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THE MARKET FOR CONSERVATION AND OTHER HOSTAGES

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ABSTRACT

A conservation good, such as the rainforest, is a hostage: it is possessed by S who may prefer to consume it, but B receives a larger value from continued conservation. A range of prices would make trade mutually beneficial. So, why doesn't B purchase conservation, or the forest, from S?

If this were an equilibrium, S would never consume, anticipating a higher price at the next stage. Anticipating this, B prefers to deviate and not pay. The Markov-perfect equilibria are in mixed strategies, implying that the good is consumed (or the forest is cut) at a positive rate. If conservation is more valuable, it is less likely to occur. If there are several interested buyers, cutting increases. If S sets the price and players are patient, the forest disappears with probability one.

A rental market has similar properties. By comparison, a rental market dominates a sale market if the value of conservation is low, the consumption value high, and if remote protection is costly. Thus, the theory can explain why optimal conservation does not always occur and why conservation abroad is rented, while domestic conservation is bought.

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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 this, either individually or collectively through the World Bank or the United Nation. The REDD (Reducing Emissions from Deforestation and Forest Degradation) initiative intends to do exactly this, but REDD is a recent phenomenon, offered to a limited extent, and so the puzzle remains: why isn't the North buying conservation from the South?[2]

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).

take place immediately if the buyer's consumption value is larger than the seller's. For conservation goods, however, the buyer is happy 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 preserve the good today if the buyer is likely to pay tomorrow, but the buyer is in no hurry to cash out as long as the seller waits. This contradiction implies that conservation must end at a positive rate, I find.

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). Bohm (1993) and Harstad (2011) have argued that a climate coalition would benefit from purchasing and conserving foreign fossil fuel deposits. The puzzle 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]

To formalize the market for conservation, I present a model with a seller (S), a buyer (B), and a good (e.g., the forest). S prefers to consume (or "cut") the good but B's value of conserving it is larger. In each period, B decides whether to contact S. If done, S suggests a price and B decides whether to accept. If there is no trade, S has the possibility

[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 continued to laugh at her, but accepted the original price for the three remaining books after the woman decided to burn yet three books (Ihne, 1871:74-75).

to cut. The game stops if the good is sold or consumed. Efficiency requires that the good is never consumed.

Unfortunately, there is only one Markov-perfect equilibrium[6] 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.

There is also a set of equilibria in mixed strategies. In each of these, B is more likely to buy if the value of cutting is large, while S is more likely to cut if the conservation value is low. Each of the mixed equilibria is associated with a unique equilibrium price. The set of equilibrium prices is a closed interval. For a high equilibrium price, B is less likely to buy, while S is more likely to cut. The aggregate welfare is therefore maximized at the lowest possible price. However, if S can announce the equilibrium price (in addition to the price in the current period) at the meeting with B, S selects the highest possible price.

These equilibria survive if the forest can be cut gradually. In fact, the equilibrium probability of cutting can be interpreted as the random or deterministic expected fraction that is being cut every period. Thus, random actions are not necessary for the argument.

It is easy to analyze questions regarding incentives in this model. For example, if S had 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. If the seller were able to invest and raise the market value of cutting, the incentives to do so would be stronger than if conservation were not an issue. The reason is that, if the value of cutting increases, B

[6]Dynamic games with multiple subgame-perfect equilibria often restrict 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.

buys with a higher probability.

Is a rental market better? After all, the renter is then committing to only one period, and this reduces the cost of contacting the seller. A rental market is also more similar to the existing REDD contracts, and the reader may be interested in analyzing them for that reason. Unfortunately, I find that the rental market is not necessarily more efficient that the sales market. In fact, the rental market has exactly the same problems and comparative statics as the sales market: The only pure strategy equilibrium is that B never rents, while S always cuts. There is a range of equilibria in mixed strategies and, in each of these, B is more likely to pay for conservation if the consumption value is large. For every equilibrium in the sales market, there exists an equilibrium in the rental market giving identical payoffs.

By comparison, however, the rental market and the sales market are not identical. On the one hand, the rental market may be strictly worse since the equilibrium is in mixed strategies in every period as long as the good is not consumed. Thus, the forest is cut in finite time almost for sure in the rental market. On the other hand, if there is a cost of protecting the good (to prevent illegal logging or re-nationalization, for example) and this cost is higher for B than for S (who is "local"), then the rental market (i) minimizes protection costs, (ii) exists for a larger parameter-set than does the sales market, and (iii) permits the first-best is an equilibrium outcome (while the sales market does not). 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 countries will be rented.

All results survive if time is continuous and there are multiple buyers or sellers.[7] If the

[7]If there are multiple sellers with different goods, the buyer(s) may play the described game with each

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. Furthermore, the most likely buyer (or renter) has a high protection cost and a relatively low value of conservation.[8] These results are perverse and lead to additional inefficiencies. To mitigate these inefficiencies, all potential buyers may be better off if they collectively agreed to permit some type of "privatization" (e.g., allowing for eco-tourism) that increases the owner's value even if that would reduce the total conservation value and ex post efficiency.

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. 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 reasoning in this paper: instead, it is the possibility to abstain combined with 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 requires a dynamic framework, the model is different from both durable goods markets[9] and classic

of them independently, and the results below are unchanged. In reality, there can also be multiple users of the same forest, but PES-contracts may force them to act as one seller (Phelps et al., 2010).

[8] Consistent with this prediction, Norway is one of the few active providers of REDD funds and has already initiated results-based payments through partnerships with Brazil, Guyana, and Indonesia.

[9] 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 may in fact also happen in my model, if the buyer has any bargaining power (as explained in Section 5). The intuition is, however, quite 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. More fundamentally, in contrast to the durable goods, the conservation

war-of-attrition models.[10]

As an alternative to cutting the forest, a similar game would arise if 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 Jehiel 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, as 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

good in this paper 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 is driving the inefficiency studied below.

[10]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.

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. It is also crucial for my results that the seller has all the bargaining power: if the buyer received a share of the bargaining surplus, the unique equilibrium requires the lowest possible price and, then, the buyer buys with probability one. This nonrobustness argument, to continue the debate, is itself nonrobust: no matter the allocation of bargaining power, the equilibrium is still inefficient and requires cutting if there are multiple buyers, the meeting cost is positive, or negotiation failure implies increased cutting.

The next section presents and analyzes a simple model of the sales market. Section 3 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 4 reviews the results in a continuous time model and studies the effects of multiple and heterogeneous buyers as well as policies such as privatization, coordination, and collective action. A number of extensions and robustness issues are discussed in Section 5, while Section 6 concludes. The proofs are either in the text or in the Appendix.

2. The Market for Sale

2.1. The Model

The stage game. There are two players: the seller (S or "she") and the buyer (B or "he"). At the beginning of the game, S owns a good (e.g., a forest) which B can purchase. If B does not buy the good, S decides whether to consume (i.e., "cut").

