Essays on Behavioral Economics and Fisheries:
Coordination and Cooperation

Lisa Björk

UNIVERSITY OF
GOTHENBURG

To Astrid Björk

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Introduction

A large body of theoretical and empirical research seeks to understand the conditions that facilitate cooperation in shared resource use, from contributions to public goods to harvest of common-pool resources. As the human pressure on ecosystems continues to grow, the governance of shared natural resources is one of the major challenges of our time (IPCC, 2014). Although important on all levels, particularly with respect to the establishment of successful global and regional environmental agreements between nations, many problems require a change of practices on the local level. The focus in environmental economics has traditionally been on correcting the market failures associated with natural resource use, often by means of neoclassical economic approaches (Weitzman, 1974). The bottom line is that without well-defined property rights and institutions that facilitate exchange of benefits and costs among individuals, the use of natural resources will not be efficient (Coase, 1960). This inefficiency arises because neither the benefits of sustainable use nor the costs of wasteful use of resources will be born fully by the individual. Garrett Hardin (1968) used the term *the tragedy of the commons* to describe these settings, in which individuals or groups exploiting a resource out of pure self interest will eventually deplete the resource. Accordingly, the solution to market failure is to create markets, or institutions that induce market-like incentives among the resource users, through the allocation of individual property rights. However, human behavior is far more complex than the assumption of a rational decision-maker who make consistent choices in accordance with all the available information (Arrow, 1986). Elinor Ostrom, who dedicated her research career to studying cooperation and resource dilemmas on the grassroots level, challenged the view of the inevitable tragedy of the commons. Or at least of the proposed solution to it. Her work proved that common resources may be successfully managed by communities even in absence of strong private property rights and an enforcing regulator. She showed that certain characteristics of informal governance institutions tend to be conducive to successful resource management, of which the most crucial are clearly defined boundaries of the resource, participation of users in negotiating internal management rules, and internal monitoring systems (Ostrom and Schlager, 1992). Property rights, whether individual or collective and regardless of the term used to refer to them, are hence a cornerstone of both perspectives.

Ultimately, the success of management regimes depends on the extent to which individuals are induced to cooperate, which is largely contextual. That is particularly true for transboundary environmental problems, such as pollution or the management of fish stocks, where neither the definition nor the allocation of rights is straightforward. People's decisions are likely to be influenced by perceived fairness, the allocation mechanism of rules, social norms and beliefs about others, risk perceptions, the order of events, etc. (Shogren and Taylor, 2008). When introducing new management institutions, regardless of their form, the decisions

made by individuals in the system are consequently, and not surprisingly, going to determine their policy outcomes. Still, by investigating responses to management regimes, in various settings, they are made more predictable and principles of cooperation can be better tailored to the local setting. The use of laboratory experiment and field experiments is a growing area of research seeking to provide answers on these topics to decision-makers (Falk and Heckman, 2009).

In three self-contained chapters, this thesis investigates the behavioral response of resource users to management regimes introduced in fisheries, and the general effect of uncertainty on decision making in public goods. In Chapter 1, the impact of risk and ambiguity on investments in a public good is investigated using a lab experiment. Chapters 2–3 use empirical data from Sweden to evaluate the effect of three distinct management regimes that introduce property rights collectively or individually to fishers. This introduction attempts to summarize and link the key findings of the chapters.

Summary of chapters

"[T]he world contains multiple types of individuals, some more willing than others to initiate reciprocity to achieve the benefits of collective action." – Ostrom (2000).

Laboratory public goods experiments have been extensively used to investigate cooperation in terms of contributions to the provision of a shared resource with benefits to the whole group. The basic setup involves giving participants an amount of money that they can choose to invest in a public good or to keep for themselves. If all participants contribute to the public good, the payoff for each individual will be more beneficial than if the money is kept privately. However, each individual can increase her own payoff by keeping the money for herself. Lab experiments allow to mimic key characteristics of real world social dilemmas in a highly controlled environment. This allows to study variation in one key variable at a time, while keeping all other factors constant. One major finding in experimental research, which is robust to variations in the basic setup, is the presence of different cooperator types (Fehr and Schmidt, 1999; Carlsson et al., 2014). A substantial number of experiments show that around half of the participants in experiments choose to cooperate when facing the choice to contribute to a public good, when others are expected to do the same (Chaudhuri, 2011). Another common finding is the presence of actors who are willing to forgo own profit to punish others in order to foster cooperative behavior. Elinor Ostrom (2000) identifies these two types as crucial to foster cooperative norms in collective management of natural resources.

