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The role of communication on an experimental market for tradable development rights

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Abstract: Tradable development rights (TDR) are discussed as a means of containing urban sprawl in numerous countries. Despite its theoretical superiority in ensuring an efficient redistribution of planning rights, its applicability is concerned with several open questions and potential problems. Introducing a novel experimental setting, we simulate a cap & trade TDR scheme and investigate the effects of communication, an aspect typically assumed to be irrelevant by theory. We consider communication among individual participants competing in a TDR system and team decision-making facilitated by face-to-face communication. We find the system to be quite efficient, despite overshooting certificate prices particularly in the beginning for both initial issuance in auctions and the secondary market. Communication significantly reduces auction prices, leading to substantially less income redistribution from participants to the auctioneer. This effect is explained by participants' improved understanding of the cap & trade system when communicating; despite participants' attempts, they fail to establish collusion. Team decision-making is not only shown to reduce overshooting prices; moreover, it also improves the system's efficiency. These results are interpreted as emphasizing the efficiency and political feasibility of TDR schemes when including communication among its participants.

Keywords: cap & trade, collusion, communication, economic experiment, land consumption, tradable planning permits

JEL Classification: C91; C92; D8

1. Introduction

Urban sprawl and its adverse ecological consequences have long been addressed by researchers and policy-makers. Among the regulatory options to foster a sustainable land use discussed in recent years, tradable development rights (TDR) are increasingly considered in different countries as a viable instrument achieving reductions in land consumption while allowing for the realization of the most profitable projects (van der Veen et al., 2010).[1] As with similar market-based instruments, TDR are expected to be the superior regulatory instrument for implementing constraints on land consumption. Assuming floating prices and an effective system of trading and issuing TDR, planners can reduce land consumption with near-perfect precision while reallocating development rights to the most valuable projects (c.p. Thorsnes and Simons, 1999; for more recent theoretical contributions, see e.g. Nuissl and Schroeter-Schlaack, 2009; Ward, 2013; Vejchodska, 2015).

While several studies have provided surveys on the success and problems of TDR schemes, particularly for the United States (e.g. Kaplowitz et al., 2008; Pruetz and Standridge, 2009; Tan and Beckman, 2010; Chan and Hou, 2015), their ability to provide generalizable policy implications for different national and institutional contexts remains limited (Bengston et al., 2004; Kopits et al., 2008). As a promising complement to these case-study based surveys, it has been suggested to run laboratory experiments investigating more general behavioral patterns and testing specific policy instruments (Greenstone and Gayer, 2009), e.g. for the design of CO_2 cap & trade schemes (c.p. Convery, 2009 and Grimm and Illieva, 2013).[2] Despite the potential value for improving the design of TDR schemes, few studies capture TDR experimentally; for instance, Henger (2013) compares student and professional TDR

[1] TDR are predominantly discussed by environmental economists and planners in economically developed nations such as Australia (Harman and Choy, 2011), China (Wang et al., 2009), Germany (Henger and Bizer, 2010), Italy (Micelli, 2002), the Netherlands (Janssen-Jansen, 2008), Switzerland (Mengini et al., 2015). In Germany, the discussion on TDR has increased following the federal government's commitment to drastically reduce land consumption within the next years; consequently, several large-scale trials for a nation-wide system of TDR have been conducted. The United States, in turn, have been using TDR on a broad scale since the 1970s in more than thirty states (see e.g. Pruetz, 1997 for an overview).

[2] The discussion regarding the application of experimental evidence to the institutional design in different domains of policy-making has been an ongoing debate for several years, with numerous authors arguing for a pragmatic approach of using behavioral evidence as a complement to other forms of empirical and theoretical evidence. For an introduction to the discussion, see e.g. Falk and Fehr (2003), Falk and Heckman (2009), Madrian (2014) and Chetty (2015).

trading, while Meub et al. (2016) investigate the resilience of a TDR system against exogenous shocks.

Building on these studies, we argue that the current experimental approaches have an inherent limitation similar to that of theoretical studies, namely the assumption that agents decide autonomously without communicating and potentially coordinating with other agents in the TDR system. This assumption might be unrealistic; indeed, we would suggest that it is unlikely for individuals charged with making land use decisions within a system of TDR to do so in complete isolation from other officials. Rather, it can be expected that they are members of networks at regional, state or national levels, communicate extensively about the decisions taken in the TDR system and build up long-term relationships, thus potentially making arrangements that could distort or improve market outcomes. It is therefore an open question whether communication among participants of a TDR scheme could lead to a failure in the market's capability to efficiently reallocate certificates or even increase the system's efficiency. Both outcomes would have substantial implications for the political feasibility of TDR schemes and the viability of its theoretical assumptions.

To determine the impact of communication, we build on an experimental design simulating a comprehensive TDR scheme, which allows us to measure subjects' reactions to variations of its core parameters. We investigate two prominent mechanisms of communication that potentially have a strong impact on the functioning of a TDR mechanism. Firstly, communication among all agents within a TDR market is introduced to determine whether agents establish cooperation - e.g. by collusive behavior in the auction of certificates - during their repeated interaction. Since collusion has been identified as a potential source of inefficiency in CO_2 cap & trade systems (Whitford, 2007; Ehrhart et al., 2008), its prevalence in TDR markets might similarly reduce the system's feasibility. Secondly, we investigate the effects of communication within small groups of participants representing a single agent to determine whether small group decision-making increases the overall efficiency in the TDR market. Numerous experimental studies have shown that intra-group communication leads to more rational decision-making overall (Kugler et al., 2012; Charness and Sutter, 2012). If this finding transfers to TDR schemes - where extensive communication within organizations responsible for obtaining, trading and using TDR can be assumed - specific problems of TDR systems emphasized in previous experimental studies might be mitigated, such as overshooting prices (e.g. Meub et al., 2016).

The remainder of this paper is structured as follows. The subsequent section reviews the related literature, before section three explains the experimental design and the underlying theoretical model. Section four presents our findings and section five concludes.

2. Literature review

To date, TDR systems have primarily been considered from a case-study perspective, yielding broad evidence on factors determining the success factors of TDR at a regional political level, such as strong demand for additional areas of development or regionally customized receiving areas (Pruetz and Standridge, 2009). These policy-oriented considerations are based upon a large body of review studies covering fairly heterogeneous implementations of TDR systems, particularly in the United States. Therefore, studies using qualitative indicators (e.g. Santos et al., 2015; Harman et al., 2015; Kaplowitz et al., 2008; Pruetz and Standridge, 2009; Machemer and Kaplowitz, 2002; Danner, 1997) as well as reviews using quantitative measures (Menghini et al., 2015; Kopits et al., 2008; Lynch and Musser, 2001; Lynch and Lovell, 2003) have been presented. While these studies have led to the identification of several determinants for the successful regional implementation of TDR, we argue that these conclusions are necessarily tied to the respective national and institutional contexts.

Complementary to the reviews on local implementations of TDR schemes, laboratory experiments can be used to test specific institutional parameters relevant in the context of land use decisions. Analyzing counterfactual situations with or without a specific regulation (Charness and Fehr, 2015 and Santos, 2011), a limited number of studies have provided initial laboratory evidence. Testing the general applicability of results obtained by observing student participants to land use decisions, Henger (2013) compared the performance of students and regional planners in a TDR scheme, yielding the result that both groups achieve efficient reallocations of development rights overall. Meub et al. (2014) extend this basic setting and investigate the influence of political business cycles on the efficiency of TDR schemes, pointing to potential distortions in TDR schemes due to politicians' self-serving incentives. Meub et al. (2015) compare different mechanisms of issuing development rights, finding that auctioning introduces several sources of inefficiency, making grandfathering the superior institutional choice from a welfare perspective. Proeger et al. (2015) have considered the effects of sustained high investment risk, finding that TDR schemes lose efficiency when confronted with higher levels of risk. Finally, Meub et al. (2016) investigate the resilience of a

TDR scheme to exogenous economic shocks, finding that the system compensates shocks fairly well.

