Designing Payments for Avoided Deforestation under capital constraint

- A Framed Lab-in the-Field Experiment[1]

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Abstract

Tropical deforestation is among the biggest environmental problems of the 21st century. Under the UN mechanism for reducing emissions from deforestation (REDD+), substantial amounts of new finance for tropical forest conservation are expected to become available. Conditional payments for ecosystem services (PES) promise an efficient way to achieve forest conservation goals.

We designed a simulation game to model the economic decision situation of a typical cattle ranch in the Brazilian deforestation hotspot Tocantins, using realistic values for all parameters. The game features the option to deforest, the choice between extensive and intensive pasture use and a capital constraint. We used the game to conduct a framed lab-in-the-field experiment with cattle related stakeholders on site.

The experiment introduced five different PES contracts as treatments in the computer game. These contracts were different combinations of two conditionality types and three different pricing schemes. Weakly conditional payments were designed to mimic payments per hectare of forest as practiced in some governmental PES schemes, while strongly conditional payments were designed to mimic REDD+ payments in the voluntary carbon market.

Weakly conditional payments were found to lead to a slow, but steady deforestation, while strongly conditional payments were found to suppress deforestation more effectively and efficiently. But on the other hand, weakly conditional payments increased agricultural output while strongly conditional payments had no effect on output. Payment modalities such as indexing payments to opportunity costs, fixed payment levels or volatile payments did not have a significantly different effect on deforestation in the experiment. Weakly conditional payments below the opportunity cost of extensive grazing were found to still suppress deforestation, showing that the opportunity cost concept needs to be adjusted when capital is constraint and land use options of different capital- and land-intensity are available.

[1] We would like to express our gratitude towards everybody who contributed to complete this work. The European FP7 project CiVi.net provided funding and logistic support. The following people provided decisive support for the planning and executing of the project: Stefano Merlin, Divaldo Rezende, Peterson Sacconi, Rubens Ribeiro da Silva, Corombert Leão de Oliveira, Ofra Bosma and Elisabeth Gsottbauer. Additionally, we would like to thank Nicolaj van der Meulen and Danilo Wanner of The Basel School of Design for supporting us as reflective practitioners with their expertise in game design.

We conclude that strongly conditional payments are likely to be more effective and efficient in suppressing local deforestation than weakly conditional payments under the circumstances given in Tocantins. While our results are clear for local deforestation, the effect of global CO_2 emissions remains ambiguous, as the global effect also depends on the size of the positive spill-over effects on other regions through market leakage caused by an increase in production under the per hectare payments.

Despite the ambiguity, our results indicate that research into variations of conditionality in payment contract design has higher policy relevance than research on pricing modalities.

1 - Introduction

Tropical deforestation and forest degradation are responsible for 15 – 20% of the annual global greenhouse gas emissions. Brazil is the country with the largest national forest related emissions globally (FAO, 2006). Commercial agriculture is the single largest driver of deforestation globally, and in particular in Latin America where it is responsible for 68% of all deforestation (Hosonuma et al, 2012). In Brazil, 74% of newly deforested land is used for extensive cattle ranching (Wassenaar et al. 2007). These facts combined make commercial cattle ranching in Brazil the single largest cause of deforestation globally, when differentiating by country and land-use type. At the same time, Brazil has more than 80 million ha of extensively used pasture available that could be sustainably intensified to produce at least three times more cattle than today (EMBRAPA, 2013).

Reducing emissions from deforestation is the main goal of the United Nations Framework Convention on Climate Change (UNFCCC) mechanism "REDD+".[2] REDD+ is based on conditional cash transfers, i.e. buyer governments make a commitment to pay seller governments based on monitored forest carbon stocks. The funding from such government-to-government payments can inter alia be used to finance payments to landholders. Payments for Ecosystem Services (PES) to landholders for avoided carbon emissions are considered an important tool to halt tropical deforestation (Engel et al, 2008; Jack et al, 2008; Wunder, 2009; Angelsen 2010, Farley & Costanza, 2010; Pattanayak et al, 2010; Palmer 2011; Wünscher & Engel, 2012). Uncertainty about future commodity prices lead to concerns about changing incentives over time and potential reversal of emission reductions achieved through such payments (Engel et al, 2013; MacKenzie et al, 2012). If the future the non-use value of forests is rising but uncertain, while agricultural returns are certain, Bulte et al. (2002) claim that rates of deforestation can be excessive. Uncertainty over agricultural returns might alter this result (see e.g. Zinkhan, 1991). On the other hand, Schatzki (2003) claim that it can be optimal for landowners to delay deforestation when deforestation costs are sunk and the returns from agriculture are uncertain. The situation is further complicated when taking into account the fact that the decision to deforest is irreversible and risk preferences unknown (Engel et al, 2013).

As the results from abstracts models are rather inconclusive on the issue, we found it reasonable to reduce the scope of the question by specification and base an inquiry into optimal PES design on a case study, involving local decision makers in model development and specifying contextual details.

[2] The official UNFCCC name of the mechanism in its full length and beauty is: "Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries"

This study is based in Tocantins, Brazil and investigating the cattle ranching sector. In contrast to many other locations relevant for REDD+, in the case of Tocantins the property rights are well defined, law enforcement is fairly well established and there are few land title conflicts. Thus the common conclusion that REDD+ would work best through government capacity building and a market-based approach should be avoided does not apply in this case. Most arguments against market-based approaches are derived from the assumption of an incomplete property rights situation.[3]

Using an experimental game as model allows capturing otherwise unobservable behavioral properties of the decision makers such as uncertainty preferences or the use of heuristic decision rules. The method also allows using a rather complex model and an assessment of pre-equilibrium pathways. The specificity of the structure and parameters used in the model limits the generalizability of the results, but increases the validity of the results for the case study itself and situations with similar characteristics as the case study. Accordingly we expect our results to be valid for commercial cattle ranchers throughout the Brazilian "Arc of Deforestation", but not elsewhere and neither for small-scale ranchers.

Our experimental work contributes to the following research question: Assuming a willingness to pay for emission reductions from avoided deforestation - how should the payments be designed to achieve real and additional emission reductions from Brazilian cattle ranchers, accounting for price uncertainty and long time horizons?

2 - The Model

We model the decision situation of an individual cattle rancher using a simulation game. The game has the following properties:

Decision Space

- The model allows two types of pasture (extensive and intensive) and one type of (unproductive) forest.

- Decisions can be made every round for 46 rounds.

- Land-Use decision can be made individually for 64 cells.

- Extensive pasture degrades, with productivity halving after 8 years of grazing.

- All cells are equivalent except for the initial land-use, i.e. they generate the same marginal rate of return under the same land-use.

- The returns are uncertain, as the cow price changes every year according to a random walk model (see Annex III for details).

Decision Constrains

- Decisions have a cost and capital is constraint. The decision space is thus limited by the initial endowment and profit made over time.

- Land is constraint. The total amount of land is fixed to 64 cells and cannot be increased.

[3] See Vatn & Vedeld (2013) for an overview of the literature on the issue of market based versus governmental approaches to REDD+

- Land conversions are irreversible. Forest can be converted to extensive pasture and extensive pasture to intensive pasture. No other conversions are possible.

- There are no outside investment opportunities.

All values and the design of an appropriate decision space were based on a case study and a participatory process involving local cattle ranchers, politicians and agricultural universities in Tocantins, Brazil. The parameters are scaled so that a single cell in the game corresponds to 25 hectares of land. Details on the design process, a full, formal description of the simulation model and a link to an online version including the source code of the game are provided in Annex III.

The simulation game does not include a model of the decision maker. A human player is required to make all decisions. The following section describes the evolution of land use in the model without environmental payments, if played by an experienced player as reference. This is also the profit-optimizing strategy.

3 - Typical evolution of land use in the game without environmental payments

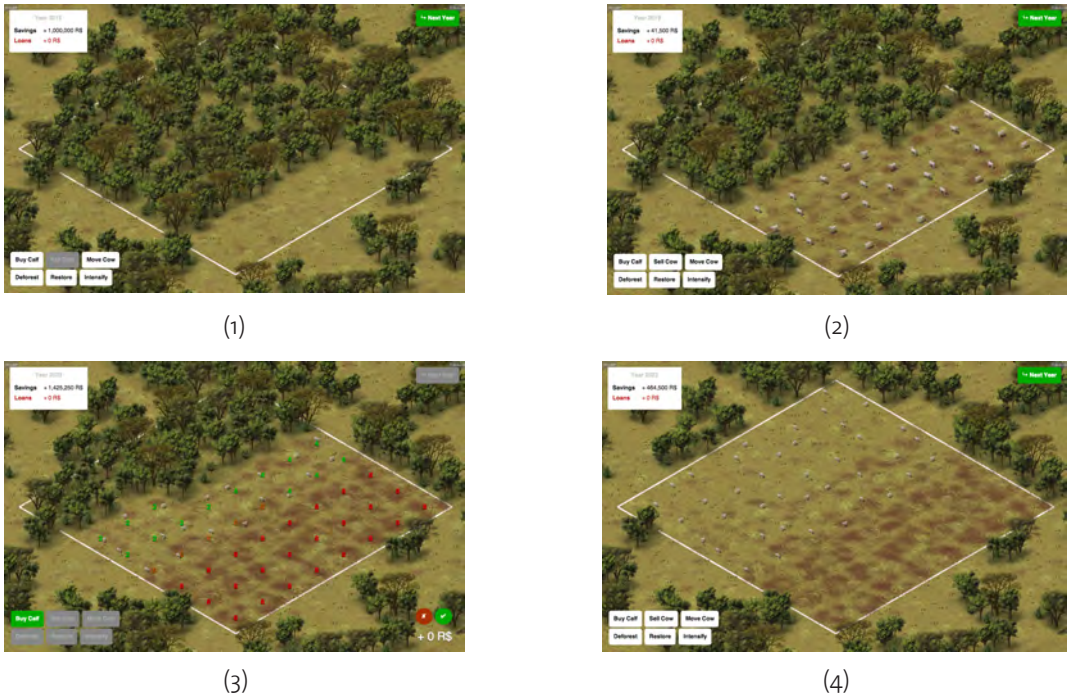
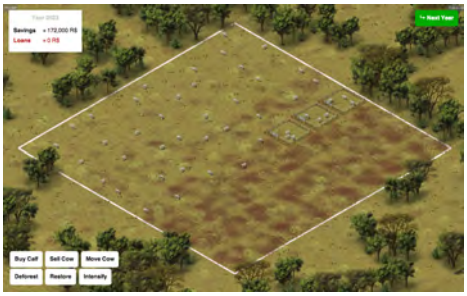


Figure 1 – Beginning of typical game evolution without payments

Figure 1, picture (1) shows the first round of the game. The land is initially 20% extensive pasture and 80% forest. The player can only use the square of land demarked by the white line. The most profitable strategy is to deforest and extensively utilize the pasture at the capital limit every round. Picture (2) shows the game in round four, when deforestation is ongoing. Picture (3) shows round 8, when degradation on the initially used area reaches a critical stage. The lowest three rows of land cannot be used in this round and need to regenerate, as indicated by the red “8” on the land. As the player does not purchase cattle on those cells, enough capital is available to deforest and stock the remaining land with cattle, as shown in picture (4). This is when the land constraint becomes binding.



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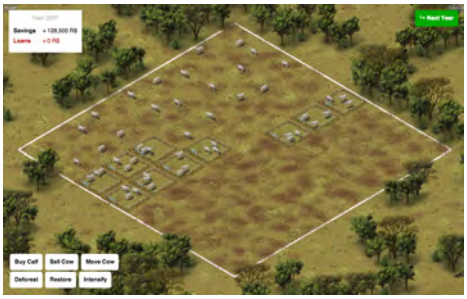


(6)

(7)

(8)

Figure 2 – further rounds of the game without payments

Figure 2, picture (5) is still in round eight. After stocking the remaining non-degraded extensive pasture, some capital is left. The only available investment opportunity is now intensification, as all forest is already removed. Picture (6) and (7) show the further development, as extensive and intensive grazing co-exist and all profit is re-invested into intensification. Picture (8) shows the final state of the game. In this stage no more investments are possible. This is the most profitable state of land use.

This is the rational solution to the game without environmental payments and the path most real players followed as shown in the results section. It can be achieved by following the decision rules described in Box I. Local stakeholders confirmed verbally that this evolution is the typical land-use development on the Brazilian forest frontier over the decades.

BOX 1

Heuristic solution to the game without environmental payments

A player can generate the evolution described above and get close to the maximum payoff in the game without environmental payments by following decision rules outlined here every year:

1) Sell all 2-year-old cows.

2) Reserve enough cash to cover the annual cost till the next sale of cows, but not more.

3) Buy 3 calves on all intensified cells.

4) Buy 1 calf on every cell with 6 or less degradation.

5) Use any excess cash to deforest and buy 1 calf per cell on the newly deforested cells.

6) If there is still cash left after the previous steps, and no more forest: Intensify cells of degradation 4 and buy three calves per intensified cell. Predict the amount of cash left two years later. Move cows away from degraded pasture cells to allow enough cells to regenerate to degradation 4, so all cash left in two years can be invested into intensification.

This heuristic is not explained to the players in the experiment.

Unreasonable Play

a) Players should never have zero cows on cells of 3 or less degradation.

b) Players should never have less than 3 cows on intensified cells.

c) Players should never have more money at the end of the year than needed to cover the annual cost till the next time they can sell 2-year old cows, unless all 64 cells are intensified and occupied by 3 cows.

d) Players should always sell cows after 2 years, not later or earlier.

e) Players should never have a cell of more than 8 points of degradation.

Players are trained in before starting the incentivized game to avoid unreasonable play. See Annex IV for details.

4 - Validity and limitations of the Model

The rational of using a game is based on the scientific principle to model those processes that are well understood but use experimental data for those where sound understanding of the basic mechanisms is missing. Thus the prices, land-use technologies and ecological pasture parameters are modeled, while human decision making under uncertainty is investigated experimentally within the simulation. Our data for prices and farm parameters is rather detailed and reliable (see Annex III). We also sampled the participants in the experiment from the same population who is responsible for the real-world decisions that our model represents. While we cannot guarantee that decision behavior in the game is predictive for real-world behavior, we can ensure that any such potential differences are not due to sampling mistakes.

A key to realism of the game is the level of the capital constraint. Ranchers in Tocantins can take up to 60% of the value of their land in subsidized, quasi-zero interest loans from government banks.[4] For a farm of the size modeled in the game this is approximately equal to the initial endowment of 1'000'000 R$ (2 R$ =~ 1 USD). Obviously, real land values vary depending on location and soil properties. The simulated farm is roughly representing the average farm in Tocantins.[5]

The model has the following important limitations:[6]

- Land speculation was mentioned several times by stakeholders as an important factor to consider. We found it too complex to include land markets that could give rise to speculation in the model, as this would have required interaction between many buyers and sellers.

- The costs for monitoring, reporting and verification (MRV) required for REDD+ are not considered. Here we assume that the buyer or an intermediary carries those costs, as this model to finance MRV was successfully used for the first carbon-financed projects in forest protection in Tocantins.

- Illegal deforestation is not part of the model. We assume complete monitoring and enforcement of the environmental legislation, in particular the legal reserve requirement of the Brazilian Forest Code.[7] In the real world, even though regulations are very well enforced in Tocantins, actual enforcement is less than 100%.

- Our model is unable to elicit incentivized pure time preferences for the long timespans involved. As the game-time horizon of 46 years spans more than one generation, it is likely that there are non-linearities in the real world time preferences not captured in the model.

- The game does not feature disruptive events. This may cause a distortion, as livestock is known to be kept also for its function as asset value, coined "Live Stock" by Siegmund-Schultze, et al. (2011). The asset function of livestock is not relevant in the

[4] The nominal interest rate is around 6%, slightly below the inflation rate.
[5] As data on both land prices and farm sizes is not very precise, we used rounded values in the mean of the range provided by Banco di Amazonia.
[6] Despite the common claim that a models quality should not be judged by its assumptions but the predictions it makes (Friedman, 1953), we consider the limitations implied in the assumptions highly relevant for our study. This is due to our problem to fulfill the second part of Friedman's claim: Our model aims to make a prediction for a unique case study over the course of several decades, including predictions for several mutually exclusive future development paths. It thus cannot be evaluated empirically based only on the quality of the predictions it makes. Some of the conditions for which it makes predictions will never realize, and for those that do, the sample size is too small for a thorough empirical evaluation.
[7] The forest code requires landowners to keep a minimum of 35% of their land in forest in the Cerrado region of Brazil. Only forests beyond this legally required minimum could be eligible for payments.

game, as we do not introduce hyperinflation, bank runs, civil war, extreme price shocks or similar events that can make other assets risky. Such events are rather likely to occur in the real world over the 46-year timespan modeled. The asset value of livestock can make overgrazing a rational choice (Costa & Rehman, 2005).

- While creating a substantially stronger virtual reality than experiments using a so-called "neutral" frame (Wanner, 2013), we still expect the correlation between game and real-world behavior to be far from perfect.[8]

- The game does not include all technologies for land intensification. In particular more capital-intensive agriculture with a high per hectare return such as soy or eucalyptus are excluded from the model. This feature could be added to future versions of the game.

- There is also no reforestation in the model. While many ranchers and local officials would have been interested in this option, it is not viable under REDD+, as the Cerrado forest dominant in Tocantins requires >20 years to fully regenerate its carbon stock. Additionally, carbon payments for A/R generally exclude areas which were deforested less than 20 years ago and thus most of the area in Tocantins.

[8] See e.g. Haruvy (2011) for a more detailed analysis of the methodological aspects of using computer game simulations and virtual realities for economic experiments.

5 - Experimental Setup and Sample

The experiment was implemented in three phases: Training, baseline phase and treatment phase. At the beginning of each phase the game was re-set to the initial conditions. Randomization was applied in the treatment phase only, while all previous phases were equal for all players. The cattle price development was different across phases, but the same in each phase for all players and treatments. Baseline phase and treatment phase were incentivized, while the training phase was not. The Baseline phase was played for 26 rounds, the treatment phase for 46 rounds.[9]

The compensation paid to the subjects was proportional to the profit made in the game. It was calculated as the sum of savings and land value at the end of the baseline phase plus the sum of savings and land value at the end of the treatment phase. The baseline phase was shorter than the treatment phase, thus 80% of the maximum payoff could be made in the treatment phase. We used an "exchange rate" of 2 R$ (approximately 1 USD) real money for 1'000'000 R$ of in-game money in the two incentivized phases (baseline phase and treatment phase). The players could earn up to 115 R$ in the game and received a minimum reward of 30 R$ if they made less.[10] This rather high value was chosen as the most important stakeholders are large ranch owners who are the wealthiest individuals in the region and a lower incentive would not have been taken seriously and potentially considered insulting. Even at 110 R$ the larger ranchers considered the reward as only of symbolic meaning. Each session took between 90 and 180 minutes in total. Most players remained engaged and interested for this rather long time period, which we attribute to the "immersion" in the sense of Brown and Cairns (2004) induced by the game form of the experiment.

Ten players were gathered in one room for every session, each equipped with a 10.1-inch tablet computer and a set of earphones. As all players played with earphones, including background music and sound effects of the game, verbal communication was difficult and rarely observed during the game. While it was found a cultural impossibility to prohibit all communication among the players especially at the beginning of the sessions, it was made sure that there was no talking during the Baseline- and Treatment Phase of the game.

Once all players had arrived, a short introductory presentation was given by the experimenters, explaining the purpose of the game and the relevance of the subject for the participants. After this the participants filled out a very short socio-economic survey and the rules of the game were communicated in private via a video on the tablets. Additionally, each subject had two A4 pages with instructions, repeating the content of the video.

