The Market for Conservation and Other Hostages

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Abstract

This paper introduces the notion of "conservation goods" and shows how they differ fundamentally from traditional goods in dynamic settings. A conservation good (such as a tropical forest) is owned by a seller who is tempted to consume (or cut) it, but a buyer benefits more if the good is conserved. The buyer is unwilling to pay as long as the seller conserves, but the seller conserves only if the buyer is expected to buy. This contradiction implies that the market for conservation cannot be efficient, and conservation ends at a positive rate. Conservation is less likely if many buyers would benefit from it or if consumption has a low value. A rental market is similarly inefficient, and it dominates a sales market only if the value of conservation is low, the consumption value high, and if remote protection is costly. The theory explains why optimal conservation often fails and why conservation abroad is rented, while domestic conservation is bought.

Key words: Conservation, deforestation, sale versus rental markets
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1. Introduction

Everyone is talking about it, but few do anything to stop deforestation. On the one hand, the South benefits from selling the timber and clearing the land for agriculture or oil extraction. On the other, the North prefers conservation because the tropical forests are among the most biodiverse areas in the world, they are inhabited by indigenous people, and deforestation contributes to 15-20% of the world's carbon dioxide emissions, causing global warming.[1] If the North's conservation value is larger than the South's value of logging, Coasian bargaining should ensure that the forest is preserved: the North will simply buy the forests from the South, or pay the current owners for conservation. The North has plenty of opportunities to do so, either individually or collectively through the World Bank or the United Nation. The REDD (Reducing Emissions from Deforestation and Forest Degradation) initiative intends to provide such financial incentives to conserve, but REDD is a recent phenomenon and offered to a limited extent.[2] The puzzle remains: why isn't the North buying conservation from the South?

Earlier studies have pointed to corruption, electoral cycles, unclear property rights, multiple users and owners, multiple buyers, leakage, and the difficulties to monitor and enforce contracts.[3] But even when we abstract from these obstacles, the current paper shows that inefficiencies continue to exist in the market for conservation, and they are fundamentally tied to the nature of the good. For traditional goods, the owner may sell the good to a potential buyer who intends to consume it. Trade is then predicted to

[1] IPCC (2007). Negative externalities from forest loss and degradation cost between $2 trillion and $4.5 trillion a year according to The Economist (Sept. 23rd, 2010, citing a UN-backed effort, The Economics of Ecosystems and Biodiversity, TEEB).

[2] There are several ways of defining the REDD funds; see Karsenty (2008) on details or Parker et al. (2009) for a summary of the various proposals and the distinction between RED, REDD, and REDD+. The 2010 Cancun Agreements (UNFCCC, 2010) recognize the importance of reducing deforestation and forest degredation, but are quite imprecise regarding who should pay and how this should be implemented.

[3] See, for example, Alston and Andersson (2011), Burgess et al. (2011), Angelsen (2010), and the references therein. For an earlier overview of the sources of deforestation, see Angelsen and Kaimowitz (1999). Although there are often multiple users of the same forest, REDD-contracts may force them to act as one single seller (Phelps et al., 2010).

take place immediately if the buyer's consumption value is larger than the seller's. For conservation goods, however, the buyer is satisfied with the status quo. He does not desire to consume the good, but only to prevent the seller from consuming it in the future. The seller is willing to conserve today if the buyer is likely to pay tomorrow, but the buyer is in no hurry to cash out as long as the seller conserves. This paradox has so far been overlooked in the literature.

To formalize the market for conservation, I present a dynamic model with a seller (S), a buyer (B), and a good (e.g., the forest). In each period, B decides whether to buy. As long as B has not yet bought, S has the possibility to cut. The game is a stopping game which ends after sale or consumption. In dynamic games with multiple subgame-perfect equilibria one often restricts attention to Markov-perfect equilibria since they are robust and simple. Strategies are then conditioned on only the coarsest payoff-relevant partition of histories; see Maskin and Tirole (2001) for more on definition and justification. Unfortunately, there is only one such equilibrium in pure strategies: B never buys; S always cuts. In particular, it cannot be an equilibrium that B purchases the good with probability one at a decent price. If B followed such a strategy, S would conserve the good until B's next chance of buying the good. Anticipating this, B has an incentive to deviate. The best equilibria are in mixed strategies but, in each of these equilibria, S is more likely to cut if the conservation value is low and, perversely, B is more likely to buy if the value of cutting is large.

The basic model is simple and can be extended in multiple ways. If S has the possibility to invest and increase the conservation value, she would never make such an investment: even if the price would increase following such an investment, S would not benefit since B would be less likely to buy. A rental market has exactly the same problems and comparative statics as the sales market. By comparison, the model predicts the rental market, rather than the sales market, to be both better and the equilibrium choice if and only if the conservation value is small relative to the consumption value, while B's protection cost is high relative to S' protection cost. In other words, domestic conservation will be bought, while conservation across the border will be rented. If the number of buyers grows, the aggregate value of conservation increases, and it becomes more important to buy the forest and prevent cutting. Unfortunately, the equilibrium implies the opposite: the cutting rate increases with the number of buyers. All equilibria survive if the forest can be cut gradually. In fact, the equilibrium "probability" of cutting can be interpreted as the fraction that is being cut every period, so random actions are not necessary for the argument.

Conservation goods are different from traditional goods, but they are not confined to rainforests. There are many examples of payments for environmental/ecosystem services (PES; Engel et al., 2008). In fact, this author has recently argued that a climate coalition could greatly benefit from purchasing and conserving foreign fossil fuel deposits (Harstad, 2012); the puzzle, then, is why this is not observed in reality. The conservation good can also be real captives or hostages,[4] a peace of art, or historical ruins: as long as the good is conserved, the buyer may be in no hurry to pay. A legendary example is the nine books of Sibylline prophecy that were offered to the last King of Rome, Tarquinius Superbus. Books with prophecies were consulted in stress of war, or in time of plague or famine, and the King was perhaps in no hurry to pay as long as these books would be available later. Consequently, the seller had to gradually burn six books before the King accepted to buy the remaining three.[5]

[4] The present model, predicting whether an *exogenously* given hostage will be killed or released, contributes to the literature on hostage-taking (surveyed by Sandler and Arce, 2007). However, I ignore how the incentive to *take* hostages is affected by commitment (Selten, 1988), reputation or uncertainty (Lapan and Sandler, 1988).

[5] According to the legend, the seller was a strange woman who appeared before the King. She asked for a steep price and the King declined. The woman asked again for the exact same price for six books after burning three of them. The King laughed at her, but after the woman burned another three books, he accepted the original price for the last three books (Ihne, 1871:74-75). I am thankful to Wiola Dziuda for suggesting this example.

The paper contributes to the debate surrounding the Coase theorem. Coase (1960) argued that if property rights are well defined and there is no transaction costs, then the outcome is efficient and invariant to the initial allocation of rights. However, Coasian bargaining may break down if there are small transaction costs (Anderlini and Felli, 2006) or private information (Farrell, 1987). Dixit and Olson (2000) and Ellingsen and Paltseva (2011) have argued that when the agents are free to opt out of the negotiations, some of them may prefer to "stay home" if the others are, in any case, providing some (although inefficiently little) public goods. These assumptions are not necessary for the inefficiencies detected in this paper: instead, it is the nature of the good that leads to inefficiency, since the buyer prefers to buy later rather than sooner - as long as the seller does not consume the good in the meanwhile.

While this reasoning here requires a dynamic framework, the model is quite different from both durable goods markets[6] and classic war-of-attrition models.[7] The closest theoretical literature is instead the relativelly few papers on sales in the presence of externalities. Note that the game in this paper would be similar if, as an alternative to cutting the forest, the owner could sell the forest to a logger. Such a sale would then create a negative externality on the buyer interested in conservation. Sale in the presence of externalities were first discussed by Katz and Shapiro (1986) and later analyzed by Je-

[6] As conjectured by Coase (1972) and shown by Bulow (1982), the seller of a durable good has an incentive to later reduce the price for the remaining customers, implying that the buyers are not willing to pay a high price today, either. If time is infinite and each period short, the price collapses to the seller's own valuation. This can in fact also happen in my model if the buyer has bargaining power (as explained in Section 6), but the explanation is very different: For durable goods models, it is essential that there is more than one buyer valuation, and the price is then gradually dropping over time so as to sell to more and more of the remaining buyers. In this paper, there is only one buyer type and the price does not drop over time. In contrast to the durable goods, a conservation good is something the buyer would prefer to buy later rather than sooner, as long as it continues to exist and the price remains the same. This preference is driving the inefficiency studied here.