While several core factors regarding TDR schemes have been investigated in laboratory settings, it is important to emphasize that the experimental designs uniformly assume individual decision-making, excluding interaction among agents. Since this should be considered an overly strict assumption for the study of behavioral patterns in TDR systems, previous results might only insufficiently represent the actual decision situation. Rather, the broad results of economic group research should be taken into account, pointing out that decisions taken by groups are regularly closer to game-theoretically optimal behavior across a wide range of economic contexts (Kugler et al., 2012; Charness and Sutter, 2012). Overall, three distinct reasons are given concerning why groups show superior rationality when compared to subjects in settings of individual decision-making. First, teams have higher cumulated cognitive abilities than individuals, which increases the likelihood of reaching better decisions. Examples of this include the Beauty-Contest game (Kocher and Sutter, 2005), urn experiments on first-order stochastic dominance (Charness et al., 2007) or the Linda Paradox game, involving the correct interpretation of probabilities (Charness et al., 2010). Second, teams anticipate the behavior of other persons more efficiently, which enhances their ability to derive better responses conditional on other players' potential decisions. For instance, this is shown in the limit-pricing game (Cooper and Kagel, 2005) or simple two-player games with unique pure-strategy, Pareto-inefficient Nash equilibria (Sutter et al., 2010). Third, groups have been shown to develop stronger self-interested preferences than individuals, e.g. shown in the trust game (Kugler et al., 2007), the centipede game (Bornstein et al., 2004) or prisoner's dilemma games (Charness et al., 2007). This is explained by their reduction of social considerations through establishing in-group norms for maximizing the collective income (Charness and Sutter, 2012). Overall, groups have been shown to be cognitively superior, more anticipatory and less restricted by social concerns, bringing them closer to rational decision-making. Accordingly, introducing communication and the ability to cooperate within a TDR scheme might substantially alter the results presented in previous experimental implementations of TDR, such as overshooting prices or endowment effects.

Since cooperation might enhance rational decision-making in a TDR scheme, this might lead to collusive efforts aimed at reducing the price of certificates paid to the auctioneer. This strategic behavior is shown in several theoretical and experimental studies as a consequence of a broad range of auction mechanisms. While it is accepted that the auction design should reduce the likelihood of collusion among bidders (Whitford, 2007), the detrimental effect of communication and collusion has been shown for different auction formats. Using a theoretical model, this problem is shown for the EU-ETS[3] system by Ehrhart et al. (2008). Burtraw et al. (2009) report experiments on collusion for different formats of auctions, in which subjects were allowed to use chat communication, which lead to lower prices in the auctions and a redistribution of revenues from the auctioneer to participants. Mougeot et al. (2011) show that uniform price auctions with sealed bids maximize the auctioneer's income once speculators are included. However, there is a tradeoff between higher revenues from auctions with speculators and the efficiency of the respective auction. Llorente-Saguer and Zultan (2014) consider the effects of first- and second-price auctions on collusion, showing that - contrary to theoretical predictions - there are identical levels of collusion and losses in efficiency. Most recently, Matousek and Cingl (2015) have shown that communication leading to collusion can also increase the overall efficiency in multi-object auctions. Overall, collusion is considered a substantial problem that potentially distorts the functioning of cap & trade systems as intended by regulators. Therefore, an experimental test involving a TDR scheme incorporating the element of communication is required to estimate the potential losses in efficiency and auctioneer revenues, as well as assessing whether a different institutional design is required to ensure an efficient reallocation of development rights.

[3] The EU-ETS system is used to trade CO_2 certificates since. Despite its numerous problems at present, its introduction can be considered a successful example for using both theoretical and experimental evidence to inform policy-making, as many institutional choices have been influenced by previous behavioral studies (Convery, 2009 and Grimm and Illieva, 2013 provide introductions to the literature).

3. Experimental design

3.1 A laboratory implementation of TDR

For our experimental investigation, we choose a fairly universal design of TDR that transfers to various institutional settings. Our experimental approach builds on previous laboratory studies of TDR and those simulating cap & trade systems for CO_2 emissions whereby experimental participants simulate economic agents that might represent municipalities, firms or individuals involved in a cap & trade system on land consumption.

Subjects are required to accumulate certificates to conduct building projects associated with land consumption. Due to the limited number of certificates issued by public authorities, not all desired projects can be realized; rather, an efficient TDR system reallocates certificates to the agents endowed with the most valuable projects.

The issuance of certificates in each period is conducted in two ways: first, half of the certificates are allocated among the players for free ("grandfathering"); and second, there is an auction for the remaining half of the certificates. Consequently, each player receives a distinct number of certificates and can bid on additional certificates in the ensuing auction. Subsequently, there is a trading phase, during which all players can buy and sell certificates; optimally, this leads to a redistribution of certificates to the players endowed with the most profitable projects, who consequently show the highest willingness to pay.

While the process of accumulating certificates and conducting projects is identical for all players, all agents have different characteristics, namely a different endowment with building projects and a different number of certificates grandfathered. This heterogeneity of agents simulates the different sizes of economic agents within a TDR scheme that might well be reflected in the grandfathering of certificates and the diverging availability of projects with a varying profitability.

While the basic setup implemented in our laboratory study simulates a system of TDR without any interaction among agents as a benchmark, our two additional treatments capture the element of communication. We assume that communication within networks of public or private participants in a system of TDR necessarily leads to a broad variety of arrangements that potentially undermine the efficient functioning of TDR. Since economic agents communicating openly have been shown to reach superior cognitive performance, to be more anticipatory of other players' behavior and less restricted by fairness norms than individual players, this may lead to quite different outcomes of a TDR scheme. We test the relevance of this effect by implementing two distinct communication channels prevalent in real-world land use decisions, namely immediate communication and cooperation within a small group representing a single agent and communication among all participants on a market, simulating broader networks, are implemented as separate treatments.

3.2 An outline of the game

The experimental design used in this study extends previous designs used e.g. by Meub et al. (2016). All experimental subjects are matched to markets of six players, which remain constant throughout the fifteen periods of the game. Subjects are endowed with different projects, whose realization generates payoff after the game's final period. This design feature simulates the duration of building projects and the resulting delay in the realization of respective payoffs. Furthermore, payoff can be generated by trading certificates on the secondary market. There is a starting endowment of 700ECU independent of player types.

Subjects are randomly assigned a "player type", which determines the number and type of available projects and the number of certificates grandfathered in each period. These different characteristics simulate that agents are likely to have different "sizes", i.e. possessing more or fewer potential building projects, having higher political clout or a greater market power. The assigned player types remain constant during the game. The different endowments for the six players per market are provided in table 1.