The video was followed by the Training Phase, in which the players could re-start the game any time and ask questions. The Training Phase was interrupted three times for further explanations of the functioning of the game (See Annex IV for the protocol).

The training phase was followed by the (incentivized) Baseline Phase without payments. The baseline phase was played for 26 rounds. After the Baseline Phase, a treatment was randomly assigned and introduced by a treatment video. Additionally, a treatment manual was handed to the player and discussed one on one with the experimenters. The treatment phase was played for 46 rounds.

[9] We had to make a compromise here. A longer baseline phase would have been preferable, but was not considered feasible given that some players already took three hours to complete the experiment as it is.

[10] The monthly minimum wage in Brazil is 675 R$, but a salary of 10R$ per hour is considered normal for student jobs in Palmas, the capital of Tocantins. Ranchers make substantially more than the minimum wage.

After the treatment phase, the players' final outcome was calculated and paid out in cash by the experimenter.

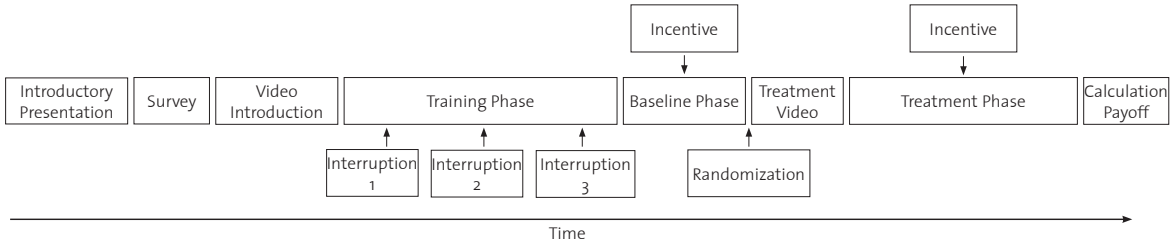


Figure 3: Timeline of each experimental session

The sample of players consisted of three types of participants: 42 ranch owners and 304 local students of land use related subjects (Agriculture, Environmental Studies and Forestry) of whom 109 were ranch owners' family members. While a sample of 100% ranch owners would have been preferable to improve external validity, logistic constraints did not allow such an ideal situation. We did not find significant differences in player behavior between the different player types and thus analyze them jointly. See Annex I for randomization tests and tests for differences between player types.

6 - The Treatments

All treatments have in common that an additional payment is added to the simulation. It should be noted that none of the payments is high enough to be more lucrative than the profit made from a fully deforested and intensified ranch. Thus, without capital constraint, players could optimize their profit by deforesting and intensifying the whole ranch in the first round in all treatments, similar to the final round of the control as described in picture 8 of figure 2 on page 5. The treatments can generate differences in the temporal evolution of the land use pattern due to the capital constraint but are expected to lead to the same equilibrium state after sufficient time to accumulate capital.

We tested five different payment designs that differ in pricing and conditionality of the payments on deforestation. All treatments except for treatment five give payments for 25 rounds and then continue for another 21 rounds without payments.[11] Treatment five has continuous payments over the entire period. The conditionality types are designed to mimic existing, real world PES contracts, namely the governmental PES schemes in Costa Rica and Ecuador (weak conditionality) and the REDD+ schemes in the voluntary carbon market using the Verified Carbon Standard (VCS), (strong conditionality).[12]

6.2 - Strong Conditionality

Treatment one and two use strong conditionality. Strong conditionality is mimicking a carbon market were emission reductions are a tradable commodity and accounted for in carbon budgets. It is implemented the following way:

[11] In pre-testing, most players reached the equilibrium state of full deforestation and intensification in less then 10 rounds after the end of the payments. We chose to use 21 rounds as a compromise between allowing less skilled players to reach equilibrium and the game getting boring for players who play well. The total number of years was chosen as an even number as cattle is sold every two years.

[12] The VCS is a standard used for carbon accounting in the voluntary carbon market. It provides a mechanism to calculate, monitor and verify carbon emission reductions from individual REDD+ projects and is applied in a number of REDD+ pilot projects. More information can be found at http://www.v-c-s.org

The player has a baseline carbon budget. This is given exogenously and equal for all players. We define the baseline carbon budget based on the deforestation of a rational player without payments and the rules for baseline setting of the VCS. As shown in section 3, a rational player would deforest the entire area until round 8 and increase the speed of deforestation over time. A baseline with increasing deforestation rate over time is called "back-loaded". According to the rules of the VCS, the baseline is stretched over 25 years to give a more permanent conservation incentive. This "stretching" common practice in baseline determination under the VCS. Additionally, the baseline is smoothened to avoid discontinuities in the payments. See Annex III for the exact numbers used in the game and more details.

The baseline carbon budget is visualized by the blue line in figure 4. A player's actual carbon budget (black) is the sum of all emission reductions sold and all emissions in tons of CO_2. If her actual carbon budget stays below the baseline carbon budget (blue) in one round, she automatically sells the difference and receives a payment proportional to the difference, marked in green as "Carbon Sold". The black, horizontal line demarks passing of one round.

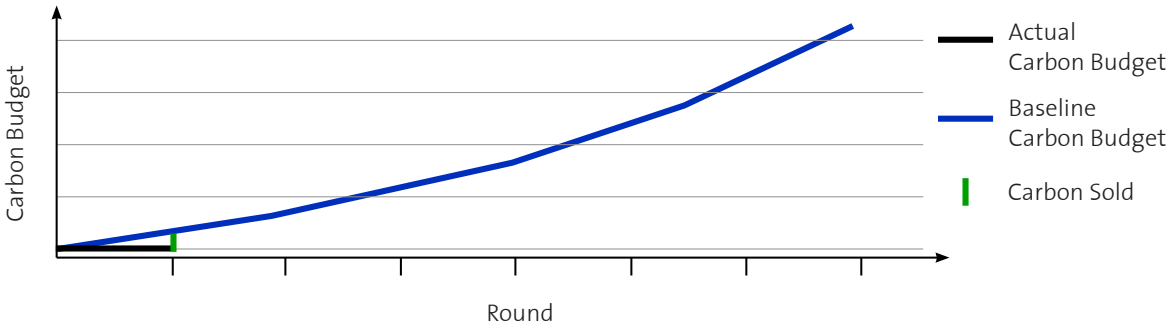


Figure 4 – Carbon Budget without deforestation (1)

Once paid for, the emissions are no longer on her budget. In the next year, again the difference between the baseline carbon budget and the actual carbon budget is paid for. The difference exists because the baseline carbon budget increases every year.

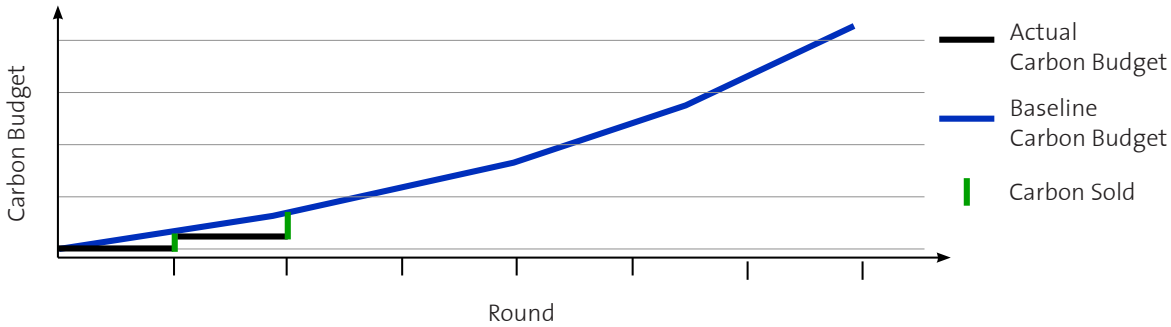


Figure 5 – Carbon Budget without deforestation (2)

Emissions from deforestation are accounted for by increasing the actual carbon budget. Accordingly, in the year after deforestation, the payment is reduced. Emissions are marked in red in Figure 6.

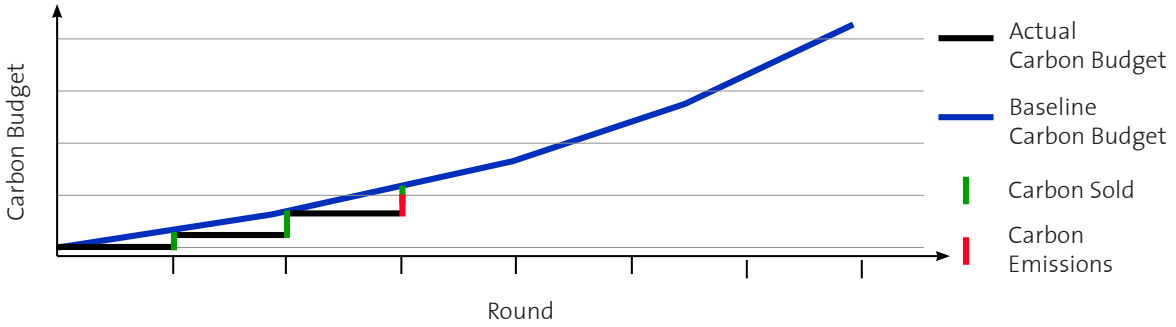


Figure 6 – Carbon Budget with one cell of deforestation

If a player deforests several cells in one year, so that her actual carbon budget is higher than the baseline carbon budget, the payments are zero until the baseline carbon budget catches up with the actual carbon budget. Once the baseline has caught up with the actual carbon budget, the payments continue regularly.

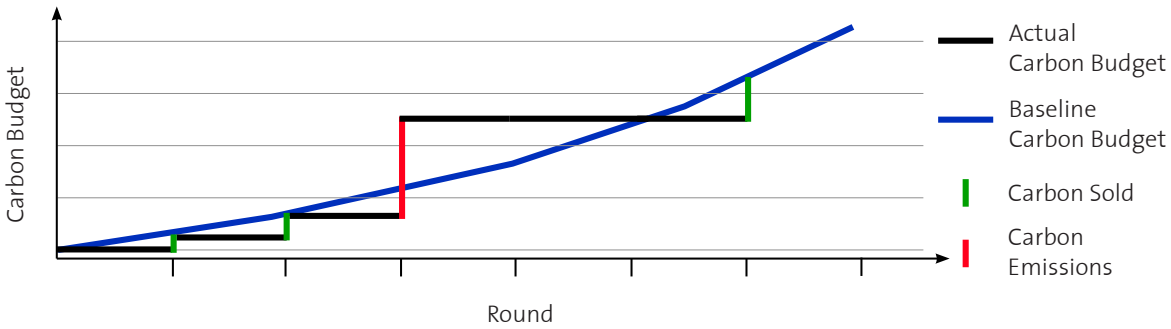


Figure 7 – Carbon Budget with several cells of deforestation

We call this "strong conditionality", as the punishment (=reduction in payments) for deforestation is concentrated in the very next payments. Deforestation of a single cell leads to a significant reduction in income in the next round.

In treatment one, from here on called "carbon volatile", the price paid for carbon emission reductions is volatile and the player uncertain about the future price. We used the historic volatility of the Clean Development Mechanism (CDM) carbon credit price to calibrate a price trajectory. Figure 8 shows the carbon price over time used in treatment one. The carbon price trajectory is not correlated to cattle price trajectory.

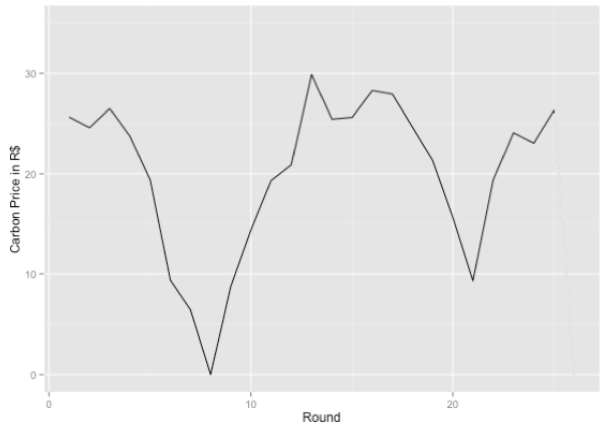


Figure 8 – Carbon price trajectory in Treatment 1

In treatment two, from here on called "carbon fixed" the carbon price is constant at 20 R$ per ton. This is well in the range of what would be expected for the price of CO_2 and the average price of Treatment 1. Fixed price, long-term off-take agreements have sometimes been granted by government buyers under the CDM. As one cell was set to represent a forest with a carbon stock of 5'000 tons of CO_2, the reduction in payments for deforesting one cell at a price of 20 R$ is 100'000 R$.

6.2 - Weak Conditionality

Treatments three, four and five are characterized by weak conditionality. We implement weak conditionality by defining the payment in a year as proportional to the amount of forest on the players land in the same year. We refer to this as "weak conditionality" as the punishment (=reduction in payments) for deforestation is only small for the very next payments.

In treatment three, from here on called "per hectare fixed", the players receive a fixed amount of 4'000 R$ for each cell of forest on their ranch. Thus, deforesting one cell in the first round reduces the total subsidies by 100'000 R$ over the remaining 25 rounds. Wunder et al. (2008) found that fixed per hectare payments are the most common type of PES contract globally in a review of PES schemes around the world.

In treatment four, from here on called "per hectare indexed", the payment is indexed to the cow price. The initial value is set to 4'000 R$ for each cell of forest, but the price is adjusted to follow the cow price. In years of high cow price the payments are high, in years of low cow price the payments are low. Such a payment design has been suggested by Benítez et al (2006) and Angelsen and Dutschke (2008) to improve the permanence of emission reductions under PES and uncertain future opportunity costs.

Treatment five, from here on called "per hectare forever", is the only treatment in which payments do not end after 25 years. The idea behind this treatment is to use the funding available for conservation today as an investment in an international fund and pay only the interest to the landowners. A similar suggestion was made for the Yasuni ITT initiative in Ecuador and aims to keep a permanent incentive for conservation (Correa, 2007). To make it comparable to the other treatments, we calibrate the payments to have he same net present value as the other treatments, assuming a 3% discount rate. The rate is fixed accordingly at 2'100 R$ per cell.

6.3 – Comparing the Treatments

Table 1: Overview of the treatments

Treatment	Conditionality	Price Setting	Duration
T1 – Carbon Volatile	Strong, immediate	Volatile Price	25 years
T2 – Carbon Fixed		Fixed Price	25 years
T3 – Per Hectare Fixed	Weak, over time	Fixed Price	25 years
T4 – Per Hectare Indexed		Indexed Price	25 years
T5 – Per Hectare Forever		Fixed Price	Infinite
T6 – Control	Control	-	-

Figure 9 visualizes the difference between the strong and weak conditionality using an example. The graph shows the payment that a player would receive if she deforests one cell in round two, four cells in round four and ten cells in round ten for T2 (in blue) and T3 (in green) over the 25 rounds payment period. The semi-transparent lines indicate the maximum payment the player could have received without deforestation.

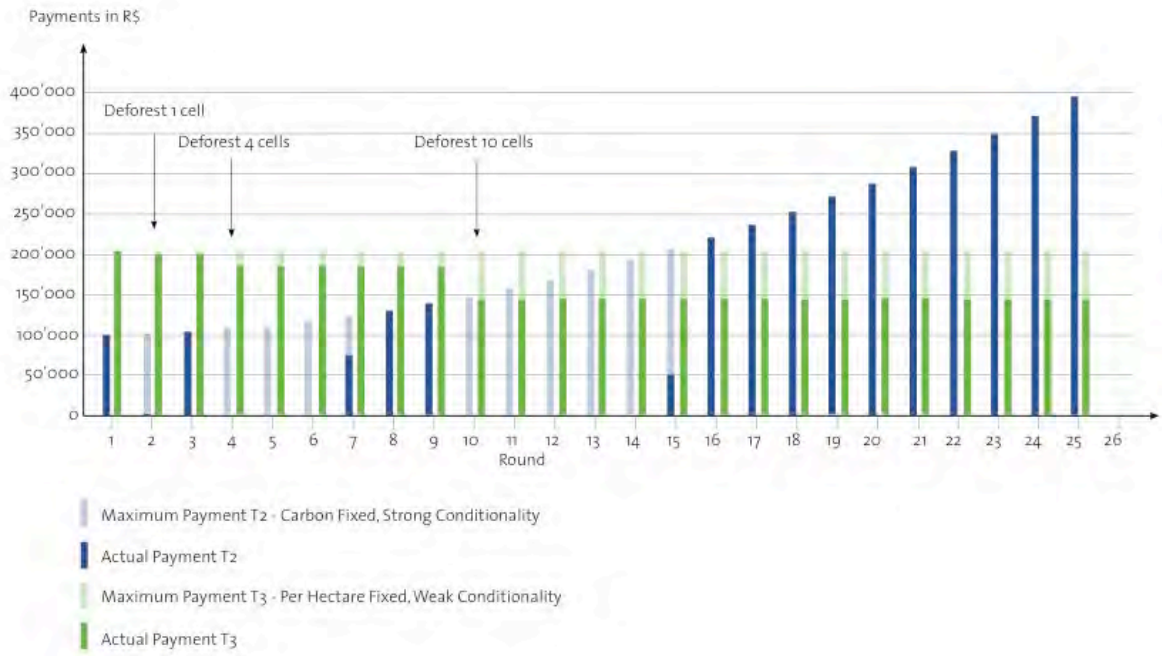


Figure 9 – Difference in Payments between treatment 2 and treatment 3 with the same deforestation events

Note that the sum of the maximum payments is equal for both treatments (5'100'000 R$), while the sum of the actual payments is smaller in T2 than in T3 (3'615'000 R$ in T2 versus 4'012'000 R$ in T3). This is due to the immediate punishment. The punishment for deforestation in round 10 in T3 would sum up to the same amount as the punishment in T2 only if summed up over 25 years. It is lower as only 15 years of payments remain, reaching 60'000 R$ at the end of the payment period, instead of the 100'000 R$ per cell reduction in the next rounds in T2.

7 - Results

All players went through the exact same training and baseline phase, thus the players were still in a ceteris paribus condition except for the type of payment in the treatment phase. Accordingly, any significant outcome difference between the treatment groups can be identified as causally induced by the differences in the payment conditions during the treatment phase. Assignment to the treatments was random.[13]

We considered excluding players with low total payoff from the analysis but decided against this option, because choosing a threshold for exclusion would have added an arbitrary degree of freedom to the analysis. It could rightly be argued that players with low payoff did not fully understand the game and thus should not be analyzed. On the other hand, it could also be argued that including all players increases realism, as there are ranchers going bankrupt in the real world, so not everybody understands perfectly well how to play the "real-world game" either. All trends reported below are robust and hold also if players with payoff less than 30 (or 50) Reais out of the maximum of 115 are excluded.

7 – 1 Descriptive Results

Particular attention is paid to the outcome in round 25, which is the last year of payments in T1-T4. After round 25 the incentives in T1-T4 and T6 are the same again. Round 47 is the last round of the game. Table 2 shows descriptive statistics for the key variables in those rounds.

Table 2, Overview of the means of key variables per treatment. "Deforested", "Intensified" and "Cows Sold" are cumulative values. The unit of "Deforested" and "Intensified" is cells (out of a maximum of 51 for deforested respectively 64 for intensified). The unit of "Cows Sold" is in animal units. Standard Errors in brackets.