Yet, most of the experimental evidence regarding the human cooperative nature is based on public goods experiments in which the marginal return to investment in the public good is known with certainty. However, some degree of uncertainty is present in all natural re-

source systems. To what extent is cooperation hampered when the outcome of sustainable practices is unpredictable? In the first chapter, **Cooperation under risk and ambiguity** (co-authored with Martin Kocher, Peter Martinsson, and Pham Khanh Nam), we introduce uncertainty in a standard public goods experiment in the lab. Specifically, we set up a linear public good game in which participants choose to either invest money to a public good or keep it for themselves. The investment return is either certain, risky (known probabilities), or ambiguous (unknown probabilities) and always exceeds the return from keeping it for yourself - if everyone contributes. Uncertainty in public goods does not stem only from unpredictability with respect to the investment return (natural uncertainty), but also from the fact that the behavior of others is uncertain (strategic uncertainty). To study the simultaneous effect of natural and strategic uncertainty, we let participants make decisions under two different conditions: a one-shot investment decision and ten repeated investment decisions with feedback on how others behaved in the previous round. To study natural uncertainty in isolation, we let participants make investment decisions for predetermined levels of others' behavior, implying that the strategic uncertainty is removed. Our findings are similar, regardless of the condition: whether returns to investment are risky or ambiguous does not affect investment decisions compared with a situation in which returns are deterministic. This suggests that the findings from the wealth of previous linear public good games with deterministic outcomes generalize to situations in which the investment return is uncertain. One implication of our findings is that strategic uncertainty seems to matter more than natural uncertainty for cooperative outcomes. If this would be translated to a resource management context, management regimes that include measures to increase the predictability of others' choices may be more likely to induce cooperation.

"*In a sense we are arguing for a change in research focus from the behavior of fish to the behavior of fishermen... [T]he fisherman's decision as to effort level is perhaps the most important type of behavior to be understood.*" – Opaluch and Bockstael (1984)

Around 90 % of the world's fish stocks are either fully fished or over-fished (FAO, 2016). As a consequence, a substantial share of the potential rents from marine fisheries is not being captured. The World Bank (2009) estimates that $50 billion is lost due to poor fisheries management, *every year*. Moreover, they conclude that the negative trend of the destruction of natural capital in fisheries is getting worse. To what extent are then management systems centered around property rights allocation successful in recovering some of the lost resource rent?

Property rights in fisheries can be assigned in many ways, including by means of territorial user rights (TURF) to harvest within a geographically determined area (Christy, 1982), co-management arrangements between fishers and other stakeholder groups (Carlsson

and Berkes, 2005), and market-based individual transferable quota (ITQ) systems (Christy, 1973). The second chapter, **Coordination effects of common pool resource management - empirical evidence from the Swedish shrimp fishery** (single authored), uses a quasi-natural experiment to quantify the revenues obtained from fishing before and after the introduction of a TURF and a co-management in the Swedish shrimp fishery. Both systems were introduced at a time when the focus of European fisheries policies shifted towards including an explicit aim of conserving coastal communities and preserving the broader marine eco-system, which mirrors the highly political nature of fisheries management. In 2000, regional and national regulatory agencies and around 27 fishers agreed to co-manage the Koster Fjord. In 2004, five fishers were granted exclusive access to fish within the Gullmar Fjord. The rest of the shrimp fishers continued as usual. By comparing the revenues obtained from fishing trips carried out in the three respective regimes over time, I establish the effect of the TURF and co-management regimes on obtained revenues. The main results show that the establishment of the TURF has led to an average increase in participant revenues by 26–28 %. In contrast, revenues decreased by on average 4–5 % in the co-management. These results are in line with the cooperative principles identified by Ostrom (1992). The TURF fishers were successful in setting up internal management rules to coordinate fishing efforts within the fjord, and more importantly, others were excluded from fishing in that area. In additional analysis I show that one of the revenue-creating mechanisms in the TURF regime was that the fishers started to plan *when* to harvest and became more likely to fish when expected revenues were high. In the co-management regime, the boundaries defining access to the fishing area are less exclusive compared to the TURF, and particularly, the number of participants is much higher. The loss in revenues for the co-management fishers was a combined effect of increased within-group competition, a change in harvest composition, and lower harvest efficiency.

Is revenue creation really the best indicator of the success of a management regime? The important link between revenue creation and long-term sustainability of the stock is well-established in the economics literature. However, sustainable management might also incur economic losses in the short- and medium-term as the resource users adjust their harvesting effort and practices to the new equilibrium. Part of the explanation for the decrease in revenues for co-management fishers was a shift to a gear type with improved selectivity. The gear was adopted to reduce by-catch, but may also have been the cause of the documented decrease in the share of valuable large shrimp in the harvest. Short- and medium-term revenue measures fall short of accounting for such conservation efforts. This illustrates the many competing objectives of fisheries policies and the difficulties in finding a way to account for all changes brought about by a regime when evaluating its effect. Marty Smith (2012) argues that the struggle of modern fisheries economics is to "understand, quantify, and design incentives across many margins." Still, the findings highlights that the allocation of secure

rights to harvest can be successful in creating incentives for coordination, both with respect to within-seasonal seasonal effort distribution, and to the adoption of conservation strategies.