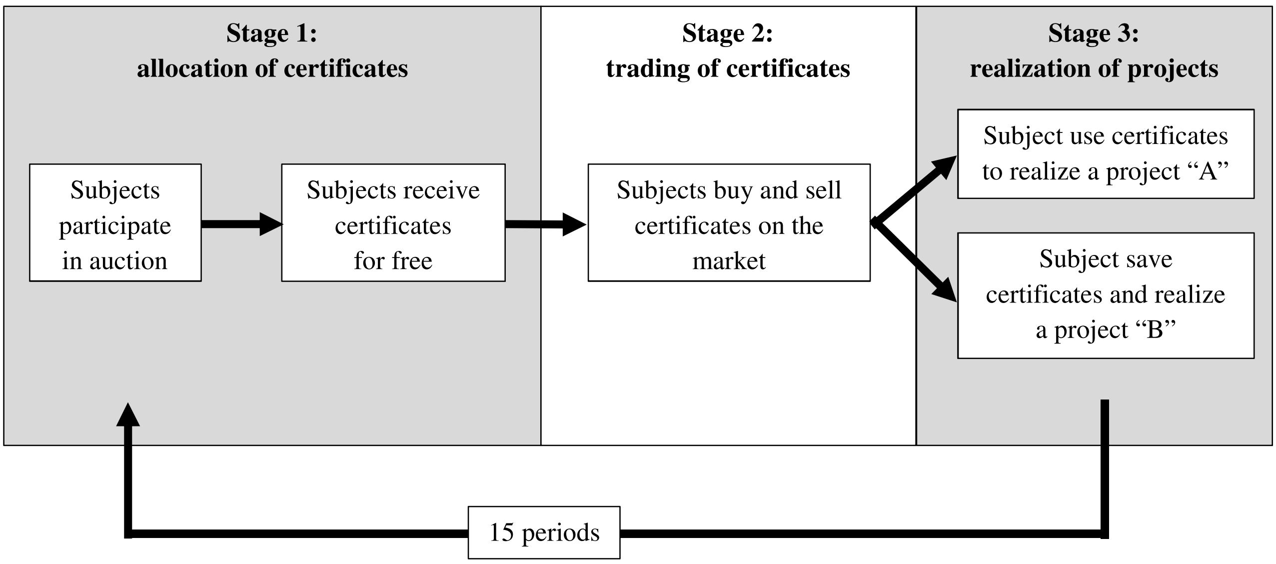
There are main projects denominated "Type A", whose realizations yield between 0- and 100ECU, whereby 100ECU converts to 1€. Subjects need to acquire eight certificates to conduct one of the six different Type A projects. Thereby, regardless of its value, each project type requires the same number of certificates. This assumption is made to increase the comprehensiveness of the game for the participants. The secondary project type is denominated "Type B", it has a uniform value of 10ECU and can be considered subjects' outside option when an insufficient number of certificates were accumulated in the respective period. Note that only one project can be conducted by each subject in each period. Hence, a total of fifteen projects can be realized by each subject during the game. The different projects are shown below in table 1.

project	type	A-1	A-2	A-3	A-4	A-5	A-6	B			
	value	100	80	60	40	20	0	10			
	certificates	8	8	8	8	8	8	0			
									total	**certificates period (total)**	
										#grandfathered	#auctioned
agent	**1**	10	8	6	4	2	0	15	**45**	4(60)	-
	2	8	10	6	4	2	0	15	**45**	3(45)	-
	3	6	8	10	4	2	0	15	**45**	2(30)	-
	4	4	6	8	10	2	0	15	**45**	1(15)	-
	5	2	4	6	8	10	0	15	**45**	1(15)	-
	6	0	2	4	6	8	10	15	**45**	1(15)	-
	total	**30**	**38**	**40**	**36**	**26**	**10**	**90**	**270**	**12(180)**	**12(180)**

Table 1. Player and project types and certificates allocated.

Each period comprises three stages; an overview is provided in figure 1.

Figure 1. Overview of the game's three stages.



Stage one involves the issuance of certificates by the auctioneer and the resulting accumulation by subjects. As shown in table 1, 12 of the 24 certificates issued in each period are auctioned in a uniform price auction with sealed bids, in which bids are ranked according to price. The lowest bid granted certificates subsequently determines the uniform price for all certificates auctioned in the respective period. The other half of the certificates are grandfathered to subjects according to their player type.

Stage two enables subjects to trade certificates in a simple double auction market for three minutes. There are no trade limits and no transaction costs. Subjects are, however, restricted by their budget constraint, which precludes borrowing to buy certificates.

Stage three allows subjects to realize one Type A project if they have accumulated enough certificates or one Type B project, requiring no certificates. Only one project can be realized per period, whereby the respective revenue is paid after the final period.

Our treatments introduce two distinct forms of communication into this basic framework. The treatments are fully identical to our benchmark treatment (*BENCHMARK)*, with the exception of the two modes of communication, whereas all other features of the game remain constant. Please note that *BENCHMARK* is also used as a baseline in Meub et al. (2016).

The first treatment (*CHAT*) introduces communication through a chat box implemented in z-Tree (Fischbacher, 2007) among all six market participants. In all stages of the game, the chat box enables the unrestricted communication among subjects.

In the second treatment (*TEAM*), teams of two subjects are randomly matched and decide as a single agent during the game. Since decisions are taken as a single player at one computer, the communication is conducted face-to-face and unanimous decisions are required. The payoff generated during the game is paid to each of the two players. Since the number of agents in each market remains constant, there are now twelve subjects, corresponding to six team agents.

3.4 Experimental procedure

All treatments were conducted in the Laboratory for Behavioral Economics at the University of Goettingen using z-Tree (Fischbacher, 2007) and ORSEE (Greiner, 2004). There were 48/24/48 participants for *BASELINE/CHAT/TEAM*. A common understanding of the game was ensured through prior control questions. Subjects were only allowed to participate in a single session. The instructions for the game were in German and can be obtained from the authors upon request, while an English translation is documented in the appendix. The sessions took 80 minutes on average. The average payment was 14.76 €, including a fix amount of 4€. Participants were recruited from various academic disciplines, comprising undergraduate and graduate students.

3.5. Expected behavior

The setup of the game incentivizes all player types to conduct exclusively Type A projects. Without a cap, 6 Type A projects would be realized by the 6 agents of a market in all 15 periods, which would result in a total of 90 Type A projects being realized. Introducing the cap on land consumption restricts the realization of Type A projects in each market by 50%. As each Type A project requires 8 certificates, 24 certificates are issued in each period to implement this cap on land consumption.

We derive the expectations about the prices of certificates by calculating agents' willingness to pay (WTP). The most valuable Type A projects generate a payoff of 100ECU. Taking into account the outside option of realizing Type B projects paying 10ECU, the WTP for one certificate for an agent endowed with a Type A-1 project is given by (100ECU-10ECU)/8=11.25ECU. The same procedure can be applied to Type A-2 projects, which gives a WTP of (80ECU-10ECU)/8=8.75ECU. No further calculations are needed as it is not expected that Type A-3 projects worth 60ECU are realized, given the overall cap of 45 Type A projects and the aggregate endowment of a market with 30 Type A-1 and 38 Type A-2 projects (cp. table 1). Overall, assuming unanimously optimal decision-making, we expect prices not to exceed 11.25ECU and not to fall below 8.75ECU.[4] Over the course of the game, we expect (for each market) all 30 Type A-1 projects to be realized, as well as 15 Type A-2 projects and 30 Type B projects.