[7] War-of-attrition games were first studied by Maynard Smith (1974) in biological settings, but are often applied in economics. According to Tirole (1998:311) "the object of the fight is to induce the rival to give up. The winning animal keeps the prey; the winning firm obtains monopoly power. The loser is left wishing it had never entered the fight." Muthoo (1999:241) provides a similar definition. In this paper, in contrast, the buyer is perfectly happy with the staus quo, and he does not hope that the seller will act. Once the buyer acts, he is also very happy that he did not give in earlier.

hiel et al. (1996) who let the seller commit to a sales mechanism. Jehiel and Moldovanu (1995a) allow for negotiations after the seller is randomly matched with one of several potential buyers. If the time horizon is finite, delay can occur if several periods remain before the deadline, whether the externality is positive or negative. With negative externalities, this delay is generated by a war of attrition game between potential "good" buyers who each hope the other good buyer will purchase the good before the bad buyer does (causing negative externalities on the good ones). This story requires at least three buyers. Furthermore, trade will take place with certainty closer to the deadline. If the buyers have bounded recall, Jehiel and Moldovanu (1995b) detect delay even with infinite time. However, all these strategies are in pure strategies - and they are not stationary. In fact, Björnerstedt and Westermark (2009) show that there cannot be delay for sales under negative externalities when restricting attention to stationary strategies. In other words, trade occurs as soon as the seller is matched with the "right" buyer. This result is nonrobust, the current paper shows. Formally, the main difference is that I endogenize matching between the buyer and the seller. Rather than imposing an exogenous matching, as in the literature just mentioned, I follow Diamond (1971) by letting the buyer choose whether to contact the seller. The nonrobustness is obviously a two-edged sword, implying that the delay, emphasized in this paper, would not survive if a buyer was always forced to meet with the seller.[8]

The next section illustrates the main result in a simple model where the price is exogeneous. The full model for the sales-market is analyzed in Section 3, while Section 4 analyzes the rental market, compares it to the sales market, and makes predictions for when we ought to see one rather than the other. Section 5 reviews the results in a continuous time model and studies the effects of multiple and heterogeneous buyers as well as privatization, which would effectively endogenize the characteristics of the good.

[8] Jehiel and Moldovanu (1999) presented a related model where the identity of the original owner turns out to be irrelevant for the determination of the final consumer.

Section 6 is briefly discussing the additional extensions that are further analyzed in the working paper version (Harstad, 2011). Section 7 concludes while the Appendix contains the proofs that are not in the text.

2. The Main Result in a Simple Model

2.1. The Stage Game

There is a seller (S or "she"), a buyer (B or "he"), and a price, P. The timing of events is as follows. First, B decides whether to buy. If B does not buy, S decides whether to consume (or "cut") the good. Payoffs are normalized to zero in the status quo. So, if S cuts, B looses the conservation value attached to the good and receives the payoff $-V < 0$. The seller's benefit from consumption is $M \in (0, V)$, perhaps best interpreted as the market value of timber or the accessible land (or the sum of these). If B buys, S receives the payoff P while B receives the payoff $-P$. The price P may be determined in the market or in a bargaining game, but both the origin and determinants of P are irrelevant for the main result. Thus, this section takes as exogenous a price $P \in (M, V)$. The game is illustrated in Figure 1.

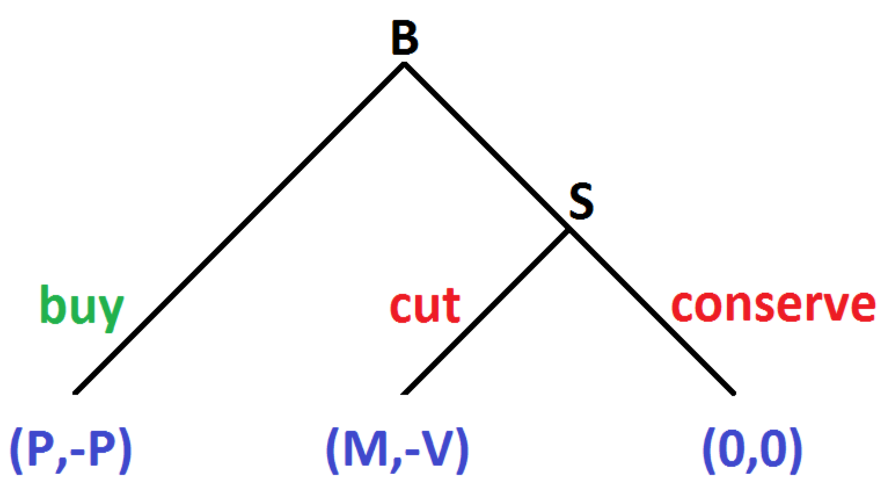

Fig. 1: If B does not buy, S decides whether to cut. The terminal nodes present the seller's payoff, the buyer's payoff.

In this simple game, B's strategy is the probability $b \in [0, 1]$ at which it buys, while S' strategy is the probability $c \in [0, 1]$ at which it cuts, given that she reaches her decision node. The outcome is said to be efficient, or first-best, if the sum of payoffs is at its maximum.

PROPOSITION 0. *Consider the static version of the game. There is a unique equilibrium:* $b = 1$, $c = 1$, *and the outcome is first-best.*

So, in the stage game, the good is simply just like any other normal good, and trade takes place if and only if the buyer values the good more than the seller, as long as the price is in between the valuations. This changes dramatically in the dynamic version of the game.

2.2. The Dynamic Game

With an infinite time horizon, the game terminates only after sale or consumption. If there is neither trade nor consumption in a given period, we enter the next, identical, period. Let $\delta \in (0, 1)$ measure the common discount factor. If v measures the per-period or flow conservation value, then $V \equiv v/(1-\delta)$. Again, the first-best is implemented whether S sells or conserves, but not if she consumes.

As in most dynamic games, there are multiple subgame-perfect equilibria.[9] Since the game itself is simple, I will select a simple equilibrium by restricting attention to Markov-perfect equilibria where the players only condition their strategies on payoff-relevant histories. In this game, the only payoff-relevant partition of histories is whether or not the game has terminated (following Maskin and Tirole, 2001). Thus, the Markov-perfect strategies are necessarily stationary. The equilibria are described by the following

[9] It is easy to construct subgame-perfect equilibria that are first-best. For example, suppose B buys in period 1, $1+\tau$, $1+2\tau$, and so on, unless the game has already ended. The frequency τ can be chosen such that S is willing to cut if and only if a sale is at least τ periods away. The equilibrium outcome is sale in period 1. However, this equilibrium is neither stationary nor Markov-perfect and, perhaps more importantly, it is also not renegotiation-proof.

proposition and illustrated in Figure 2.

Proposition 1. *(i) Suppose $P \in (M/\delta, V)$. There is a unique equilibrium: B buys with probability*

$$b = \frac{M}{P - M}\left(\frac{1-\delta}{\delta}\right) \in (0,1),$$

and S consumes with probability

$$c = \frac{(1-\delta)P}{V - \delta P} \in (0,1).$$

(ii) If $P \in (M, M/\delta)$, the unique equilibrium is $b = 1$ and $c = 1$.

(iii) If $P = M/\delta$, then $b = 1$ and any $c \in [(1/\delta - 1)M/(V-M), 1]$ constitute an equilibrium.

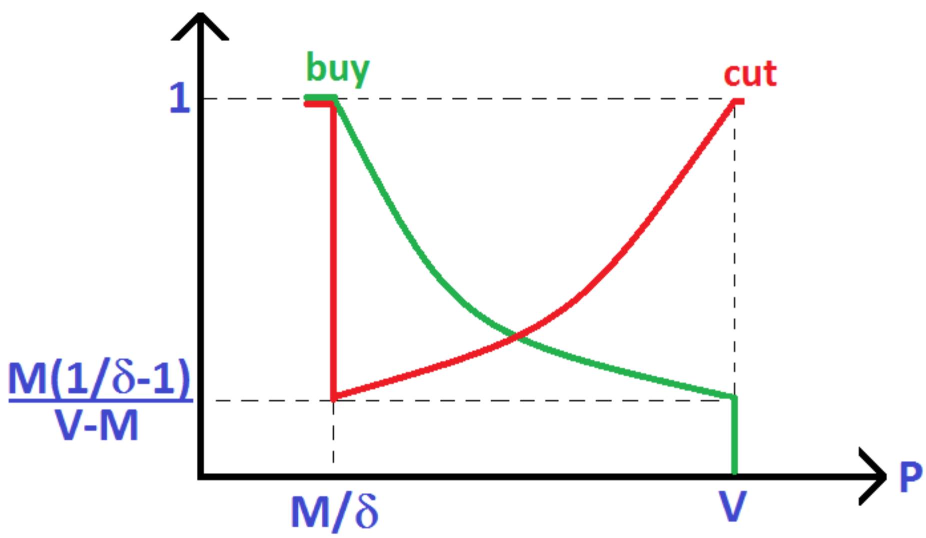

Fig. 2: The equilibrium b and c are functions of P.