Treatment	Defor-ested in round 25	Defor-ested in round 47	Intensi-fied in round 25	Intensi-fied in round 47	Cows Sold in round 25	Cows Sold in round 47	Savings in round 25 in 1'000 R$	Total in-game PES Payment in 1'000 R$	Final Payoff to subject in R$
Carbon Volatile	18.5 (1.7)	43.7 (1.9)	19.1 (2.0)	43.0 (3.3)	388 (26)	1'631 (108)	3'000 (230)	3'480 (180)	61.3 (3.2)
Carbon Fixed	17.3 (1.7)	37.7 (2.3)	18.0 (2.0)	38.2 (3.6)	363 (28)	1'445 (121)	2'760 (210)	3'420 (160)	53.8 (3.6)
Per Hectare Fixed	25.6 (2.5)	41.8 (2.0)	25.4 (3.2)	40.7 (3.3)	532 (51)	1'689 (146)	3'170 (240)	3'570 (170)	57.8 (4.0)
Per Hectare Indexed	29.1 (2.3)	41.8 (1.9)	25.1 (3.0)	38.7 (3.4)	556 (44)	1'747 (134)	3'200 (230)	3'410 (140)	61.3 (3.6)
Per Hecate Forever	25.2 (2.1)	36.0 (2.2)	25.7 (2.4)	39.0 (3.2)	512 (35)	1'679 (123)	1'590 (150)	2'800 (160)	57.8 (3.5)
Control	36.9 (1.9)	45.0 (1.6)	11.5 (1.4)	36.0 (3.7)	365 (18)	1'293 (98)	410 (80)	0	52.1 (3.5)

[13] See Annex I for a confirmation of the successful randomization over the treatments. The analysis is clustered at the individual player. As there was no interaction between the players, each observation is independent. Consecutive rounds played by the same player are not independent.

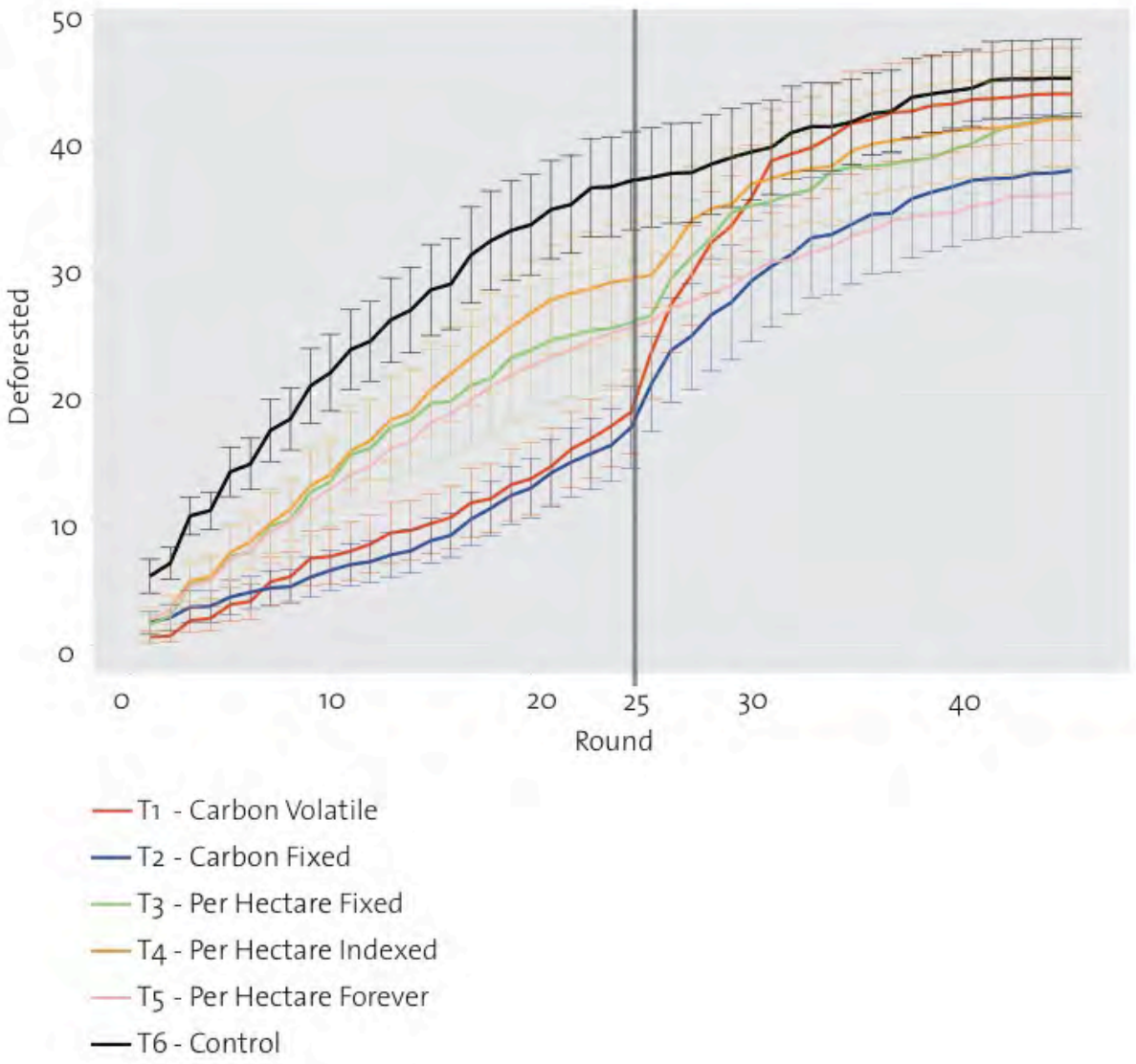


Figure 10: Average cumulative deforestation each round differentiated by treatment

Figure 10 shows the mean cumulative deforestation over time in each treatment. The error bars are standard errors clustered per round. After round 25 there is a rapid increase in deforestation in T1-T4 as expected due to the end of the payment in this round. The difference in cumulative deforestation in round 25 between control (T6) and all other treatments was found significant, but the difference within the same type of conditionality, namely between T1 and T2 and between T3, T4 and T5 are insignificant.

When comparing deforestation over all weakly conditional payments with all strongly conditional payments in round 25, the difference is highly significant ($p < 10^{-6}$). See Annex II for the analytic details and a pairwise comparison of means.

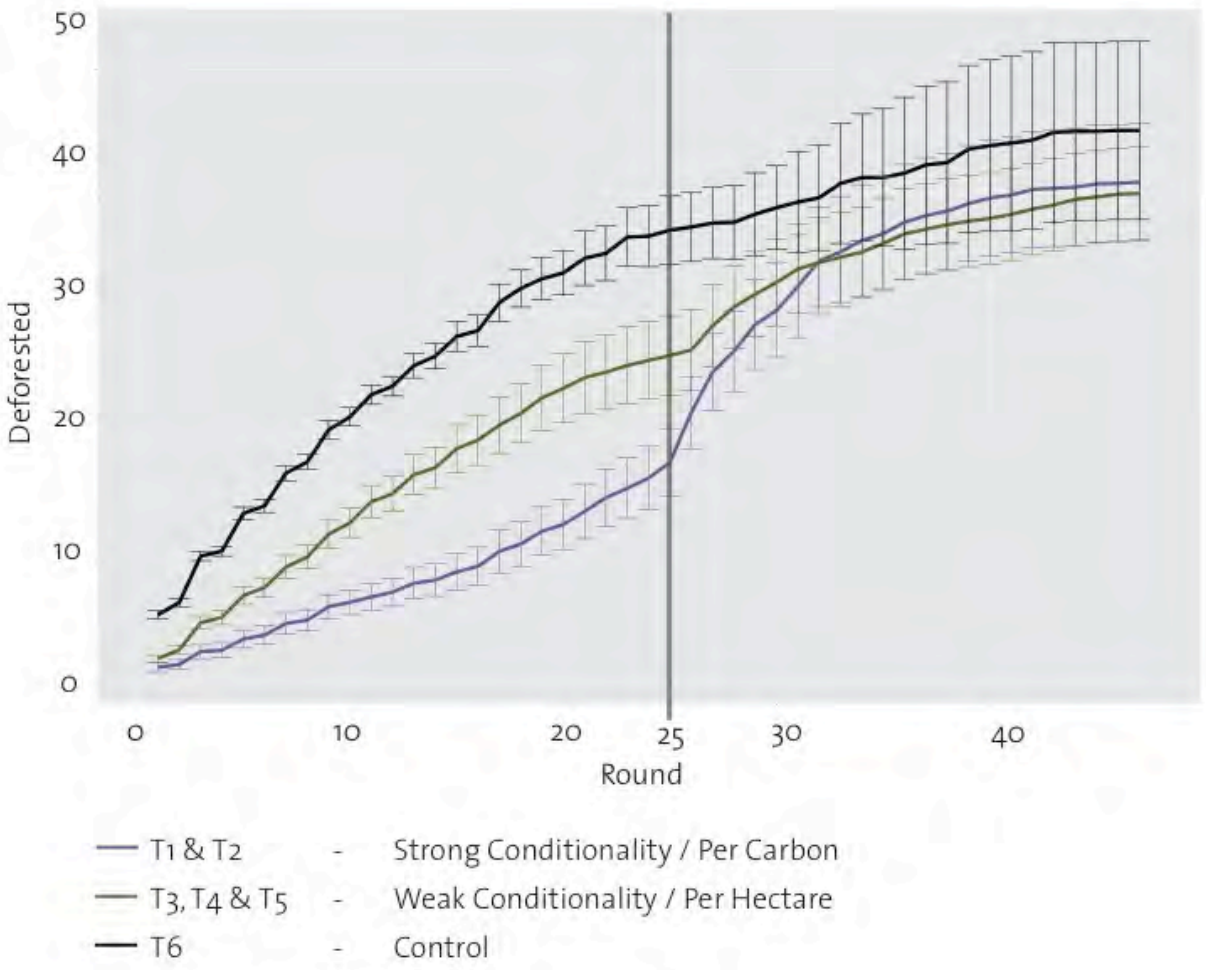


Figure 11: Average cumulative deforestation each round differentiated by treatment type

Figure 11 collapses the treatments with strong conditionality and those with weak conditionality. This illustrates the strong impact of conditionality, which was found to far outweigh the within-conditionality differences in pricing between the treatments. This holds not only for deforestation but also for the other variables such as intensification or number of cows sold (see below).

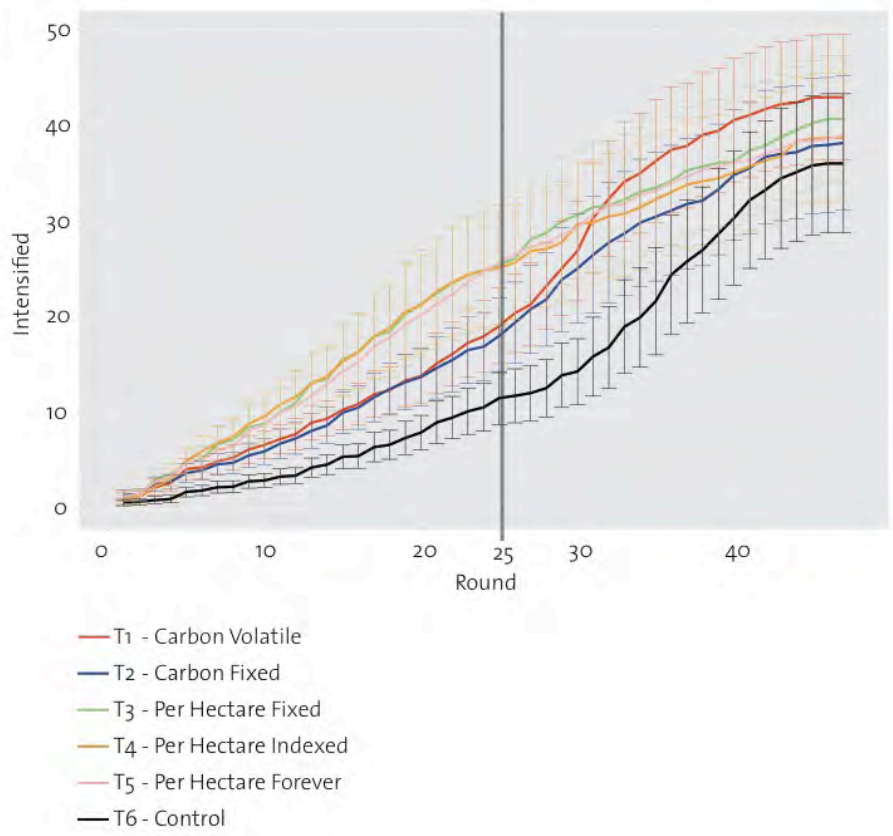


Figure 12: Average cumulative intensification each round for all treatments

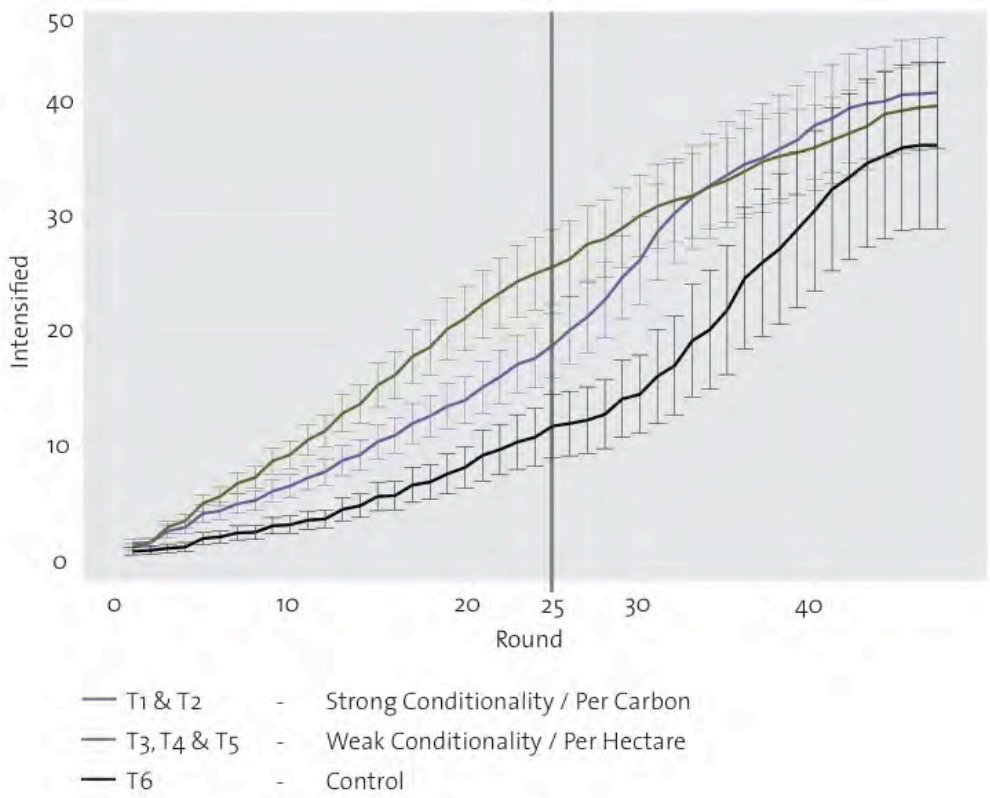


Figure 13: Average cumulative intensification each round for all treatments

As for deforestation, the results for intensification are very similar for all treatments of the same conditionality, but different between conditionality types as visible from figure 12 and 13. The highest rates of intensification are found in the weakly conditional treatments, followed by the strong conditional treatments. All treatments have significantly higher rates of intensification than the control prior to round 25. This can be explained by a tendency to intensify all available land with both weakly and strongly conditional payments, but an increased deforestation and thus more land available to intensify in the weakly conditional treatments. In the control T6 the intensification is significantly lower than in all other treatments in round 25 and starts to pick up only around round 30. As visible in Figure 10, this is also when deforestation starts to slow down, and can be explained by a majority of players in the control who do not have more land available to deforest from round 30.