"*A port with a fishing vessel that is not actively used for fishing is not proof for a vital fishing industry... Commercial fishery is one thing, fishing with tourists is another. The question that we constantly struggle with is how our members are going to make money. That is the central question for all actors within the fishing industry.*" – letter from the Swedish Pelagic Federation to the governmental Committee on Environment and Agriculture (Swedish Government, 2016)

One policy change likely to have a large impact on shaping fisheries management in the coming years, is the landing obligation (or discard ban) introduced with the 2014 common fisheries policy of the European Union. The landing obligation implies that all fish species subject to catch limits must be landed and counted against its national quota which determines the total allowable catch. The policy implies a fundamental shift in fisheries management from controlling what is brought ashore to controlling what is harvested at sea. The expectation is that fishers will improve the methods to reduce unwanted catch as they will internalize its cost (European Parliament, 2015b). However, if selectivity is difficult, the catch limit for some species might be reached already early in the season. To avoid additional harvest of such a choke species, the whole fishery may have to close for the season, which brings negative economic consequences on many fishers. The suggested way forward is to allocate fishing rights that allow for flexibility in terms of quota use over time, across nations, and between individual fishers (European Parliament, 2015a).

Individual transferable quotas (ITQs) are perhaps the most flexible system in fisheries management, and its use in Europe is likely to increase. It is a cap-and-trade system in which fishers are allocated private rights to a share of a capped fish stock. These rights can be bought and sold in a quota market, or they can be leased in or out over the fishing season. The third chapter, ***Who do you know? Transaction relations in the Swedish pelagic ITQ system*** (single authored), studies a system of this type that was introduced in Sweden in 2009. In particular, the study focuses on determining the role that social networks have in shaping the outcomes of quota trade. Theoretically, ITQs provide an efficient mechanism for reallocating fishing capacity from the least to the most efficient fishers within a system, regardless of how the initial rights were allocated (Arnason, 2012). Yet, if markets are not perfect, transaction costs, rather than differences in expected marginal rents, may determine with whom you trade. By combining information for 2010-2016 about all realized quota transactions, the geographical location and characteristics of the full population of traders, and their relations to each other, I can analyze the network of trade flows. The results show that quota ownership is concentrated to the Swedish west coast over time, and that

ownership is highly correlated with the initial allocation of quotas. As for the lease market, higher volumes of trade are transacted between actors who already occupy a central market position, and between actors who are more likely to interact frequently because they share a relation to a third party. This suggests that information asymmetries and other transaction costs may determine trade relations. The introduction of the landing obligation in 2015 is associated with an increased frequency of trade involving a larger group of traders. This suggests that the lax regulations in the Swedish ITQ system, prior to 2015, partly explained the thin market, which may have prevented certain actors from participating in beneficial trade.

The use of markets as a means to manage scarce natural resources is a contentious political subject with socio-economic implications. In Sweden, as well as in many other settings, the design of the ITQ system had multiple goals: reducing fleet capacity to remedy overfishing and stimulate economic efficiency without excessive harm for coastal communities. As pointed out by Arnason (2012), ITQs are not sufficient for achieving full efficiency in the fishery, an optimal use of ecosystems, and to harmonize conflicting uses of marine resources across time and space. ITQs are consequently likely to be adopted together with other regulations aiming at balancing different policy objectives. In the Swedish ITQ system restrictions on maximum ownership of quotas and regional set-asides were adopted to prevent 'imbalances' in the system. Still, the results show a clear geographic divide between owners and leasers of quota. The design of an ITQ system and its expected impact on the distribution of economic benefits (and losses) realized within the system is consequently a highly political process. However, the results suggest that the introduction of ITQ systems considered by many European countries, may be more likely to successfully promote economic efficiency if certain features of the system design are considered. Firstly, quota prices should be reported and public. Secondly, it should be recognized that the common approach of allocating initial quota based on historical catches may not be neutral to how the market evolves. Thirdly, too lax regulations with respect to how catches are counted against held quota are less likely to stimulate market transactions and capacity redistribution within the system. Finally, a data collection strategy should be part of the system design in order to enable proper evaluation of the market functioning and system outcomes.

In summary, the results in this dissertation emphasize the importance of understanding the conditions that facilitate cooperative behavior with respect to the utilization of, and contribution to, shared natural resources. I have provided new insights on the role of uncertainty on decisions to invest in public goods as well as on the behavioral responses to different property-rights based management regimes in fisheries. However, given all the complexities related to the evaluation of natural resource management, these insights are limited. I hope to be able to generate further understanding in future research, that is both of academic interest and of direct relevance to policymakers.

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Chapter I

Cooperation under risk and ambiguity[*]

Lisa Björk [†1], Martin Kocher [‡1,2,3], Peter Martinsson [§1,4] and Pham Khanh Nam [¶5]

[1] *University of Gothenburg, Sweden*
[2] *Institute of Advanced Studies, Vienna, Austria*
[3] *LMU Munich, Germany*
[4] *Linköping University, Sweden*
[5] *Ho Chi Minh City University of Economics, Vietnam*

Abstract

The return from investments in public goods is almost always uncertain, in contrast to the most common setup in the existing empirical literature. We study the impact of natural uncertainty on cooperation in a social dilemma by conducting a public goods experiment in the laboratory in which the marginal return to contributions is either deterministic, risky (known probabilities) or ambiguous (unknown probabilities). Our design allows us to make inferences on differences in cooperative attitudes, beliefs, and one-shot as well as repeated contributions to the public good under the three regimes. Interestingly, we do not find that natural uncertainty has a significant impact on the inclination to cooperate, neither on the beliefs of others nor on actual contribution decisions. Our results support the generalizability of previous experimental results based on deterministic settings. From a behavioural point of view, it appears that strategic uncertainty overshadows natural uncertainty in social dilemmas.