Welfare is calculated by the aggregate value generated by realized projects, whereby we do not discriminate between the respective income of the auctioneer and the agents. Hence, we consider payments in the auction merely as a redistribution of income. The efficiency of the cap & trade system might only be distorted when certificates are not allocated optimally - i.e. not the most valuable projects are realized - or when they are forfeited at the end of the game. Nonetheless, the desirability of a cap & trade system as a regulatory instrument might be driven by the expected redistribution of income. Particularly the distribution of income between land consuming agents and the auctioneer might substantially determine the political feasibility of this instrument. In our framework, certificates should be valued between 11.25ECU for Type A-1 projects and 8.75ECU for Type A-2 projects, which allows us to derive the expected income for the auctioneer when assuming that two-thirds of the total 180

[4] Please note that agent are not informed on the actual distribution of projects and their respective values and therefore prices might well exceed 8.75ECU, which would be the fair price under full information and perfect foresight.

certificates auctioned throughout the game (12 certificates in each of the 15 periods) are actually sold at 11.25ECU and one-third at 8.75ECU. The fractions are deducted from the share of the specific project types that we expect to be realized under the cap regulation, i.e. 30/45 Type A-1 projects and 15/45 Type A-2 projects.

Table 2 outlines our expectations when considering optimal behavior by all agents. These expectations represent the efficient outcome that might be achieved by the cap & trade system.

project	**type**	A-1	A-2	B	
	value	100	80	10	
	certificates	8	8	0	
					total
land consumption	**# realizations**	30	15	45	**90**
wealth	**total value**	3000	1200	450	**4650**
certificates	**# bought**	120	60	0	**180**
	# free	120	60	0	**180**
income	**agents**	1650	675	450	**2775**
	auctioneer	1350	525	0	**1875**

Table 2. Theoretical predictions for an efficient cap & trade regulation

It should be noted that all expected results derived are based on the assumption of agents with identical cognitive abilities and understanding of the game. Speculation motives and path dependencies are excluded from our consideration and we assume that agents are capable of an ex ante evaluation and optimal decision-making, while expecting that all others have the same capabilities. Although we expect some of these assumption to fail when observing actual behavior in our experiment, the expected results still define a benchmark that allows appropriately interpreting our results, given that distortions can only be defined as systematic deviations from an otherwise efficient system if there is a benchmark representing optimal behavior.

Behavior in CHAT

In *CHAT*, all agents within a market can communicate. This treatment condition does not alter any expected behavior derived above as it does not affect agents' WTP. Overall, communication is nothing more than cheap talk and – from a rational agent's perspective – successful collusive behavior should not occur in the first place.

However, one might expect collusive behavior at the expense of the auctioneer, which might be built up during the fifteen periods of the game. Without communication, the understanding of being rivals competing for the accumulation of certificates and the realization of building projects might be predominant. Introducing communication might lead agents to understand each other in terms of potential partners with whom they should cooperate within a framework dominated by the auctioneer. However, there is no possibility to punish defective behavior and sealed bids in the auction cannot be directly observed. If agents agree upon a unit price and give identical bids, the beneficiaries of the auction are determined randomly. An agent who did not receive any certificates might feel betrayed as there is no chance to verify whether all the other agents had conformed to the agreement; thus, collusive behavior can easily break down. Nonetheless, the transmission of some information through chat communication among the competing agents can be expected. Consider some agent proposing to agree upon a unit price for the auction. This price simultaneously serves as a benchmark and might convey information about appropriate certificate pricing, which might be particularly relevant for subjects of limited cognitive abilities and imperfect understanding of the game. These considerations illustrate some potential behavioral reactions to chat communication among competitors. Therefore, our treatment *CHAT* can be characterized as being somewhat explorative and potential observations become interesting when abstracting from perfect rational behavior.

Behavior in TEAM

Having two-subject teams decide does not change our theoretical expectations, at least if one assumes that all participants fully understand the game with perfect foresight and following optimal behavior. However, economic small group research has emphasized the superiority of teams compared to individuals in intellective tasks (Kugler et al., 2012, Charness and Sutter, 2012), thus rehabilitating the expectation of rational behavior to some degree. In our setting, this superiority of small group decision-making might lead to prices closer to fair values. Hence, certificates might be reallocated more efficiently, i.e. according to WTP derived by projects' values and not according to agents' understanding of the game and the resulting ability to deduct fair prices. Overall, the efficiency of a cap & trade system to constrain land consumption might thus work more efficiently, although the effect on income distribution among agents and between agents and the auctioneer remains an open question, which will be addressed by analyzing our data.

4. Results

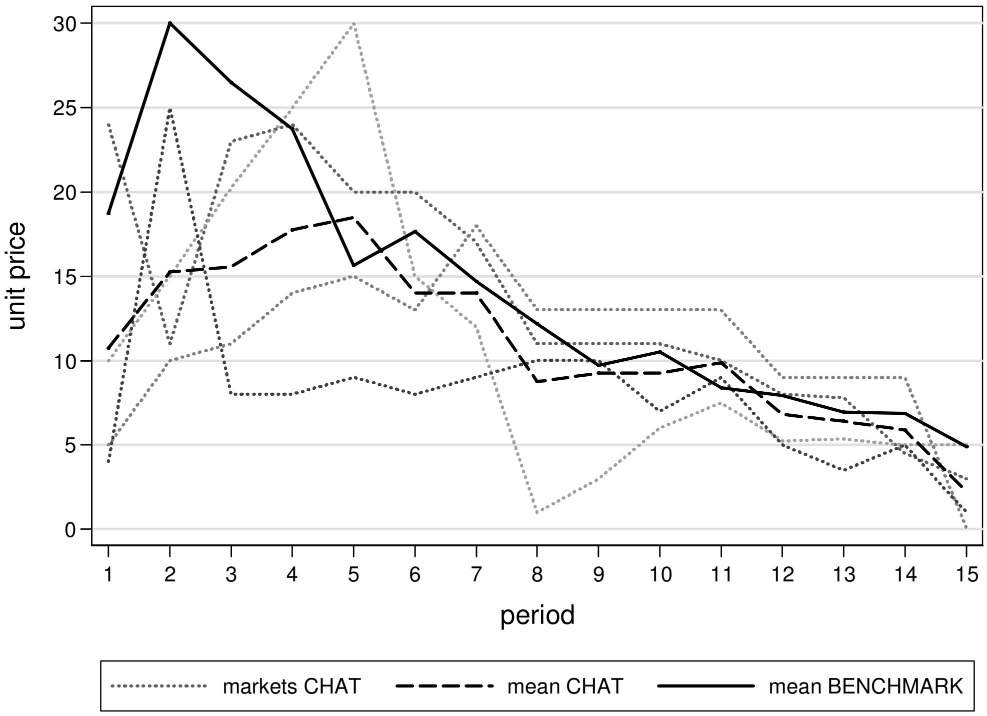
We analyze our data with respect to the treatment conditions, whereby we investigate price dynamics in the auctions and the secondary market, the distribution of income and the overall efficiency of the cap & trade system.

4.1 *CHAT*

Price dynamics

In *CHAT*, all agents of one market were allowed to communicate during the auction biddings and the trading in the secondary market. We first evaluate price dynamics, which are illustrated in Figures 2 and 3. Recall that certificate prices should not exceed 11.25EC, i.e. the fair value given a Type A-1 project worth 100ECU. This benchmark applies for unit auction prices as well as market prices.

Figure 2. Unit auction prices in *CHAT*



Prices are decreasing over the course of the game for both *CHAT* and *BENCHMARK*. In the beginning, prices tend to exceed the fair value, whereas in the end they tend to fall below the fair value. While the pattern in price dynamics is similar in *CHAT* and *BENCHMARK* from period 5 onwards, there are substantial differences at the beginning of the game. In all markets of *CHAT*, a unit auction price below the average unit auction price of *BENCHMARK* emerges. Applying a Wilcoxon-Rank-Sum test for the first five periods gives significant differences, with z=1.868 and p=.0617.[5] This might hint at collusive behavior that breaks down quickly as the game proceeds. We test this hypothesis by evaluating the chat protocols documenting the communication within the first periods.

