_t exploits $x_t > 0$, K will offer the same amount of conservation compensation (per unit) at $t+1$.

Proposition 2. *With D-1, the equilibrium k is given by the following, and the total cost decreases in k and increases in Δ:*

$$k\frac{\delta}{1-\delta} = \frac{1}{p}\left(c\frac{1-\delta}{\delta p} + Z_1 - \frac{\delta b_p}{1-\delta} - \sqrt{\left(c\frac{1-\delta}{\delta p}\right)^2 + 2c\frac{1-\delta}{\delta p}Z_1 - 2c\frac{b_p}{p}}\right).$$

It is easy to verify that this k decreases in p and increases in $Z_1 - Z_p$. The intuition is that if p is larger, it is more likely that P_t will enjoy the future compensations too, and thus the necessary compensation falls. The compensation increases in A_1 (or Z_1) because this variable measures P_t's benefit from exploitation right away.

If $p = 1$, the cost, $k\frac{\delta}{1-\delta}$, becomes:

$$k\frac{\delta}{1-\delta} = c\frac{1-\delta}{\delta} + Z_p - \frac{\delta b_p}{1-\delta} - \sqrt{\left(c\frac{1-\delta}{\delta}\right)^2 + 2c\frac{1-\delta}{\delta}Z_p - 2cb_p}. \tag{8}$$

Which coincides with the cost of the loan, (7). So, in a "stable" system without rotation of political power, both schemes are equally effective. However, because k decreases in p and increases in Δ, while L_K does the reverse, the loan is strictly less costly than REDD+ if $p < 1$, and the cost saving increases when p declines or Δ increases.

Corollary 1. *The alternative costs of conserving from $t+1$, i.e., REDD+ ($k\frac{\delta}{1-\delta}$) and the loan (L_K), are the same if both $p = 1$ or $\Delta = 0$. However, if p decreases, or Δ increases, the cost of REDD+ increases, the cost of the loan decreases, and K's benefit from offering the loan instead of REDD+ increases.*

REDD+ with trigger strategies.

This subsection simply shows that the above results hold, qualitatively, without Assumption D-1. We can, instead, assume:

Assumption D-2. If P_t exploits $x_t > 0$, K will not offer conservation compensation in the future.

Proposition 3. *With D-2, the equilibrium k is given by the following equation, and the total cost of the compensations decreases in p and increases in .*

$$\frac{\delta k}{1-\delta} = \delta\left(v_s - \frac{b_p}{1-\delta}\right) + \delta(1-p)\frac{\Delta\frac{1}{c}(Z_1 - \delta v_s) + \delta\left(v_s - \frac{b_p}{1-\delta}\right)}{1-\delta(1-p)}, \text{ so}$$

$$\frac{\delta k}{1-\delta} - L_K = \delta(1-p)\frac{\Delta\frac{1}{c}(Z_1 - \delta v_s) + \delta\left(v_s - \frac{b_p}{1-\delta}\right)}{1-\delta(1-p)}.$$

As before, the costs are the same if $p = 1$. However, $\frac{\delta k}{1-\delta}$ increases in $(1-p)$ and Δ, while L_K does the reverse. Hence, the previous corollary continues to hold, as before.

Combining REDD+ and loans. There might be limits to how large the loan can be. For instance, K might be liquidity constrained, or P_t might be tempted to default

if the loan is too large. Then, to ensure that x_s is reduced to $x_A < x_s$, K might need to combine the loan with compensations, k. Here, we take L as given and calculate the necessary k and, more importantly, the present-discounted cost for K of guaranteeing that x_s is reduced to x_A.

Proposition 4. *The total present-discounted cost for K is independent of L iff $p = 1$, but strictly decreasing in L iff $p < 1$.*

V. Uncertainty, Private Credit Markets, and Sovereign Default

Here, we emphasize that there are two other major benefits of loans for conservation, relative to the traditional instruments.