If $P \leq M/\delta$, S prefers to cut rather than wait and sell in the next period. Anticipating cutting, the buyer prefers to buy, so $c = b = 1$, just like in the static setting. Things are more interesting if $P > M/\delta$. Then, S would prefer to conserve today in order to sell in the next period. The buyer, however, prefers to buy only if the seller is going to cut. This contradiction implies that there is no equilibrium in pure strategies for $P \in (M/\delta, V)$. The only equilibrium is in mixed strategies: each player will randomize such that the opponent is just indifferent and, hence, also willing to randomize. The comparative statics are interesting. Take an equilibrium $(b, c; P)$ and suppose P increases. Given the original equilibrium, B would strictly prefer to wait but, then, S would strictly prefer to cut. In equilibrium, the probability at which S cuts must increase so that B is still willing to buy. At the same time, for a larger P, S becomes inclined to conserve and, thus, B will buy with a smaller probability (as in Fig. 2) to ensure that S is willing to cut. For a given price, the seller finds cutting more attractive if the market value, M, increases or if the future is more discounted, in that δ decreases. In fact, S would cut with certainty after such changes, unless b increased. The result is that, perversely, B is more likely to buy conservation if the value of cutting is large.[10]

2.3. Payoffs and Incentives

When $P \in (M/\delta, V)$, B's equilibrium payoff, U_B, is pinned down by the fact that buying is always a best response. The seller is indifferent between cutting and waiting for its discounted equilibrium payoff, U_S. Thus,

$$\begin{aligned} U_B &= -P, \\ U_S &= \frac{M}{\delta}. \end{aligned} \tag{2.1}$$

Given these equilibrium payoffs, we can easily study the players' incentives to influence any of the parameters in the model, if they could. Although I have not formally modelled any such influence, it follows straighforwardly that S has no incentive to raise B's value of conservation, for example. For a given P, this would make it more attractive for B to contact S unless, as will happen in equilibrium, S cuts slower. S' payoff is unchanged. Even if P happened to increase following such an eagerness, S would not benefit since B is less likely to buy if P is large. A raise in P is always associated with a corresponding decrease in b, ensuring that S' payoff is not altered.

[10] If $P \in (M/\delta, V)$, the probability that the good will eventually be consumed is:

$$\frac{(1-b)\,c}{1-(1-b)\,(1-c)} = \frac{\delta P - M}{\delta P - M + (V/P - \delta)\,M} \in (0,1)\,.$$

Interestingly, note that $\partial U_S/\partial M = 1/\delta > 1$. Thus, S' incentive to raise the market value, M, is larger than it would have been if conservation had not been an issue (then, $\partial U_S/\partial M = 1$). With conservation, B buys with a positive probability, so S has a smaller chance of being able to enjoy M. This effect ought to reduce S' incentive to increase M, particularly when P is given. However, if M increases marginally, B must buy with a larger probability. This effect is very beneficial for S and it strongly motivates S to raise M. In reality, S can raise M by investing in roads and access to the threes or by negotiating market access with trading partners.[11]

Corollary 1. *The seller has no incentive to increase the value of conservation but strong incentives to raise the consumption value, M.*

We can also consider the incentives of the buyer. A boycott, for example, reducing M, may not necessarily benefit B. In fact, in isolation (for a fixed P), a lower M reduces the sum of payoffs and thus efficiency. The small M makes it less tempting to cut and, thus, B can buy with a smaller probability. It is then less likely that B eventually buys before S has already cut. The buyer can only benefit from a reduced M if that will decrease the price, P.

2.4. Purification and Interior Solutions

If the good is divisible, then randomization is not necessary for the equilibrium described above. For simplicity, assume that V, M, and P are measured per unit of the forest (i.e., they do not change as the forest shrinks and all players are risk neutral). Then, c can be interpreted as the *fraction* of the forest that is cut in each period or, more generally, the

[11] The model can easily be reformulated to let also S enjoy some conservation value. If V_S represents the seller's present discounted value of conservation, she will enjoy this value unless the good is cut. As long as $V_S < M$, $b > 0$ and the seller's equilibrium payoff is $V_S + (M - V_S)/\delta$, which is decreasing in V_S! Intuitively, if V_S increased, S would be less willing to cut and, to make her indifferent, B must be less likely to buy. This decrease in b harms S. Thus, if S could invest in eco-tourism, for example, she would have no incentive to do this.

expected fraction that is cut. Likewise, b can be interpreted as the expected fraction that is purchased in each period.

COROLLARY 2. *Suppose the good is divisible. The equilibria in Proposition 1 survive if b and c are interpreted as the expected fraction that is bought and cut, respectively.*

Proof. To see the corollary, let x_t measure the size of the forest at the start of period t, while y_t is the size of the forest at the subsequent cutting stage. Given b and c, we have $\mathrm{E}y_t = x_t(1-b)$ and $\mathrm{E}x_{t+1} = y_t(1-c)$. The buyer is indifferent whether to buy or not if and only if:

$$x_t P = x_t (cV + (1-c) P),$$

while S is indifferent between cutting and conserving if:

$$y_t M = \delta b y_t P + \delta (1-b) y_t M.$$

Note that x_t and y_t drop out. Solving the equations with respect to b and c confirms Proposition 1. *QED*[12]

3. The Market for Sale

3.1. The Model

From now on, the illustrative model above is extended in two reasonable ways.

First, the price is endogenized in a simple way. The exact timing of the stage game is now the following. First, the buyer decides whether to contact the seller. In contrast to the traditional literature (reviewed in the Introduction), I do not assume that the buyer and the seller *necessarily* and *exogenously* match. Instead, I endogenize this matching by letting the buyer make the choice of whether to visit the seller (as in Diamond, 1971, for example). If B does contact S, S proposes a price and B decides whether to accept. If indifferent, it is conventionally assumed that B accepts S' proposal. If there is no trade, S decides whether to consume.

[12] When the good is divisible, we may have other MPEs, as well, if strategies can be conditioned on the fraction consumed so far. However, note that the amount of the good that is left is not "payoff relevant" because x_t and y_t drop out when comparing payoffs in the proof. Using the reasoning from Maskin and Tirole (2001), one may thus argue that the fraction that is so far cut is not payoff-relevant and that the MPEs should not be conditioned on it. With such reasoning, the equilibrium b and c are unique for $P \in (M, M/\delta)$ and $P \in (M/\delta, V)$, and they are in line with Proposition 1.

Second, it may be costly to conserve or protect the good for the next period. For example, if S wants to conserve the forest, she may have to police or guard the forest to prevent illegal logging. Also if B has purchased the forest, he may has to protect it if he fears that S will otherwise renationalize the forest and recapture its value. Let g_i, $i \in \{B, S\}$, measure i's per-period cost when conserving or protecting the good against illegal logging or nationalization. The status-quo payoffs are still normalized to zero so, if S cuts, she benefits $M + G_S$, where $G_S \equiv g_S/(1-\delta)$ is the present-discounted value of the saved protection costs. If S sells at price P, she benefits $P + G_S$, because S has no incentive to protect the good after it has been sold. If B buys, he receives the payoff $-P - G_B$, where $G_B \equiv g_B/(1-\delta)$, since the cost of protecting the good must be paid by B from now on. It may be realistic to assume that protection is more costly for a foreign buyer, implying $G_B \geq G_S$ (see, e.g., Alston et al., 2011, or the references therein). I add G_B and G_S only to get additional insight in the later sections. The main results do not hinge on a positive G_B or G_S and, to simplify, the reader is free to limit attention to the special case $G_B = G_S = 0$.

The first-best outcome is easily described. If $G_B \leq G_S$, immediate sale implements the first-best. If $G_B > G_S$, the first-best requires the players to never end the game. If $G_B = G_S$, the first-best is implemented by both these outcomes.

3.2. Equilibrium Strategies

Restricting attention to Markov-perfect equilibria, B's strategy is simply his probability of contacting S, $b \in [0, 1]$, and the probability of accepting an offer from S as a function of the proposed price. S' strategy specifies a price offered to B, in case B contacts S, and the probability of cutting, $c \in [0, 1]$, if the good is not sold. One can easily show that B will employ a cutoff-strategy by accepting any price lower than some threshold, P, and S will ask for this exact price. Thus, we can summarize the equilibrium strategies as (b, c, P).