JEL classification: C91, D64, D81, H41

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[†]Department of Economics, University of Gothenburg, Box 640, 405 30 Gothenburg, Sweden. Email: lisa.bjork@economics.gu.se

[‡]Department of Economics, LMU Munich, Geschwister-Scholl-Platz 1, D-80539 Munich, Germany. E-mail: martin.kocher@lrz.uni-muenchen.de

[§]Department of Economics, University of Gothenburg, Box 640, 405 30 Gothenburg, Sweden. E-mail: peter.martinsson@economics.gu.se

[¶]School of Economics, Ho Chi Minh City University of Economics, Ho Chi Minh City, Viet Nam. E-mail: khanhnam@ueh.edu.vn

1 Introduction

Understanding cooperation in social dilemmas is a major research theme in the social sciences in recent decades. Social dilemmas are characterized by individual incentives to free ride on the cooperation of others at an efficiency cost to the whole group or society. In economics, this type of situation has been studied experimentally by applying variants of the prisoner's dilemma game and, more recently, the public goods game (Chaudhuri, 2011). Almost the entire experimental literature assumes that benefits from public goods, i.e. the return that cooperation yields to the group, are deterministic. Since the contributions of other group members are unknown in a simultaneous setting, returns from public goods are usually characterized by strategic uncertainty. However, the literature so far has neglected the uncertain nature of many public goods, i.e. even when total contributions of other group members are known, the individual and collective benefits from the public good may still be uncertain. In other words, the returns from investing in a public good could be risky or truly uncertain (ambiguous).

For example, when countries invest in CO2 emission reduction, they have only a vague idea about how their investment translates into the benefit of a more slowly rising temperature on Earth.[1] When a team member invests effort in joint production, the benefit of one extra hour of work for the whole team might be uncertain. When fishers limit their fishing activity to contribute to the replenishment of the stock in a lake, they do not know how exactly this contribution converts into stock protection. In short, although we know a lot about the strategic uncertainty in social dilemmas and how it affects the decision to contribute or not, we know almost nothing about how people contribute under natural uncertainty.

Does natural uncertainty of the benefits in the provision of a public good increase or decrease individual contributions? Does natural uncertainty interact with strategic uncertainty? How does it affect the efficiency of public good provision? We answer these questions by implementing a laboratory experiment that draws on the linear voluntary contribution mechanism (VCM). We implement a standard version of the simultaneous VCM that is very close to the one used in Fischbacher and Gächter (2010), and that allows us to compare our results directly with a large body of existing literature. The experiment starts with a one-shot game that elicits unconditional and conditional contributions (e.g. Fischbacher et al., 2001, 2012; Kocher et al., 2008; Martinsson et al., 2015). This provides us with a characterization of cooperating types and enables a comparison of contributions in a situation that

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[1]The Green Climate Fund can be taken as an example. It was initiated at the 21st United Nations Climate Change Conference in Paris 2015. The goal is to raise USD 100 billion per year by 2020. The funds will be used to assist developing countries in mitigation and adaptation efforts to fight climate change (Green Climate Fund, 2014). Contributions to the fund are obviously characterized by a high degree of uncertainty; both strategic in terms of the contribution decisions of others, and natural as the impact of the monetary contributions on the intended purpose of combating climate change is truly uncertain.

includes strategic uncertainty (i.e. the unconditional simultaneous contribution decision) to contributions in a situation that isolates strategic uncertainty (i.e. the conditional contribution schedule where others' contributions are fixed). After the one-shot game, participants in the experiment play a repeated game with a finite horizon, eliciting only unconditional contributions.

By introducing three between-subject conditions, we address our research questions related to the impact of the natural uncertainty of the public good returns on contribution behaviour. Depending on the condition, the marginal per capita return (MPCR) from investment in the public good is either (i) deterministic (CONTROL condition), (ii) risky, with a 50% probability of being either low or high (RISK condition) or (iii) ambiguous, with an Ellsberg urn (Ellsberg, 1961) determining whether the return is high or low (AMBIGUITY condition).[2] Regardless of the condition and the realization of the MPCR in conditions (ii) and (iii), the contribution decision remains a social dilemma, i.e. the MPCR is always set so that it is individually optimal to free ride (to contribute nothing to the public good) for a money-maximizing decision maker, regardless of risk/ambiguity attitudes. For all conditions, it is ex-ante and ex-post socially optimal to cooperate (to contribute the entire endowment), regardless of risk- and ambiguity attitudes. In order to allow a direct comparison across conditions, the deterministic MPCR is set to the expected value of the MPCR in the risky condition, and to the implied expectation in the ambiguous condition.