If B does not buy and S does not consume, the status quo stays in place and payoffs are normalized to zero. If S consumes the good, B looses his conservation value and receives the payoff $-V$. S, on the other hand, benefits from consumption. For some applications and results it is fruitful to distinguish between two consumption values:

First, consumption gives the direct benefit M, which may be interpreted as the market value of timber or the accessible land (or the sum of these). In addition, by consuming, S can stop to guard or protect the forest (for illegal logging, for example), and these savings are measured by G_S. In sum, consumption gives S the payoff $M + G_S$.

If S sells at price P, S' payoff is $P + G_S$ since, also in this case, S has no incentive to guard the good and the guarding cost is saved. B's payoff, in this case, is $-P - G_B$, where G_B is the buyer's cost of guarding or protecting the good.

The results below do hinge on a positive G_B or G_S and, to simplify, the readers may want to limit attention to the special case $G_B = G_S = 0$. I add these parameters only to get additional insight in the later sections. Furthermore, 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).

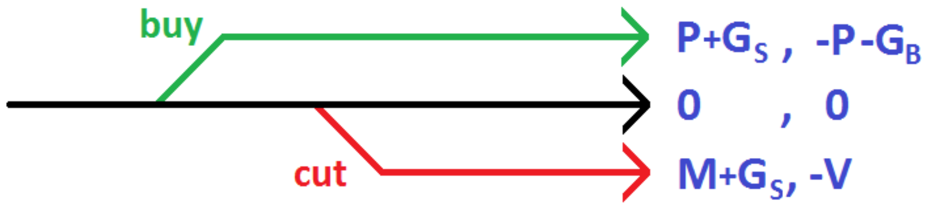

Fig. 1: The seller's and buyer's payoffs depend on whether the buyer buys or seller cuts

The exact timing of the stage game is 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.

With only one period, the equilibrium is straightforward:

Proposition 0. *Suppose there is only one period:*
(i) *For any exogenous* $P \in (M, V - G_B)$*, B buys with probability one.*
(ii) *When S proposes the price,* $P = V - G_B$*, and there is an equilibrium where B buys with probability one.*
(iii) *These equilibria lead to conservation and, if* $G_B \leq G_S$*, the first-best.*

Part (i) shows that the good is conserved with probability one for any exogenous $P \in (M, V - G_B)$. This part is for illustration only, since the rest of this paper assumes that S proposes the price once B contacts S. Then, S proposes $P = V - G_B$ and trade with probability 1 is still an equilibrium. To complement part (ii), note that also other equilibria exist since B is indifferent when contacting S (B may randomize). To complement part (iii), note that the first-best is never an equilibrium outcome if $G_S < G_B$, since the first-best would then require that B does not buy and that S does not cut. For $G_S = G_B$, the good in the stage game 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. This changes dramatically in the dynamic version of the game.

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 g_S and g_B measure the per-period or flow protection costs, then $G_S \equiv g_S / (1 - \delta)$ and $G_B \equiv g_B / (1 - \delta)$. Similarly, $V \equiv v / (1 - \delta)$, where v is the buyer's value of conservation each period.

Again, the first-best outcome can easily be 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.

As in most dynamic games, there are multiple subgame-perfect equilibria. For simplicity, I will restrict 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 equilibrium strategies are necessarily stationary.

2.2. 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's 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 $V - G_B > M/\delta + G_S(1-\delta)/\delta$.[11]

Proposition 1. *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

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

[11]However, 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 suggests the price $V - G_B$ 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).

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.

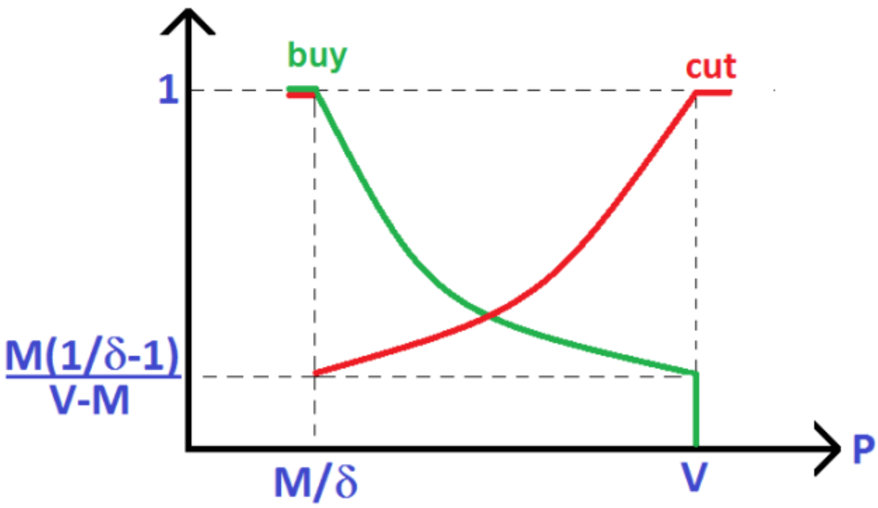

Fig. 2: The special case $G_S = G_B = 0$

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 always requires exactly this price. If, then, B contacts S for sure ($b = 1$), then 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.

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 Section 2.4, S announces the *equilibrium price* as well as this period's price; leading to a unique equilibrium).

Each player randomizes such that the opponent is just indifferent and, hence, also willing to randomize. This explains the comparative static. Suppose P increases (i.e., compare an equilibrium with a large price to an equilibrium with a small price). Then, B is less tempted to buy and, to be willing to randomize, S must be more likely to cut. At the same time, S becomes inclined to wait for the high price and, thus, B will buy with a smaller probability (as in Fig. 2). For a fixed P, the seller finds cutting more attractive if the market value, M, increases; if the protection cost, G_S, increases; or if the future is more discounted, in that δ decreases. To ensure that S is still willing to cut in these situations, the probability for sale, b, must increase. Hence, B is more likely to buy conservation if the market value is large, the price for conservation small, and if S finds protection costly. Similarly, for a given price, the buyer finds it less attractive to contact S if the value of conservation is low and protection is costly. To ensure that B is willing to buy, nevertheless, S must cut with a larger probability in these circumstances.

Some of these comparative statics are counter-intuitive, and they may deserve a second thought. If M increases, for example, a first guess may be that S should cut more since cutting becomes more attractive. In fact, S's probability of cutting should jump to one, if initially indifferent. If this happened, however, B would buy with probability one and, as a best response, S would never cut. Since there is no such equilibrium in pure strategies, this first guess proved wrong. Instead, B is going to buy with a somewhat larger probability, and S is still willing to randomize. The result is that, perversely, B is more likely to buy conservation if the value of cutting is large.