If $M > V - G_B$, no trading price exists that can make trade mutually beneficial. Furthermore, if $M + G_S > \delta (V - G_B + G_S)$, there exists no mutually beneficial price that would discourage S from cutting, given the chance. From now on, I thus assume $M + G_S < \delta (V - G_B + G_S)$, implying $V - G_B > M/\delta + G_S (1 - \delta) / \delta$.[13]

PROPOSITION 2. *Suppose* $V - G_B > M/\delta + G_S (1 - \delta) / \delta$.
(i) *There is exactly one equilibrium in pure strategies:*

$$b = 0, c = 1, P = V - G_B.$$

(ii) *There are multiple equilibria in mixed strategies: For every price*

$$P \in \left[\frac{M}{\delta} + \frac{1 - \delta}{\delta} G_S, V - G_B \right]$$

there is an equilibrium where B buys with probability

$$b = \frac{M + G_S}{P - M} \left(\frac{1 - \delta}{\delta} \right),$$

S consumes with probability

$$c = \frac{(1 - \delta)(P + G_B)}{V - \delta (P + G_B)},$$

B rejects any price higher than P, and S suggests exactly the price P if B contacts S.

Part (i) describes the unique equilibrium in pure strategies. It is easy to check that this is indeed characterizing an equilibrium: When considering S' offer, B is willing to accept $P = V - G_B$ since S cuts for sure otherwise. At this P, however, it is a best response for B to never contact S. Since there is no chance for trade, S cuts. Unfortunately, there is no other equilibrium in pure strategies: If S cuts for sure ($c = 1$), she can always require exactly this price, $P = V - G_B$. If, then, B contacts S for sure ($b = 1$), S would not cut - a contradiction. Similarly, $c = 0$ cannot be an equilibrium since B would then prefer to never buy, and S must prefer to cut.

[13] If $M \in (\delta (V - G_B) - G_S (1 - \delta), V - G_B)$, then there exists a price $P \in [M, V - G_B]$ which is such that, although it does not discourage cutting, it makes trade mutually beneficial at the trading stage. Then, if B contacts S, S will suggest the price $V - G_B$ and B will accept. Anticipating this, B is indifferent when considering to contact S, and every $b \in [0, 1]$ is a best response and a possible element of an equilibrium (b, c, P).

Part (ii) shows that there are multiple equilibria in mixed strategies. Each equilibrium is characterized by some equilibrium price and B is indifferent when considering whether to show up while S is indifferent when considering to cut. Thus, if B contacts S and he anticipates the equilibrium price P, he is indifferent between paying P and continuing the game as if B had never contacted S; S cannot obtain a price higher than the equilibrium P, and she proposes exactly this price. This explains why multiple prices are consistent with an equilibrium even if S can make a take-it-or-leave-it offer when proposing this period's price (in the next subsection, I let S announce the *equilibrium price* as well as this period's price. This leads to a unique equilibrium).

For a given P, the "comparative static" is similar to that of Proposition 1. The equations for b and c are actually identical when $G_B = G_S = 0$, but otherwise we get additional results. If S' protection cost increases, S becomes tempted to cut and thus B must be more likely to buy: in equilibrium, b must therefore increase in G_S, given P. If B's protection cost increases, then B becomes less eager to buy and, thus, S must be more likely to cut: in equilibrium, c must therefore increase in G_B, given P.

3.3. Prices and Welfare

From Proposition 2, the equilibrium payoffs follow as a corollary since a best response for the buyer is to buy, while a best response for the seller, at the cutting stage, is to cut rather than wait for the next period's continuation value:

$$\begin{aligned} U_B &= -P - G_B, \\ U_S &= \frac{M + G_S}{\delta}. \end{aligned} \tag{3.1}$$

Let welfare be an increasing function of both U_B and U_S. Of all equilibria, welfare is certainly larger in the equilibria characterized by a small price. For the lowest possible equilibrium price, B buys with probability one. For the highest price in the possible interval, S cuts with probability one.

How is the equilibrium P selected? The equilibrium price is the anticipated equilibrium, which both S and B may take as given. Anticipating this equilibrium, I have let S propose a price for the current period once B contacts S. Given the power to set the price, one may argue that it is reasonable that S picks the equilibrium price, as well. For example, once B contacts S, S may make the following statement: "You may think that the equilibrium price is P, but let me propose that you purchase at price P'. Since I am willing to propose P' now, it is reasonable that I will propose this P' tomorrow, as well, and thus P' is the price I will consider the equilibrium price, from now on." As long as $P' \in [M/\delta + G_S(1-\delta)/\delta, V - G_B]$ and S believes B to accept the new equilibrium, this is self-sustaining and it is thus credible that S will propose P' forever: S does not need to *commit* when announcing such an equilibrium. If B believes this speach, he will immediately accept, since B is indifferent trading at P' if this is, indeed, the new equilibrium price. If S has such power to announce the equilibrium price, once B contacts S, S will certainly ask for the highest price in the feasible interval. Thus, S suggests $P = V - G_B$ and B accepts. Of course, if S' power to announce the equilibrium price, once B contacts S, is anticipated, then b and c are given by Proposition 2 for $P = V - G_B$. To summarize:

COROLLARY 3. (i) *Total welfare is decreasing in* P. (ii) *If S announces the equilibrium* P *when meeting B, then:*

$$\begin{aligned} P &= V - G_B \Rightarrow \\ b &= \frac{M + G_S}{V - G_B - M}\left(\frac{1-\delta}{\delta}\right), \\ c &= 1, \\ U_B &= -V, \\ U_S &= \frac{M + G_S}{\delta}. \end{aligned}$$

Endogenizing P in this way, the probability for conservation is simply b, perversely increasing in the value of cutting and decreasing in the value of conservation. Note that, as $\delta \to 1$, $b \to 0$ and the good is consumed always and immediately. In short, the sales market fails tragically.

4. The Rental Market

4.1. A Model of the Rental Market

The above sales market has several shortcomings: the likelihood for conservation may be small; conservation by sale is inefficient if $G_B > G_S$; in fact, the sales market does not even exist if $G_B > V - M$; finally, a sale requires foreign ownership when B and S are different countries. In fact, the threat of nationalization may contribute to a large G_B. For all these reasons, we may be interested in how a rental market performs.

Rental contracts are assumed to last only one period, and future contracts cannot be negotiated in advance (this assumption is relaxed in the next section, where the rental contract can be of any length). Since a rental contract does not end the game, in contrast to a sale, S has an incentive to protect the good herself to ensure that it can be rented (or logged) also in the future. Thus, assume that the payment of the rent is conditioned on conservation, as is the typical rental contract for conservation (e.g., the REDD funds).[14] Otherwise, the game is similar to before: In every period, B first decides whether to contact S. If B has contacted S, S suggests a rental price, p. If B accepts, B pays p to S and the good is conserved until the next period. If B declines or does not contact S, then S decides whether to consume or conserve. Consumption ends the game and gives the payoff $M + G_S$ to S and $-V$ to B, just as before. If S does not consume, the game continues to the next period. Thus, only consumption ends the game.

Just as before, I limit attention to Markov-perfect equilibria that are only conditioned on whether the good still exists. One can easily argue (with the reasoning of Maskin and

[14] Note that S is actually indifferent when considering to protect the good at the cutting stage, whether or not B has rented the good for this period. If S is assumed to protect the good with the same probability if the good is rented and if it is not, then there is no value of a rental arrangement, B will never rent, and the rental market is dominated by the sales market.

Tirole, 2001) that any other aspect of the history is not payoff relevant.

4.2. The Equilibrium in the Rental Market

The buyer's strategy specifies his probability of contacting S in any given period, $b \in [0,1]$, and the threshold price, p, for when he would accept the proposed rental contract. The seller's best strategy is to propose exactly this price, p, if B does contact S. At the cutting stage, S' strategy specifies her probability of cutting, $c \in [0,1]$. The equilibrium can thus be summarized by (b, c, p).

If $M + G_S > V$, no p exists that can make renting mutually beneficial. Furthermore, if $(M + G_S)/\delta > V$, there exists no mutually beneficial trading price that would discourage S from cutting at the cutting stage. From now on, I thus assume $(M + G_S)/\delta < V$.[15]

Proposition 3. *Suppose* $(M + G_S)/\delta < V$.
(i) *There is only one equilibrium in pure strategies:*

$$b = 0, c = 1, p = (1 - \delta) V.$$

(ii) *There are multiple equilibria in mixed strategies: For every price satisfying*

$$\frac{p}{1-\delta} \in \left[\frac{M + G_S}{\delta}, V\right]$$

there is an equilibrium where B rents with probability

$$b = \frac{M + G_S}{p} \left(\frac{1-\delta}{\delta}\right),$$

S consumes with probability

$$c = \frac{p(1-\delta)}{V(1-\delta) - \delta p},$$

B rejects any rental price larger than p, and S proposes exactly this price.