Uncertainty. In reality, parameters change every period in ways that are hard to forecast. For example, the prices of timber and agricultural products fluctuate, and the country's activity and unemployment level will also change over ways. Shocks in the parameters will influence the benefit from exploiting the resource. To be robust, a REDD+ scheme must include a compensation k that is sufficiently high to motivate conservation, also in cases in which the benefit from exploitation is high. Uncertainty is, therefore, increasing the equilibrium k, making it more costly for K to ensure conservation. With a loan, in contrast, the current policymaker forgoes the benefit that future policymakers can exploit. This benefit at time $t + 1$ is unknown at time t, so K must compensate P for the expected benefit that P forgoes. The expected value is smaller than the maximal value, of course, and the larger is the difference, the larger is the benefit from conservation by lending compared to REDD+.

A simple way to capture this uncertainty is to assume that with some probability, $1-q$, independent across the periods, the realization of the parameters are such that it is not attractive for P to exploit any of the resource in that particular period. (Equivalently, P might be unable to exploit the resource.) We assume that K does not learn the outcome of this lottery before it has already offered a certain compensation in return for conservation.

Proposition 5. *If q is smaller, L_K is smaller, and K's saving from conserving by lending instead of by REDD+ increases.*

Private Credit Markets and Sovereign Default.

P can borrow on the private credit market only if it is costly for P to default. The cost of default can motivate conservation, too, if K ensures conservation by lending at such a high interest rate (if P exploits) that P would rather default than to repay the loan to K. If the cost of default increases when P has the capacity to export more agricultural products, then P might be tempted to default without exploiting, or to exploit without defaulting, but doing both at the same time is less attractive to P. Conservation by lending removes the possibility to exploit without defaulting, and thus P's incentive to exploit is reduced. This reduction implies that conservation by lending is less costly for K than are the alternatives.

A key assumption for this idea to work is that P's cost of default is larger if P has exploited more of the resource (i.e., if P has more land available for agricultural production) and that P cannot selectively default on K's loan and not as well as on P's loan from private creditors. Selective defaults can be avoided when the loan contract between P and K is written and enforced by a legal system that excludes that other debt issued by P is senior to the debt issued to K.

In the following, we will formalize this idea.

We allow the policymaker, P, to borrow from the private credit market. We will assume that private lenders, and also the contributor, K, discount future utility by using the discount factor $\overline{\delta} \geq \delta$, where δ is the discount factor used by P. This implies that private lenders request that for every dollar lent at time t, P should pay $R = 1 + r = 1/\overline{\delta}$ in return. If P starts the period with the loan from the past, l_t, and borrows l_{t+1} to be repaid at time $t+1$, then P consumes $l_{t+1} - Rl_t + w_t$, where w_t is the country's potential GDP

The GDP can have an exogenous component, w_0, and it can depend on past and current land-use change, since the amount of beef or agricultural products is likely going to be proportional to the amount of land, Y_t, where $Y_{t+1} = Y_t + x_t$, and each unit of land produces $a = (1 - \delta) A$. Thus,

$$w_t = w_0 + a\left(Y_t + x_t\right) - \frac{c}{2}x_t^2.$$

The benefit of the forest does not contribute to the GDP or the cost of default, we assume.

If $\overline{\delta} > \delta$, P would like to borrow as much as possible. However, the debt is defaultable. If P defaults, P can no longer borrow and faces the cost $\phi = \kappa w_t$ in every future period, implying a future production of $(1-\kappa) w_t$.

Timing: In every period, the timing is as follows. P starts with the stock (l_t, Y_t) and decides, simultaneously or sequentially, whether to repay Rl_t and extract x_t. If the loan is repaid, P can borrow l_{t+1} for the next period. P borrows as much as possible, while creditors ensure that the loan so large that P prefers to default in the next period.

Simplifications. Compared to the earlier model, we simplify by assuming that $p = 1$, because we do not need P's time inconsistency problem to emphasize the following results. We also remove subscripts on the parameters refering to p or the time, t.