Compared to the one-period version of the game, two differences are striking. First, for any exogenous price between the two valuations, the good is conserved with probability one in the static game, but not in the dynamic version. Second, if S can propose the price, the equilibrium price can be anything between the valuations in the dynamic game, but it must equal the upper boundary in the static version.

Purification. If the good is divisible, then randomization is not necessary for this equilibrium. Instead, c can be interpreted as the *fraction* of the forest that is cut in each period, as long as it is not sold. More generally, c must be the *expected* fraction that is cut in every period. The equilibria described by Proposition 1 survive if the good can be gradually consumed or cut in this way. Likewise, b can be interpreted as the expected fraction that is purchased in each period.[12]

2.3. Payoffs and Incentives

From Proposition 1, the equilibrium payoffs follow as a corollary:

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

B's equilibrium payoff is pinned down by his payoff when purchasing conservation, while S's payoff must be such that, when discounted, it is equal to her value of cutting. Given this, 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 increase V or decrease G_B, for example. Any of these changes would raise B's value of conservation. For a given P, this would make it more attractive for B to contact S unless, as will happen in equilibrium,

[12]For these equilibria, we may have other MPEs, as well, if strategies can be conditioned on the fraction consumed so far. However, using the reasoning from Maskin and Tirole (2001), one may argue that the fraction cut is not payoff-relevant and that the MPEs should not be conditioned on it.

For b to be interpreted as a fraction, it is necessary that B cannot revise its choice of b after observing P.

S cuts slower. S' payoff is unchanged. Even if P happened to increase following such an eagerness, S would not benefit since B must be less likely to contact S if P is large - in order to keep S indifferent. A raise in P is always associated with a corresponding decrease in b, ensuring that S' payoff is not altered.

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 (and pay $P > M$) with an even larger probability. This is beneficial for S, and it may strongly motivate S to raise M, for example by facilitating trade in tropical timber.

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 $V_S < M + G_S$, $b > 0$ and the seller's equilibrium payoff is $V_S + (M + G_S - V_S)/\delta$, 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. Similarly, she would have no incentive to reduce her own cost of protection, since this, as well, would reduce B's likelihood of paying for conservation.

Corollary 1. *The payoffs are given by (2.1). Thus, S has no incentive to increase the values of conservation or reduce the costs of protection, but strong incentives to raise the consumption value, M.*

We can also consider the incentives of the buyer. A boycott, for example, reducing M, would not necessarily benefit B. In fact, in isolation (for a fixed P), a lower M reduces the sum of payoffs and thus efficiency: A small M would make 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. However, since U_B is also a function of P, the conclusion might be different if the selected equilibrium price were a function of M.

2.4. Prices and Welfare

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 this 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. Thereafter, B 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 1 for $P = V - G_B$. To summarize:

COROLLARY 2. (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 miserably.

3. The Rental Market

3.1. A Model of the Rental Market

The above sales market has several shortcomings: (i) the probability of consumption may be quite large, (ii) if $G_B > G_S$, the equilibrium is always inefficient since the first-best requires no trade and no consumption, (iii) the sales market does not even exist if $G_B < V - M$, and, finally (iv) a purchase may require foreign ownership if 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.

A rental contract means that B pays S to not cut but instead conserve the good for one period. By assumption, rental contracts 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.

Assume that the pay is conditioned on conservation, as is the typical rental contract for conservation (e.g., the REDD funds). Otherwise, the game is similar to before: In every period, B first decides whether to contact S. If done, S suggests a rental price, p. If B accepts, B pays p to S and the good is conserved until the next period. If no rental contract is signed, S decides whether to consume. 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.

If the model had only one period and p were exogenously given, the equilibrium outcome would be unique and first-best for any $p \in (M - G_S, V)$. This remains an equilibrium if $p \in [M - G_S, V]$. When S sets the price, she suggests $p = V$ and a best response for B is to contact S and accept this price. But, as before, another best response for B is to not contact S. Note that the static rental game is identical to the static sales game when $G_B = G_S = 0$.

Just as before, I limit attention to Markov-perfect equilibria that are only conditioned on whether the good exists. One can easily argue that any other aspect of the history is not payoff relevant.

3.2. The Equilibrium in the Rental Market

As before, I let b and c represent the probabilities that B contacts S and that S cuts at her decision node. Thus, B's strategy is simply (i) his probability of contacting S in any given period, $b \in [0, 1]$, and (ii) the threshold, p, for when he would accept the contract. S' strategy is to offer exactly the price, p, if B contacts S and, at the cutting stage, S' strategy specifies her probability of cutting, $c \in [0, 1]$. The equilibrium can 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, given the chance. From now on, I thus assume $(M + G_S)/\delta \le V$.[13]

[13]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

Proposition 2. *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.

3.3. Analogies

Proposition 2 is clearly analogous to Proposition 1. Its intuition is similar, as well, and thus skipped. Instead, 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 3. *Take an equilibrium P for the sales market and an equilibrium p for the rental market. The two equilibria are identical in that:*
(i) *B's payoff is the same 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.*
(iv) *Total welfare decreases in the equilibrium price.*
(v) *If S announces the equilibrium price,* $U_B = -V$ *and* $c = 1$.

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).

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. Part (ii), in contrast, 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. Thus, if the equilibrium p increases, for example, B is less likely to buy, and the two effects cancel. Given this, Parts (iii)-(v) hold for the same reasons as before. In particular, the price maximizing welfare is the smallest possible price, $p = (1-\delta)(M+G_S)/\delta$, 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 $p = (1-\delta)V$. Anticipating this, $b = (M+G_S)/\delta V < 1$ while $c = 1$, so the good is consumed relatively fast.

3.4. Buy or Rent Conservation?

Despite the similarities just mentioned, the sales market and the rental market are not equivalent: (i) In the rental market, the game ends only after consumption. Before that occurs, 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 then 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, he may want to, instead, propose a price P for sale. When can S benefit from this?

Proposition 4. (i) *Take an equilibrium in the sales market characterized by P. There exists a rental market equilibrium that is better for both B and S at the negotiation stage if:*

$$P + G_B < \frac{M + G_B}{\delta}. \tag{3.1}$$

(ii) *Conversely, take an equilibrium in the rental market characterized by p. There exists a sales price such that both B and S are better off trading at this price if:*

$$\frac{p}{1-\delta} > \frac{M + G_B}{\delta}. \tag{3.2}$$

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

$$V > \frac{M + G_B}{\delta}. \tag{3.3}$$

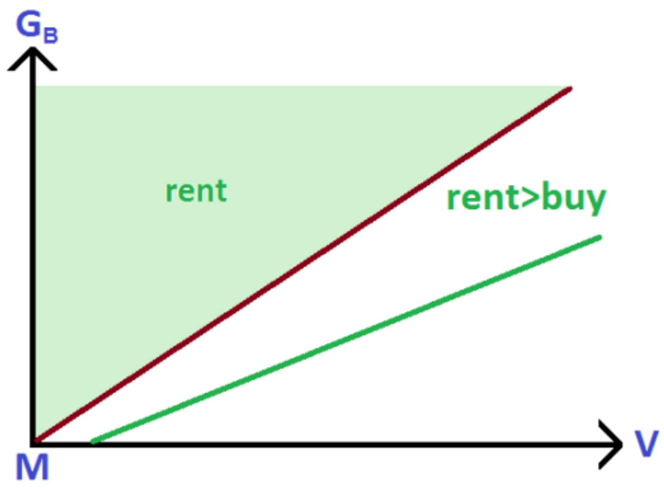

Fig. 3: Renting is predicted if G_B is large while $V - M$ is small

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 pay S for this job.