[15] However, if $M + G_S \in (\delta V, V)$, then there exists a price $p/(1-\delta) \in (\delta V, V)$ which is such that, although it does not discourage cutting if there is not renting, it makes renting mutually beneficial at the trading stage. Then, if B contacts S, S suggests the price $p = (1-\delta)V$ and B accepts. Anticipating this, B is indifferent when considering to contact S, and every $b \in [0,1]$ is a best response and an element in an equilibrium (b, c, p).

4.3. Analogies

Proposition 3 is clearly analogous to Proposition 2. Its intuition is similar, as well, and thus skipped. This subsection discusses some further similarities, while the next compares the two markets. Note that the equilibrium payoffs are:

$$U_S = \frac{M + G_S}{\delta},$$
$$U_B = -\frac{p}{1-\delta}.$$

PROPOSITION 4. *Take an equilibrium P for the sales market and an equilibrium p for the rental market. The two equilibria are identical in that:*
(i) *Both B's payoff and c are the same in the two markets if*

$$\frac{p}{1-\delta} = P + G_B.$$

(ii) *For any p and P, S' payoff is the same in the two markets.*
(iii) *Thus, S' incentive to affect M, V, G_S, or G_B is the same in the two markets.*
(iv) *Total welfare decreases in the equilibrium price in both markets.*
(v) *If S can announce the equilibrium price, $U_B = -V$ and $c = 1$ in both markets.*

To explain part (i), note that B's payoff is determined by his payoff when he always buys/rents. This payoff is obviously a function of the price, and there should be no surprise that, for some p and P, B's payoff is identical in the two markets. To make B just willing to contact S, c must be the same for this price. Part (ii) says that S' payoff is identical no matter p and P. The reason is that in both equilibria, when S randomizes, her discounted payoff must equal the value of cutting. Parts (iii)-(v) hold for the same reasons as before. In particular, the price maximizing welfare is the smallest possible price since, then, $b = 1$. In this equilibrium, the outcome is actually first-best. However, if S can announce the equilibrium p when meeting with B, then S announces the highest possible price ($p = (1-\delta)V$), B is not very likely to buy ($b = (M + G_S)/\delta V$), and $c = 1$. Hence, the conservation ends relatively fast.

4.4. Buy or Rent Conservation?

Despite the similarities, the rental market and the sales market are not equivalent: (i) In the rental market, the game ends only after consumption. As long as the good is not consumed, B randomizes between renting or not in every period, no matter whether he has rented earlier. (ii) In the rental market, S is protecting the good and not B. (iii) Thus, if $G_S < G_B$, the first-best is a possible equilibrium outcome in the rental market, while this happens almost never in the sales market. Finally, (iv) a sales market only exists if $G_B < V - M$, while the rental market exists whenever $G_S < V - M$.

To make positive predictions, suppose that, once B has contacted S, S can propose either a rental price or a sales price. In the sales market, for example, B anticipates some equilibrium price, P, and S cannot charge a higher price. However, S may want to propose a rental contract, instead, at some price, p. The question is whether there exists some p such that S would benefit from proposing p, rather than P, and B would accept. In the rental market, similarly, B anticipates some equilibrium p. If B contacts S, S cannot charge a higher rental price. However, she may want to, instead, propose a price P for sale. When can S benefit from this?

Proposition 5. (i) *Take an equilibrium in the sales market characterized by P. Once B has contacted S, there exists a rental price that is acceptable to B and better for S if and only if:*

$$P + G_B < \frac{M + G_B}{\delta}. \tag{4.1}$$

(ii) *Conversely, take an equilibrium in the rental market characterized by p. One B has contacted S, there exists a sales price that is acceptable to B and better for S if and only if:*

$$\frac{p}{1-\delta} > \frac{M + G_B}{\delta}. \tag{4.2}$$

(iii) *If S announces the equilibrium price, conservation will be sold rather than rented if and only if:*

$$V > \frac{M + G_B}{\delta}. \tag{4.3}$$

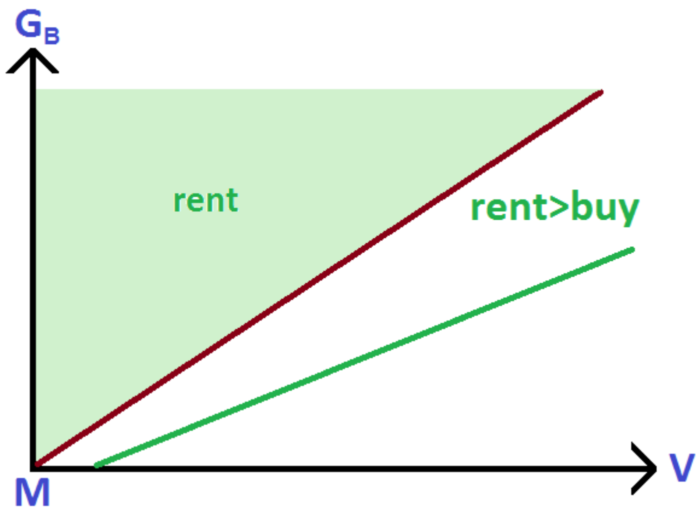

Fig. 3: Renting is predicted if G_B is large while $V - M$ is small

Interestingly, parts (i) and (ii) say that a sale is more likely if the equilibrium price (for sales or rentals) is large. If P is large, for example, S can suggest a high p to keep B indifferent. At a high p, B rents with a small probability and S cuts with a high probability in every period. The inefficiencies are then large and, rather than risking these randomizations, S and B are better of trading once and for all. Similarly, a sale is more attractive if M is small, since B is then unlikely to show up (and rent) again. If G_B is large, however, B finds it costly to guard the good and it is better to rent to give S an incentive to protect instead.

If S can announce the equilibrium price, the condition for sale in part (i) and (ii) are identical and rewritten in part (iii). If the conservation value is high, the price becomes high, and this makes it better with sale to end the inefficient randomizations. Thus, if conservation is sufficiently valuable, conservation is bought rather than rented.

Note that G_S does not appear in Proposition 5. Intuitively, one may guess that if G_S is large, then S may prefer to sell, saving the cost of protection. On the other hand, a higher G_S implies that B is more likely to contact S also in the future, and this reduces the inefficiences when renting. Obviously, the two effects cancel.[16]

4.5. Multiple Buyers

In reality, there may be multiple potential buyers considering to pay for conservation. To analyze this, and to motivate the next section, let the game above be unchanged with one exception: Suppose that, in every period, every $i \in N = \{1, ..., n\}$ decide, at the same time, whether to contact S. If more than one buyer try to contact S, each of them is matched with S with an equal probability. The buyers may have different valuations, protection costs, and they may expect to pay different equilibrium prices. In any case:

PROPOSITION 6. *There is no equilibrium where more than one buyer buys or rents with positive probability:*

$$b_i \cdot b_j = 0 \forall (i, j) \in N^2, j \neq i$$

.

The result is disappointing since a larger number of benefitting countries ought to make conservation *more* important. Unfortunately, the only symmetric (pure or mixed) equilibrium is that no-one ever buys/rents conservation from S, while S cuts immediately and with probability one. The intuition is the following: If a country buys with probability one, no-one else buys. If buyer i randomizes, i must be indifferent when considering to contact S. In addition, i must be indifferent when S proposes the equilibrium price to i. This double indifference requires that i is indifferent to be matched with S, given that i tries to contact S. This, in turn, requires there to be no chance than any other buyer is instead matched with S.

On the one hand, Proposition 6 shows that the analysis above, assuming exactly one active buyer, is relevant even if there are third (passive) parties that also benefit from

[16] Note that the last condition in Proposition 5 can be rewritten as $\delta V > (M + G_S) + (G_B - G_S)$. The last term shows that renting is better if $G_B - G_S$ is positive and large. At the same time, renting is better if $(M + G_S)$ is large, since B is then quite likely to rent also in the future. Parameter G_S appears in both terms - but with opposite signs.

conservation. On the other hand, the reasoning behind Proposition 6 relies on discrete time (since j does not want to contact S if also i might at the same *exact* time). This motivates the next section which allows time to be continuous.

5. Multiple Buyers and Continuous Time

This section is gradually extending the model in several ways. First, by letting time be continuous, I allow the seller to cut and a buyer to contact the seller at any point in time. Second, the rental contract can be of any length. If there is an upper boundary on this length, T, then it is easy to show that this constraint will always bind in equilibrium. Thus, let $T \leq \infty$ be the (maximal and equilibrium) length of a rental contract. Third, I will allow for any number of potential buyers that do not coordinate, and these buyers can be heterogeneous. Fourth, I will let the good have private as well as public good aspects, and I will endogenize these benefits. If there were multiple sellers with different goods, the buyer(s) may play the described game with each of them independently, and the results below may be unchanged.[17]

5.1. A Single Buyer - Revisited

As a start, the above results are restated for the case with continuous time. The common discount rate is r, while b and c denote the Poisson rates at which B contacts S and S cuts, respectively, if the game has not yet ended.