For what follows, it is helpful to clearly define terms: We use the term uncertainty as an umbrella term for risk (known probabilities) and ambiguity (unknown probabilities). Natural uncertainty refers to uncertainty implied by nature, whereas strategic uncertainty means uncertainty that originates from the choice of other decision makers.[3] Natural uncertainty can stem from for example the nature of the public good returns, from conflicting pieces of information, from limited experience with a certain phenomenon and from a lack of understanding of the interplay between variables affecting an outcome.

While the early literature on decision making under uncertainty focused almost exclusively on individual settings, there is a rapidly growing literature in behavioural and experimental economics on the effects of risk taking in settings that involve social interaction, such as social comparison and peer effects, and settings that involve risky decision making for others.[4] However, the existing literature examining the effects of natural uncertainty on cooperation in social dilemmas or closely related setups is very small (Berger and Hershey, 1994; Dickinson,

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[2]It is a well-established fact that, for (implied) probabilities around 50%, decision makers in lottery choices on average display an additional aversion against ambiguity, over and above the generally observed risk aversion (Kocher et al., 2015a).

[3]There is evidence that individuals dislike risk originating from strategic interactions more than risk that does not originate from deliberate (human) choices. In the literature, this disparity is referred to as betrayal aversion (see e.g. Bohnet and Zeckhauser, 2004; Bohnet et al., 2008, 2010 and the discussion in Section 2).

[4]See e.g. Bolton and Ockenfels, 2010; Linde and Sonnemans, 2012; Brock et al., 2013; Cappelen et al., 2013; Gächter et al., 2013; Bursztyn et al., 2014; Lahno and Serra-Garcia, 2015; Krawczyk and Le Lec, 2016.

1998; Levati et al., 2009; Levati and Morone, 2013; Dannenberg et al., 2015; Köke et al., 2015). We discuss the results and experimental setups of these studies in detail in Section 2.

Our paper provides several innovations compared with the existing literature: First, our design and results are directly comparable to a large literature of VCM games with deterministic MPCRs. In contrast, however, most of the existing studies on natural uncertainty and cooperation deviate from the VCM in several dimensions (for instance by introducing thresholds, loss framing, etc.). Second, we can clearly distinguish between strategic uncertainty and natural uncertainty and, further, assess the effects of natural uncertainty in situations that do, and do not, involve strategic uncertainty. Third, we differentiate between risk and ambiguity with respect to the MPCR in the VCM. This is an important distinction since ambiguity seems to better resemble the nature of the uncertainty related to benefits from investments in most of the above-mentioned examples of social dilemmas outside the laboratory (Boucher and Bramoullé, 2010; Millner et al., 2013). Fourth, we can compare contribution behaviour in a one-shot respectively a repeated setting using partner matching, which allows us to study the importance of reputation building.

Our decision environment - the standard VCM, altered by the introduction of risky or ambiguous benefits from the public good in the respective conditions - is set up such that theoretical predictions are as straightforward as possible. As already mentioned, free riders contribute nothing in all three conditions regardless of their risk/ambiguity attitudes (see also Kocher et al., 2015b). This is not true for decisions makers with social preferences as can be demonstrated by specifying a model with altruistic preferences implemented in the most parsimonious way possible. We show that depending on the exact specification of risk preferences, reflected by the concavity of the utility function, such a model renders two predictions; one where natural uncertainty with respect to the benefits of contributions do not affect decisions of neither risk-averse nor ambiguity-averse decision makers, and one where risk- and ambiguity-averse decision makers have a stronger inclination to contribute to the public good under uncertain returns. These results follow from the linearity of our model; linear models of altruism provide a cut-off level of the altruism parameter that determines whether a decision maker contributes nothing or her entire endowment to the public good. For certain specifications, this cut-off level is lowered for risk- and ambiguity-averse decision makers under uncertain public good returns, which leads to higher average contributions. Evidently, the choice of model and specification is somewhat arbitrary which motivates empirical results.

The results from our laboratory experiment, on a large sample, show that risky and ambiguous benefits from the public good have only a very weak effect on average contribution levels. If anything, contributions are slightly lower under natural ambiguity than under natural risk or a deterministic setting. Furthermore, we do not find an interaction between strategic uncertainty and natural uncertainty. In summary, from a behavioural point of view,

it appears that strategic uncertainty overshadows natural uncertainty in social dilemmas. We think that this is an informative and important null result. Our findings are highly relevant from a methodological perspective as they establish that results from experimental linear public goods with deterministic returns translate to more realistic setups with uncertain benefits. Thus, it seems that it is perfectly fine to abstract from uncertainty when studying social dilemmas as long as it does not change the nature (Köke et al., 2015) or perception (e.g. Dannenberg et al., 2015) of the game. We conclude that the usage of standard, more parsimonious experimental designs is justified. Our results also have implications for the design of mechanisms aimed at alleviating social dilemma situations outside the laboratory; since natural uncertainty seems to play a less important role in determining decision-making in social dilemmas that intuition would imply, we should probably direct efforts towards designing mechanisms that reduce strategic uncertainty. However, if possible, we should aim at designing more deterministic mechanisms of return to investment, since - if at all - there is a tendency of less cooperation under uncertainty.