If S announces the equilibrium price, the condition for sale in part (i) and (ii) are identical, and rewritten in part (iii). Since the price is then higher if the conservation value is high, S is better of selling to B rather than continuing the inefficient randomizations. Thus, if conservation is sufficiently valuable, conservation is bought rather than rented.

Note that G_S does not appear in Proposition 4. 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 cost of renting. Obviously, the two effects cancel.[14]

3.5. 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.

Proposition 5. *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 countries makes conservation *more* important, from any planner's point of view. Unfortunately, the only symmetric (pure or mixed) equilibrium is that no-one ever buys/rents conservation from S, while

[14] Note that the last condition in Proposition 4 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.

S cuts immediately and with probability one. The intuition is the following: First, 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 is no chance than any other buyer is matched with S instead.

Proposition 5 shows that the analysis above, assuming exactly one active buyer, is relevant even if there are third (passive) parties that would also benefit from conservation. However, the reasoning behind Proposition 5 relies on discrete time (since j does not want to contact S if also i might at the same exact time). This motivates our next section, allowing time to be continuous.

4. Continuous Time and Multiple Buyers

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. The common discount rate is r. Second, I let the rental contract 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, and the buyers can be heterogeneous. Fourth, I will let the good have private as well as public good aspects, and I will endogenize these benefits.

4.1. A Single Buyer - Revisited

As a start, the above results are restated for the case with continuous time.

Proposition 6. *Suppose time is continuous and a rental contract can be of length T.*
(i) *In the sales market, the only pure strategy equilibrium is $b = 0$, $c = 1$, $P = V - G_B$. In addition, for every $P \in [M, V - G_B]$ there exists a mixed strategy equilibrium where:*

$$\begin{aligned} b &= r\frac{M + G_S}{P - M - G_S}, \\ c &= r\frac{P + G_B}{V - P - G_B}, \\ U_B &= -P - G_B, \\ U_S &= M + G_S. \end{aligned} \tag{4.1}$$

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

$$\begin{aligned} b &= r\frac{M + G_S}{p - (M + G_S)\left(1 - e^{-rT}\right)}, \\ c &= \frac{r}{V\left(1 - e^{-rT}\right)/p - 1}, \\ U_B &= -\frac{p}{1 - e^{-rT}}, \\ U_S &= M + G_S. \end{aligned} \tag{4.2}$$

(iii) *Once B contacts S, anticipating to buy at price P, a rental contract is preferred 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, a sales contract is preferred 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:*

$$V - G_B \geq M + (G_B - G_S)\frac{1 - e^{-rT}}{e^{-rT}}. \tag{4.3}$$

Part (i) is similar to Proposition 1, 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 2 if $T = \Delta$ and $\Delta \to 0$.

Parts (iii)-(v) are also quite similar to the above results, Proposition 4, 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, (4.3) can never hold unless $G_S \geq G_B$. If $T \to 0$, however, (4.3) is equivalent to (3.3) when $\delta \to 1$.

4.2. 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 rate at which S is contacted by some buyer. Thus, in a symmetric equilibrium, every i contacts S at the rate $b_i = 1 - (1-b)^{1/n}$.

Amazingly, most of the results continue to hold:

Proposition 7. *Suppose there are n identical potential buyers. Proposition 6 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 6, the result is disappointing. If more countries benefit from conservation, and the 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, to still be willing to randomize, S must cut at a faster rate.

The outcome is even 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 (if the equilibrium price happens to decrease in V_i, however, this effect is somewhat mitigated). As another prediction, in this situation renting would be more likely as n grows, since Proposition 6 states that renting is more likely when the buyer's value is low.

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 to randomize only if the rate at which *some* buyer will drop by, b, multiplied by the price, makes S indifferent. Furthermore, in equilibrium, every buyer receives the payoff pinned down by the payoff he would receive if contacting S with probability one. 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.

4.3. 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.

PROPOSITION 8. (i) *In the sales market, there are multiple equilibria in mixed strategies. For every $P \in (M, \min_i \{V_i - G_i\})$, S is contacted at rate (4.1), while S cuts at the rate:*

$$c = \frac{r + b_{-i}}{V_i/(P + G_i) - 1} \; \forall i \mid b_i > 0.$$

(ii) *In the rental market, as well, there are multiple equilibria in mixed strategies. For every $p/\left(1 - e^{-rT}\right) \in (M - G_S, \min_i V_i)$, S is contacted at rate (4.2), while S cuts at the rate:*

$$c = \frac{r + (b - b_i)\left(1 - e^{-rT}\right)}{V_i\left(1 - e^{-rT}\right)/p - 1} \; \forall i \mid b_i > 0.$$

Corollary 3. (i) *In the sales market, buyer i is more likely to buy than buyer j if $V_i/(P+G_i) < V_j/(P+G_j)$.* (ii) *In the rental market, i is more likely to rent than j if $V_i < V_j$.*

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.[15]

4.4. Remedies

Privatization. With multiple buyers, conservation becomes a public good. As we already know, public goods are under-supplied. A remedy may be to raise the *private* value when buying (or renting) the good, even if it 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, although it may have detrimental impact on the conservation value of other countries. Increasing the private value can increase the probability of purchasing in the first place. To evaluate when such "privatization" is socially optimal, suppose privatization increases the buyer's conservation value by W units and the world's conservation value by $-Z < 0$. Ex post (after sale), it is obviously beneficial with privatization if only if $W > Z$.

Proposition 9. *Ex ante, privatization is beneficial 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 suboptimal ex post, but beneficial ex ante. The reason is, of course, that under privatization each buyer benefits more from a purchase and less from another country's purchase. They are thus more tempted to buy, and the

[15]Proposition 8 presumes that all buyers face the same price. If the prices differ, subscript i should be added to the prices, as the Appendix shows.

equilibrium cutting rate declines. Note that the condition $W > Z/n$ is identical to the condition under which privatization is individually optimal 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. Obviously, privatization is not an ideal remedy and it may not always be feasible for realistic applications.