PROPOSITION 7. *Suppose time is continuous and a rental contract can be of length T.*
(i) *In the sales market, the only pure strategy equilibrium is $b = 0$, $c = \infty$, $P = V - G_B$.*

[17] The game and the results are unchanged with multiple sellers if the benefits of consuming and conserving one good are independent of whether the other goods are consumed or conserved. Future research should investigate the effect of multiple sellers without assuming such independence.

In addition, for every $P \in [M, V - G_B]$ *there exists a mixed strategy equilibrium where:*

$$\begin{aligned} b &= r\frac{M+G_S}{P-M-G_S}, \\ c &= r\frac{P+G_B}{V-P-G_B}, \\ U_B &= -P-G_B, \\ U_S &= M+G_S. \end{aligned} \tag{5.1}$$

(ii) *In the rental market, the only pure strategy equilibrium is* $b = 0$, $c = \infty$, $p = rV$. *In addition, for every* $p/\left(1-e^{-rT}\right) \in [M - G_S, V]$ *there exists a mixed strategy equilibrium where:*

$$\begin{aligned} b &= r\frac{M+G_S}{p-(M+G_S)\left(1-e^{-rT}\right)}, \\ c &= \frac{r}{V\left(1-e^{-rT}\right)/p-1}, \\ U_B &= -\frac{p}{1-e^{-rT}}, \\ U_S &= M+G_S. \end{aligned} \tag{5.2}$$

(iii) *Once B contacts S, anticipating to buy at price P, S prefers a rental contract if:*

$$P \leq M + (G_B - G_S)\,\frac{1-e^{-rT}}{e^{-rT}}.$$

(iv) *Once B contacts S, anticipating to rent at price p, S prefers a sales contract if:*

$$p/r - G_B \geq M + (G_B - G_S)\,\frac{1-e^{-rT}}{e^{-rT}}.$$

(v) *If S can announce the equilibrium price, the good is sold rather than rented if:*

$$V - G_B \geq M + (G_B - G_S)\,\frac{1-e^{-rT}}{e^{-rT}}. \tag{5.3}$$

Part (i) is similar to Proposition 2, and in fact identical when the discount rate is $\delta = e^{-r\Delta}$, Δ is the length of a period, and one takes the limit as $\Delta \to 0$. Part (ii) is also identical to Proposition 3 if $T = \Delta$ and $\Delta \to 0$.

Parts (iii)-(v) are quite similar to Proposition 5, but the effect of T is new. Remember that the disadvantage with a rental contract is that the players continue to randomize as soon as one rental contract has expired. If B and S can commit to a longer rental contract, then this disadvantage is somewhat mitigated, and a rental contract becomes more attractive compared to a sales contract. Thus, if T is sufficiently large, (5.3) can never hold unless $G_S \geq G_B$. If $T \to 0$, however, (5.3) is equivalent to (4.3) when $\delta \to 1$.

5.2. Multiple Buyers

The continuous time model can easily allow multiple buyers. To simplify, suppose there are n identical potential buyers (heterogeneity is allowed in the next subsection). Thus, every $i \in N = \{1, ..., n\}$ receives the payoff $-V$ when S cuts, the payoff $-P - G_B$ if i buys, and zero if $j \neq i$ buys. In the rental market, the payoffs are analogous. As before, let b represent the Poisson rate at which S is contacted by some buyer. Thus, in a symmetric equilibrium, every i contacts S at the rate $b_i = 1 - (1-b)^{1/n}$.

Perhaps surprisingly, most of the results continue to hold:

Proposition 8. *Suppose there are n identical potential buyers. Proposition 7 continues to hold, with the exception that, in the symmetric equilibrium:*
(i) *Consumption increases in n in the sales market:*

$$c = r \frac{1 + (1 - 1/n)(M + G_S) / (P - M - G_S)}{V / (P + G_B) - 1}.$$

(ii) *Consumption increases in n also in the rental market:*

$$c = \frac{r + (1 - 1/n)\left(1 - e^{-rT}\right) b}{V\left(1 - e^{-rT}\right)/p - 1}.$$

In comparison to Proposition 7, the result is disappointing. If more countries benefit from conservation, and a planner would be more eager to conserve the good, the outcome is the reverse. The rate at which some buyer (or a renter) turns up is unchanged if n grows, but S cuts faster! The intuition is the following. When n is large, every buyer i benefits since another buyer may contact S and pay for conservation, rather than i. This reduces i's willingness to contact S and, for i to still be willing to randomize, S must cut at a faster rate.[18]

Nevertheless, the similarities to the one-buyer case may be more surprising than the differences. First, b is independent of n, given the price. The reason is that S is willing

[18] The outcome is still worse if the aggregate conservation value is held constant while n increases (i.e., if the buyers go from acting collectively to acting independently). Then, $V_i = V/n$ and, for a given P or p, S cuts even faster when n grows, since also V_i decreases (however, if the equilibrium price happens to decrease in V_i, this effect is somewhat mitigated). As another prediction, in this situation renting would be more likely as n grows, since Proposition 7 states that renting is more likely when the buyer's value is low.

to randomize only if the rate at which *some* buyer will drop by, b, multiplied by the price, makes S indifferent. Second, in equilibrium, every buyer receives the payoff pinned down by the payoff he would receive if contacting S immediately. Thus, they do not, in equilibrium, gain from the presence of other buyers: The benefit that the other countries may pay for conservation cancels with the cost of the faster cutting rate, for a given price. For related reasons, the buy-versus-rental decision is also independent of n: in both markets, the payoffs to $i \in N$ as well as to S are unaffected by n.

5.3. Heterogeneous Buyers

In reality, potential buyers differ widely in their conservation values as well as in their protection costs. Let V_i be the loss, experienced by i, if S cuts. If buyer i buys, his protection cost is G_i.[19]

PROPOSITION 9. (i) *Suppose both i and j are active buyers in the sales market at equilibrium price P. Then:*

$$\frac{V_i}{P+G_i} < \frac{V_j}{P+G_j} \Leftrightarrow b_i > b_j.$$

(ii) *Suppose both i and j are active in the rental market at equilibrium price p. Then:*

$$V_i < V_j \Leftrightarrow b_i > b_j.$$

Intuitively, if one buyer has a low conservation value or a high protection cost, he is less willing to contact S unless he expects that the other buyers are unlikely to pay for conservation. For these reasons, S should expect to be contacted by a buyer that has a relatively low conservation value and a high cost of protection. Obviously, this is likely going to lead to the "wrong" types of buyers in the sales market.

[19] This subsection restricts attention to equilibria where every buyer was required to pay the same when contacting S. The Appendix allows for the possibility that the expected price may differ among the buyers.

5.4. Privatization

With multiple buyers, conservation becomes a public good and public goods are typically under-supplied. A remedy may be to raise the *private* value when buying (or renting) the good, even if that comes at the cost of the aggregate conservation value. For example, if the buyer of a tropical forest is allowed to invest in eco-tourism, he may earn some private revenues and, although this may have detrimental impacts on the conservation value of other countries, every country may be more tempted to buy conservation in the first place. To evaluate when such "privatization" is socially optimal, suppose privatization reduces every country's conservation value by Z/n but the actual buyer receives the additional revenue W. Ex post (after sale), the actual buyer would prefer privatization, or commercialization, if $W > Z/n$, but this would be socially optimal only if $W > Z$.

Proposition 10. *Ex ante, privatization is socially optimal if $W > Z/n$. This holds for the sales market as well as for the rental market.*

If $W \in (Z/n, Z)$, privatization is socially inefficient ex post, but beneficial ex ante. The reason is that under privatization each buyer benefits more from a purchase and less from another country's purchase. Each buyer is thus more tempted to buy, and the equilibrium cutting rate declines. Note that the condition $W > Z/n$ is identical to the condition under which privatization is individually rational to buyer i after i has purchased the good. Consequently, the privatization decision can be left to the new buyer in the above model, even though privatization generates negative externalities on the rest of the world. In equilibrium, every other country's ex ante payoff is pinned down by the fact that it, too, could be the actual buyer in the game, enjoying the same privatization value.

6. Additional Extensions

The model above is simple and can be used as a workhorse for several extensions. Such extensions may help us to understand the robustness of the results and they might generate new results of interest. A large number of extensions is analyzed in the working paper version (Harstad, 2011): it permits nonrandom equilibrium strategies (using purification arguments) and allows for continuous decision-variables (such as the extent to which the forest can be protected) to show that the main results of this paper hinge neither on the mixed-strategy equilibria nor on the binary action variables.