The rest of the paper is organized as follows. Section 2 provides a very brief overview of the relevant literature. In Section 3, we introduce the details of our experimental design and derive theoretical predictions. Section 4 contains the empirical analysis and Section 5 concludes the paper.

2 Related literature

For reasons of succinctness, we focus solely on experimental papers in economics that deal with decision making under uncertainty in social interactions, with a particular focus on natural uncertainty and social dilemmas.

That individuals, on average, contribute a significant share of their endowment to an efficiency-enhancing public good despite the free-rider problem has become a stylized fact (Cox and Sadiraj, 2007). Many of the models that have emerged to explain the patterns of data involve other-regarding preferences such as inequity aversion (Fehr and Schmidt, 1999) and altruism (Anderson et al., 1998). The question of how natural uncertainty influences pro-sociality has received increasing attention in recent years, and the matter is far from resolved. Bohnet and Zeckhauser (2004) analyse the impact of natural and strategic uncertainty on individual willingness to take risk in trust and dictator games in which the outcome for the recipient is determined by a chance device. Their findings suggest that individuals are more likely to take risk in situations where the risk is attributable to 'nature' rather than to the behaviour of another player - a concept they refer to as betrayal aversion. Replicating the study in six different countries, Bohnet et al. (2008) conclude that betrayal aversion seems to be a robust finding across cultures. Building on these results, Bolton and Ockenfels (2010) design a dictator game to investigate whether and how social comparisons influence decisions

in situations with natural risk. Their findings point in two directions: on the one hand, subjects are more willing to take risks when another certain option implies unequal payoffs, which is in line with previous findings of inequity aversion (Fehr and Schmidt, 1999); on the other hand, subjects are more prone to choose an outcome with a risky and socially unequal outcome than a certain outcome that implies an equal distribution of resources, which goes against inequity aversion. The authors argue that these contradictory findings could be a consequence of notions of procedural fairness. When the social inequality can be attributed to the chance mechanism, which is realized *after* the choice is made, it is less costly (in terms of utility) than when it is *directly* attributed to the decision. Brock et al. (2013) use dictator games in which the probabilities of outcomes for both the dictator and the recipient vary, to explicitly study whether decision makers care about the distribution of outcomes among players *ex ante* (in expected values) or *ex post* the resolution of uncertainty. Their results indicate that, on average, both considerations have positive weight in the decision function. However, for the category of pro-social subjects, ex-ante comparisons are more important, and the behaviour in standard dictator games is shown to be generalizable to risky dictator games. The reported results from risky dictator games indicate that the exact way in which ex ante and ex post concerns with respect to social equity enter the decision function in risky situations remains unsettled (Krawczyk and Le Lec, 2016).

The impact of uncertainty on pro-social behaviour in settings that combine natural and strategic uncertainty is discussed in a small but emerging literature on voluntary contributions to public goods or to reduce risk. The few available studies do not give a conclusive picture of the effects of uncertainty on contributions, or of the potential mechanisms that are driving the differences in contributions. One issue that complicates the reading is the variation in experimental design. The two most evident differences are whether contributions involve a binary or a more continuous choice set, and whether the uncertainty of the payoffs is conditioned on a threshold being reached (or avoided), or on a chance mechanism that could either be independent of *or* positively related to the sum of contributions to the public good. Since binary contributions might frame a decision-making situation differently than a more continuous choice set, and threshold-structured public goods games change the set of Nash equilibria, it is difficult to distinguish a general conclusion from the previous studies. In an attempt to sort the literature, we begin by discussing studies looking at contributions as a device to reduce or prevent risk, and then discuss studies of prisoner's dilemma/public goods contributions under uncertainty. Berger and Hershey (1994) investigate insurance behaviour in a repeated public goods game. Each player is exposed to a risk of incurring a private loss of probability $1/n$. In each round, players can decide to invest a fixed amount in a collective insurance pool from which all losses, irrespective of whether the player has contributed, are refunded. If the sum of losses exceeds the value of the insurance pool, subjects need to divide the additional cost among them. Compared with a situation of certain losses, investment

in the insurance pool was significantly lower under risky losses. The authors reason that a combination of increased risk-seeking preferences under stochastic returns and a feeling of less responsibility to cooperate when losses can be attributed to 'bad luck' explain the results. A similar effect on risk taking in the loss domain is found in a study by Suleiman et al. (1996), who conduct a sequential common pool resource game where the uncertainty regarding the resource size is determined by a draw from one of three different uniform distributions of common knowledge to the subjects. They find that subjects tend to increase their withdrawal of resources as the level of uncertainty regarding the size of the common pool increases. The authors explain this result as a consequence of wishful thinking, i.e. subjects base their estimate of the unknown resource on a weighted average of the interval end points, with a bias towards the larger value.[5]

In a recent study, Köke et al. (2015) examine protective and preventive behaviour in an infinite horizon public goods game, in which subjects face a binary decision of whether to cooperate or defect to reduce the magnitude of a loss, or the probability of losing the entire endowment. They find that subjects are more likely to cooperate and to sustain cooperation when they can reduce the probability of experiencing a full loss, rather than marginally reduce the magnitude of the loss. Rather than risk aversion, the authors attribute the results to a combination of anticipated regret aversion and learning dynamics. They argue that subjects learn to defect more slowly when the probability of a loss is reduced - a finding that has an optimistic flavour from the point of view of sustained preventive actions to counter climate change.