Collective action. The free-rider problem among potential buyers can be solved in two alternative ways. The simplest way is to revert to an *asymmetric equilibrium* where only one country is a potential buyer. Both this buyer and the seller are indifferent to this change of equilibrium, for a given equilibrium price, but every other buyer is strictly benefitting. Thus, the sum of the buyers' payoffs in this case, referred to as U_A, is larger than the sum of payoffs in the previous section. If there is more than one conservation good, or it is divisible, then every country would strictly benefit by clearly defining which buyer is responsible for buying and conserving which good. The war of attrition between the competing buyers is then solved, but the equilibrium is still inefficient and as described by Proposition 1.

A potentially better solution is for the multiple buyers to solve their collective action problem by *acting as one* player. Then, the outcome is as described by Proposition 1, where the buyer's valuation is now the sum of the individual valuations. The sum of the payoffs in this case, referred to as U_C, is also larger than the sum of the payoffs in the previous section. The larger valuation decreases the cutting rate, benefitting all the players if the equilibrium price stays unchanged. If the seller can announce the equilibrium price, however, she will raise the price accordingly and in line with Corollary 2. It is then easy to show that the buyers would prefer the asymmetric equilibria, rather than acting as one.

PROPOSITION 10. *For a given price, acting as one is better than the asymmetric equilibrium:* $U_C > U_A$. *If S can announce the equilibrium price, however, the reverse is true:* $U_C < U_A$. *Both statements hold for the sales market as well as for the rental market.*

5. Robustness

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 above, and they may generate new results that are of interest. A large number of extensions is analyzed below: I there derive nonrandom equilibrium strategies (using purification arguments) and allow 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. I also allow for communication costs, buyers with bargaining power, and non-Markovian strategies (in particular, the possibility that bargaining-failure leads to faster cutting).

5.1. Purification of Strategies

As is well-known, mixed strategies can be "purified" by introducing some noise regarding future variables. Thus, it is not necessary for the results that the agents are using mixed strategies in equilibrium, as long as the opponent is uncertain regarding the action taken.

To illustrate this in a simple manner, suppose that the market value of timber, M, is uniformly distributed on the interval $\left[0, \overline{M}\right]$. Furthermore, suppose that the realization of M is iid across periods and the realization of the future M is not known to S when S considers to cut in a given period. With these assumptions, it does not matter whether the realization is known also to B, as long as B is unaware of its realization when taking its own action. In any case, S is going to cut at its decision node if and only if:

$$
\begin{aligned}
M &\geq \delta U_S \Rightarrow \\
c &= 1 - \frac{\delta U_S}{\overline{M}}.
\end{aligned}
\tag{5.1}
$$

The seller's payoff is then given by:

$$
\begin{aligned}
U_S &= bP + (1-b)\left(c\mathrm{E}\left(M \mid M \geq \delta U_S\right) + (1-c)\,\delta U_S\right) \\
&= bP + (1-b)\left(\left(1 - \frac{\delta U_S}{\overline{M}}\right)\left(\frac{\overline{M} + \delta U_S}{2}\right) + \frac{\delta U_S}{\overline{M}}\delta U_S\right) \\
&= bP + (1-b)\left(\frac{\overline{M}}{2} + \frac{\left(\delta U_S\right)^2}{2\overline{M}}\right).
\end{aligned}
\tag{5.2}
$$

As before, P cannot be larger than V. Furthermore, P cannot be smaller than $\overline{M}/2$, since the seller would then reject the buyer's offer. For a larger P, c must increase, to keep B indifferent. Then, (5.1) implies that U_S must decrease. This, from (5.2), requires a smaller b. For a given P, if $\overline{M}$ increases, S becomes more tempted to cut, and is willing to wait only if b increases. The comparative static is thus similar to the one before.

For any given anticipated P, B is indifferent whether to buy and S can therefore charge exactly this P. Again, there is a range of mixed equilibria characterized by different prices, and for a large price, c must increase but b must decrease.

Proposition 11. *Suppose $M \sim U\left[0, \overline{M}\right]$. There is a continuum of MPEs, each characterized by an equilibrium price $P \in \left[\overline{M}/2, V\right]$. S' decision whether to cut is deterministic and depending on the realization of M, but the comparative static is similar to before: As P increases, b decreases and c increases. For a given P, b increases in $\overline{M}$ and c decreases in V.*

Thus, the main results emphasized above continues to hold. However, if V increases and c declines, b must increase. Therefore, in this variant of the model, a valuable conservation good is less likely to be consumed, in contrast to the setting where S can announce the equilibrium price.

5.2. Purification and Interior Solutions

As already mentioned, c could be interpreted as the fraction S is cutting in each period. Furthermore, rather than having a linear utility in c, making S willing to mix, S could have concave preferences, pinning down a unique best response for the seller. Similarly, if one interprets the value of cutting as S' saved protection costs, one could let the probability that cutting occurs be a random function of the protection cost. The more S spends on protection, the more likely it is that the forest survives.

To illustrate this in a simple way, suppose that protecting the good with probability q costs the seller the amount $q^2k/2$, where k is an arbitrary positive constant. The first-order condition for q is:

$$bP + (1-b)\left(\frac{\overline{M}}{2} + \frac{(\delta U_S)^2}{2\overline{M}}\right)$$

$$\begin{aligned} q &= \delta U_S/k \Rightarrow \\ c &\equiv 1-q = 1-\frac{\delta U_S}{k}, \text{ and} \\ U_S &= bP + (1-b)\left(-\left(\delta U_S/k\right)^2 k/2 + \left(\delta U_S/k\right)\delta U_S\right) \\ &= bP + (1-b)\left(\delta U_S\right)^2/2k \Rightarrow \\ U_S &= \frac{k}{(1-b)\,\delta^2} - \frac{k}{(1-b)\,\delta^2}\sqrt{1-2(1-b)\,\delta^2 bP/k}. \end{aligned} \tag{5.3}$$

For U_S to be stable, we require $(1-b)\,\delta U_S/k < 1$. Note that $\delta U_S/k = 1-c$, so this is satisfied. Note that both c and U_S have the similar form as in the previous subsection.

As before, P cannot be larger than V. For a reduced P, c declines, to make B indifferent. Then, (5.3) implies that U_S increases, which requires a larger b. Once $b=1$, $U_S = P$ and (5.3) implies that $c = 1-\delta P/k$. For this c to be positive, we must have

$P < k/\delta$. Combined with B's indifference-condition, we get that $b = 1$ only when:

$$1 - \frac{\delta P}{k} = \frac{(1-\delta)\,P}{V - \delta P} \Rightarrow$$
$$P = \underline{P} \equiv \frac{k + \delta V}{2\delta^2} - \frac{1}{2\delta^2}\sqrt{(k+\delta V)^2 - 4\delta^2 kV}.$$

As before, a range of prices constitute an equilibrium. If P is larger, c must increase, i.e., q must decrease. This is possible only if b decreases. If V increases, c declines, U_S must increase, implying that b must raise. If the protection cost k increases, S would be less likely to protect, unless U_S increases, which requires b to increase. Thus, larger protection cost for S makes B more likely to buy.