Because the cost of default is larger if P can produce a lot, it will be less attractive for P to exploit after P has defaulted. Thus, x_t declines if P defaults. To simplify, we will assume that κ is so large that P does not bother to exploit more of the resource if P has defaulted. This requires that P's benefit from conserving is so large that $b > (1-\kappa) A$.

Definition 1 *Define the thresholds*

$$b^D \equiv (1-\kappa) A$$
$$b^M \equiv (1-\kappa) A + \frac{R(1-\beta)}{R-1} A\kappa.$$

Assuming $b \in \left(b^D, b^M\right)$, P exploits *iff* P has not defaulted.

The Detrimental Effect of the Credit Market (Without the Compensator)

We first study the *laissez-faire* market equilibrium when P logs at its own chosen pace and borrows and lends at the world-market interest rate R, subject to the costraint that default is avoided. Logging in the market equilibrium is a constant fraction of the remaining forest. The comparative statics are intuitive: x_t is increasing in κ; strictly increasing in A, strictly falling in b, and falling in c, δ, and q. Here, we emphasize the following.

Proposition 6. *(i) Because P's cost of default increases in κ and in x_t, P can borrow more if κ and x_t are large (i.e., $\partial l_t/\partial x_t > 0$ and $\partial l_t/\partial \kappa > 0$). (ii) The in-*

centive constraint ensuring that P will not default will, in equilibrium, bind, and, then, $\partial^2 l_t/\partial x_t \partial \kappa > 0$. *(iii) Consequently, P exploits more when* κ *is large.*

In other words, a well-functioning credit market (with a large κ) will increase deforestation. The reason is that the credit market allows P to borrow and enjoy a higher consumption at time t if P exploits at time t, because exploitation increases P's willingness (and ability) to repay debt at time $t+1$.

The equilibrium x_t will decrease in q because when q is large, it is more likely that P can extract also in later periods. If, instead, q is small, P will extract more when conditions are right.

Mechanism Design Approach: To understand the limits of what is possible, we can take a mechanism-design approach to conservation. Suppose K can dictate a consumption path for P, but must ensure to satisfy P's incentive constraint (so that P prefers to conserve and not default) and participation constraint (so that P prefers to not default and remain in "autarky"). We refer to "Program MD" as K's problem of minimizing the present-discounted cost of P's consumption subject to these constraints. Because $\delta \leq \overline{\delta}$, it is optimal for K to front-load the consumption of P, while ensuring that P's participation constraint is satisfied at every point in time in the future.

Implementation: Program MD can be implemented with conservation by lending where K lends L_K to P at time 0, where the repayment is requested in the first period in which exploitation is positive. There is no repayment requested as long as P always conserves. If P exploits, the amount of repayment must be sufficienly high, so that P is not better off compared to defaulting. (Every interest rate that is sufficiently high will then lead to the same outcome.) In addition to L_K, P will elicit loans from the private market to the point at which P will be indifferent between serving that debt and defaulting. P will not be able to borrow more than that.

Proposition 7. *(i) implements program MD, and conserves at least cost, by offering a loan* L_K *that must be repaid when, and only when, P exploits.*

(ii) The cost-saving of K's loan, compared to REDD+ (i.e.,a compensation in every period) is zero if $\delta = \overline{\delta}$ *and* $q = 1$.

(iii) The cost-saving of K's loan, compared to REDD+, is strictly positive if $\delta < \overline{\delta}$ *or* $q < 1$ *and it decreases in* δ *and* q *but inreases in* κ*.*

The intuition part (i) is that when the interest rate is sufficiently high, then if P deviates in any way, P will end up with the default utility (where P, by assumption, will not benefit from further exploitation.) P will itself ensure that this condition holds, because P has an incentive to borrow as much as possible. Thus, it is not possible to guarantee conservation at lower cost to K than with conservation by lending.