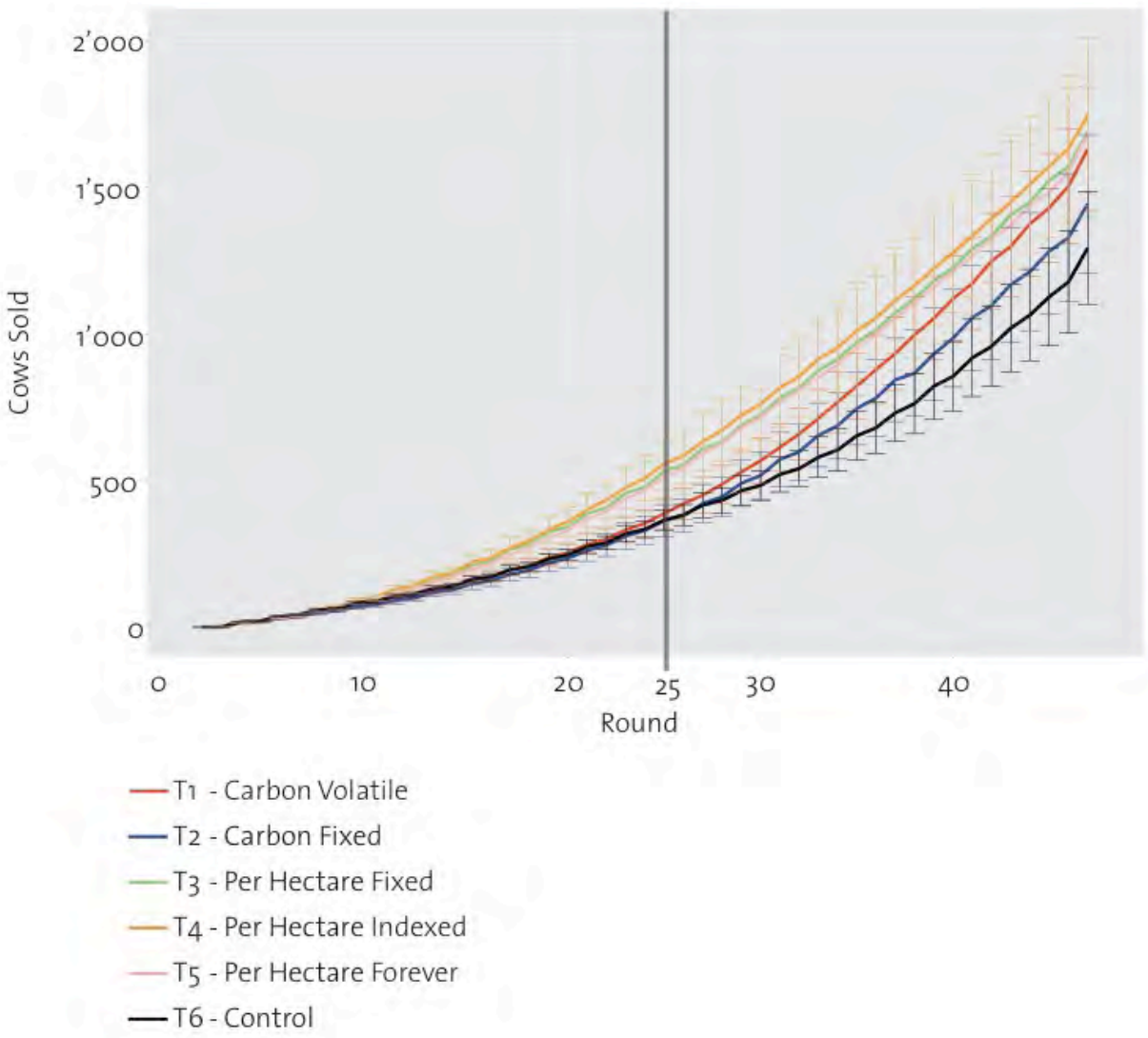


Figure 14: Average cumulative Cows Sold each round for all treatments

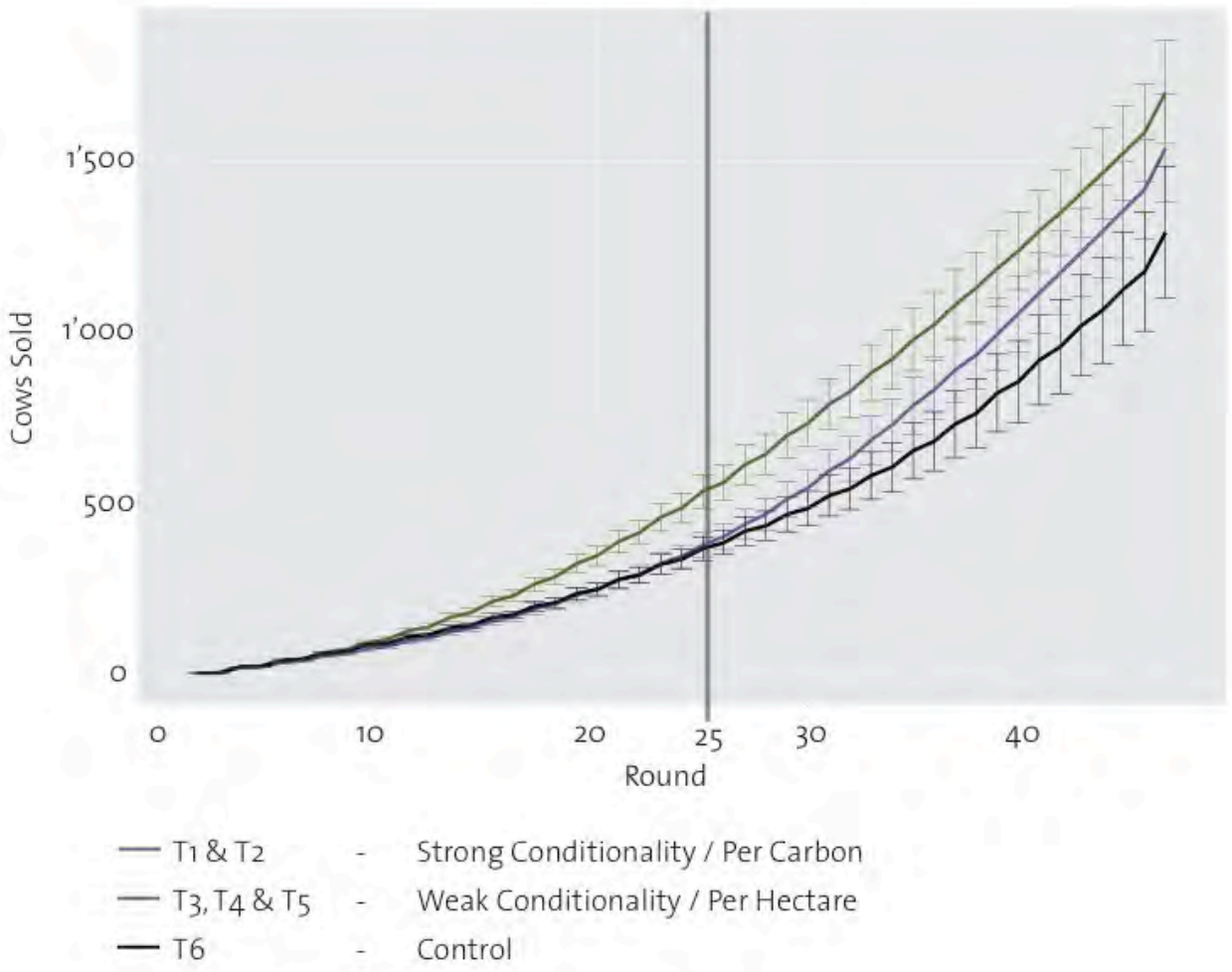


Figure 15: Average cumulative Cows Sold each round differentiated by treatment type

Figure 14 and 15 show the average cumulative number of cows sold in each treatment respectively type. Cattle production in the weakly conditional treatments is higher than in the strongly conditional treatments and also higher than in the control treatment This is in line with the finding of higher deforestation and intensification rates. Again, in round 25, there were no significant differences found between T1 and T2 or between T3, T4 and T5, but a highly significant difference when collapsing T1 and T2 (mean 376) and comparing it to the collapsed T3,T4 and T5 (mean 533). There is no significant difference between the cows sold in the strongly conditional treatments and the control (mean 365) in round 25.

Note that the absence of a significant difference in cattle production between the strongly conditional treatments and the control in the first 25 rounds is probably an artifact of the initial land settings in the game of 20% pasture and 80% forest. We would expect a different pattern for other initial conditions. The difference between the strongly conditional treatments and the control after round 25 can be explained by higher average savings in round 25 in the strongly conditional treatments, allowing a more rapid investment in land use change after the end of the payments.

Table 3 OLS in round 25

Treatment	Influence on cumulative deforestation in round 25 (OLS[14])
Intercept (Control)	36.9 (2.1) ***
1 - Carbon Volatile	-18.4 (3.0) ***
2 - Carbon Fixed	-19.6 (3.0) ***
3 - Per Hectare Fixed	-11.3 (3.0) ***
4 - Per Hectare Indexed	-7.8 (3.0) **
5 - Per Hectare Forever	-11.6 (3.0) ***

In an OLS regression, all treatments were found to have a highly significant negative impact on the cumulative deforestation compared to the control. The effect of the strongly conditional treatments is almost twice the effect of the weakly conditional treatments. The difference between different pricing regimes under the same conditionality type is not significant, but the difference between conditionality types is significant.

[14] We report only an OLS for ease of interpretation. A tobit regression and a general linear model using annual deforestation over rounds 1 to 25 instead of cumulative deforestation in round 25 with "player ID" as random effect lead to similar results and are reported in Annex II. Including socio-economic control variables did not alter the results significantly.

7.2 - Effectiveness and Efficiency in reducing global CO_2 emissions

Table 4 repeats the average values for round 25 of all treatments for cumulative deforestation and the cumulative cattle production as well as the average sum of payments made and the payments net present value (NPV) at 3% discount rate in round 25. These values are the basis for comparing environmental effectiveness and efficiency and agricultural output between the treatments.

Table 4: Total cumulative average cells deforested and number of cows sold. All values are for round 25, standard errors in brackets.

Treatment	T1	T2	T3	T4	T5	T6
Average cumulative payments Round 25	3'430'000 R$ (180'000)	3'410'000 R$ (160'000)	3'530'000 R$ (170'000)	3'400'000 R$ (140'000)	1'840'000 / 2'930'000 R$[15] (160'000)	0 R$
Net Present Value of payments at 3% discount rate in round 25	2'150'000 R$	2'140'000 R$	2'570'000 R$	2'490'000 R$	1'350'000 / 1'730'000 R$[16]	0 R$
Average cumulative Deforestation Round 25	18.5 cells (1.7)	17.3 cells (1.7)	25.2 cells (2.5)	29.1 cells (2.3)	25.7 cells (2.1)	36.9 cells (2.0)
Average cumulative Cows sold Round 25	388 Cows (26)	363 Cows (28)	526 Cows (51)	556 Cows (44)	520 Cows (35)	365 Cows (18)

The differences in deforestation and agricultural production have already been shown above. The average cumulative payments are not significantly different for treatments T1, T2, T3 and T4 (see Annex III for all pair wise Mann-Whitney tests). The payments in T5 are significantly lower than in the other treatments in round 25. When taking the entire period and the increase in land value into account, the difference in payments between T5 and the others is significant, but only slightly. The NPVs of T1 and T2 are lower than those of T3 and T4. This follows from the back-loading of payments in T1 and T2 as visible in Figure 8 on page 12. For T5, it is even lower as payments continue for 21 further discounted years. For the following calculations we use the NPV for cost and collapse T1 / T2 and T3 / T4 using the average of both treatments.

We define the **theoretical carbon cost** of a treatment as the NPV of all payments made over the sum of cumulative avoided emissions in round 25 when calculated using the baseline as reference. According to this baseline scenario, in round 25 the entire ranch area would be deforested. Table 2 lists the theoretical carbon cost expressed as payments divided by the difference between total deforestation of all 51 cells and actual deforestation.

[15] Note that in T5 the payments continue after round 25 while for all other treatments the payments stop. 1'840'000 R$ have been paid on average in round 25 in T5. In round 46, 2'730'000 R$ have been paid, and the land value of the forest area on the average farm in T5 was increased by 200'000 R$ to account for the promise to pay for the longer future.

[16] Accordingly, this is the NPV of all payments made till round 46 + the 200'000 R$ from the land value increase in round 46.

Table 5: Theoretical Carbon Cost

Treatment	T1 / T2	T3/ T4	T5
Theoretical Carbon Cost	13.0 R$/ton	21.4 R$/ton	13.7 R$/ton

The theoretical carbon cost is lowest in the treatments with strong conditionality (T1/T2), followed by T5, the "per hectare forever" treatment. The weakly conditional and temporally limited treatments have the highest theoretical carbon cost. The ranking is the same when using the sum over all payments instead of the NPV (not shown).

We define the **actual carbon cost** of a treatment as the sum of all payments made divided by the sum of all emission reductions when calculated as the difference between the actual emissions in the treatment and the actual average emissions in the control in round 25. The actual deforestation in the control treatment in round 25 (36.9 cells) is significantly lower than the baseline (51 cells).[17] Table 3 lists the actual carbon costs for all treatments.

Table 6: Actual Carbon Cost

Treatment	T1 / T2	T3/ T4	T5
Actual Carbon Cost	22.6 R$/ton	54.0 R$/ton	30.9 R$/ton

Table 6 has the same ranking as Table 5, so the strongly conditional treatments are also more efficient when using a measured baseline (the control treatment) to calculate the emission reductions. It should be noted, that these carbon price calculations so far do not take into account any leakage or permanence.

7.3 - Leakage

"Leakage" refers to any off-site effects causally induced by an intervention aimed to reduce CO_2 emissions. In the case of export-oriented cattle production, the most relevant type of leakage is through market effects, i.e. changes in the incentives for other producers due to the change in supply from the producers affected by the REDD+ payment, mediated by market price. For all weakly conditional treatments (T3, T4 and T5) a positive leakage effect can be expected, as the cattle supply in the market is increased compared to the control by round 25, potentially reducing deforestation elsewhere through market effects. To calculate the global impact, emission changes through leakage need to be added to the calculation of emission reductions. As there is no agreed-upon way to calculate leakage, we approximated the average emissions per cow sold using the data from the control treatment. We define the emissions per cow as cumulative emissions in the control treatment in round 25 over cumulative cows sold in the control treatment in round 25. We then calculate leakage by multiplying this factor with the difference in cow production between control and treatment in round 25.[18] The following table shows the resulting carbon prices for 0 - 100% leakage:[19]

[17] The higher actual carbon cost than the theoretical carbon cost in the game points towards the problems of ex-ante baseline determination. While the baseline chosen in the game was rather conservative, using a deforestation rate three times slower than the optimal deforestation of a rational player, the actual players deforested significantly less. This issue is not an artifact of the game but one of the big unsolved real-world problems of REDD+. The problem is discussed in more detail in Reutemann (2014).

[18] Note that the calculated results would be different if using a rational player instead of the control treatment as reference, and would also be different if using a different time span than 25 rounds. Arguments could be made against both these choices. Unfortunately, there is no agreed upon solution to the calculation of leakage or emission factors of land-use products.

[19] A meta-analysis of theoretical and econometric literature on leakage by Sathaye & Andrasko, 2006) finds highly divergent results with 0 – 92% of area leakage, which can translate into >100% carbon leakage if leakage is from a low carbon density forest to a high carbon density forest. Accordingly, Wunder (2008) states that "we thus do not really know how large REDD leakage is" and

Table 7: Actual Carbon Cost when assuming 100% leakage in round 25 in R$/ton

	T1 / T2	T3/ T4	T5
Actual Carbon Cost at 0% leakage	22.6	54.0	30.9
Actual Carbon Cost at 25% leakage	23.1	35.9	23.2
Actual Carbon Cost at 50% leakage	23.6	27.1	18.6
Actual Carbon Cost at 75% leakage	24.1	21.8	15.5
Actual Carbon Cost at 100% leakage	24.7	18.2	13.3

Thus, depending on the assumptions on leakage, the efficiency ranking regarding global CO_2 emissions between the strongly conditional and weakly conditional treatments reverses. With 100% leakage, strongly conditional payments are least efficient. The efficiency of T1/T2 and T3/T4 equalizes under an assumption of 64% leakage at 23.9 R$/ton, while the efficiency of T1/T2 and T5 equalizes under an assumption of 26% at 23.2 R$/ton.

7.4 - Permanence

"Permanence" refers to a reversal of emission reductions after they have been sold. The terminology only makes sense in the treatments with strong conditionality, as the other treatments do not include an act that could be called "selling of emission reductions". When such a reversal occurs, the actual carbon budget rises above the baseline and above 100% of the entire carbon stock. This scenario is possible as the carbon budget is the sum of emission reductions sold and emissions[20].

Two types of reversal should be differentiated for the interpretation of the results, emission reversal during the crediting period and emission reversal after the end of the crediting period.

Emission reversal during the crediting period occurs if a player first sells emission reduction, increasing his actual carbon budget and later deforests faster than the baseline increase. In such a case the actual carbon budget rises higher than the maximum of the baseline carbon budget, making the sum of sold and emitted CO2 larger than the entire carbon stock of the area. Figure 16 shows how the carbon budget would look in such a situation.

that "asking for credible leakage estimates or leakage-proof design recipes is premature. It is helpful to play around with the numbers, but prediction ranges remain unacceptably wide".

[20] Thus the maximum of the actual carbon budget is twice the carbon stock, in the extreme scenario when first the entire carbon stock is sold as emission reduction and then, once the baseline reaches 100%, the entire carbon stock is emitted. Permanence is an important problem that arises whenever emission reductions are accounted for based on carbon stock. See Reutemann (2014) for a more detailed discussion of the issue.

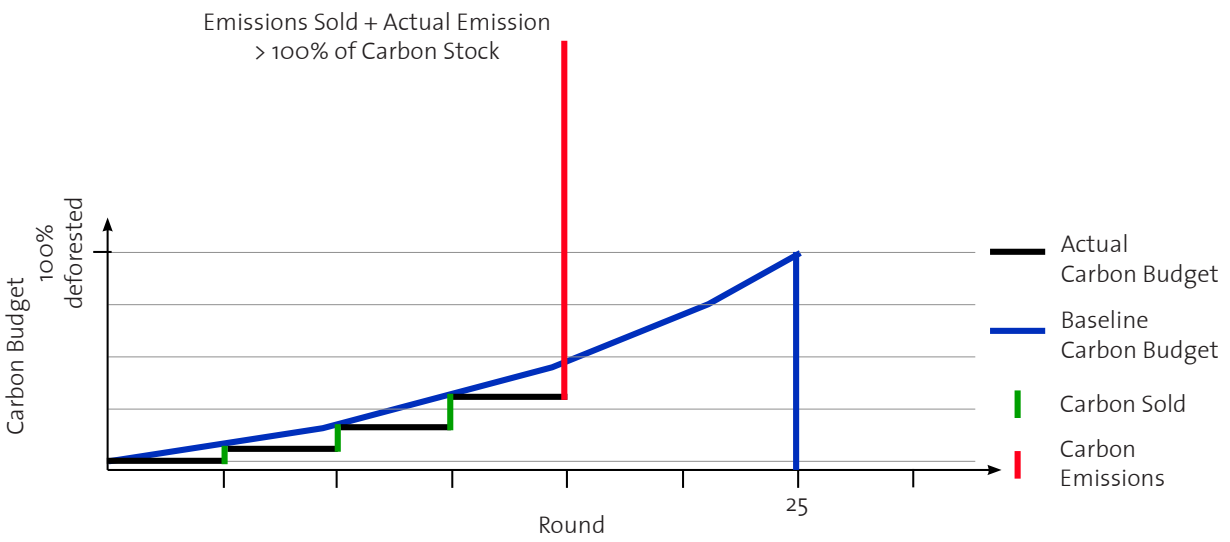


Figure 16: Emission budget when reversal occurs during the crediting period.

If this type of behavior was common, the theoretical carbon cost in round 25 would be > 20R$ in the fixed price treatment (T2), using the sum, not the NPV. This is not the case, with a sum-based theoretical carbon cost of only 20.3 R$ per ton, indicating very few occurrences of emission reversals during the crediting period.

Emission reversal after the end of the crediting period occurs if a player deforests after the end of the payments.

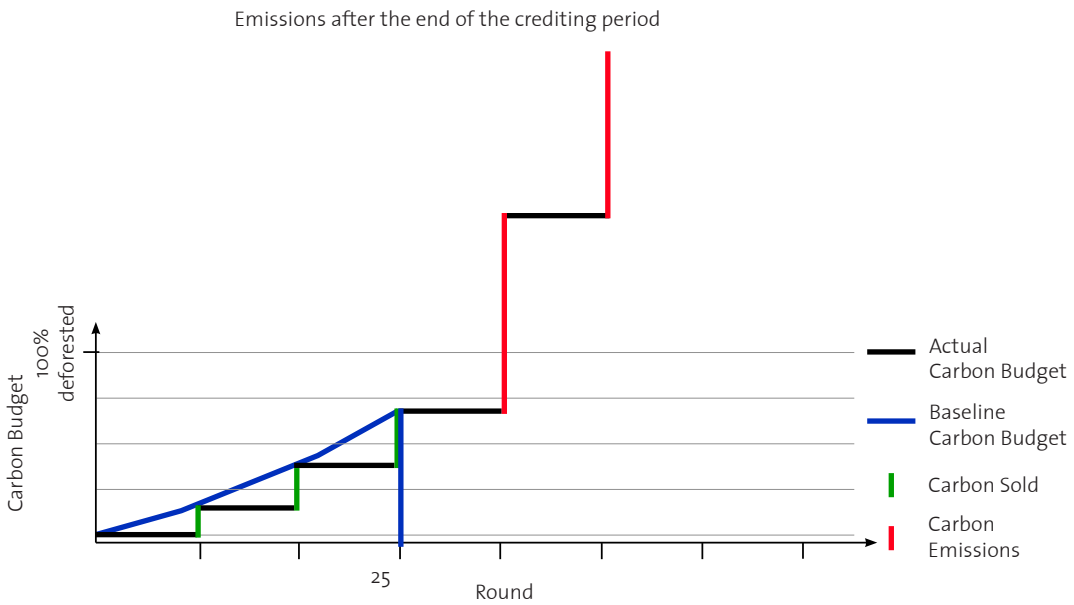


Figure 17: Emission budget when reversal occurs after the crediting period.

As already visible in figure 10 on page 16, this happens in all treatments, albeit more slowly in treatment 5. Table 8 reports the results of an OLS regression of deforestation in the last round of the game on treatment.