Market #1: a total of 26 messages sent, 54%(58%) within the first (five) periods

Practically all meaningful communication takes place in the very first period. One subject during the auction stage asks how many certificates the other subjects are grandfathered and all others answer truthfully. This adds new information to the game as the distribution of certificates is not provided in the instructions. Furthermore, one subject suggests distributing certificates "justly", which is not answered by the other subjects. In the secondary market stage of the first period, another subject asks whether any of them has succeeded in the auction and obtained some certificates. Two subjects reply that they were not successful and one subjects notes that she was granted one certificate. The same subject then asks again at what price certificates were granted in the auction, although no one answers. In the second period, one subject states that there is a discrepancy between supply and demand, which is the last message sent until period 8. From this point onwards, no meaningful conversation occurs; rather, subjects merely tend to complain about prices being too high.

In sum, chat communication leads to the revelation of some information, i.e. the distribution of certificates grandfathered. There is an attempt to establish a cooperative regime by suggesting to distribute certificates justly, which is not picked up by other agents and attempts to cooperate break down altogether after the second period.

Market #2: a total of 38 messages sent, 11% (13%) within the first (five) periods

In the first period, one subject asks about the appropriate price for a certificate, whereby three other subjects reply that they do not know. In period 5, one subject asks why everybody wants to sell off certificates, but does not receive an answer. No more communication takes place until period 8. Subsequently, a discussion evolves, in which the incentives for each agent (accumulate many certificates at minimal prices) are correctly identified. It is noted that lying might generate some advantage and distinctively the fair value of certificates conditional on the availability of a Type A-1 project is derived. Some subjects undertake the attempt to agree bilaterally on a trading price or ask about the remaining project endowment of other subjects.

Again, there is no successful collusion that explains the lower prices within the first periods when compared to *BENCHMARK*. However, the general properties of the game and the optimal pricing are explicitly mentioned in the discussion during the second half of the game.

[5] If not mentioned otherwise, all tests are carried out treating one market as one observation only.

Market #3: a total of 10 messages sent, 0% (100%) within the first (five) periods

In the second period, one subject explicitly suggests that all agents should bid less as certificates would become cheaper for all of them. This attempt to collude is referred to in period 3 by another subject and these two subjects agree upon a certificate price of 6ECU, which is about half of the fair value. In the secondary market of period 3, these two subjects complain that the agreement was obviously not followed by anyone else. There is no further communication after period 3.

Overall, in this market the explicit attempt to collude supported by at least two subjects failed and thus no further communication indicating cooperation occurred.

Market #4: a total of 11 messages sent, 18% (18%) within the first (five) periods

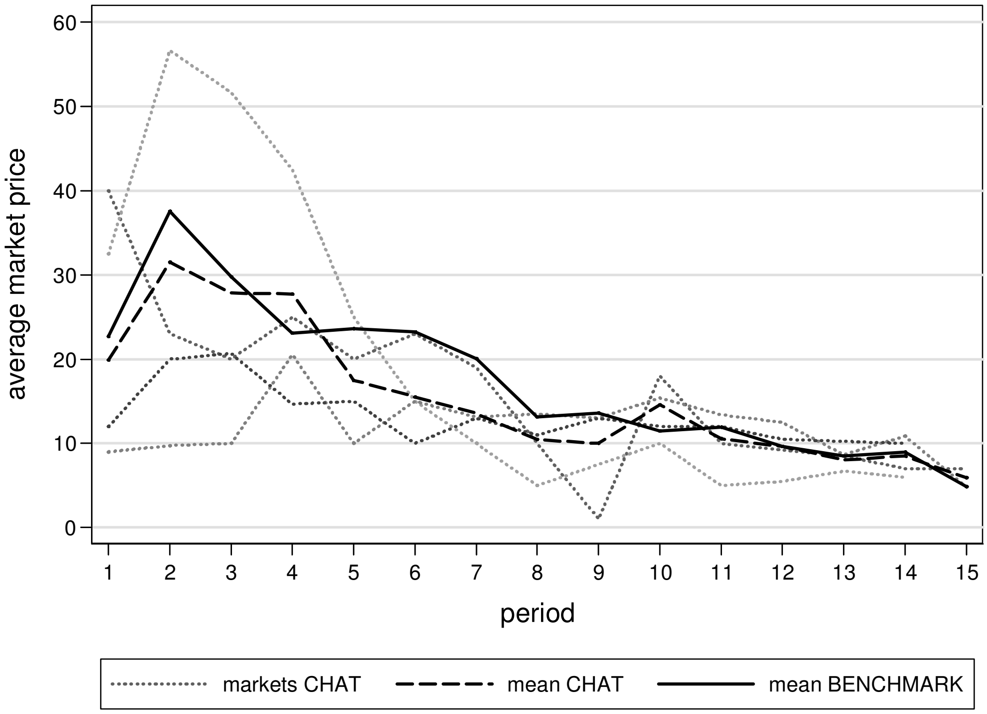
In this market, no meaningful messages are sent until period 13, when one subject notes that there will be a loss in income for the buyer at a price of 20ECU. Another subject states that it might make sense if one subject only misses out on one or two certificates, which is again answered by the first subject, who hints at the possibility to accumulate certificates over periods.

The few messages sent show no sign of cooperation or collusive behavior, which might explain lower unit auction prices when compared to *BENCHMARK*.

Result 1a: *Independent of chat communication among agents, prices tend to exceed fair values at the beginning before gradually decreasing below fair values at the end of the game. Chat communication leads to initially lower prices, which cannot be explained by collusive behavior.*

Considering average market prices, there is no such evident drop in prices when we allow for chat communication, as can be seen in figure 3.

Figure 3. Market prices in *CHAT*



As previous studies have emphasized (Meub et al., 2014, 2015, 2016; Proeger et al., 2015), average market prices tend to exceed unit auction prices, which might be explained by the endowment effect (Kahneman et al., 1991).[6]

Result 1b: *Average market prices decrease over the course of the game and tend to exceed unit auction prices independent of the possibility to communicate.*