If $q = 1$ and $\delta = \overline{\delta}$, as in part (ii), P does not benefit from borrowing or front-loading the consumption. Furthermore, the loan does not have the added benefit that it must only compensate P for the average instead of the maximal realization of the parameters. But these benefits arise if either $q < 1$ or $\delta < \overline{\delta}$, as in part (iii), and they are naturally larger if q or δ are small.

One way of explaining why loans are more effective is as follows. With REDD+, there are two incentive constraints that must be satisfied. If P cannot log (which happens with probability $1 - q$), P must prefer to serve its debt instead of defaulting. If P can log, P must prefer to conserve. If, however, P did exploit, P would prefer to not default at the same time, because P's cost of defaulting is larger if P exploits. The possibility to exploit without defaulting makes it more tempting for P to exploit than if P is forced to default as soon as P exploits. In other words, conservation by lending relaxes the incentive constraint that will motivate P to conserve. Thus, K can guarantee conservation by lending at a lower cost than if K used REDD+. Clearly, this argument requires $\kappa > 0$. If $\kappa \to 0$, the benefit from conserving by lending, compared to REDD+, vanishes. This explains the intuition for the last part of part (iii).

Appendix: Proofs

Notation: To facilitate the extensions, the proofs permit the per-period benefit from conservation to be b_1 for the party in power, b_0 for a party not in power, and $b_p \equiv (1-p)\, b_0 + p b_1$. I will also define $Z_p \equiv A_p - b_p$ and $\Delta \equiv Z_1 - Z_0$, so that $Z_1 - Z_p = Z_1 - [(1-p)\, Z_0 + p Z_1] = (1-p)\, \Delta$.

Proof of Lemma 1. Suppose every future x_τ is independent of the stock, and is measured by stationary x_s. Then, a player's expected continuation value, starting from $t+1$, is:

$$\begin{aligned}
&\sum_{\tau=t+1}^{\infty} \delta^{\tau-(t+1)} (1-x_s)^{\tau-(t+1)} \left[S_{t+1} x_s A_p + S_{t+1} (1-x_s)\, b - S_{t+1} c x_s^2/2 \right] \\
&\qquad = v_p(x_s)\, S_{t+1}, \text{ where} \\
&v_p(x_s) = \frac{x_s A_p + (1-x_s)\, b - x_s^2 c/2}{1 - \delta(1-x_s)} \text{ and } A_p \equiv (1-p)\, A_0 + p A_1. \qquad (9)
\end{aligned}$$

Given the continuation value $v_p(x_s)\, S_{t+1}$, the optimal x_t is:

$$\arg\max_{x_t} S_t x_t A_1 + S_t (1-x_s)\, b - S_t x_s^2 c/2 + \delta (1-x_t)\, v_p(x_s)\, S_t. \qquad (10)$$

There is a unique $x_t = x_s$ solving (10). This solution is clearly independent of S_t. QED

Proof of Proposition 0.

The continuation value is:

$$v_p(x_s) = \frac{x_s Z_p + b_p - x_s^2 c/2}{1 - \delta(1-x_s)}, \text{ if } Z_p = A_p - b\,, \qquad (11)$$

With stationary x_s, P_t's per-unit continuation value at any $\tau > t$ is similar to (9):and the f.o.c. with respect to (w.r.t.) x_t, following (10), becomes (similar to (2)):

$$x_t = \frac{Z_1 - \delta v_p(x_s)}{c} = \frac{1}{c}\left(Z_1 - \delta \frac{b_p + Z_p x_s - x_s^2 c/2}{1 - \delta(1-x_s)} \right). \qquad (12)$$