The working paper is also permitting the following extensions: (i) the buyer faces a cost $k \geq 0$ when contacting the seller; (ii) the price is determined by the generalized Nash bargaining solution where the buyer is capturing a fraction $\beta \in [0, 1]$ of the bargaining surplus; and (iii) negotiation failure leads the seller to increase consumption in the subsequent period by the amount $\Delta \geq 0$. Extension (iii) may be considered to violate (and thus relax the assumption of) Markov-perfectness, but its intuition is that bargaining failure can make the seller pessimistic about the likelihood for a future sale.

The model above has assumed $\beta = k = \Delta = 0$. Giving the buyer some bargaining power, by letting $\beta > 0$, is destroying the result that multiple prices can be part of an equilibrium. Instead, the price will be uniquely pinned down, and it will decrease in β but increase in k, Δ, and n. The intuition for these comparative statics is the following: a buyer with bargaining power will demand a large share of the surplus, and this requires a smaller price. In fact, if $k = \Delta = 0$ and $n = 1$, then, for any $\beta > 0$, the equilibrium price is the lowest in the feasible interval, so $P = M/\delta + G_S (1 - \delta) / \delta$. At this price, $b = 1$ and the good is conserved. However, if it is costly for the buyer to contact the seller ($k > 0$), then the seller can take advantage of the buyer's eagerness once the contacting-cost has been paid and sunk, and the equilibrium price will thus increase in k.[20] If Δ is large, the

[20] In fact, if $n = 1$ and $\Delta = 0$, the equilibrium price is $P = M + k (1/\beta - 1)$.

buyer has a lot to fear if the negotiations fails, since cutting will thereafter increase. Given this credible threat, the seller can request a higher price.[21] Finally, suppose n is large: if a buyer randomizes and is indifferent when deciding whether to contact the seller, then, once such contact is established, the buyer suddenly learns that no other buyer established a contact with the seller at this time and, therefore, the buyer gains a positive surplus when reaching an agreement. The larger n is, the larger is this surplus, and the larger the unique equilibrium price. Consequently, the price increases (and becomes larger than the lowest boundary of $P = M/\delta + G_S (1-\delta)/\delta$) as soon as n grows from one, if k increases from zero, or if Δ increases from zero. The larger are these parameters (and the smaller is β), the larger is the equilibrium price. These extensions complement the earlier results, they are available upon requests, and can be found in the working paper version.[22]

7. Conclusions

Conservation goods are special. The seller conserves only if she believes the buyer will buy; but the buyer buys only if he believes the seller will consume. Thus, in no equilibrium will conservation occur for sure in a dynamic model. The Markov-perfect equilibria are in mixed strategies and the outcome is inefficient. A rental market may perform better or worse than the sales market and, by comparison, the results predict that domestic conservation will be bought, while conservation in other countries will be rented. This seems consistent with anecdotal evidence: REDD contracts are rental arrangements; national parks are not.

While the outcome is bad with one buyer, conservation is less likely to occur with multiple potential buyers. If the buyers are heterogeneous, the results predict that, per-

[21] Suppose that the seller cuts with probability one following a negotiation failure (i.e., $\Delta = 1 - c$). Then, if $n = 1$ and $k = 0$, the price follows simply from the generalized Nash bargaining solution:
$P = \beta M + (1-\beta)(V - G_B)$.

[22] Unfortunately, the analysis is quite complicated when both $n > 1$ and $\beta > 1$, explicit solutions are not available, and a serious analysis of this case must warrant another paper.

versely, the most likely renter (or buyer) is going to have a relatively low conservation value (and a high cost of enforcing protection). The emergence of Norway's REDD funds is consistent with this prediction: Norway has already initiated results-based payments through partnerships with Brazil, Guyana, and Indonesia.

To isolate the key feature of conservation goods, I have abstracted from uncertainty, private information, reputation-building, learning, moral hazard, and more complicated utility functions, bargaining procedures, or equilibrium refinements. These aspects should be included in future research to teach us more about the important and puzzling nature of conservation markets.

8. Appendix: Proofs

Proof of Proposition 1. Let P denote the equilibrium price, b the probability that B contacts S, and c the probability that S cuts, given the chance (i.e., at her decision node). Let $U_i(b,c)$ describe the equilibrium payoff (and thus the continuation value) for $i \in \{B,S\}$. We have:

$$\begin{aligned} U_B(0,c) &= -cV + \delta(1-c)U_B(b,c), \\ U_B(1,c) &= -P, \\ U_S(b,0) &= bP + (1-b)\delta U_S(b,c), \\ U_S(b,1) &= bP + (1-b)M. \end{aligned}$$

(i) If $P \in (M/\delta, V)$, B's best response is $b=1$, i.e., $U_B(1,c) \geq U_B(0,c)$, if and only if $c \geq (1-\delta)P/(V-\delta P) \in (0,1)$. S' best response is $c=1$, i.e., $U_S(b,1) \geq U_S(b,0)$, if and only if $b \leq M(1-\delta)/\delta(P-M) \in (0,1)$. To illustrate, the two best-response functions are drawn in Figure 4: they cross exactly once and for the b and c described by the proposition.

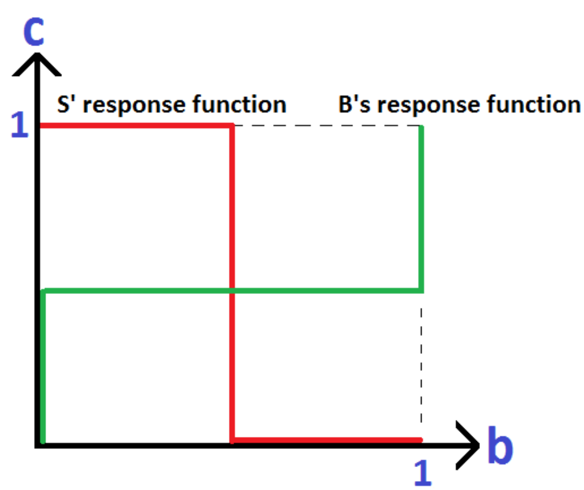

Fig. 4: For every $P \in (M,V)$ the best-response functions cross only once.

(ii) If $P \in (M, M/\delta)$, $U_S(b,1) > U_S(b,0)$ for every $b \in [0,1]$, so S' dominant strategy is $c=1$. B's best response is $b=1$ since $U_B(1,1) > U_B(0,1)$ for $P \in (M, M/\delta)$.

(iii) If $P = M/\delta$, $U_S(b,1) \geq U_S(b,0)$, and the inequality is strict if and only if $b<1$. But for $c=1$ and $P=M/\delta$, $b=1$ would be B's best response. Thus, $b=1$ in equilibrium, and this remains B's best response for any $c \geq (1-\delta)P/(V-\delta P) = (1-\delta)M/\delta(V-M)$, and any such c can be part of the equilibrium. *QED*

Proof of Proposition 2. (i) It is easy to verify the described equilibrium. Suppose there were other pure-strategy equilibria: If $c=1$ and $b=1$, S would propose $P = V - G_B$. If $b=1$ at such a high price, S' best response would be $c=0$; a contradiction. If $c=0$, B's best response would be $b=0$ but, then, S' best response would be $c=1$; a contradiction.

(ii) Suppose the equilibrium price is $P \in [M/\delta + G_S(1-\delta)/\delta, V-G_B]$. The derivation of b and c is omitted since it would follow the same steps as in the proof of Proposition 1(i), which follows as a special case. Given that B is indifferent buying at the equilibrium (b, c, P), P is the highest price B would be willing to accept, and S will propose exactly this price. Note that the equilibrium b and c are unique for $P \in [M/\delta + G_S(1-\delta)/\delta, V - G_B)$: If c was higher for a given P, for example, B would strictly prefer to buy and S could ask for a higher price. At the upper boundary, $P = V - G_B$, B is willing to buy only if $c = 1$, but any $b \leq (M + G_S)(1-\delta)/\delta(P - M)$ is also part of an equilibrium. There is no equilibrium where $P > V - G_B$, since B would reject such an offer, or where $P < M/\delta + G_S(1-\delta)/\delta$, since S would then be expected to cut with probability one if B rejects and, for $c = 1$, B would accept buying at a higher price. *QED*

Proof of Proposition 3. The proof is analoguous to the proof of Proposition 2. With a slight abuse of notation, let now b be the probability that B contacts S to rent, while c is the probability that S cuts at her decision node. In equilibrium, we must have:

$$\begin{aligned}
U_B(0, c) &= -cV + \delta(1-c)U_B(b, c), \\
U_B(1, c) &= -p + \delta U_B(b, c), \\
U_S(b, 0) &= bp + (1-b)\delta U_S(b, c), \\
U_S(b, 1) &= bp + (1-b)(M + G_S).
\end{aligned}$$

Since $c \in [0, 1]$, $U_B \in [-V, 0]$, and $p > V/(1-\delta)$ would be rejected and thus never requested by S. Since S can always cut, $U_S \geq M + G_S$ and S would always prefer to cut if $M + G_S > p\delta/(1-\delta)$, implying that $p < (M + G_S)(1/\delta - 1)$ cannot be an equilibrium (since under that threat, S could charge a higher price. If $p \in [(M + G_S)(1/\delta - 1), V/(1-\delta))$, then there is an unique equilibrium where b and c must be such as specified by Proposition 3. If $p = V/(1-\delta)$ then, in addition, there exist equilibria where b is smaller than what is specified by Proposition 2: any $b \in [0, (M + G_S)/\delta V]$ is then part of an equilibrium. Since the buyer is indifferent whether to buy for every equilibrium in which $p \in [(M + G_S)(1/\delta - 1), V/(1-\delta)]$, S cannot charge a higher price and S asks for exactly p, confirming that every such price is an equilibrium. *QED*

Proof of Proposition 4. The proof follows from the text and the earlier propositions.