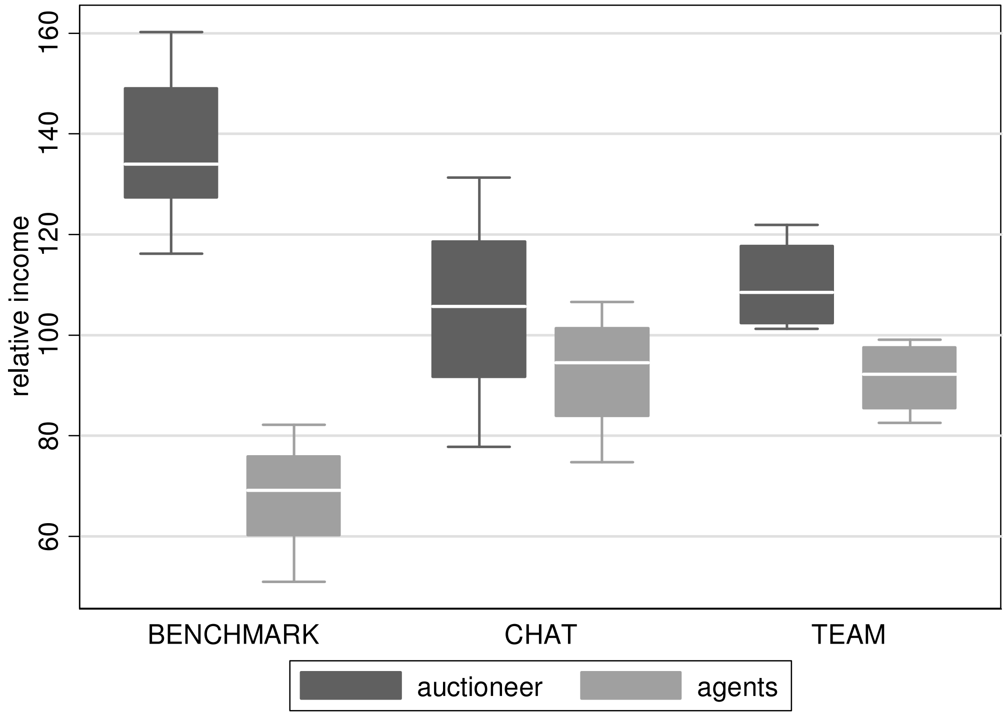
Distribution of income

While the distribution of income between the auctioneer and the market participants is not relevant for assessing the efficiency of a cap & trade regulation, the general political feasibility might well be influenced by the expected distributional effects.

Figure 4 illustrates the distribution of income between the auctioneer and the agents in the markets of *CHAT*. For a better comparability of income levels, we rely on aggregate income relative to the theoretical values derived above. A society's income is given by its aggregate value of realized projects, whereas the auctioneer's income is given by total payments made in the auction stage over the course of the game.

[6] Following our test for unit auction prices within the first five periods and applying a Wilcoxon-Rank-Sum test we find no significant differences with z=0.679 and p=.4969. For a more detailed analysis of the endowment effect in this TDR scheme, we refer to Meub et al., 2016.

Figure 4. Distribution of income between auctioneer and agents by treatment



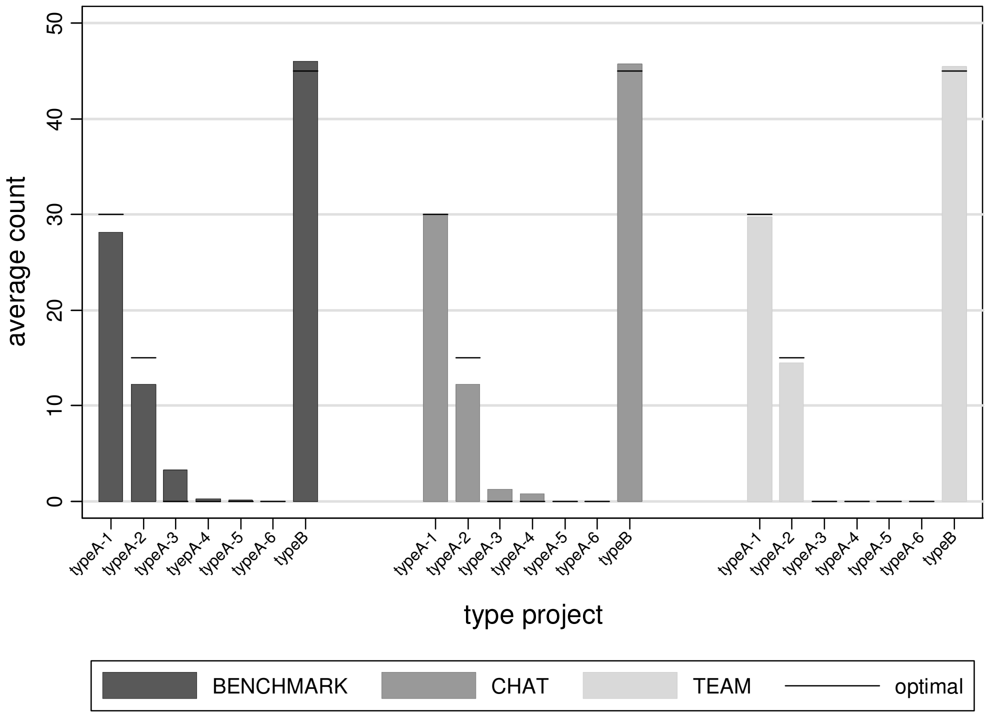
The boxplots clearly indicate a substantial discrepancy in relative income between the auctioneer and the market participants for *BENCHMARK*. By contrast, no such substantial difference occurs in *CHAT*. This pattern follows from higher auction prices in *BENCHMARK*, particularly at the beginning of the game

Result 1c: *In the absence of chat communication, overshooting unit auction prices induces a substantial redistribution of income in favor of the auctioneer.*

Efficiency of the cap & trade system

Recall that the cap & trade system's efficiency is measured by the aggregate value of realized projects. Certificates should optimally be reallocated such that the maximal aggregate value is achieved. Figure 5 depicts the average number of realized projects types by treatment condition.

Figure 5. Average number of project realizations by treatment



Comparing *BENCHMARK* and *CHAT*, there are no substantial differences. On average, societies in *BENCHMARK* reach 95.9% of the maximal aggregate project value, whereas in *CHAT* the degree of efficiency amounts to 97.7% on average. In both treatments, the expected pattern of about 30 Type A-1, 15 Type A-2 and 45 Type B projects evolves.

Result 1d: *The cap & trade system achieves high degrees of efficiency in regulating land consumption. Enabling agents to communicate does not change the expected pattern of realized projects and the overall efficiency remains high.*

4.2. *TEAM*

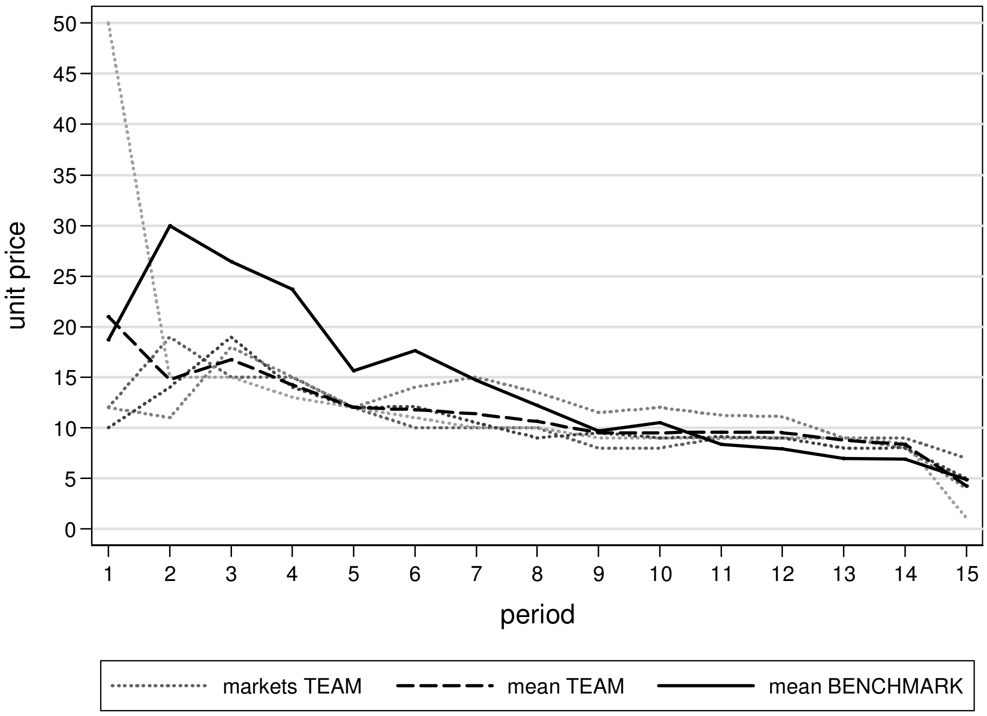
Price dynamics

Figures 6 and 7 illustrate price dynamics in the auctions and the secondary market for *TEAM* markets. Again, keep in mind that the fair value of one certificate amounts to 11.25ECU and there should be no differences across treatments.