Motivated by environmental problems and the 'tipping-point' properties of many ecosystems, Dannenberg et al. (2015) study a ten-period repeated sequential threshold public good game in groups of six players. Uncertainty is introduced on the threshold level of contributions that has to be reached to avoid a catastrophic event that destroys 90% of the remaining individual endowment of each player. Players are informed about 13 potential threshold levels with either equal or unknown probability of realization, depending on the treatment. Compared with a control treatment with a known threshold level, risk and ambiguity have a negative effect on the ability of groups to reach the threshold. The result is largely driven by individual cooperative preferences. Conditional cooperators are able to coordinate to reach the unknown threshold when enough group members signal their willingness to contribute early on. Hence, the authors conclude that one mechanism to increase the level of cooperation under uncertainty is to find ways to incentivize high initial contributions.

The relevance of loss aversion in explaining lower contributions in situations involving uncertainty, is examined by Levati and others in two studies. In the first, Levati et al. (2009) implement a repeated prisoner's dilemma game with either low or high risky marginal re-

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[5]In relation to this, it is interesting to note that Hsee and Weber (1997) find that individuals base their predictions about others' risk preferences on a weighted average of own risk preferences and risk neutrality.

turns to contributions. The game is calibrated such that full contributions are not socially beneficial when the low marginal return is realized. Compared with a situation with certain marginal returns, the risky treatment significantly reduced average contributions. This result is completely driven by lower initial contributions as the time trends of the contributions over the rest of the periods are similar in the two treatments. Revisiting the setup, Levati and Morone (2013) modify the 2009 study by calibrating marginal returns such that full contributions are socially efficient for both realizations. They also add a treatment with ambiguous marginal returns. This time, they find no significant differences in contribution behaviour in situations involving risky, ambiguous, or deterministic marginal returns of investment. The authors attribute their previous findings of lower contributions under risk to loss aversion rather than risk aversion.[6]

Lastly, Gangadharan and Nemes (2009) study a repeated linear public goods game in a within-subject design and let groups of five players participate in seven treatments in which the probability distributions of the private and public investments are either certain, probabilistic or endogenously determined by the level of contributions. In the control treatment, the MPCR is set to 0.3 and the private return to 1. The risky realizations of the investment returns are determined by a known Bernoulli distribution with expected values of 0.3 for public investments and 1 for private investments. In the ambiguity treatments, the probability distribution of the realizations of the returns to private and public investments is unknown. However, the authors allow participants the choice to forgo 1/5 of their endowment to find out about the probability distribution in the ambiguity treatments.[7] This design makes it hard to determine the pure effect of ambiguity on contributions, since group members either know the probability distribution, or might suspect that other group members know it, which could affect their beliefs of others' behaviour. The authors find that subjects invest less in the account subject to uncertainty, regardless of whether it is private or public. However, when the uncertainty is related to the public good, the combination of strategic and natural uncertainty has an additional negative impact on contributions.

Of the existing studies, the experiments in Levati and Morone (2013) and Gangadharan and Nemes (2009) are closest to ours, although there are several differences. Most importantly, in addition to the repeated game, we implement a one-shot decision, which is more likely to detect potential differences between deterministic and stochastic MPCRs. In the

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[6]Similarly, Dickinson (1998) finds null results in a repeated public goods game with uncertainty on the level of the MPCR. He studies how uncertainty regarding the MPCR influences contributions in a repeated public goods game in groups of five, using a within-subject design. The MPCR is known in the first seven periods. In the subsequent seven periods, the returns are risky with a mean-preserving spread resolved with the help of a bingo cage. In the last seven periods, the MPCR is set to zero with a probability negatively correlated with the level of contributions to the group account. The order of these two last conditions is altered between sessions. Dickinson finds no difference in contribution levels across the three within-subject treatments.

[7]This option is used by 43 % and 17 % of the subjects to find out about the probability distribution of the returns to the private and public investments, respectively.

repeated setting, reputation concerns are known to dominate other behavioural motivations, and thus our design allows us to clearly distinguish between strategic uncertainty and natural uncertainty. Further, we are able to see how uncertainty of returns affects the contribution decisions of different types of players, since the contribution schedules from the preference elicitation in our experiment allows for classification of behavioural types in terms of contribution patterns. We also measure individual attitudes to risk and ambiguity. Finally, the relationship between strategic and natural risk can be directly addressed in our experiment.