Note that the second-order condition holds. With the fixed point $x_t = x_s$, (12) gives:

$$\begin{aligned}
&[1 - \delta(1-x_s)]\, c x_s = Z_1 [1 - \delta(1-x_s)] - \delta \left[b_p + Z_p x_s - x_s^2 c/2 \right] \Leftrightarrow \\
&\delta c x_s^2/2 + ((1-\delta)\, c - \delta (Z_1 - Z_p))\, x_s + \delta b_p - (1-\delta)\, Z_1 = 0 \Leftrightarrow \qquad (13) \\
x_s &= -\frac{(1-\delta)\, c - \delta (1-p)\, \Delta}{\delta c} \pm \frac{1}{\delta c} \sqrt{((1-\delta)\, c - \delta (1-p)\, \Delta)^2 - 4 \frac{\delta c}{2} (\delta b_p - (1-\delta)\, Z_1)} \\
&= \frac{(1-p)\, \Delta}{c} - \frac{1-\delta}{\delta} \pm \sqrt{\left(\frac{1-p}{c} \Delta - \frac{1-\delta}{\delta} \right)^2 + \frac{2}{c} \left(\frac{1-\delta}{\delta} Z_1 - b_p \right)}. \qquad (14)
\end{aligned}$$

The assumption that some extraction is optimal requires $\frac{1-\delta}{\delta} Z_1 > b_p$. When we require $x_s \geq 0$, (14) permits exactly one stationary MPE, (6).

Note that if $(1-p)\Delta = 0$, then $x_M = x_1$, where $x_1 = x_p$, given by (5) when $p = 1$. However, $x_M > x_1$ if $(1-p)\Delta > 0$, and x_M increases in $(1-p)\Delta$, because:

$$\frac{dx_M}{d\left[(1-p)\Delta\right]} = \frac{1}{c}\left(1 - \frac{\frac{1-\delta}{\delta} - \frac{(1-p)\Delta}{c}}{\sqrt{\left(\frac{1-\delta}{\delta} - \frac{(1-p)\Delta}{c}\right)^2 + \frac{2}{c}\left(\frac{1-\delta}{\delta}Z_1 - b_p\right)}}\right),$$

which is strictly positive, given the assumption that $\frac{1-\delta}{\delta}Z_1 > b_p$.

QED

Proof of Proposition 1.

The loan offered by K, L_K, taking effect from next period on, must at least compensate for the reduction in continuation value. When $A := x_s - x_A$, this is:

$$L_K/\delta = \frac{x_s Z_p + b_p - x_s^2 c/2}{1-\delta(1-x_s)} - \frac{(x_s - A)Z_p + (1-x+A)pk + b_p - (x_s-A)^2 c/2}{1-\delta(1-(x_s-A))},$$

where we also permit a transfer k per unit of the forest. (We use this extension below.) We get:

$$\begin{aligned}
L_K/\delta &= \frac{AZ_p - x_s Ac + A^2 c/2}{1-\delta(1-(x_s-A))} - \delta A \frac{x_s Z_p + b_p - x_s^2 c/2}{\left[1-\delta(1-x_s)\right]\left[1-\delta(1-(x_s-A))\right]} - \frac{(1-x+A)pk}{1-\delta(1-(x_s-A))} \\
&= \frac{AZ_p - x_s Ac + A^2 c/2}{1-\delta(1-(x_s-A))} - \delta A \frac{v_p(x_s)}{\left[1-\delta(1-(x_s-A))\right]} - \frac{(1-x+A)pk}{1-\delta(1-(x_s-A))} \\
&= \frac{AZ_p - x_s Ac + A^2 c/2}{1-\delta(1-(x_s-A))} - A\frac{Z_1 - cx_t}{\left[1-\delta(1-(x_s-A))\right]} - \frac{(1-x+A)pk}{1-\delta(1-(x_s-A))} \\
&= \frac{A^2 c/2 - A(Z_1 - Z_p)}{1-\delta(1-(x_s-A))} = \frac{A^2 c/2 - A(1-p)\Delta}{1-\delta(1-(x_s-A))} - \frac{(1-x+A)pk}{1-\delta(1-(x_s-A))} \\
&= \frac{(x_s - x_A)^2 c/2 - (x_s - x_A)(1-p)\Delta}{1-\delta(1-x_A)} - \frac{(1-x_A)pk}{1-\delta(1-(x_s-A))}.
\end{aligned}$$