We find the same basic pattern of decreasing unit auction prices throughout the game. Applying a Wilcoxon-Signed-Rank test gives significant differences in prices between the first and second half of the game (for *BENCHMARK* z=2.521 and p=.0117; for *TEAM* z=1.826 and p=.0679). However, aside from a single outlier in the very first period, unit auction prices in *TEAM* are substantially lower and the decline over the course of the game is much weaker.[7] Auction prices are quite homogenous across the markets of *TEAM* and prices are closer to fair values.

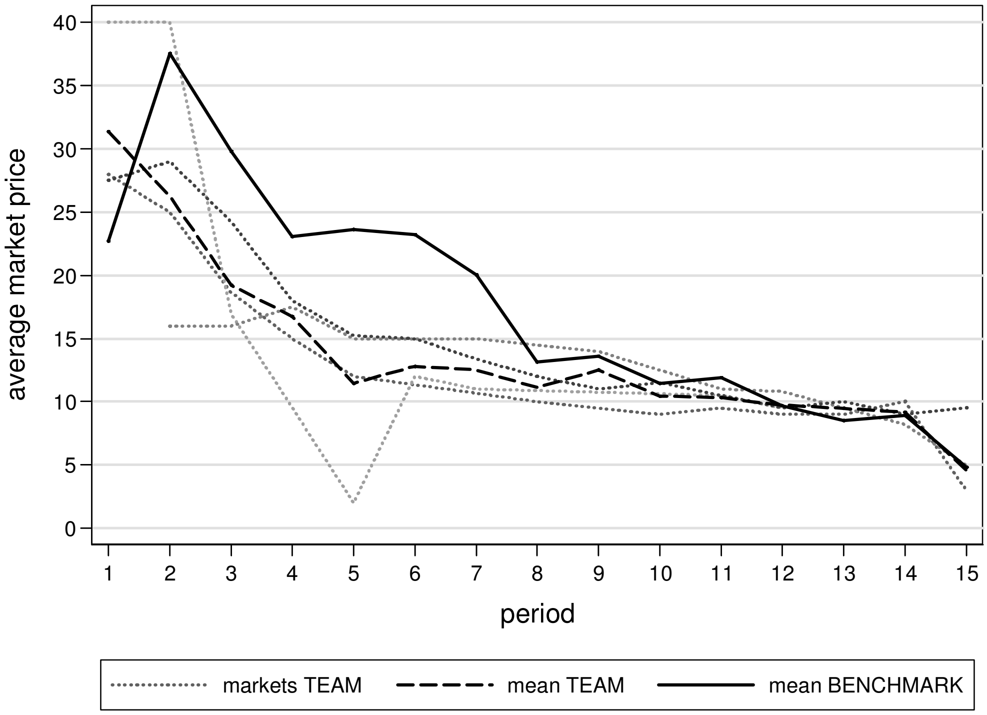
Result 2a: *Team decision-making brings unit auction prices closer to theoretically fair certificate prices. Thereby, price differences between the beginning and end of the game become much weaker as prices show high stability throughout the game across markets.*

Figure 6. Unit auction prices in *TEAM*



[7] For *BENCHMARK*, the average market price in the first (second) half of the game amounts to 27.28 (9.70), in Team the average amounts to 18.95 (9.97).

Figure 7. Market prices in *TEAM*



When considering prices in the secondary markets, we find that average market prices are lower in *TEAM* in the first half of the game when compared to *BENCHMARK* and they more rapidly approach the fair certificate value (Wilcoxon-Rank-Sum test, for the first half of the game gives z=1.868 and p=.0617; for the second half of the game z=-0.340 and p=.7341). However, the initially overshooting prices are not completely avoided when decisions are taken in teams.

Result 2b: *Team decision-making brings market prices closer to theoretically fair certificate prices, particularly in the first half of the game. Nonetheless, in the first third of the game, average market price still substantially exceed fair values.*

Distribution of income

As illustrated by figure 4, team decision-making decreases the auctioneer's income as unit auction prices are substantially lower and closer to fair values. The income distribution closely follows the theoretical predictions.

Result 2c: *Introducing team decision-making shifts the distribution of income in favor of the market participants as unit auction prices are substantially lower. The auctioneer realizes substantially less income.*

Efficiency of the cap & trade system

Figure 5 shows the distribution of projects realized on average for all treatments. The pattern of project realizations in *TEAM* evidently replicates the optimal distribution derived above. Almost 30 Type A-1, 15 Type A-2 and 45 Type B projects are realized on average. This finding should be interpreted as strong evidence in support of the assumption that team decision-making increases rationality, overcomes cognitive limitations and consequently results in a superior efficiency of the cap & trade system overall. Comparing the average relative efficiency of 99.0% achieved in *TEAM* to the 95.9% in *BENCHMARK* supports this conclusion (Wilcoxon-Rank-Sum test gives z=-2.727 and p=.0064).

Result 2d: *Introducing team decision-making leads to a more efficient reallocation of certificates as the distribution of realized projects is close to optimal across markets. Overall, when compared to individual decision-making, the cap & trade system shows superior efficiency if agents are represented by teams.*

5. Conclusion

This study presents experimental evidence on the feasibility of a system of TDR. We suggest that behavioral evidence can fruitfully complement previous qualitative and quantitative surveys as well as theoretical studies on the success factors of TDR schemes. While this approach adds novel evidence from counterfactual analyses to the discussion of optimal policy designs to reduce urban sprawl and foster sustainable land use, it has certain limitations. For instance, laboratory studies require a number of assumptions and restrictions to enhance their comprehensibility to participants and provide benchmarks of rational decision-making, thus reducing the extent to which real-world complexity can be implemented in experimental designs. Furthermore, student participants might act differently from decision-makers in the respective institutions. These aspects necessarily limit the direct transferability of our results. Despite these restrictions, we suggest that our counterfactual analysis on the effects of communication provides novel evidence unattainable by case studies. We extend previous experimental studies by relaxing the assumption of autonomous individual decision-making, which has constituted a strong deviation from the actual process of decision-making faced by agents in actual TDR schemes. By contrast, they are very likely to participate in networks and collaborate with other persons within their institutions when engaging in auctions and trading land use certificates.

We find that communication within teams making decisions in the TDR system reduces auction and market prices. Teams perform closer to game-theoretical predictions, which resonates with previous results in economic group research (Kugler et al., 2012, Charness and Sutter, 2012). This shifts the distribution of income in favor of market participants, thereby reducing the auctioneer's income. The efficiency of the cap & trade system substantially improves when decisions are made by teams rather than individuals.

While there is no equivalent improvement in overall efficiency when competitors within a market are allowed to communicate, we find that auction prices are similarly lower and thus closer to fair values. The same holds true for secondary market prices. Nevertheless, no collusion occurs. This result somewhat contradicts previous theoretical approaches emphasizing the likely problems posed by collusion; apparently, the structure of a TDR scheme impedes price arrangements among subjects. We find that competitors communicating via chat reveal additional information that is not available to subjects deciding autonomously. This enables subjects to make better informed decisions and presumably benefits, which particularly applies for subjects with a limited understanding of the system and cognitive limitations. Hence, biddings in the auctions and trades in the secondary market reflect fair prices more appropriately. In short, allowing subjects - even when competing - to communicate in a TDR system reveals some information, and - similar to the process of a group discussion within teams – more information leads to better decisions.