Proposition 12. *Suppose S can protect the good with probability q at cost $q^2k/2$. For each $P \in [\underline{P}, V]$, there is an equilibrium where S' effort is given by (5.3) and B buys with probability $b \in [0,1]$. The comparative static is similar to that before.*

To this, one could add costly probabilistic protection also if B ends up buying the good. Perhaps the cost for B would be larger than the cost for S, as argued above. Furthermore, it would be desirable to have more general cost functions (for protection). These and other issues must await further research.

5.3. Buyers with Bargaining Power

Above, for any $P > M/\delta$, the buyer is randomizing and thus indifferent between trading at P and not trading at all. This indifference implies that the buyer received literally no bargaining surplus from its interaction with the seller. The seller, empowered to make a tioli-offer, captures the entire gains from trade. Thus, if the buyer has some bargaining power, we cannot have $P > M/\delta$. It is easy to see that if the buyer's bargaining power is represented by $\beta > 0$, the unique equilibrium requires $P = M/\delta$ and that the buyer buys with probability one.

Proposition 13. *Suppose the buyer has bargaining power β while the generalized Nash Bargaining Solution characterizes the outcome for P. If $\beta > 0$, the unique equilibrium requires $P = M/\delta$ and $b = 1$.*

At first, the result is very encouraging: All that is necessary is to give the buyer some bargaining power, and efficiency will result. However, the fact that $P \to M/\delta$ when $\beta > 0$ hinges on a number of assumptions. In particular, one needs to assume that it is only one buyer, there is no cost of contacting the buyer, and there is no penalty following bargaining-failure. These three assumptions are relaxed in the following three subsections, where I continue to let β measure a buyer's bargaining power.

5.4. Costly Negotiations

Suppose that B must pay $k \geq 0$ when contacting S. This cost could represent the physical relocation cost or set-up cost of a meeting with S, or it could represent the political obstacles necessary to overcome in the domestic arena when initiating such a conservation policy.

If B is indifferent whether to trade with S at price P, once B has paid the cost k, B's surplus of this trade is the cost just paid, k. If S had all the bargaining power, S could extract this surplus and, anticipating this, B would never have contacted S in the first place. If B has some bargaining power, however, the equilibrium price is determined by the fact that S' surplus must equal the total surplus of trade, multiplied by its bargaining power $1-\beta$:

$$P - M = (1-\beta)(P - M + k)$$
$$P = M + \frac{1-\beta}{\beta}k.$$

Naturally, the larger is the buyer's bargaining power, the lower is the price. Just as before, b and c are given by the equations above. As before, we still have $c > 0$ and $b < 1$ as long as $P > M/\delta$. This requires:

$$\beta < \frac{k}{(1/\delta - 1)M + k} \tag{5.4}$$

Proposition 14. *Suppose B must pay* k to contact S. If (5.4) holds, $b < 1$ and $c > 0$. If

k increases or β declines, the unique equilibrium P increases and, as a result, b declines while c increases.

5.5. Bargaining Failure Leads to Cutting

In the above equilibrium, S is indifferent whether to cut and it is assumed that S continues to randomize, even if an attempt to negotiate with B has just failed. This a bargaining failure does not occur in equilibrium, however, it may be reasonable to assume that S is puzzled by this failure, and concludes that bargaining is not likely to succeed in the future, either. The best response for S would then be to cut immediately.

Given this threat, S can negotiate a higher price. By using the generalized Nash Bargaining Solution, the price will be given by:

$$P = P_N \equiv \beta M + (1 - \beta) V. \tag{5.5}$$

Just as before, we get $c > 0$ and $b < 1$ if $P > M/\delta$. This requires:

$$\beta < \frac{V - M/\delta}{V - M}$$

Note that this condition holds trivially when periods get short and $\delta \to 1$.

Proposition 15. *Suppose S cuts if negotiations fail. Then, $P = P_N$, given by (5.5), increases in M and V but decreasing in β.*

Again, we get the perverse results that as V increases, the probability that B shows up to conserve the forest declines.

5.6. Multiple Buyers with Bargaining Power

With multiple buyers having a positive probability of buying, it is not possible that $b = 1$ since that would require $b_i = 1$ for each of them, and one buyer would find it optimal to leave the purchase to the other. Similarly, $b = 0$ is not possible when $\beta > 0$, since that would require $c = 1$ and a negotiated price (P_N) that would make it strictly better for a buyer to contact S. Thus, each buyer must be indifferent whether to buy. To investigate this setting in a simple way, it is here assumed that all potential buyers are identical. Given b, this implies that each buys with a probability b_i such that:

$$1 - b = (1 - b_i)^n \Rightarrow b_i = 1 - (1 - b)^{1/n}.$$

If several buyers decide to buy in a given period, the seller is matched with each of them with equal probability. Thus, in equilibrium, a buyer receives the payoff:

$$\begin{aligned} U_B &= -P\frac{b}{n} - (1 - b)\left(cV - \delta(1 - c) U_B\right) \\ &= -\frac{bP/n + (1 - b) cV}{1 - \delta(1 - b)(1 - c)}, \end{aligned}$$

since the good is purchased in this period with probability b at price P and, if so, the probability that i is the buyer is $1/n$. Instead of buying with probability b_i, another best response to a buyer is to not buy in this period. This would give the payoff:

$$\begin{aligned} U_B &= -(1 - b_i)^{n-1}\left(cV - \delta(1 - c) U_B\right) \\ &= -(1 - b)^{1-1/n}\left(cV - \delta(1 - c) U_B\right) \\ &= -\frac{(1 - b)^{1-1/n} cV}{1 - \delta(1 - b)^{1-1/n}(1 - c)}. \end{aligned} \tag{5.6}$$

A buyer is willing to randomize only if these payoffs are identical. By substituting the latter equation into the former, we have:

$$U_B = -P\frac{b}{n} + (1 - b)^{1/n} U_B \Rightarrow U_B = -\frac{Pb/n}{1 - (1 - b)^{1/n}}. \tag{5.7}$$

If negotiations break down, a buyer's continuation value is $-cV + \delta(1 - c) U_B$, which, using (5.6), is equal to $(1 - b)^{1/n-1} U_B$. Thus, once a buyer is matched with the seller, his bargaining surplus is:

$$\begin{aligned} -P - (1 - b)^{1/n-1} U_B &= \frac{P(1 - b)^{1/n-1} b/n}{1 - (1 - b)^{1/n}} - P \\ &= \frac{Pb/n(1 - b)}{(1 - b)^{-1/n} - 1} - P. \end{aligned}$$