Table 8 OLS in round 46

Treatment	Influence on cumulative deforestation in round 25 (OLS[21])
Intercept	45.0 (2.1) ***
1 - Carbon Volatile	-1.2 (2.8)
2 - Carbon Fixed	-7.3 (2.9) *
3 - Per Hectare Fixed	-3.1 (2.8)
4 - Per Hectare Indexed	-3.2 (2.8)
5 - Per Hectare Forever	-9.0 (2.8) **

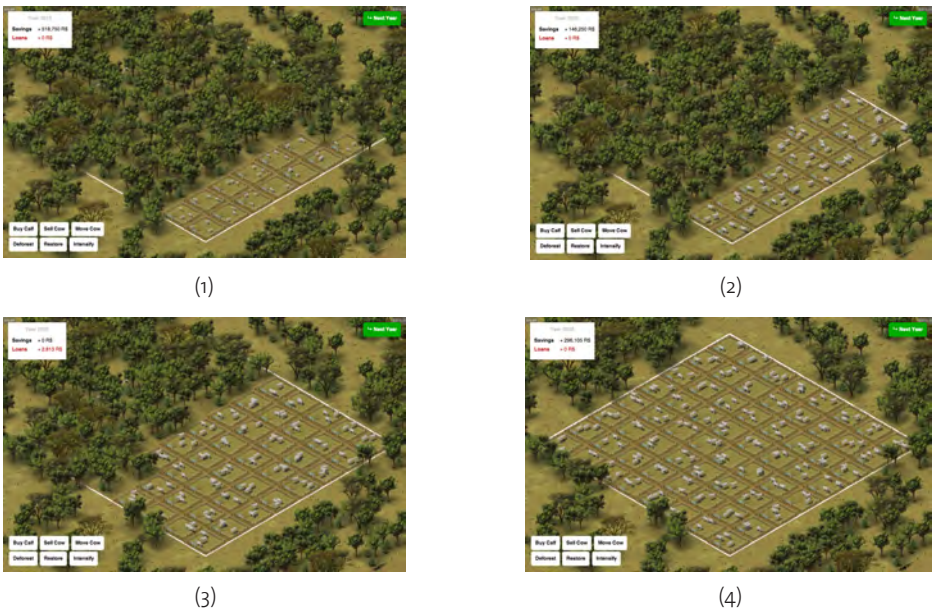
Only treatment 5, which continues payments for forest till the end of the game, has a highly significant effect on cumulative deforestation in round 46, as expected. We also see a significant negative effect of Treatment 2, which is surprising. We do not have a satisfying explanation for this effect. The regression coefficients for treatment 1, 3 and 4 become insignificant from round 30 onwards (not shown), indicating a very fast emission reversal in those treatments at the end of the crediting period.

[21] A tobit regression leads to a very similar result. Socio economic variables did not have a significant influence.

8 - Interpretation

As for the control treatment, it helps for the interpretation of the results to look at a decision path of an idealized typical player in the treatment conditions.

8 – 1 Typical evolution of the game under weak conditionality



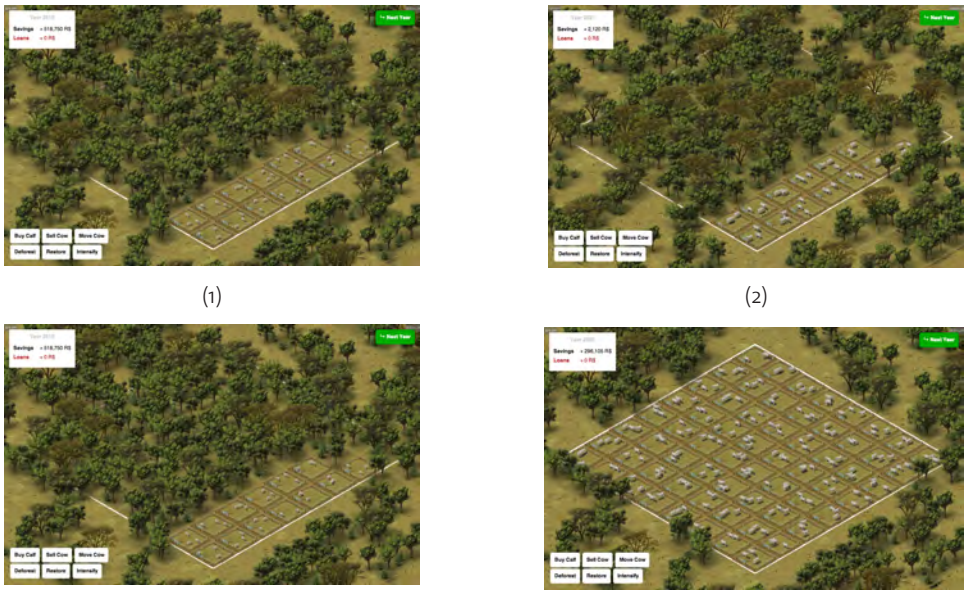
(1) (2)

(3) (4)

Figure 18: Game evolution under weak conditionality

Under weak conditionality the players first intensify the initial pasture. As they start to generate further profit and acquire more capital, they deforest further forest cells and immediately intensify them. So they steadily deforest and intensify till they reach the steady state of picture (4) in figure 17, without ever using extensive grazing.

8.2 - Typical evolution of the game under strong conditionality



(1) (2)

(3) (4)

Figure 19: Game evolution under strong conditionality

Under strong conditionality, the players first intensify the initial pasture. As they generate further profit, they start to accumulate capital as savings. They continue building up further savings for several rounds. At some point, either when the payments stop or enough savings are acquired, they deforest and intensify the entire area at once.

8.3 - Treatment 5 and Opportunity Costs

According to the estimates on carbon costs and permanence, treatment five seems to be the most promising of the tested treatments. It is also particularly curious as it successfully reduces deforestation while offering a payment 50% below opportunity costs of extensive grazing.[22] Treatment 5 thus shows how a calculation of opportunity costs per hectare is not necessarily the true cost of conservation under capital constraint and with more than one option for land use.

When modifying the game to have a constant cow price at 40'000 R$, a player in T5 using the same strategy as optimal in the control treatment (see Box 1) makes only 16% more profit by round 27 than a player using the strategy describes as typical evolution of the game under weak conditionality.

With the difference that small, under the uncertain future prices as used in the experiment, even slight uncertainty aversion is sufficient to make the strategy of intensification prior to deforestation more attractive than a strategy of deforestation prior to intensification. Thus the players actually acted reasonable in choosing a conservation strategy, despite the payment being only 50% of the opportunity costs of extensive grazing. The actual cost of conservation in the game is the payment that leads to equal payoff for these two strategies, which is significantly lower than the opportunity costs of extensive grazing.

The model nicely shows how a static opportunity cost concept can be misleading in a capital constraint scenario. Extensive pasture is the most profitable land-use decision in the control treatment. The payments under weak conditionality in T3 and T4 are higher than the opportunity cost of extensive grazing, while those in T5 are lower. If this was the end of the story, there should not be any deforestation in T3 and T4, while players should deforest heavily in T5. We do not observe this behavior due to two factors in our model:

1) Opportunity costs depend on capital availability.

Extensive grazing is only the most profitable land-use decision as long as capital is constraint. Once this constraint is loosened by the payments, intensive pasture becomes a more profitable alternative. Thus the opportunity costs increase with capital availability and players start to deforest as soon as they can no longer invest elsewhere.

2) The cost of conservation is not the profit differential between doing nothing and extensive grazing, but the profit differential between deforestation and intensification of existing land.

When land is less constraint than capital and intensification possible, the opportunity costs per hectare are misleading. The actual cost of conservation is the difference in

[22] 25 years of extensive grazing on one cell generate ~100'000 R$ of profit (under constant cow price at the initial value of 40'000 R$ per cow unit), while 25 years of payments for one cell in treatment 5 generate only ~50'000 R$ of profit.

return on investment between deforestation and intensification. Thus even the low payment of T5 can be sufficient to induce players to play a conservation strategy.

Such dependencies of opportunity costs on capital availability and intensification potential needs to be taken into account when estimating the cost of REDD+.

8.5 - Leakage

As demonstrated in section 7.3, how leakage is accounted for plays a crucial role in the evaluation of effectiveness and efficiency of a payment mechanism for global CO_2 emission reductions. Contrary to the discussion of leakage in the literature (e.g. Wunder, 2008), the introduction of REDD+ payments in our experiment did not cause a *reduction* in the production of beef but an *increase*. While counterintuitive at first, this result makes sense with large intensification potential and capital constraint producers.

It could be argued that weakly conditional payments include payments for non-additional deforestation, as a player receives some payment even if he deforests just as much as in the control treatment. This non-additionality can explain the higher average production, as the non-additional part of the payment can be understood as a regular, unconditional agricultural subsidy relaxing the capital constraint and allowing more production. A player in the weakly conditional payments would produce more than the control even if she uses the exact same strategy as described in Box 1 due to the higher capital availability before reaching full deforestation, even though this strategy is suboptimal in the treatment condition. Nevertheless, this is not what we observe in the experiment. The subsidy is used to finance rapid and ongoing intensification, which increases production above the state without subsidies.

The experimental results also confirm the feasibility of the leakage accounting approach introduced in Reutemann (2014) for cattle producers. Under this approach, 100% leakage is assumed if the production is reduced compared to the baseline to avoid various issues in carbon accounting.[23] In our model, the REDD+ payments would not be reduced even with a 100% leakage assumption, as the cattle production is at least as high with the payments as in the control.

In the model as presented here, the strongly conditional treatments do not have a significant leakage effect, as the production is equal to the control treatment. It can be assumed that this does not hold for all initial conditions. If a farm has less initial pasture available than the 20% used in the experiment, production can be expected to decrease compared to the control. It might be necessary to allow joint REDD+ projects between pasture owners and forest owners to avoid such situations.

8.6 - Permanence

The result of quasi-zero emission reversal during the crediting period is in line with the incentive structure of the model, as deforestation under strong conditionality has the best return when done early in the crediting period because of the long amortization time of investments in intensive pasture. Closer to the end of the payments, it is more profitable to wait with deforestation till after the end.

It should be noted however, that this result also depends on the length of the crediting period and the rate of capital accumulation. With the values used in the game, even an excellent player does not acquire enough capital to deforest and intensify the entire area prior to the end of the crediting period. Under a longer crediting period, this might

[23] See Reutemann (2014) for details.

be different, potentially leading to instances of non-permanence during the crediting period. In the real world, this effect could be counterbalanced by capital absorbed into other investment opportunities such as higher degrees of intensification than those offered in the game.

At the end of the crediting period, a rapid emission reversal is observed. It is important to note that the annual deforestation rate just after round 25 is higher than in the control treatment in all treatments except for treatment five. In the real world similar effects have been observed by some integrated conservation and development projects (Blom, Sunderland and Murdiyarso 2010). Such projects aimed to indirectly reduce deforestation by providing non-forest income opportunities. If such additional income provides capital required for faster deforestation, they can backfire in terms of conservation. Thus, at the end of the period when conditional payments no longer provide an incentive for conservation, rapid deforestation should be expected.

One possible way out is to create other, less carbon-intensive investment opportunities. Unfortunately this is easier said than done, as farmers typically have strong know-how in land-use investments, but not in any other financial market. More intensive, sustainable ranching technologies such as confinements with manure treatment plants might be a viable solution.

9 - Conclusions and next steps

The most important result of the model and experiment presented here is that the details of conditionality matter more than price volatility for the success of a PES scheme. Strong conditionality in the form of an immediate, drastic reduction in the following payments in case of deforestation was found to be significantly more effective in reducing local deforestation than a weakly conditional payment proportional to the amount of forest currently held.

We also show how a temporally limited PES scheme for avoided deforestation can rapidly revert to the same level of deforestation as without any payments. This effect is explained with higher capital availability at the end of the PES scheme due to the payments.

Another effect of increased capital availability can be a raise of the opportunity costs for production systems with intensification potential. Thus neglecting changes in capital availability over time in an equilibrium analysis can underestimate the opportunity cost when capital availability increases. On the other hand, the cost of conservation in a system with intensification potential is overestimated when using the absolute return of the most profitable land-use as opportunity cost of the land. Under capital constraint and intensification potential, the actual cost of conservation is the differential in return between a strategy of deforestation and extensive land-use and a strategy of intensive land-use of existing pasture.

It should be noted that the results presented here cannot be expected to extended to other drivers of commercial deforestation such as palm oil, where the new plantations driving deforestation typically operate at maximum intensity already and the main actors are multinational companies with less capital constraint. The results should also not be expected to extended to non-commercial deforestation by subsistence smallholders, were entirely different constraints and motivations are at work. We thus also call for a more differentiated investigation of REDD+ scheme design, paying more attention to the specific properties of locally dominant drivers of deforestation.

As a next step, it would be in particular interesting to further investigate variations of the most efficient treatment, number five which paid only an interest rate out of a fund but never stopped paying. Such a second round of experiments could test various combinations of different absolute prices, strong conditionality or back-loading under the condition of paying forever. Back-loading of an interest payment without end could be achieved by paying out only 50% of the interest and use the rest to increase capital stock in the investment fund over time, and thus increase later payments.

Last but not least, the game used in this experiment has been published open-source, allowing other researchers to re-use and modify it.[24]

[24] The game can be played and all documentation downloaded at http://www.n.ethz.ch/~stim. The raw data and R-Code for the analysis done here can also be downloaded there. Any modifications of the game can be made and published on github, where the source-code can be found under this link: https://github.com/danilowanner/Cattle-Farming-Game/commits/master

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ANNEX I: Randomization & Player Types

Player Types

To confirm the validity of our sample, we performed a series of MANOVA tests to test if player type has any influence on the outcome of the game or the questionnaire responses. Unfortunately, it will not be feasible to analyze differences between player types for each treatment separately, as the number of observations for each player type is too small in a single treatment, e.g. N=7 for ranch owners in T1. We thus compare them in the baseline phase and collapsed over all treatments.

The first MANOVA tests the influence of player type at the end of the game in the treatment phase (round 47) on cumulative cells deforested, cumulative cows sold, cumulative cells intensified and risk preference as well as financial risk preference from the initial questionnaire and final payoff over all treatments:

Table I – 1, MANOVA, player type on end of game variables

Player Type Dummy	Pr (>F)
Owner	0.77
Student	0.76
Family Member	0.11

n= 346

No significant influence was found.

The second MANOVA is the same as the first, but in round 25 of the treatment phase:

Table I – 2, MANOVA, player type on round 25 variables

Player Type Dummy	Pr (>F)
Owner	0.43
Student	0.22
Family Member	0.37

n= 346

No significant influence was found.

The third MANOVA is the same as the first, but in the last round (27) of the baseline phase

Table I – 3, MANOVA, player type on end of baseline variables

Player Type Dummy	Pr (>F)
Owner	0.59
Student	0.55
Family Member	0.82

n= 346

No significant influence was found.

While MANOVA is preferable for testing several variables at once and its ability to identify cross-influences it relies on an assumption of normal distribution. We thus also performed the following Kruskal-Wallis non-parametric tests to test the if there are any difference between the of the cumulative cells deforested, cumulative cows sold, cumulative cells intensified for round 25 and round 46 of the treatment phase as well

as round 26 of the baseline phase in the sample if grouped by players role (Owner, Family Member or Student).

Table I – 4 p-values for Kruskal-Wallis comparison of means

	Def 25	Int 25	Cow 25	Def 46	Int 46	Cow 46	Def BL 26	Int BL 26	Cow BL 26
p-values for Kruskal-Wallis test on Role	0.30	0.77	0.79	0.31	0.71	0.75	0.41	0.08	0.42

No significant effects were found.

The equality of in-game behavior between player types is also confirmed visually in the following six plots (cumulative deforestation, intensification and cows sold over all rounds of the Baseline Phase and Treatment Phase, all treatments combined)

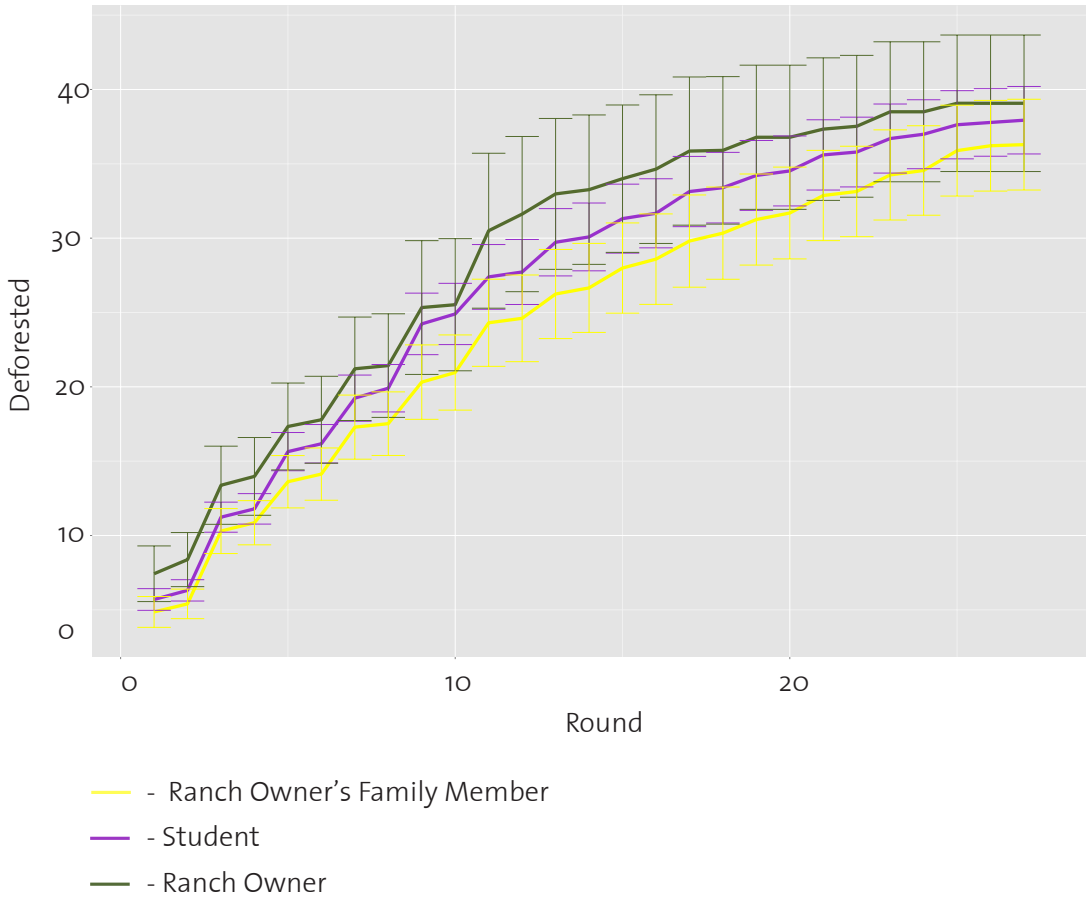

Figure I – 1, Deforestation over round in the baseline phase, for each player type

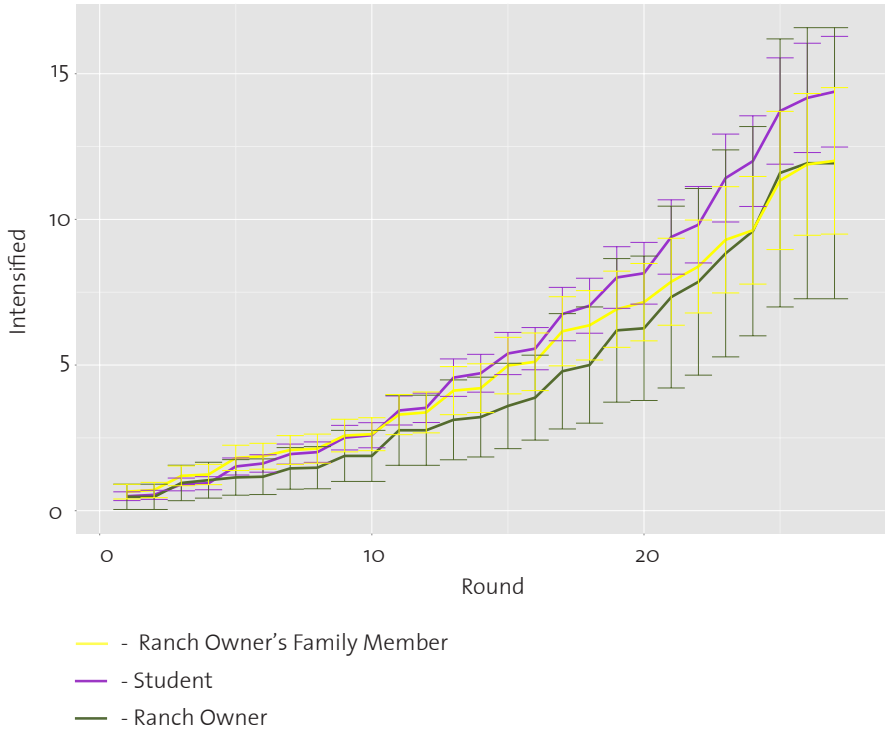

Figure I – 2, Intensification over round in the baseline phase, for each player type