The proposition follows when $k = 0$. QED

Proof of Proposition 2. If the fraction x_t is exploited, the compensation per unit of forest at t is, for $t+1$, reduced to $(1-x_t)k$. The out-of-equilibrium exploitation level will be x_{ou}, given by:

$$cx_{ou} = Z_1 - \delta v_k, \text{ where } v_k = \frac{pk + b_p}{1-\delta}.$$

The cost of deviating from this level is given by $\frac{c}{2}x_{ou}^2$. Thus, to conserve everything even in this period, the compensation must be $\frac{c}{2}x_{ou}^2$, which, in equilibrium, must equal k. Hence:

$$k = \frac{c}{2}x_{ou}^2 = \frac{1}{2c}\left(Z_1 - \delta\frac{pk + b_p}{1-\delta}\right)^2 = \frac{1}{2c}\left(Z_1^2 - 2Z_1\delta\frac{pk+b_p}{1-\delta} + \left(\delta\frac{pk+b_p}{1-\delta}\right)^2\right).$$

Combined with the previous equation, it is simple to see that k decreases in p and increases in Δ. To solve for k:

$$\begin{aligned}
0 &= \frac{1}{2}\left(\delta\frac{pk+b_p}{1-\delta}\right)^2 - \left(\delta\frac{pk+b_p}{1-\delta}\right)Z_1 - ck + \frac{1}{2}Z_1^2 \\
0 &= \frac{1}{2}\left(\delta\frac{pk+b_p}{1-\delta}\right)^2 - \left(\delta\frac{pk+b_p}{1-\delta}\right)Z_1 - c\frac{1-\delta}{\delta p}\left(\delta\frac{pk+b_p}{1-\delta}\right) + c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) + \frac{1}{2}Z_1^2 \\
0 &= \frac{1}{2}\left(\delta\frac{pk+b_p}{1-\delta}\right)^2 - \left(\delta\frac{pk+b_p}{1-\delta}\right)\left(Z_1 + c\frac{1-\delta}{\delta p}\right) + c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) + \frac{1}{2}Z_1^2 \\
\delta\frac{pk+b_p}{1-\delta} &= Z_1 + c\frac{1-\delta}{\delta p} - \sqrt{\left(Z_1 + c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) - Z_1^2} \\
\delta\frac{pk}{1-\delta} &= Z_1 + c\frac{1-\delta}{\delta p} - \frac{\delta b_p}{1-\delta} - \sqrt{\left(Z_1 + c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) - Z_1^2}
\end{aligned}$$

$$\begin{aligned}
\delta\frac{k}{1-\delta} &= \frac{Z_1}{p} + c\frac{1-\delta}{\delta p^2} - \frac{\delta b_p/p}{1-\delta} - \frac{1}{p}\sqrt{\left(Z_1 + c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) - Z_1^2} \\
\delta\frac{k}{1-\delta} &= \frac{Z_1}{p} + c\frac{1-\delta}{\delta p^2} - \frac{\delta b_p/p}{1-\delta} - \frac{1}{p}\sqrt{\left(c\frac{1-\delta}{\delta p}\right)^2 + 2c\frac{1-\delta}{\delta p}\left(Z_1 - \delta\frac{b_p}{1-\delta}\right)} \\
\delta\frac{k}{1-\delta} &= \frac{Z_1}{p} + c\frac{1-\delta}{\delta p^2} - \frac{\delta b_p/p}{1-\delta} - \frac{1}{p}\sqrt{\left(c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{1-\delta}{\delta p}\left(\delta\frac{b_p}{1-\delta}\right) + 2c\frac{1-\delta}{\delta p}Z_1}
\end{aligned}$$