Consequently, as communication tends to reveal information and improve subjects' understanding of the cap & trade system's working mechanism, TDR function equally or even more efficiently in comparison to a situation of autonomous individual decision-making. Certificates are reallocated almost optimally, enabling the realization of the most profitable projects. From a policy perspective, these results mitigate previous doubts about the feasibility of TDR schemes due to irrationally overshooting prices in both auctions and secondary markets. Subjects' ability to improve their understanding and learn when enabled to communicate thus precludes an overly strong redistribution of income in favor of the auctioneer, which would substantially hamper its political feasibility. Concerns about collusive behavior manipulating prices might similarly be less problematic as no price arrangements to the disadvantage of the auctioneer are realized. In sum, doubts about the feasibility of a TDR scheme due to participants' non-optimal or strategic behavior combined with the system's susceptibility to price manipulations appear less problematic.

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Appendix: Instructions for the *BENCHMARK* treatment. The differences for *CHAT/TEAM* are indicated in braces.

Overview of the Game

You can earn money in this game by realizing projects and trade with certificates. At the beginning, you will be randomly assigned to a group of 6 players, which will remain constant during the 15 periods of the game. {*CHAT*: You can communicate with these players using a chat box during the game. *TEAM*: Further, you have a teammate, with whom you will have to take your decisions.} All prices and values in the game will be paid in ECU with up to two positions after decimal point. 100 ECU convert to 1€ for your payoff. {*TEAM*: Your gains from the game will fully be paid to each of the two players.}

Projects

Overall, each player has 30 projects of **Type A** and 15 projects of **Type B**. Both types of projects have different values, which are shown in this table:

Type of project	Project value (in ECU)
A	0 to 100
B	10

In each period, only one project can be realized. Before the game starts, the values of all Type A projects will be assigned and shown to you. All players are assigned different Type A projects.

Certificates

For the realization of Type A projects, you need 8 certificates each, Type B projects do not require certificates. Certificates are assigned to you at the beginning of each period and auctioned. Additionally, certificates can be traded among the players. In the game, you receive an endowment of 700 ECU which you can use to buy certificates at the auction and from the other players. You can also sell certificates and thus increase your payoff.

Your payoff

The payoffs you receive in the course of the game, as well as the sum of all realized projects add up to your final payoff. Further, a basic payoff of 400 ECU will be added.

Course of the Game

Each of the 15 periods follows an identical course, which consists of three phases.

Phase 1: Allocation and auctioning of certificates

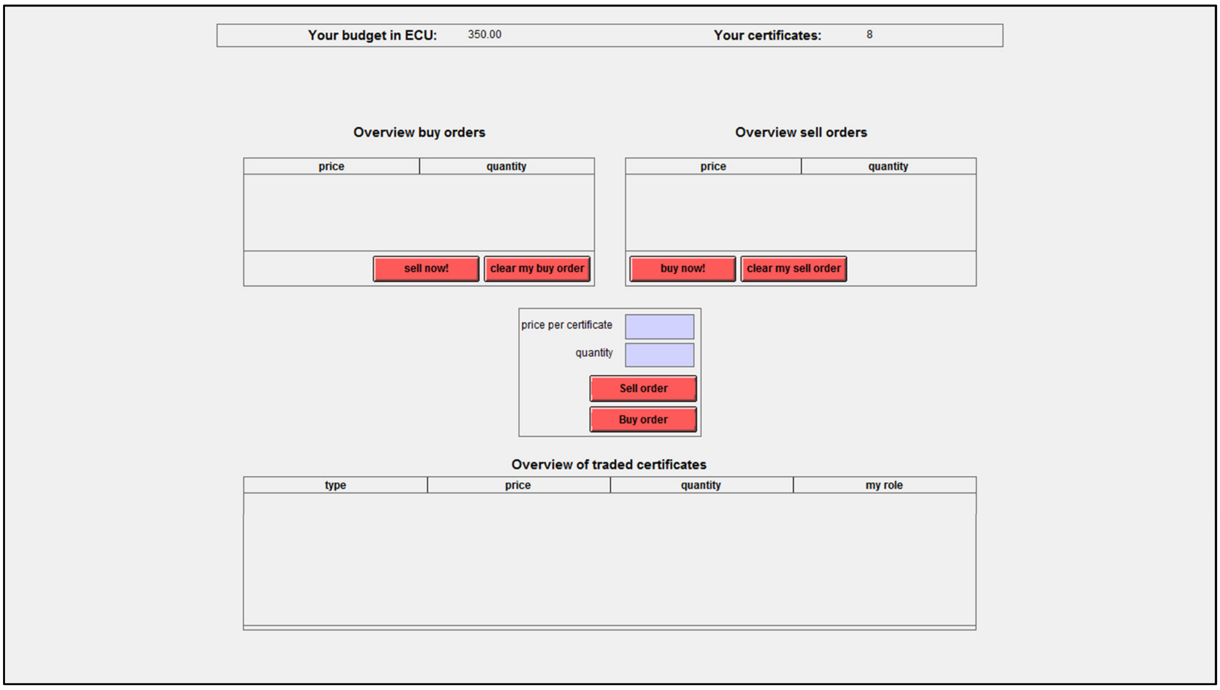
At the beginning of each period, 12 certificates are allocated. The number of certificates a player receives is determined randomly at the beginning of the game and does not change during the game.

Additionally, after the allocation, 12 certificates are auctioned. Depending on your current funds, you can bid for a number of certificates of your choosing at a unitary price. The 12 highest bids will receive the certificates to the price of the lowest successful bid.

Phase 2: Trading of certificates

Following the allocation and auctioning, this phase lets you trade with the other five players, i.e. buy and sell certificates. You can offer a trade yourself and also accept offers from other players. To clarify this, you see the respective screen of the trading phase below:

{Translated screenshot for *BENCHMARK / TEAM*:}



{Translated screenshot for *CHAT*:}

Offering a trade

In the {BENCHMARK/*TEAM*: lower} {*CHAT*: left-hand mid-level box} box, you can enter a price (in ECU) and the respective amount of certificates that you would like to buy.

- **By clicking “searching”**, all players are shown your buying desire in the {BENCHMARK/*TEAM*: left} {*CHAT*: upper}box. Once another player agrees to your offer, you will receive the respective number of certificates. The total value (price x quantity) of the trade will be withdrawn from your funds.
- **By clicking “offering”**, all players are shown your sell offer in the {*CHAT*: upper} box {BENCHMARK/*TEAM*: on the right}. Once another player accepts your offer, you sell the respective number of certificates. The total value (price x quantity) of the trade will be added to your funds.

Accepting another player’s offer

In the boxes on the {*CHAT*: upper}right and left side, you can see all current buy and sell offers for certificates. If you choose an offer and click on “sell now!” or “buy now!”, you make the trade with the respective player.

You are allowed to trade as often as you please. You can also make multiple sell and buy offers at the same time. The trading phase ends automatically once **2 minutes** have passed.

Phase 3: Realizing projects

In the third phase of the game, you can realize one of your projects. You will receive the respective payoffs (project value in ECU) at the end of the game. After the third phase, the next period begins. Certificates that are not used in one period can be saved for subsequent periods. Note, however, that you will not receive a payoff for certificates that remain unused until the end of period 15!