Proof of Proposition 5. Take a sale P-equilibrium and a rental p-equilibrium. B prefers buying at P to the rental p-equilibrium (before as well as at the meeting with S) if:

$$P + G_B \leq p/(1-\delta). \tag{8.1}$$

At their meeting, B prefers selling at P to the p-equilibrium if:

$$P + G_S \geq p + \delta U_S^r = p + M + G_S. \tag{8.2}$$

(i) Consider an equilibrium P. A p exists violating both (8.1) and (8.2) if (4.1) is violated. Too see this, select the p, as a function of P, making one player indifferent and check whether the other condition holds.
(ii) Take p as given. Then, a P exists satisfying (8.1) and (8.2) if (4.2) holds. Too see this, select the P, as a function of p, making one player indifferent and check whether the other condition holds.

(iii) When S announces the equilibrium price, $P + G_B = p/(1-\delta)$ and (8.1) and (8.2) coincide with (4.3). *QED*

Proof of Proposition 6. The proof is similar to the argument in the text and thus omitted.

Proof of Proposition 7. The proposition follows from Proposition 8 when setting $n = 1$.

Proofs of Propositions 8 and 9. The proofs allow for heterogeneous values and prices. *The sales market:* The aggregate b and expected P making S willing to randomize follows from:

$$\begin{aligned} M + G_S &= \int_0^\infty e^{-t\left(r+\sum_i b_i + c\right)} \left(\sum_i b_i P_i\right) dt = \frac{\sum_i b_i P_i}{r + \sum_i b_i} \Rightarrow \\ b &= \sum_i b_i = \frac{r(M+G_S)}{\sum_i b_i P_i / b - (M+G_S)} \\ &= \frac{r(M+G_S)}{\mathrm{E}P - (M+G_S)}, \end{aligned} \tag{8.3}$$

where $\mathrm{E}P \equiv \sum_i b_i P_i$.

Buyer i is willing to randomize when:

$$\begin{aligned} P_i + G_i + Z_i - W_i &= \int_0^\infty e^{-t(r+b_{-i}+c)} (cV_i + b_{-i}Z_i)\, dt = \frac{cV_i + b_{-i}Z_i}{c + b_{-i} + r} \Rightarrow \\ c &= \frac{(P_i + G_i + Z_i - W_i)(b_{-i} + r) - b_{-i}Z_i}{V_i - (P_i + G_i + Z_i - W_i)} \\ &= \frac{r(P_i + G_i + Z_i - W_i) + b_{-i}(P_i + G_i - W_i)}{V - (P_i + G_i + Z_i - W_i)}, \end{aligned} \tag{8.4}$$

where I used the definition $b_{-i} \equiv b - b_i$. Setting $W_i = Z_i = 0$, (8.4) becomes:

$$c = \frac{r + b_{-i}}{V_i/(P_i + G_i) - 1} = \frac{(r+b)(P_i + G_i) - b_i(P_i + G_i)}{V_i - (P_i + G_i)}.$$

Since $b_i = b - \sum_{j \neq i} b_j$ and b is given by (8.3), b_i decreases by adding another buyer, b_{-i} increases, and this requires c to increase. Imposing symmetry, $b_i = b/n$.
The rental market: If S is willing to mix, $U_S = M + G_S$ and:

$$\begin{aligned} M + G_S &= \int_0^\infty e^{-t\left(r+\sum_i b_i\right)} \sum_i b_i \left(p_i + U_S^r e^{-rT}\right) dt = \frac{\sum b_i \left(p_i + (M+G_S)e^{-rT}\right)}{r + \sum_i b_i} \Rightarrow \\ b &= r\frac{M+G_S}{\mathrm{E}p + (M+G_S)e^{-rT} - (M+G_S)} = r\frac{M+G_S}{\mathrm{E}p - (1-e^{-rT})(M+G_S)}. \end{aligned}$$

If buyer i is willing to rent and pay p_i at interval T, $U_i = W_i - Z_i - p_i/\left(1 - e^{-rT}\right)$. If i

is willing to randomize, then, in addition:

$$\begin{aligned}
U_i &= -\int_0^{\infty} \left(cV_i + b_{-i}\left[Z_i\left(1-e^{-rT}\right) - e^{-rT}U_i\right]\right) e^{-t(r+b_{-i}+c)}dt \\
&= -\frac{cV_i + b_{-i}\left[Z_i\left(1-e^{-rT}\right) - e^{-rT}U_i\right]}{r+b_{-i}+c} \Rightarrow \\
c &= \frac{-\left(b_{-i}+r\right)U_i - b_{-i}\left[Z_i\left(1-e^{-rT}\right) - e^{-rT}U_i\right]}{V_i+U_i} = \frac{-rU_i - b_{-i}\left(Z_i+U_i\right)\left(1-e^{-rT}\right)}{V_i+U_i} \\
&= \frac{-r\left(W_i - Z_i - p_i/\left(1-e^{-rT}\right)\right) - b_{-i}\left[W_i\left(1-e^{-rT}\right) - p_i\right]}{V_i + W_i - Z_i - p_i/\left(1-e^{-rT}\right)}.
\end{aligned}$$

If $W_i = Z_i = 0$, this boils down to:

$$c = \frac{r/\left(1-e^{-rT}\right) + b_{-i}}{V_i/p_i - 1/\left(1-e^{-rT}\right)}.$$

By comparison: Since the buyer is willing to always buy in the sales market, and to always rent in the rental market, his payoffs in the two markets are identical if:

$$\frac{p_i}{1-e^{-rT}} = P_i + G_i. \tag{8.5}$$

Once B has contacted S, S prefers sale if and only if:

$$P_i + G_S \geq p_i + e^{-rT}U_S = p_i + e^{-rT}\left(M + G_S\right). \tag{8.6}$$

Thus, even for the most expensive rental contract which B would be willing to accept (i.e., ensuring that (8.5) holds), S prefers sale (the inequality (8.6) is satisfied) if:

$$\begin{aligned}
P_i + G_S &\geq \left(1-e^{-rT}\right)\left(P_i + G_i\right) + e^{-rT}\left(M + G_S\right) \Rightarrow \\
P_i e^{-rT} &\geq \left(1-e^{-rT}\right)G_i - \left(1-e^{-rT}\right)G_S + e^{-rT}M \Rightarrow \\
P_i - M &\geq \left(1/e^{-rT} - 1\right)\left(G_i - G_S\right).
\end{aligned} \tag{8.7}$$

Equivalently, S prefers selling to an existing rental equilibrium if it can achieve a high price when selling:

$$\begin{aligned}
\frac{p_i}{1-e^{-rT}} - G_i + G_S &\geq p_i + e^{-rT}\left(M + G_S\right) \Rightarrow \\
p_i e^{-rT} &\geq \left(1-e^{-rT}\right)\left(G_i - G_S\right) + e^{-rT}\left(1-e^{-rT}\right)\left(M + G_S\right) \Rightarrow \\
\frac{p_i}{1-e^{-rT}} &\geq \left(G_i - G_S\right)/e^{-rT} + \left(M + G_S\right).
\end{aligned} \tag{8.8}$$

If S sets the price, (8.7) becomes $V_i - G_i - M \geq \left(1/e^{-rT} - 1\right)\left(G_i - G_S\right)$ while (8.8) becomes $V_i \geq \left(G_i - G_S\right)/e^{-rT} + \left(M + G_S\right)$, which are both identical to (5.3) when buyers are identical. *QED*

Proof of Proposition 10. The proposition follows directly from the equilibrium payoffs, since every buyer that is randomizing is also willing to buy with probability one and obtains the payoff $-P_i + W_i - Z_i - G_i$ in the sales market, and the payoff $p_i/\left(1-\delta\right) + W_i - Z_i$ in the rental market. *QED*

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