$$\begin{aligned}
\delta\frac{k}{1-\delta} &= \frac{Z_1}{p} + c\frac{1-\delta}{\delta p^2} - \frac{\delta b_p/p}{1-\delta} - \frac{1}{p}\sqrt{\left(c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{b_p}{p} + 2c\frac{1-\delta}{\delta p}Z_1} \\
\delta\frac{k}{1-\delta} &= \frac{1}{p}\left(Z_1 - \frac{\delta b_p}{1-\delta} + c\frac{1-\delta}{\delta p} - \sqrt{\left(c\frac{1-\delta}{\delta p}\right)^2 - 2c\frac{b_p}{p} + 2c\frac{1-\delta}{\delta p}Z_1}\right).
\end{aligned}$$

QED

Proof of Proposition 3. To compensate for the possibility to extract, k must be as least as large as the following:

$$\begin{aligned}
k + b_1 + \delta\frac{pk+b_p}{1-\delta} &= Z_1 x_s + b_1 - \frac{c}{2}x_s^2 + (1-x_s)\,\delta v_s \\
&= (Z_1 - Z_p)\,x_s + v_s, \text{ so} \\
k\left[1 - p + \frac{p}{1-\delta}\right] &= (Z_1 - Z_p)\,x_s + v_s - b_1 - \frac{\delta b_p}{1-\delta} \\
\frac{\delta k}{1-\delta} &= \delta\frac{(Z_1 - Z_p)\,x_s + v_s - b_1 - \frac{\delta b_p}{1-\delta}}{(1-p)(1-\delta) + p}.
\end{aligned}$$

When $b_p = b_1$,

$$\begin{aligned}
\frac{\delta k}{1-\delta} &= \delta \frac{(Z_1 - Z_p)\, x_s + v_s - \frac{b_p}{1-\delta}}{1-\delta\,(1-p)} \\
&= \delta \left(v_s - \frac{b_p}{1-\delta} \right) + \delta \frac{(Z_1 - Z_p)\, x_s + \delta\,(1-p) \left(v_s - \frac{b_p}{1-\delta} \right)}{1-\delta\,(1-p)} \\
&= \delta \left(v_s - \frac{b_p}{1-\delta} \right) + \delta\,(1-p)\, \frac{\Delta x_s + \delta \left(v_s - \frac{b_p}{1-\delta} \right)}{1-\delta\,(1-p)} \\
&= \delta \left(v_s - \frac{b_p}{1-\delta} \right) + \delta\,(1-p)\, \frac{\Delta \frac{1}{c} (Z_1 - \delta v_s) + \delta \left(v_s - \frac{b_p}{1-\delta} \right)}{1-\delta\,(1-p)} \\
&= \frac{\delta}{1-\delta\,(1-p)} \left(v_s - \frac{b_p}{1-\delta} \right) + \delta\,(1-p)\, \frac{\Delta}{c} \frac{Z_1 - \delta v_s}{1-\delta\,(1-p)}.
\end{aligned}$$

QED

Proof of Proposition 4. From the proof of Proposition 1, we have have the present-discounted cost is:

$$\begin{aligned}
\frac{(1-x_A)\, k}{1-\delta\,(1-(x_s-A))} + L/\delta &= \frac{(x_s - x_A)^2\, c/2 - (x_s - x_A)\,(1-p)\,\Delta}{p\,[1-\delta\,(1-x_A)]} - \frac{L/\delta}{p} + L/\delta \\
&= \frac{(x_s - x_A)^2\, c/2 - (x_s - x_A)\,(1-p)\,\Delta}{p\,[1-\delta\,(1-x_A)]} - \frac{1-p}{p} L/\delta.
\end{aligned}$$

Note that, in contrast to REDD+, the benefit from k (even if $L \to 0$) is that the transfers commit future decision makers to set x_A because the parties can agree that P_{t+1} must repay a large amount to K if P_{t+1} extracts more. QED

The other proofs are to be included later.

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