Since S' bargaining surplus is $P - M$, and this is a fraction $1 - \beta$ of the total surplus, the negotiated price must satisfy:

$$\begin{aligned}\frac{P-M}{1-\beta} &= \frac{Pb/n\,(1-b)}{(1-b)^{-1/n}-1} - M \Rightarrow \\ \frac{P}{M} &= \frac{\beta}{1-(1-\beta)\,b/\,(1-b)\,n\left[(1-b)^{-1/n}-1\right]}.\end{aligned} \tag{5.8}$$

So, the equilibrium P increases in M and decreases in β. Furthermore:

Lemma 1. *For a given b, the equilibrium P increases in n.*

Proof: This holds if the derivative of the following is negative:

$$n\left[(1-b)^{-1/n}-1\right] = n\left[e^{(-1/n)\ln(1-b)}-1\right].$$

The derivative is:

$$\begin{aligned}&\left[(1-b)^{-1/n}-1\right] + n\,(1-b)^{-1/n}\left(\frac{1}{n^2}\right)\ln(1-b) \\ &= \frac{1-(1-b)^{1/n}+\ln(1-b)^{1/n}}{(1-b)^{1/n}},\end{aligned}$$

where the numerator is of the form:

$$(\ln x) - x + 1.$$

This function reaches its maximum at $1/x = 1$, making it zero, and everywhere else it is negative. Thus, P does indeed increase in n. *QED*

For a given P, abstention is better if

$$\begin{aligned}\frac{(1-b)^{1-1/n}\,cV}{1-\delta\,(1-b)^{1-1/n}\,(1-c)} &\le \frac{bP/n+(1-b)\,cV}{1-\delta\,(1-b)\,(1-c)} \Rightarrow \\ \left[(1-b)^{1-1/n}-(1-b)\right]cV &\le \left[1-\delta\,(1-b)^{1-1/n}\,(1-c)\right]bP/n,\end{aligned} \tag{5.9}$$

which is *less* likely to hold if c, V/P, and δ are large. If n increases, a sufficient condition for abstention to be more tempting is that the derivative of the following expression is negative:

$$n\,(1-b)^{1-1/n} = ne^{(1-1/n)\ln(1-b)}.$$

The derivative is negative if:

$$\begin{aligned}(1-b)^{1-1/n}+n\,(1-b)^{1-1/n}\left(\frac{1}{n^2}\right)\ln(1-b)<0 &\Leftrightarrow\\ 1+\frac{\ln(1-b)}{n}<0 &\Leftrightarrow\\ \frac{1}{1-b}>e^n &\Leftrightarrow\\ b>1-1/e^n&,\end{aligned}$$

i.e., if n is sufficiently large, for a given b. Then, at least, an even larger n is making it more tempting to cheat, and cutting must increase! For smaller n, a more complicated derivation would be necessary.

Thus, c must be such that (5.9) holds. If V/P is small, δ is large, and n is large and growing, then c must increase. At $c=1$, (5.9) becomes

$$\left[(1-b)^{1-1/n}-(1-b)\right]/b\leq P/Vn. \tag{5.10}$$

Then, b must be such that this holds to make a buyer indifferent. For this case, $P=P_N$. Thus, the inequality is more likely to hold if β is small, M is large, V is small, and n is large, and, in these circumstances, b must decline due the following lemma.

Lemma 2. (5.10) *is more likely to hold if b is large.*

Proof: Consider the term $\left[(1-b)^{1-1/n}-(1-b)\right]$. Its derivative w.r.t. b is:

$$-(1-1/n)\,(1-b)^{-1/n}+1=1-\frac{n-1}{n}\frac{1}{(1-b)^{1/n}}.$$

Thus, the derivative of $b/\left[(1-b)^{1-1/n}-(1-b)\right]$ w.r.t. b is positive if:

$$\begin{aligned}
(1-b)^{(n-1)/n}-(1-b)-b\left(1-\frac{n-1}{n}\frac{1}{(1-b)^{1/n}}\right) &> 0 \Leftrightarrow \\
(1-b)^{(n-1)/n}-1+b\left(\frac{n-1}{n}\frac{1}{(1-b)^{1/n}}\right) &> 0 \Leftrightarrow \\
\frac{1-b}{(1-b)^{1/n}}-1+b\left(\frac{n-1}{n}\frac{1}{(1-b)^{1/n}}\right) &> 0 \Leftrightarrow \\
\frac{1-(1-b)^{1/n}}{(1-b)^{1/n}}-\frac{b/n}{(1-b)^{1/n}} &> 0 \Leftrightarrow \\
1-(1-b)^{1/n}-b/n &> 0 \Leftrightarrow \\
n-n(1-b)^{1/n}-b &> 0.
\end{aligned}$$

Now, note that the l.h.s. is zero for $b=0$. Next, note that the inequality is *more* likely to hold for b large, since its derivative w.r.t. b is strictly positive:

$$(1-b)^{1/n-1}-1>0.$$

QED

The final proposition summarizes the key findings above.

Proposition 16. *Suppose there are multiple active and identical buyers and* $\beta>0$.
(i) *In equilibrium,* $b\in(0,1)$ *and* $c>0$.
(ii) *There is a unique equilibrium price,* P, *which decreases in* β *but increases in* M.
(iii) *The sales probability* b *increases in* β *but decreases in* n.
(iv) *The cutting probability* c *decreases in* β *but grows when* n *becomes large, until it hits the upper boundary* $c=1$.
(v) *If* M *increases or* V *decreases, then* b *is unchanged but* c *increases until c=1; and, as* M *continues to grow or* V *continues to decline,* c *stays equal to 1 and* b *decreases.*

6. Conclusions

Conservation goods are special. The buyer does not want to pay the seller unless he thinks she will consume the good. The seller does not want to consume if she thinks the buyer is going to buy. In a dynamic model, the equilibrium is in mixed strategy and the outcome is inefficient. The rental market may not perform better than the sales market but, 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, it is worse with multiple potential buyers. If the buyers are heterogeneous, the results predict that, perversely, the most likely renter (or buyer) is going to have a relatively low value of conservation (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.

In order 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 puzzling nature of conservation markets.

7. Appendix: Proofs

In the proofs below, I have allowed for a cost, $k_i \geq 0$, when buyer i decides to contact the seller. With only one buyer, this cost is k. For most of the results above, simply set $k_i = k = 0$.