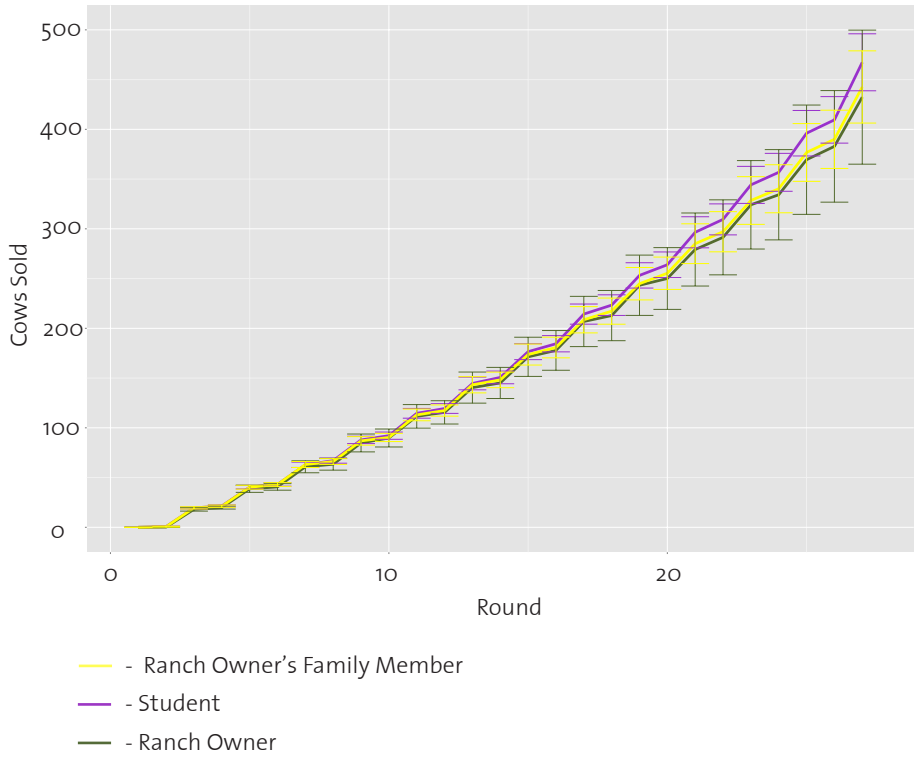

Figure I – 3, Cows sold over round in the baseline phase, for each player type

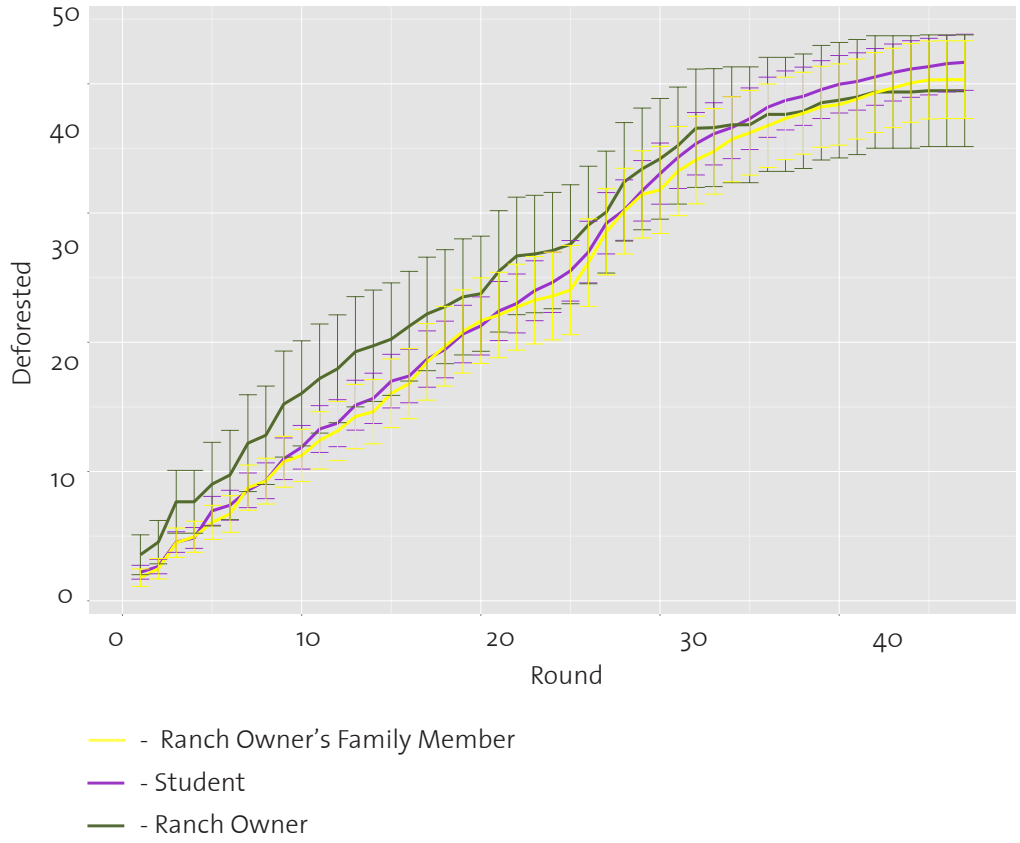

Figure I – 4, Deforestation over round in the treatment phase, for each player type

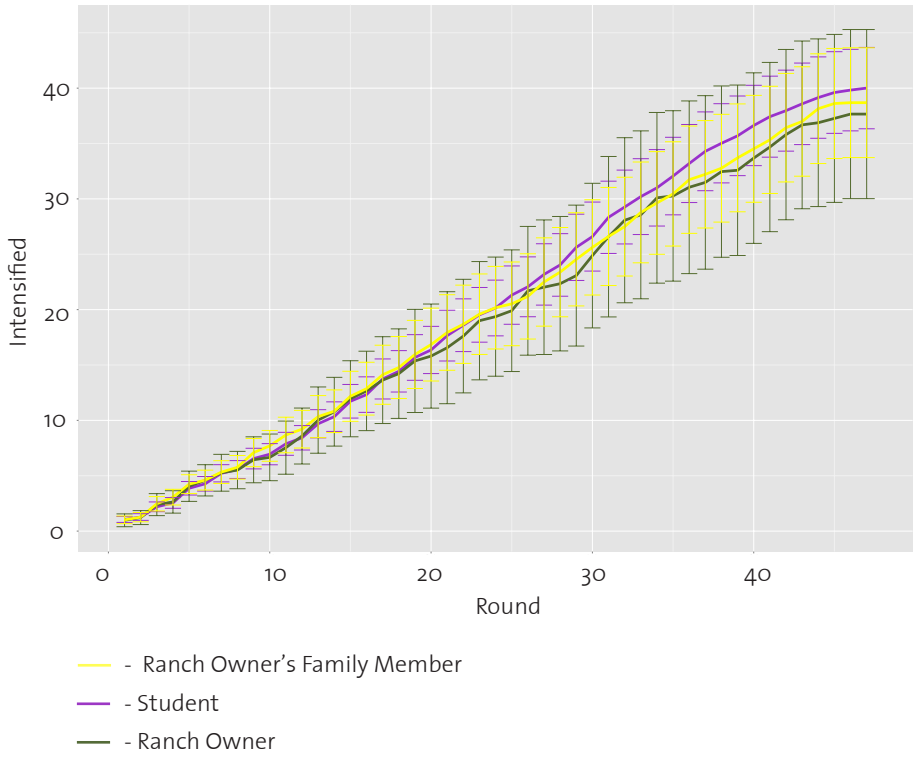

Figure I – 5, Intensification over round in the treatment phase, for each player type

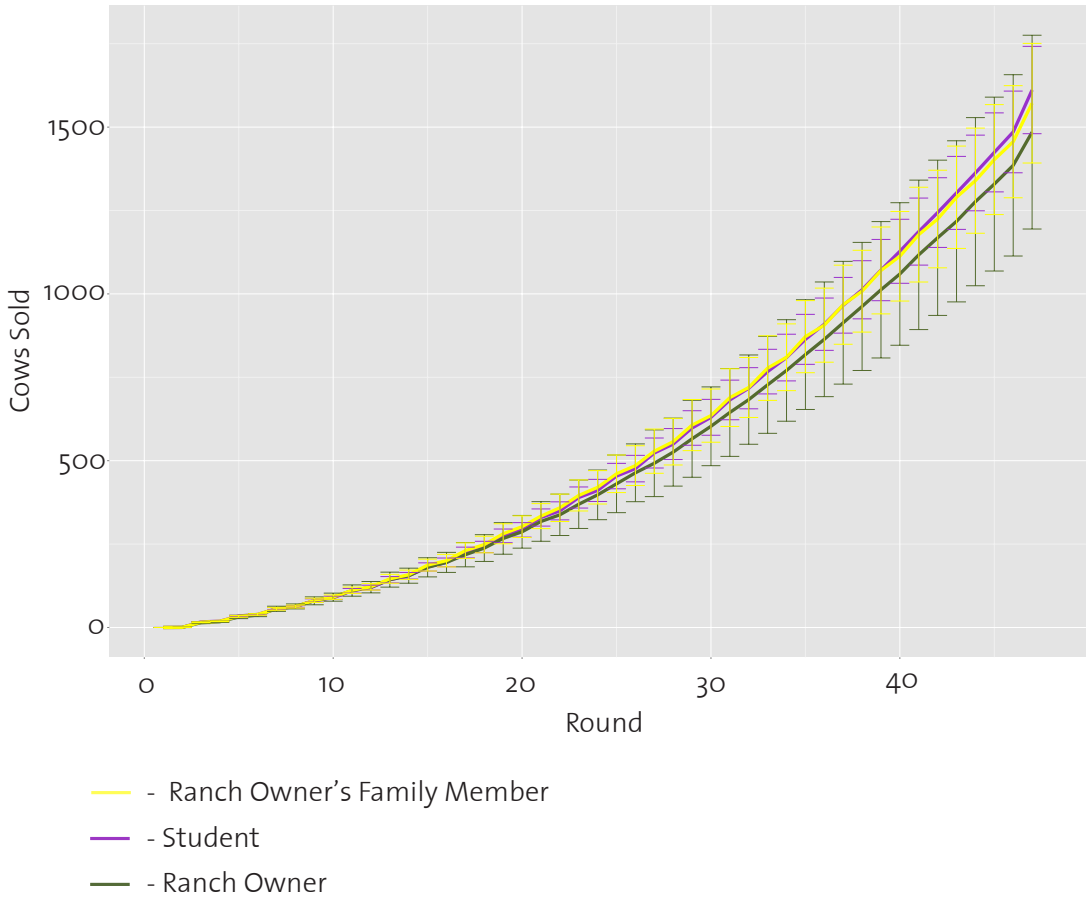

Figure I – 6, Cows Sold over round in the treatment phase, for each player type

Randomization

The players were assigned to a treatment upon finalization of the initial questionnaire in the database. The players did not know the assignment until the start of the Treatment Phase. We implemented the randomization by rotating the treatment number from 1-6 continuously through the entire experiment upon creation of the entry for the player in the database. This procedure was already used in the pre-testing and continued into the main experiment. As there was an average of 10 players per round and the counting was continuous over sessions, the player who was quickest to fill out the questionnaire ended up in a different treatment in every session. Thus there was no correlation between the time needed to complete the questionnaire and the treatment. Additionally, there was some additional random noise created by players who made mistakes in filling the questionnaire and re-started or accidentally quit the game during the training phase and had to re-start, as this lead to a new treatment assignment. Players were not allowed to re-start after finalizing the training phase.

To control for successful randomization, we tested for influence of treatment on both player characteristics and game outcome in the Baseline Phase. All players went through the exact same Training and Baseline Phase prior to receiving any treatment-

specific information, thus there should be no difference in Baseline Phase play between treatments.

We ran a MANOVA of the treatment on player characteristics and the outcome of the last round of the Baseline Phase (round 27). The MANOVA included the variables Age, Gender, Risk Preference, Financial Risk Preference, Player Type, Cumulative Deforested in Baseline Round 27, Cumulative Intensified in Baseline Round 27 and Cumulative Cows Sold in Baseline Round 27, regressed on Treatment Dummy Variables:

Table I – 5, MANOVA treatment on player characteristics

Treatment Dummy	Pr (>F)
T1	0.37
T2	0.47
T3	0.42
T4	0.21
T5	0.66

n= 346

No significant effect of treatment on any other variable was found, confirming successful randomization.

The following graphs plot the cumulative deforestation, intensification and cows sold in the Baseline Phase by treatment, visually confirming no difference in other rounds of the Baseline Phase.

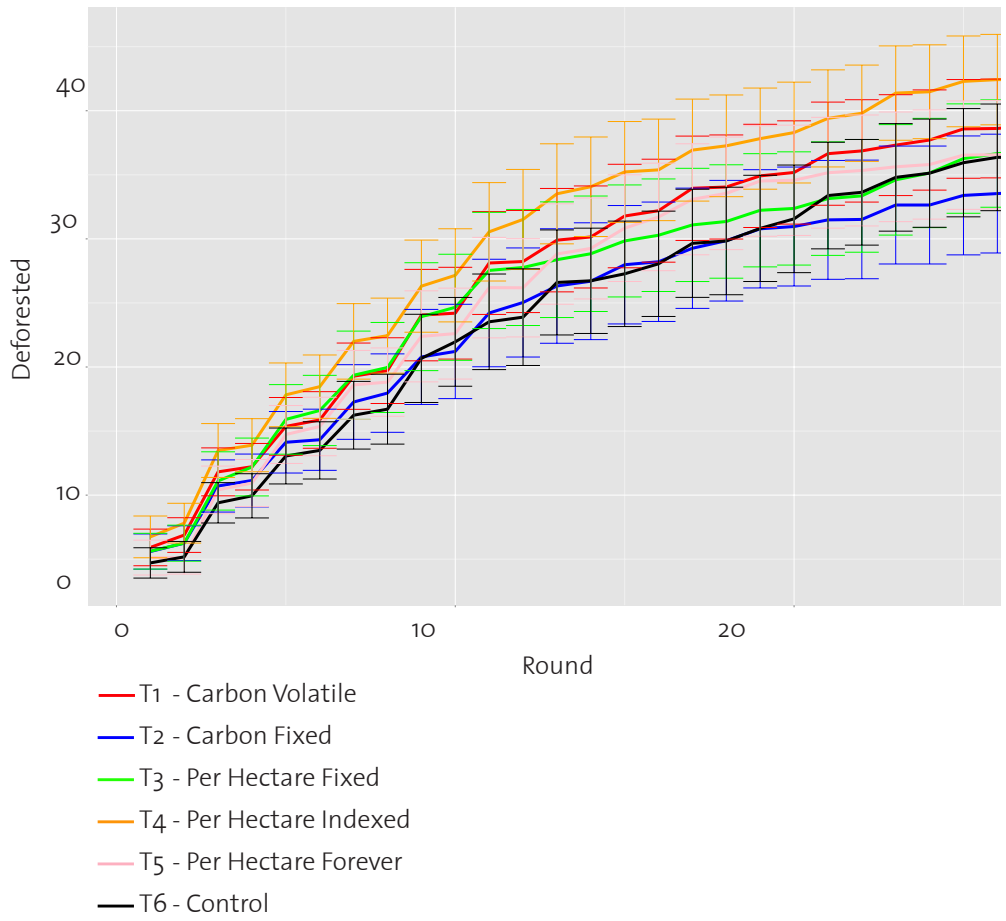

Figure I – 7, Deforestation over Round in the Baseline Phase by Player Treatment

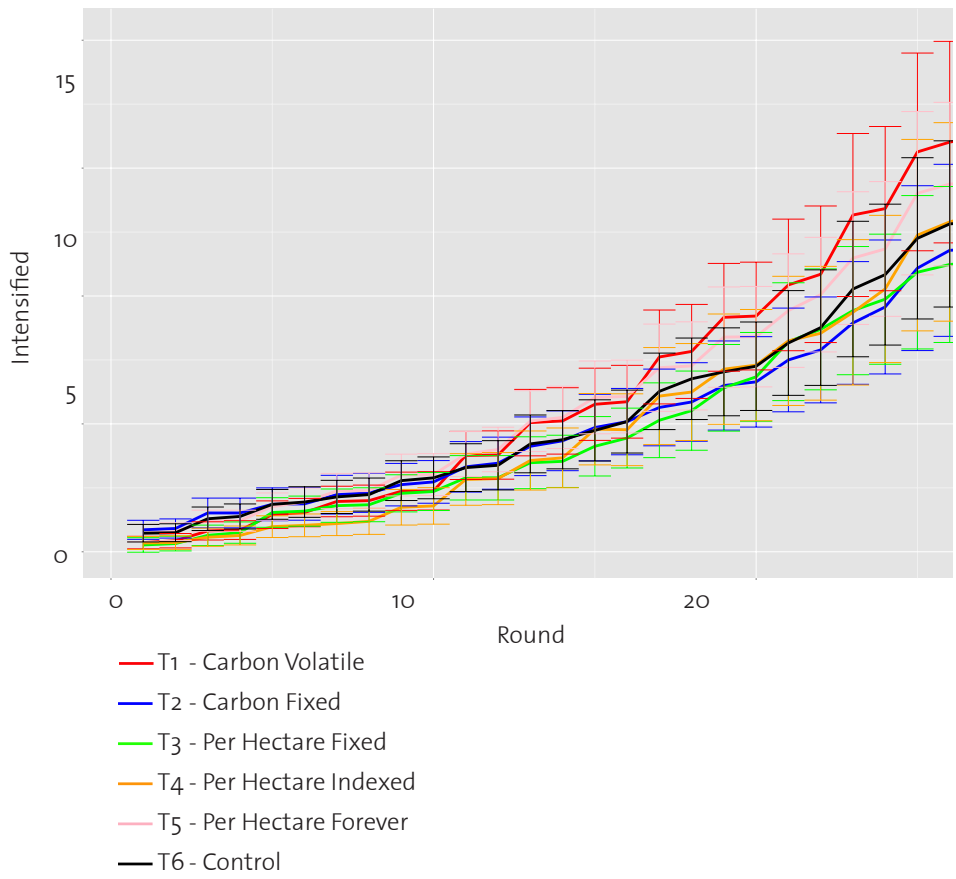

Figure I – 8, Intensification over Round in the Baseline Phase by Player Treatment

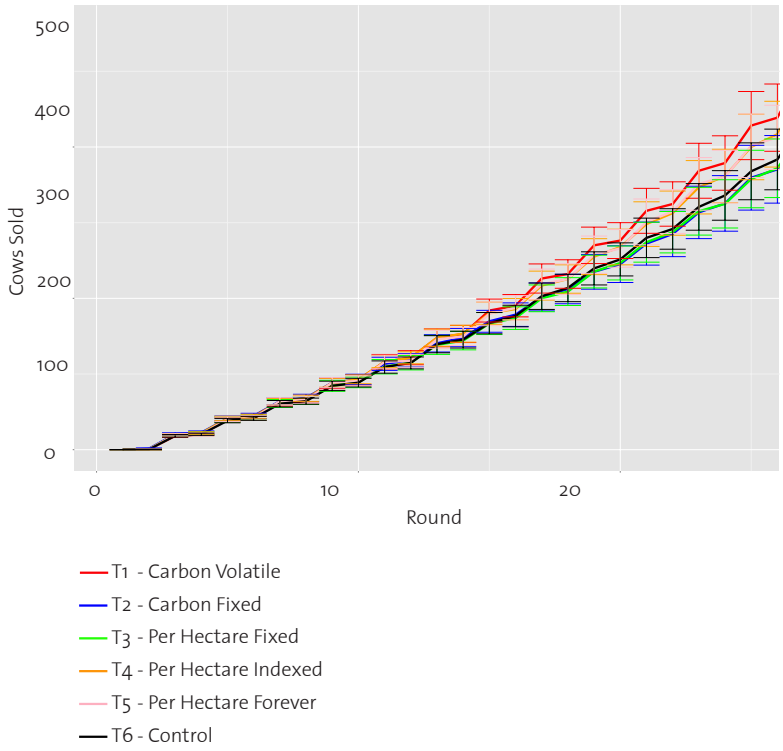

Figure I – 8, Intensification over Round in the Baseline Phase by Player Treatment

ANNEX II: Further Analytics

We did not find any significant influence of including risk preferences[25] in the OLS on deforestation. We attribute this lack of a finding to our less-than-perfect measure of risk preferences. He & Veronesi (201X?) showed that the measure we used does not predict incentivized risk preference elicitation among Chinese farmers, indicating that the positive results by Dohmen et al (2011) on German households using this measure might not extend to other populations.

Table II – 1, OLS in round 25 including risk preferences

Variable	Influence on cumulative deforestation in round 25 (OLS)
Intercept	39.8 (5.1) ***
T1	- 28.1 (6.7) ***
T2	- 24.5 (6.6) ***
T3	- 15.1 (6.9) ***
T4	- 17.3 (7.2) **
T5	- 19.4 (8.6) ***
Risk Preference	-5.6 (8.6)
Risk * Treat 1	18.7 (11.5)
Risk * Treat 2	9.6 (11.4)
Risk * Treat 3	7.1 (11.5)
Risk * Treat 4	17.6 (12.2)
Risk * Treat 5	15.5 (11.9)

Including other control variables such as gender, age, player type, location etc. did not show any significant results. There is a marginally significant impact of gender on deforestation, with males deforesting slightly more.

Using a tobit model instead of an OLS showed very similar results to the OLS reported in table 3:

Table II – 2, tobit in round 25

Treatment	Influence on cumulative deforestation in round 25 (Tobit)
Intercept	41.2 (2.8) ***
1 - Carbon Volatile	-23.2 (3.8) ***
2 - Carbon Fixed	-25.0 (3.9) ***
3 - Per Hectare Fixed	-14.1 (3.9) ***
4 - Per Hectare Indexed	-9.9 (3.9) *
5 - Per Hectare Forever	-15.2 (3.9) ***

Using a tobit could be justified as deforestation cannot be <0 or >51 due to the limitations of the game. Nevertheless, this is not due to a limitation in our measurement but a limitation in the model, thus estimating censored effects as done by tobit makes only limited sense.

[25] We used a simple question, "How do you see yourself: are you generally a person who is fully prepared to take financial risks or do you try to avoid taking financial risks?" rated from one to ten to elicit financial risk preference. Dohmen et al. (2011) found that the answer to this question is strongly correlated with more complex and time consuming measures of financial risk preference. However, we have doubts that the measure really worked in our case.

A general linear model using annual deforestation from round 1 to round 25 and player ID as a random effect also came to similar results:

Table II – 3 General Linear Model on annual deforestation

Groups	Variance	Std.Dev.
playerId	0.13	0.36
Residual	6.21	2.49

Treatment	Estimate	Error	t-value
T1	1.26	0.08	15.12
T2	-0.53	0.12	-4.64
T3	-0.64	0.12	-5.46
T4	-0.29	0.12	-2.54
T5	-0.17	0.12	-1.48
T6	-0.33	0.12	-2.86

While a general linear model is a cleaner way to show influences, as it can also take into account differences in temporal development leading to the same cumulative value, we find it less intuitive to interpret and thus prefer reporting OLS results. Additionally, the plots of deforestation over time do not indicate a difference in the temporal change of deforestation between treatments prior to round 25.

Table II-4 lists p-values from pairwise, non-parametric Mann-Whitney tests. “Def” is cumulative deforestation, “Int” cumulative intensification and “Cow” cumulative cows sold. The number indicates round 25 respectively round 46. The results are in line with the OLS results.

Table II – 4, p-values of pairwise Mann-Whitney tests

	Def 25	Int 25	Cow 25	Def 46	Int 46	Cow 46
T1/T2	0.702	0.716	0.478	0.012 *	0.228	0.303
T1/T3	0.086 .	0.370	0.188	0.013 *	0.538	0.916
T1/T4	0.001 ***	0.332	0.011 *	0.202	0.392	0.548
T1/T5	0.024 *	0.057 .	0.012 *	8.44e-4 ***	0.228	0.741
T1/T6	5.82e-9 ***	0.015 *	0.847	0.707	0.152	0.029 *
T2/T3	0.031 *	0.3	0.056 *	0.237	0.540	0.250
T2/T4	4.61e-4 ***	0.21	0.002 ***	0.185	0.676	0.093
T2/T5	0.013 *	0.025 *	0.002 ***	0.442	0.870	0.155
T2/T6	1.72e-9 ***	0.042 *	0.621	0.021 *	0.712	0.446
T3/T4	0.317	0.982	0.547	0.883	0.771	0.734
T3/T5	0.982	0.622	0.656	0.037 *	0.581	0.932
T3/T6	0.002 **	0.016 *	0.280	0.227	0.357	0.112
T4/T5	0.202	0.640	0.689	0.026 *	0.807	0.740
T4/T6	0.028 *	0.007 **	0.007 **	0.326	0.449	0.025 *
T5/T6	2.02e-4 ***	4.09e-5 ***	0.002 ***	0.001 ***	0.601	0.028 *
T1&T2 / T3,T4 &T5	6.92e-5 ***	0.032 *	1.92e-4 ***	0.267	0.694	0.175
T1&T2 / T6	1.05e-11 ***	0.010 **	0.870	0.251	0.295	0.087 .
T3,T4 &T5 / T6	2.77e-4 ***	1.74e-4 ***	0.005 **	0.028 *	0.370	0.0141 *

Table II-5 lists p-values from pairwise, non-parametric Mann-Whitney tests. Total Payment is the total amount of payments made in round 25, not including future values in T5. Total Payment 46 (only reported for comparisons including T5) is the total amount of payments made in round 46 plus the additional land value of the remaining forest. Payoff is the final payoff paid to the players after the experiment. Note that for T6, this includes a bonus of 6'000'000 R$ in game money at the end of the game to allow a fair compensation. We have chosen this value based on the difference in payoff for a rational player.

Table II – 5, p-values of pairwise Mann-Whitney tests

	Total Payment 25	Total Payment 46	Payoff
T1/T2	0.779	-	0.171
T1/T3	0.688	-	0.718
T1/T4	0.581	-	0.938
T1/T5	7.22e-10 ***	0.02 *	0.489
T1/T6	N/A	-	0.059
T2/T3	0.4737	-	0.438
T2/T4	0.930	-	0.175
T2/T5	1.83e-12 ***	0.03 *	0.406
T2/T6	N/A	-	0.738
T3/T4	0.391	-	0.509
T3/T5	1.04e-11 ***	0.007 **	0.890
T3/T6	N/A	-	0.327
T4/T5	1.21e-12 ***	0.04 *	0.451
T4/T6	N/A	-	0.097
T5/T6	N/A	-	0.259
T1&T2 / T3 &T4	0.870	-	-
T1&T2 / T6	N/A	-	-
T3 &T4 / T6	N/A	-	-

ANNEX III: Game Design Process and Game Details

Game Design Process

The game was designed to be as close to the reality in Tocantins as possible, without getting too complicated to comprehend. We thus decided to first reduce the decision situation of a rancher to a very simple model with few decision options and then approximate the prices for those options. For example, labor cost and cost for labor housing was included in the buying price of calves and cost for pasture establishment was included in the price for deforestation. We also excluded any economies of scale, transaction cost, learning cost or other non-linear effects from the game.

Most of the prices in the model were derived from an internal and, unfortunately, confidential spreadsheet used by Banco di Amazonia to calculate loans to farmers in Tocantins. These were further refined and confirmed in interviews with Prof. Rubens Ribeiro da Silva, former agricultural consultant and now Professor at the Agricultural Department of the University of Tocantins, Gurupi and Corombert Leão de Oliveira,

responsible for cattle ranching at the Secretary of Agriculture (SEAGRO) and himself owner of a large ranch.

The prior to the technical implementation, the model design was embedded in a participatory process and the problem framing was done in extensive interviews with the above-mentioned stakeholders as well as a number of Tocantins ranchers.

Once technically implemented, we pre-tested the game again in 6 sessions with ranchers and technical ranch advisors from SEAGRO and conducted further interviews on the realism and intuitive understandability of the game. Despite some minor adaptions, one major change was made in the pre-testing: Instead of starting the game with zero initial endowment and a 1'000'000 R$ credit limit at low interest (which was more realistic) we had to adapt the game to 1'000'000 R$ initial endowment and zero credit limit. While not altering the gameplay for an experienced or analytically well versed player who knows that operating at the credit limit is optimal, it made the game much faster to understand and reduced the variability between players performance drastically.

Deforestation

The price for deforestation was the most difficult parameter to identify in the field. Most sources (SEAGRO and the spreadsheet from Banco di Amazonia) indicate a price of approximately 3'000 to 5'000 R$ per hectare for deforestation, making deforestation highly unprofitable. On the other hand, the difference in land price between forest and pasture was quoted by the same sources as less than 1'000 R$ per hectare and deforestation is widespread and ongoing in the region, giving us doubts about this information. It should also be noted though that those initial sources were governmental and thus had an official anti-deforestation policy, at least in communications. For example Banco di Amazonia officially does not give credit for deforestation.

Further investigation lead to the insight that the cost cited by the first sources excluded any revenue from selling wood. Prof. da Silva explained that deforestation has an actual zero cost if the wood is sold for charcoal. Several farmers interviewed during the pre-testing also confirmed this[26].

Accordingly, in the game, we used zero as price for deforestation, but added the price for seeds and pasture establishment on newly deforested land. According to Banco di Amazonia, this value is 600 R$ per hectare on average, excluding cost for labor and gasoline. Labor and gasoline cost were estimated at 120 R$ / per hectare by Prof. da Silva, who also confirmed the value of 600 R$ for seeds and calcium from Banco di Amazonia.

We thus used a cost of 720 R$ per hectare, respectively 18'000 R$ per cell in the game for deforestation.

Intensification & Maintenance

We used a very simple and low cost form of pasture intensification in the game. The technology modeled is only rotational grazing and annual replacement of nutrients through low-level fertilization.

[26] On the side, this also lead to the insight that the "no credit for deforestation" policy by the bank can be considered a fig leave policy, as deforestation has zero cost and the bank does give credit for "pasture establishment", the first step after deforestation that has a real cost.

The cost for fencing and other equipment required for a rotational pasture was supplied by the Banco di Amazonia spreadsheet at 1'680 R$ per hectare, thus 42'000 R$ per cell in the game.

It less clear how much to add for annual maintenance and fertilization, as the equipment breakdown time was not available and the fertilizer costs varies widely depending on local soil condition. Our initial calculations based on the Banco di Amazonia spreadsheet came to 200 R$ per hectare per year, which was considered too low by Prof. da Silva and Mr. Oliveira. At their suggestion, we used a value of 320 R$ per hectare per year, respectively 8'000 R$ per cell per year in the game.

Recuperation

Banco di Amazonia did not provide per hectare data for recuperation of degraded land, but only the costs for individual fertilizers. We thus used a value provided by Mr. Oliveira of SEAGRO and confirmed by Prof. da Silva of 1'400 R$ per hectare for fully degraded land, respectively 35'000 R$ per cell for a cell of 10 points of degradation. We spread this cost linearly over lower levels of degradation, which is a rough approximation.

Land Price

The Land Prices in the game were taken directly from Banco di Amazonia, using the average value if a range was provided:

Forest: 25'000 R$ per cell

Pasture: 45'000 R$ per cell

Intensive Pasture: 65'000 R$ per cell

Degradation: -2'000 R$ per point of degradation

We did not have values from Banco di Amazonia for degraded land. We instead used the lowest end of the range given for pasture value to estimate the price for fully degraded pasture and adjusted the land value of pasture linearly in between.

In Treatment 5, we increased the land value of forest to 40'000 R$ to account for the ongoing payments. This was based on a NPV calculation of the payment, using the implicit discount rate implied by the price difference by forest and pasture cells under the assumption of a constant cattle price, which is 16.5%.

Note that we excluded the "pure" land-value ("terra nua" in PortugeseS) from all land prices. This does not alter the relative land value and thus is expected not to change the incentives for the players, but reduces the flat payment given to the players.

Cattle Price

Current cattle prices were supplied by Banco di Amazonia and confirmed by Prof. da Silva and Mr. Oliveira. The real price ratio between calves and cattle varies over time and depends on various factors such as time of the year of the transaction and individual weight. 50% is a good first approximation for the ratio of calve to cow prices. One year old cows are valued at approximately 70% of the price of two year olds.

5'500 R$ is an approximation of the amount required for labor, medical and other cost for raising 25 animals for two years.

Thus the buying price for a calve was set to 50% of the cattle price + 5'500 R$, while the selling price was 50% of the cattle price for calves, 70% of the cattle price for one year olds and 100% of the cattle price for two year olds.

Cattle Price Development

We used the historic farm-gate cattle prices in Tocantins (supplied Fundação Getulio Vargas, Brazil). We further adjusted those prices for inflation[27], starting in 1999, the first year after the Brazilian hyperinflation event.

We derived an inflation adjusted mean increase and standard deviation from this historic distribution to calibrate a random walk model for the future prices.

Note that the price development was generated randomly once but then fixed for all players. This was necessary to create comparability between the players and reduce noise. Future online versions may use a different, random price path for every player.

Carbon Price

We used a starting price of 20 R$, resp. 10 USD. This price was chosen by the authors as a realistic carbon price, and also happens to be just above the opportunity cost of extensive grazing when calibrating treatment 3 and 4.

Carbon Price Development in T1

We used historic Clean Development Mechanism (CDM) prices from Point Carbon to derive a standard deviation. We decided to have no mean change in the future carbon price, while the historic CDM prices had a strong net decrease over time. The carbon price in the game was created using a random walk model with a floor at a price of zero.

We deliberately picked a random distribution that included one price drop to zero, as we consider such price drops to zero non-random events when the price is determined in a cap-and-trade scheme.

Note that the price development was generated randomly once but then fixed for all players. This was necessary to create comparability between the players and reduce noise. Future online versions may use a different, random price path for every player.

Personal Costs

This value varies widely in the real world as farmers have different lifestyles and off-farm incomes. It was thus defined by the researchers to adjust the difficulty of the game within the range of possible real world values. During the experiment, an annual cost of 75'000 R$ was used. Note that the personal costs do not influence the profitability of different land use decisions and the results should be robust for other values.

Degradation Model

The degradation model is following an ecological growth model (Martha Júnior et al., 2003), and was further adjusted and confirmed by Prof. da Silva. While the speed of degradation is realistic, the model simplifies the impact of degradation on cow growth. In the model, the cow growth is constant between 0 and 8 points of degradation. In the

[27] The Inflation rate was taken from a private source available at http://www.inflation.eu/inflation-rates/brazil/historic-inflation/cpi-inflation-brazil.aspx

real world, the interaction is more complex as cow growth decreases with degradation. Also the natural regeneration in the game is a strong simplification, as a real pasture regenerates at first but then starts to overgrow with bushes when left alone for several years.

Credit

Most ranches in Tocantins are credit financed by governmental banks at very low interest rates. Nevertheless, we found that most players did not take credit up to the credit limit of low interest loans in the game during pre-testing, when the game was implemented using modeling this form of finance explicitly.

Additionally, we found it difficult to implement a realistic, inflation adjusted model of the low-interest loans, as the inflation adjusted interest rate is approximately at negative 2%. We thus decided to approximate the financial situation by giving the entire credit limit as an initial endowment.

The game was found a lot easier to comprehend after this adjustment.

Baseline Emissions (Treatment T1 and T2)

To derive the baseline emissions, the game was played in the control treatment according to the heuristic explained in Box I. Using this strategy, by round 8 the entire area is deforested. The resulting deforestation over time was stretched by a factor of a little more than three, leading to a 25-year baseline. The heuristic leads to a stepwise deforestation with high deforestation in the first year and increasing peaks of deforestation every two years, and another high peak after eight years, which was smoothened by approximating the stepwise increase with a parabolic function. A parabolic function was found a better fit to the stepwise deforestation over time curve than linear or exponential functions. We did not want to use a more complex function than that to avoid confusion.

Formal Description of the Game

The game is object based. **Cells** and **Cows** are objects with state variables.

Cows have only one state variable, **age**.

Cells have a state variable of **land use type**, which can have the values "extensive pasture", "intensive pasture", or "forest" and, if in state = extensive pasture, a they have another state variable for "**degradation**". "Degradation" is always >0. Every cow is located on a cell in the state "extensive pasture" or "intensive pasture", defining another cell variable, namely **"Cows on Cell$_i$"**. **"Cows on Cell$_i$"** is always <4. The total number of cells is fixed to 64.

Additionally, there are three global variables: **"Savings"** and the related variable **"Loans",** which limit the actions that can be performed by the player. "**Cow Price"** is exogenously determined and influences both costs and returns for the player.

The player has the following **action options**. If an action option has a cost or revenue, "savings" is updated immediately during the round. The player cannot take action options that have a cost higher than "savings".

"**Deforest"** changes the "land use type" of a cell from "forest" to "extensive pasture" and zero degradation. Deforestation has a cost of 18'000 R$ per cell.

"**Restore"** changes "degradation" of a cell to zero. Restoration at round t can only be applied to cells where "Cows on Cell$_i$ (t)" = 0. Restoration has a cost of 3'500 R$ * "degradation".

As a result, cells cannot be used for one year when using restoration. Restoration is in the game primarily to make mistakes in degradation management leading to degradation >8 reversible. It is generally not profitable, unless mistakes have been made earlier.

"**Intensify"** changes the "land use type" of a cell from "extensive pasture" to "intensive pasture". Intensification can only be applied to cells where "degradation" is < 5. Intensification costs 42'000 R$.

"Buy Calve" Adds a cow with "age" = 0 to a cell. The cost is 50% * "Cow Price" + 5'500 R$.

"Sell Cow" Removes a cow. The return depends on "age".

Return (**Sell Cow**, age = 0) = 50% * "Cow Price"

Return (**Sell Cow**, age = 1) = 70% * "Cow Price"

Return (**Sell Cow**, age >= 2) = 100% * "Cow Price"

Accordingly, it is never profitable to keep cows longer than 2 yeas

"Move Cow" moves a cow from one cell to another. This action has no cost.

Move cow is useful to manage degradation. This options is rarely required by a player planning ahead.

The state variables evolve in the following way from round t to round t+1

$Age_{t+1}(Cow_i) = Age_t(Cow_i) + 1$

$Degradation_{t+1}(Cell_i) = Degradation(Cell_i) + (Number\ of\ Cows\ on\ Cell_i)^2 + (IF\ (\text{“Number of Cows on } Cell_i = 0\text{” THEN “-1” ELSE “0”});$

Every round, extensive pasture regenerates by 1 point per round if no cows are on it and degrades by one point if one cow is on it. It degrades faster if more cows are on it (4 points for 2 cows, 9 points for 3 cows).