Proof of Proposition 1. Let P denote the equilibrium price, b the probability that B meets 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:

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

Since $c \in [0,1]$, U_B must be between $-V$ and 0. Thus, B never buys if $P+G_B+k > V$. Hence, for such a large P, S will always cut. Similarly, since $b \in [0,1]$, U_S must be between $M+G_S$ and $P+G_S$. Thus, S always cuts if $M+G_S > \delta(P+G_S)$, implying $P < M/\delta + G_S(1/\delta - 1)$ and, then, B always buys if $V > M/\delta + G_B + k$, since then $V > P+G_B+k$. If $P \in [M/\delta + G_S(1/\delta-1), V - G_B - k]$, $U_B(0,c) = U_B(1,c)$ for some $c \in [0,1]$ and $U_S(b,0) = U_S(b,1)$ for some $b \in [0,1]$. It is easy to see that these equalities are satisfied for b and c, as described in Proposition 1, making both players willing to randomize. For a larger (smaller) c, B always (never) buys and S would strictly prefer to never (always) cut; a contradiction. For a larger (smaller) b, S would prefer to never (always) cut and B would therefore strictly prefer to never (always) buy; a contradition. Therefore, for every $P \in [M/\delta + G_S(1/\delta - 1), V - G_B - k)$, the b and c described by Proposition 1 is a unique equilibrium. For $P = V - G_B - k$, there is in addition equilibria where B buys with a smaller probability: Any $b \in [0, (M+G_S)(1-\delta)/\delta(V - G_B - M)]$ is then part of an equilibrium.

Regarding the equilibrium price, suppose B and S believes the equlibrium price is $P \in [M/\delta, V - G_B - k]$. If B contacts S, he is indifferent to buy at P, and S cannot charge a higher P. S thus charges P, confirming that this is indeed an equilibrium. Note that a low price, $P < M/\delta + G_S(1/\delta - 1)$, cannot be an equilibrium since, if it were, S would cut for sure at her decision node, and under this threat S could demand as much as $V - G_B$. A high price, $P > V - G_B$, cannot be an equilibrim since then B would reject. $P \in (V - G_B, V - G_B + k]$ is a possible equilibrium price but B is then never contacting S. *QED*

Proof of Proposition 2. The proof is analoguous to the proof of Proposition 1. 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, $U_S > M+G_S$ 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 2. 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 (that would be rejected by B) and S asks for exactly p, confirming that every such price is an equilibrium. *QED*

Proof of Proposition 3. The proof follows from the text and the earlier propositions.

Proof of Proposition 4. 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:

$$P + G_B + k \leq (p+k)/(1-\delta). \tag{7.1}$$

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

$$P + G_S \geq p + \delta U_S^r = p + M + G_S. \tag{7.2}$$

(i) Consider an equilibrium P. A p exists violating both (7.1) and (7.2) if (3.1) 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 (7.1) and (7.2) if (3.2) 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 (7.1) and (7.2) coincide with (3.3). *QED*

Proof of Proposition 5. The proof is similar to the reasoning in the text and thus omitted.

Proof of Proposition 6. The proposition follows from Proposition 7 when setting $n = 1$.

Proofs of Propositions 7 and 8. The proofs allow for heterogeneous values and prices.

The sales market: The aggregate b and expected P making S willing to randomize follows from:

$$\begin{aligned} M+G_S &= \int_0^\infty e^{-t\left(r+\sum_i b_i+c\right)}\left(\sum_i b_i P_i\right)dt = \frac{\sum_i b_i P_i}{r+\sum_i b_i} \Rightarrow \\ b=\sum_i b_i &= \frac{r\left(M+G_S\right)}{\sum_i b_i P_i/b-\left(M+G_S\right)} \\ &= \frac{r\left(M+G_S\right)}{\mathrm{E}P-\left(M+G_S\right)}, \end{aligned} \tag{7.3}$$

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

Buyer i is willing to randomize when:

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

Setting $W_i=Z_i=k_i=0$, this becomes:

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

Since $b_i=b-\sum_{j\neq i} b_j$ and b is given by (7.3), 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:

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

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

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

If $W_i = Z_i = k_i = 0$, 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: Buyer i's benefit is the same for all p', T' such that U_i is the same:

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

While S prefers sale if and only if:

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

Ensuring that B is (just) willing to accept, this implies:

$$\begin{aligned} P_i + G_S &\geq \left(1 - e^{-rT}\right) \left(P_i + G_i + k_i\right) - k_i + e^{-rT} \left(M + G_S\right) \Rightarrow \\ P_i e^{-rT} &\geq \left(1 - e^{-rT}\right) G_i - e^{-rT} k_i - \left(1 - e^{-rT}\right) G_S + e^{-rT} M \Rightarrow \\ P_i + k_i - M &\geq \left(1/e^{-rT} - 1\right) \left(G_i - G_S\right). \end{aligned} \tag{7.4}$$

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

$$\begin{aligned} &\frac{p_i + k_i}{1 - e^{-rT}} - G_i - k_i + G_S \geq p_i + e^{-rT} \left(M + G_S\right) \Rightarrow \\ &\qquad \left(p_i + k_i\right) e^{-rT} \geq \left(1 - e^{-rT}\right) \left(G_i - G_S\right) + e^{-rT} \left(1 - e^{-rT}\right) \left(M + G_S\right) \Rightarrow \\ &\qquad\qquad \frac{p_i + k_i}{1 - e^{-rT}} \geq \left(G_i - G_S\right) / e^{-rT} + \left(M + G_S\right). \end{aligned} \tag{7.5}$$

If S sets the price, (7.4) becomes $V_i - G_i + k_i - M \geq \left(1/e^{-rT} - 1\right) \left(G_i - G_S\right)$ while (7.5) becomes $V_i \geq \left(G_i - G_S\right) / e^{-rT} + \left(M + G_S\right)$, which are both identical to (4.3) when $k_i = 0$ and buyers are identical. *QED*

Proof of Proposition 9. The proposition follows directly from the equilibrium payoffs, since each buyer is willing to randomize and get the payoff $-P_i + W_i - Z_i - G_i$, if buying, and $p_i / \left(1 - \delta\right) + W_i - Z_i$, if renting. *QED*

Proof of Proposition 10. Set $W_i = Z_i = 0$. Consider the sales market and suppose, first, that P is given. In the decentralized equilibrium, where each buyer buys with some probability, every i's payoff is $-P - G_B$. If, instead, it is well defined that only one player purchases, then, following Proposition 7, b remains constant while c declines. This is clearly *increasing* the buyers' aggregate payoff. Furthermore, if the buyers act as one, then there is still only a single buyer, but this buyer's valuation increases. Following Proposition 1, c declines, which clearly is further *increasing* total welfare (since b stays the same).

If S can announce the equilibrium price, however, a single buyer (e.g., consisting of all the countries) receives the same payoff as if the good is cut with probability one. In the asymmetric equilibrium, the buyers that have committed not to buy receives a higher payoff that $-V_i$ since, with a positive probability, the single remaining buyer purchases and conserves the good. Thus, when S sets the price, the asymmetric equilibrium leads to a larger aggregate payoff for the buyers than does the asymmetric equilibrium.

The reasoning for the rental market is analoguous and thus omitted. *QED*

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