The global variables evolve in the following way from round t to round t+1

$savings_{t+1} = savings_t - 75'000 - 8'000 * number\ of\ cells\ where$ “land use type” = “intensive pasture” $- loans_t$.

75'000 are fixed costs every round. Intensification has a maintenance cost of 8'000 per cell per round.

If $savings_{t+1} >= 0$: $Loans_{t+1}=0$

If $savings_{t+1} < 0$: $Loans_{t+1} = loans_t - savings_{t+1} + 25\% * (loans_t - savings_{t+1})$

Loans are included in the game only as a buffer to prevent bankruptcy due to small mistakes. The interest rate is 25%, which is an average credit card interest rate in the region. It is never profitable to go into loans. The game assumes that players are already at their regular credit limit due to the initial endowment. Players cannot actively take loans.

Cow Price(t) was modeled using a random walk with the same variance as historical cow prices in Tocantins, using a single, fixed price evolution for all players. At round t, the graph is visible till t to the players. Future prices are uncertain to the players.

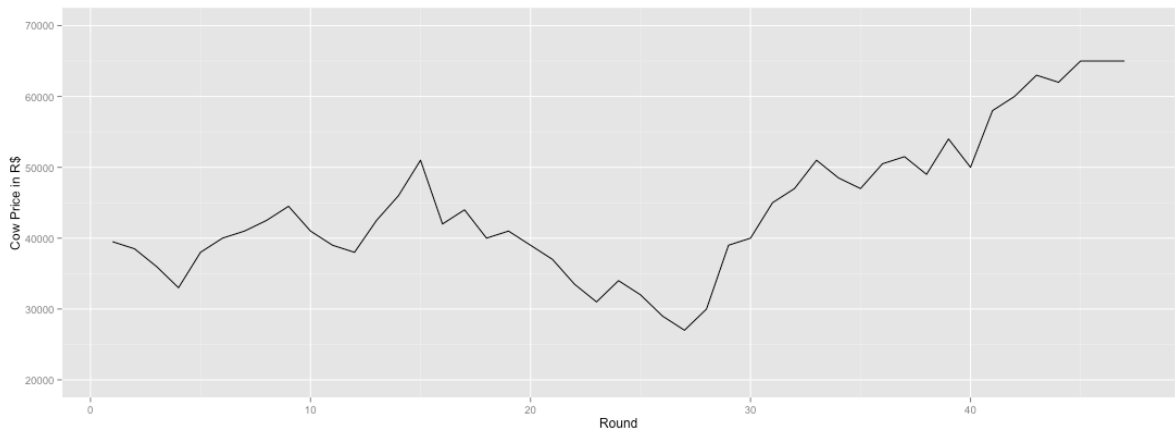

Figure III – 1 : Cow Price evolution over time

Initial Values:

Cow $Price_{t=0}$ = 40'000 R$

$Savings_{t=0}$ = 1'000'000

$State(Cell_{i<14})$ = Pasture

State $Celli_{>=14}$) = Forest

$Degradation_{t=0}(Cell_{i<14})$ = 0

Additional Payments in the Treatments

Strong Conditionality

$Savings_{t+1} = Savings_{(control)} + (Carbon\ Budget_{Baseline,\ t} - Carbon\ Budget_{actual,\ t}) * Carbon\ Price_t$

The $Carbon\ Budget_{Baseline,\ t}$ is defined by the following table

Table III – 1, Baseline Emissions

Round	1	2	3	4	5	6	7	8	9
Baseline in tCO_2	5'000	10'100	15'300	20'700	26'300	32'150	38'300	44'800	51'700

10	11	12	13	14	15	16	17
59'050	66'900	75'300	84'300	93'900	104'200	115'200	127'000

18	19	20	21	22	23	24	25
139'600	153'100	167'500	182'900	199'300	216'750	235'300	255'000

After round 25, the Baseline is zero. T1

Carbon $Price_t$ is defined by the following table for T1

Table III – 2, Carbon Prices in T1

Round	1	2	3	4	5	6	7	8	9
Carbon Price in R$ per tCO_2	25.66	24.6	26.5	23.73	19.38	9.38	6.42	0	8.74

10	11	12	13	14	15	16	17	18	19
14.38	19.33	20.9	29.88	25.45	25.63	28.3	27.95	24.64	21.33

20	21	22	23	24	25
15.66	9.32	19.37	24.09	23.06	26.32

T2

Carbon $Price_t$ is always 20R$

Weak Conditionality

$Savings_{t+1} = Savings_{(control)} + (51 - Cumulative\ Cells\ deforested_t) * Per\ Hectare\ Price_t$

T3

$Per\ Hectare\ Price_t$ = 4'000 R$; till round 25, then zero

T4

$Per\ Hectare\ Price_t$ = 4'000 R$ + ($Cow\ Price_t$ – 40'000)* 0.15 R$; till round 25, then zero

T5

$Per\ Hectare\ Price_t$= 2'100 R$; for all rounds.

ANNEX IV: Recruiting and Instructions

The ranchers were recruited through capacity building programs conducted by agricultural extension services (SEAGRO, SEBRAE and ADAPEC) in Tocantins from October 2013 to December 2013. Additionally, ranchers' family members and students of ranching-related subjects were recruited through the local universities. The sessions were played in various cities at university classrooms, seminar rooms of the agricultural extension service and occasional hotel conference rooms or other rancher meeting points. The game was pre-tested with students, ranchers, ranchers' family members and employees of the agricultural extension service. We also allowed employees of the agricultural extension services to participate in the experiment, but excluded them from the analysis, as we did not have a sufficiently large number (N=16) to test whether they behave differently from the other player groups.

As we had no secure way of testing whether a student truly was a family member of a rancher, we did not exclude students not affiliated to ranches from the experiment, as this would have set an incentive to wrongly report ranch-affiliation. The ranch owners and ranch owners' family members who participated in the game were affiliated to ranches between 17 and 7'600 ha with an average of 500 ha. We had slightly more male than female in the sample with a ration of 140 to 206.

At each session, ten players are gathered in one room, sitting on tables, each with a 10.1-inch tablet computer and a set of earphones. As all players play with earphones, including background music and sound effects of the game, verbal communication is difficult and was rarely observed during the game. While it was found a cultural impossibility to prohibit all communication among the players especially at the beginning of the sessions, we made sure that there was no talking during the Baseline- and Treatment Phase of the game.

Once all players had arrived a short introductory presentation was given by the experimenters, explaining the purpose of the game and the relevance of the subject for the participants. After this, the rules of the game were communicated in private via a video on the tablets. Additionally, each subject had two A4 pages with visual instructions, repeating the content of the video.

The video was followed by the Training Phase, in which the players could re-start the game at will and ask questions. The Training Phase was interrupted three times for further explanations of the functioning of the game.

The first interruption was done five minutes after the last player finished the video to repeat three issues explained in the video, which were found to be frequently misunderstood by the participants in the pretesting. The slide "Some Advice I" that can be found in the introductory presentation was not shown to the participants, as the advice was given only verbally and in Portuguese. This procedure was found more effective in the pre-testing than working with slides. First, it was made clear again that it is allowed to deforest the entire game area. Second, the degradation model was explained again. Third, it was repeated that the goal of the game is to make profit and the only way to make profit is to buy calves and sell cows, ideally after two years.

The second interruption follows five minutes later and explained how to avoid the "non-sense" play mentioned in Box I on page 8. The experimenter gathered all participants and showed some life gameplay. This procedure was preferred to using another video, as during the pre-testing it became clear that attention to videos is lower than to a life presentation. The second advice was introduced as very important

and elementary to making any profit in the experiment, using the following wording (in Portuguese translation):

"This tip is the most important. If you pay attention now, you will make good profit and enjoy the game. If you don't understand this, you will not make any money at all and the game will not be very interesting. There are two key principles in the game. The first principle: Pasture without animals does not make profit. So, whenever you have empty pasture with low degradation, it is most important to buy animals. This is the first thing to check every year – do I have empty pasture? Do I have money? If yes, buy animals!"

During this, the experimenter showed how to buy one animal per cell of pasture in the first year of the game.

"But now the second principle: Money on the bank does not make profit. See, I still have more than half a million Reais on my bank account and no more empty pasture. So now it is time to invest more. This is where the game gets interesting, because you have several options to invest. First, you can buy two calves per cell. This will degrade the land much faster, but also gives more profit per cell in the next year" (Experimenter illustrated buying a second calve on 3 cells in the game.))

"Or you can invest in the land. There are three options to invest in the land: First, you can deforest" (Experimenter illustrates deforesting 3 cells in the game) "but now, I have empty pasture again. So deforesting alone does not make profit. Remember the first principle. I also need to buy calves on this new pasture to make it profitable." (Experimenter buys one calve per cell on the 3 newly deforested cells.))

"The second option to invest in the land is to intensify." (Experimenter illustrates intensifying 3 cells) "When you intensify a cell, it does not degrade anymore, no matter how many animals you put there. So there is no problem to buy three animals on every intensified cell. Actually, an intensified cell with less than three animals is like normal pasture without animals – it does not make good profit! Each intensified cells costs 8'000 Reais per year, no matter if you buy animals or not. So it is the same issue as with deforestation – it does not help to intensify, if you don't buy more animals. Once you have intensified cells, you see this additional button when buying animals. This makes it easier and faster to buy three animals in every intensified cell." (Experimenter illustrates using the button "fill intensified cells" to buy three calves in every cell.)

"The third option to invest in the land is to recuperate. I cannot show it to you now, as in the first year there is no degraded land. Recuperation brings back a cell to zero degradation, but it costs 3'500 Reais per point of degradation and takes one year. Alternatively, you can let the cells regenerate naturally at no cost by one point per year, if you don't buy animals on the cells. Only cells with 8 points or less regenerate. For cells with 9 or more points, you need to pay to use them again."

"One last thing for now: It is not smart to over-invest. For example, if I deforest like this" (Experimenter deforests as many cells as possible) "I do not have any money left to buy calves. So I end up with lots of empty pasture. And empty pasture does not make profit. This is overinvesting. Also, you will need some money left to cover your annual costs" (click on next year) "As you can see here, you need to pay 75'000 Reais every year. This is for all the expenses, gasoline, food, and so on. Additionally, you need to pay 8'000 per year for every intensified cell. Because the value of your animals is best after two years, it's better to invest only so much money that you still have enough money on the bank

to pay your annual cost for two years. If you do not have enough money to cover your annual costs, you will automatically take a credit. Credit is very expensive and not useful to make profit. You can pay back the credit automatically by passing a year with enough money on the bank to pay all annual cost plus the credit. And by the way, people who use a calculator tend to make more money in the game." (Experimenter offers calculators to everybody.)

Another five minutes later, the last interruption explained a basic calculation on the profitability of different investments.

The calculation was illustrated using the last slide of the introductory presentation. The slide shows three different options to invest in a piece of land of two cells of forest, one cell of pasture and two degraded cell of 9 points of degradation. The slide was explained with the following wording: "This is the last tip. It is a bit more advanced. The previous tip was more important, so remember: Empty pasture does not make profit and money on the bank does not make profit. So if you have money left to invest into the land, you have different options. Let's look at those options again. You can deforest, recuperate or intensify. You can see those three options here. In order to compare them more easily, I'm showing you three options that produce the same amount of cattle over eight years. So after eight years, in all three cases you can sell twelve animals. So your income is the same in all three cases. But the cost is different, and also the state of the land afterwards.

Deforesting two cells costs 36'000 Reais. Then you have three cells of good pasture and can produce twelve animals in eight years, buying one animal per cell. After eight years, you have three cells of 8 points of degradation and two cells of 9 points.

If you use the second option, you recuperate two cells, this costs 63'000 Reais, and it also takes one year. After that, you also have three cells of good pasture and can produce twelve animals in eight years. After eight years, you have three cells of 8 points of degradation and two cells forest.

The last option is to intensify. If you intensify one cell of good pasture, you can now keep three animals on this one cell, so you also produce twelve animals over eight years. The cost of intensification is 42'000 Reais in the first year and 8'000 in every year, so in the end it costs 42'000 plus 64'000 Reais, is 106'000 Reais. After eight years, you have two cells of forest and two cells of 9 points of degradation and one intensified cell.

This calculation is to help you understand how the different types of investments work and which way is more profitable. Also keep in mind that this calculation is done only for the first phase of the game, when you do not receive any subsidies. You now have another twenty minutes to practice, then everybody should start the real game. If you manage to make 1'500'000 Reais in the training, you can also start earlier if you want."

After this last tip players who feel that they sufficiently understand the game and made 1'500'000 Reais in the game are allowed to start the Baseline Phase. All other players are asked to start after twenty more minutes of training with further one-on-one support for any questions. In almost all cases, the further support consisted of repeating the previous instructions from the tips and the video in various ways, as all important issues of the game had been explained at least once at this point.

During the Baseline Phase, the experimenters do not answer any further questions on the game, except for technical problems.

Once the Baseline Phase is finished, the Treatment Phase starts. Each player views a short video explaining the treatment. The video ends by asking the player to pick an envelop with a number from one to six. The experimenter has those envelopes, which contain a manual explaining how the treatment works. The manuals are read by the subject, explained by the experimenter and any remaining questions answered. Once the Treatment Phase started, no more questions are allowed.

The following wording (in Portuguese) was used to introduce the treatments, while showing the treatment manuals:

T1

"You will play the game one more time now. Everything is exactly the same, only the development of the cattle price is different. But you will play with a carbon credit project now. Let me explain you again how this works. Let me first explain what happens if you do not deforest at all. You will receive a subsidy every year. The subsidy is calculated as the number of carbon credits times the carbon price. In this list (show baseline on the manual), you see how many carbon credits you will receive in each year. In the first year, you will get 5'000 carbon credits, then a little more in the next year, and so on, 9'000 in 2027, and almost 20'000 in the last year of the subsidy.

The carbon price is a market price on a financial market. You will see each year's price in your financial statistics. For example, if the price is 20 R$ in one year, and you receive 5'000 carbon credits, you receive 100'000 R$ in subsidies.

This graph is a visualization of the process: The blue line are those numbers (point at the baseline), and the green line is sell carbon – next year (black line), green line sell carbon and so on. So every year you can sell the difference between the black line and the green line.

This is the amount of subsidies that you receive if you do not deforest at all. But what happens if you deforest? Deforesting one cell costs 5'000 carbon credits. So for example, if you deforest one cell in the first year, you receive 5'000 minus 5'000 carbon credits – nothing. If you deforest a cell in 2027, you receive 9'000 minus 5'000 carbon credits – 4'000 carbon credits.

But what happens if you deforest more than one cell? For example, if you deforest five cells in the first year? 5'000 times five is 25'000. So you do not receive credits in the first year (point at the baseline), no credits in the second year (point at second year), none here, and here, and here (point at 2019), you receive a little bit. Why? Because this plus this plus this plus this plus this (point on years 2015-2019) is more than 25'000.

Here is a visualization of the process. The red line are your emissions. So if you emit more than the baseline, you do not receive any subsidies till the baseline emissions catch up with your emissions. Afterwards, the subsidy continues normally.

2040 is the last year of the subsidies. You will receive a message reminding you when the subsidies end. After this, you will play another 21 years till 2061 without any subsidies, just like the first phases.

During this Phase, we will ask you every four years about your expectations of the future cattle price and carbon price. You can answer fall a lot, fall a little, stay more or less the same, raise a little and raise a lot. Please take the time to answer, as this is important for our analysis. Your answers do not influence the game.

If you want, you can watch the video again or start playing now."

T2

The wording in T2 is exactly the same as in T1, except for the sentence:" The carbon price is a market price on a financial market. You will see each year's price in your financial statistics. For example, if the price is 20 R$ in one year, and you receive 5'000 carbon credits, you receive 100'000 R$ in subsidies." This is replaced by the sentence: "The carbon price is 20 R$. If you receive 5'000 carbon credits in one year, you receive 100'000 R$ in subsidies."

T3

"You will play the game one more time now. Everything is exactly the same, only the development of the cattle price is different. You will play with a payment for ecosystem services now. This means, you will receive a subsidy. For every cell of forest, you will receive 4'000 Reais every year. So for example, if you do not deforest anything, you have 51 cells of forest. So you receive 204'000 Reais per year. If you for example deforest 10 cells, you only have 41 cells of forest, and thus the subsidy is reduced to 164'000 Reais.

2040 is the last year of the subsidies. You will receive a message reminding you when the subsidies end. After this, you will play another 21 years till 2061 without any subsidies, just like the first phases.

During this Phase, we will ask you every four years about your expectations of the future cattle price. You can answer fall a lot, fall a little, stay more or less the same, raise a little and raise a lot. Please take the time to answer, as this is important for our analysis. Your answers do not influence the game."

T4

The wording in T4 is exactly the same as in T1, except for the sentence:" For every cell of forest, you will receive 4'000 Reais every year." This is replaced by the sentence: "In the first year, for every cell of forest, you will receive 4'000 Reais every year. In later years, the subsidy follows the cattle price, so when the cattle price is high, the subsidy is high, and when the cattle price is low, the subsidy is low, too. For every 1'000 Reais change in the cattle price, the subsidy per cell changes by 150 Reais."

During this Phase, we will ask you every four years about your expectations of the future cattle price. You can answer fall a lot, fall a little, stay more or less the same, raise a little and raise a lot. Please take the time to answer, as this is important for our analysis. Your answers do not influence the game.

T5

"You will play the game one more time now. Everything is exactly the same, only the development of the cattle price is different. You will play with a payment for ecosystem services now. This means, you will receive a subsidy. For every cell of forest, you will receive 2'100 Reais every year. So for example, if you do not deforest anything, you have 51 cells of forest. So you receive 107'100 Reais per year. If you for example deforest 10 cells, you only have 41 cells of forest, and thus the subsidy is reduced to 86'100 Reais.

This phase lasts longer than the last phase, this time the last year is 2061.

During this Phase, we will ask you every four years about your expectations of the future cattle price. You can answer fall a lot, fall a little, stay more or less the same, raise a little and raise a lot. Please take the time to answer, as this is important for our analysis. Your answers do not influence the game."

T6

"You will play the game one more time now. Everything is exactly the same, only the development of the cattle price is different. You will play from 2015 till 2061. You were selected for the control group, so you will not receive any subsidies. As you do not receive any subsidies during the game, you will get an additional bonus of 6 million Reais in the end, so you have a fair chance to make the same amount as everybody else.

During this Phase, we will ask you every four years about your expectations of the future cattle price. You can answer fall a lot, fall a little, stay more or less the same, raise a little and raise a lot. Please take the time to answer, as this is important for our analysis. Your answers do not influence the game."

After the game, the players' final outcome is calculated and paid out in cash in by the experimenter. While offering anonymous payout, it was found that the almost all players talk about their payoffs after the game.

ANNEX V: Hard- and Software used for game development and experiment

Hardware:

Ten Samsung Galaxy Tab 2, 10.1 inch tablet computer were used to play the game.

The game was hosted locally using the experimenter's laptop as sever (Mac Book Pro™).

The connection was established through a local WiFi, which was created using a USB powered Nano-Router.

Software:

Espresso™ to create and edit the HTML files

Adobe Creative Suit™ for the design of the visuals

Camtasia™ for the tutorial videos

Sequel Pro™ to create and edit the SQL Database

MAMP™ to host the local Apache & MYSQL server

Google Chrome™ to play the game on the tablets

CyanogenMod™ operating system to improve the technical performance of the tablets

RStudio™ to analyze the data

http://www.github.org to share the code online
https://github.com/danilowanner/Cattle-Farming-Game/commits/master