3 Experimental design and predictions

3.1 Predictions

We assume that decision makers have cooperative attitudes (preferences) determining contribution strategies. In combination with the beliefs about the decisions of others, these strategies translate into actual contribution decisions. The conceptual framework for this idea is based on Fosgaard et al. (2014). According to the framework, the nature of the MPCR (deterministic versus uncertain) could affect both individual cooperative attitudes (a_i), and individual beliefs about others' contributions (b_i). Contribution strategies in the one-shot preference elicitation task are only influenced by attitudes, whereas the unconditional contribution decision, c_i, is influenced by both attitudes and beliefs, i.e. $c_i = c_i(a_i, b_i)$ with $a_i, b_i = a_i, b_i\{D, R, A\}$, where D stands for a deterministic MPCR, R for a risky MPCR, and A for an ambiguous MPCR.

The conceptual framework does not provide us with directions of possible effects of uncertainty in the MPCR. Thus, we develop the following toy model, based on the most parsimonious way of introducing pro-sociality and uncertainty in a utility model. We assume a potentially non-linear utility function and incorporate a parameter capturing unconditional altruism or warm glow, i.e. the utility derived from giving to others, as a linear component of the utility function (Anderson et al., 1998). The objective function V of a risk-neutral player in the linear VCM can then be written as:

$$V(c_{i,RN}) := (\pi_i + \alpha_i \sum_{i \neq j}^{n} \pi_j) = w - c_i + m \sum_{j=1}^{n} c_j + \alpha_i(\sum_{i \neq j}^{n} w - c_j + m \sum_{k=1}^{n} c_k), \qquad (1)$$

where $\alpha_i \geq 0$ is an individual parameter determining the level of utility derived from the sum of others' profits and the subscript RN denotes risk neutrality of the individual. Further, $\pi_k = \pi_k\{i, j\}$ denotes the profit of player k; w the endowment; m the MPCR, and n the number of group members. The maximization problem results in the usual bang-bang

solution following from the linearity of the problem:

$$c_{i,RN} = \begin{cases} full, & \text{if } \alpha_i \geq \frac{1-m}{m(n-1)} \\ zero, & \text{if } \alpha_i \leq \frac{1-m}{m(n-1)} \end{cases} \qquad (2)$$

which has the following interpretation. For full contribution, the warm-glow parameter needs to be larger than the ratio of the individual marginal return to contributions $(1-m)$ and the marginal value to all other players $(m(n-1))$; otherwise the contribution is zero. Such cut-off results of course represent a simplification. However, as can be seen below, the obtained results can still be useful to get an impression of the direction of potential effects. An important issue to keep in mind, is the effect of uncertainty with respect to the MPCR on beliefs. While this is irrelevant for free riders, beliefs are important for conditional cooperators. For them, introducing uncertainty could have an additional effect on beliefs, on top of the potential effect on cooperative attitudes. Our toy model cannot capture such positive influences on the beliefs (Chaudhuri, 2011; Smith, 2012), since the pro-social motive is assumed to be belief independent.[8] We also abstract from decision errors (McKelvey and Palfrey, 1998) and loss aversion in order to keep the model tractable. Other potential extensions to the model include non-linearity, a motivation to match the contribution of others, and additional deviations from the homo oeconomicus assumptions such as a specific form of bounded rationality.

To fix things, let us first assume that individuals exhibit constant relative risk aversion (CRRA) and that risk aversion applies only to utility derived from own profits and not to utility from other-regarding concerns. Then, equation (1) becomes:

$$V(c_{i,RA1}) := \frac{1}{1-r_i}(\pi_i)^{1-r_i} + \alpha_i \sum_{i \neq j}^{n} \pi_j \qquad (3)$$

Now the threshold level of the warm-glow parameter for full contributions is strictly smaller than that of a risk-neutral individual whenever $r_i < 1$:

$$c_{i,RA1} = \begin{cases} full, & \text{if } \alpha_i \geq \frac{1-m}{\pi_i^{r_i} m(n-1)} \\ zero, & \text{if } \alpha_i \leq \frac{1-m}{\pi_i^{r_i} m(n-1)} \end{cases} \qquad (4)$$

That is, as the utility from own monetary payoffs is discounted for risk-averse individuals, the relative weight of the other-regarding component becomes larger. Hence, the cut-off level of the warm-glow parameter for contributions is lower than that for a risk-neutral individual. This implies that average contribution levels to the public good increase, ceteris paribus,

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[8]For a discussion about how beliefs seem to be game dependent through their connection to preferences about reciprocity and guilt, see Fosgaard et al. (2014).

the more risk averse individuals are. As an aside, note that the belief regarding the level of risk attitudes of other group members should affect unconditional contributions, but not conditional contributions. A straightforward extension of the model shows that if a risk-averse, conditionally cooperative player assumes that another player is risk neutral, she should adjust the belief and contribute less than when facing another risk-averse player in her group. The second option is to consider risk aversion over the entire utility function, i.e.:

$$V(c_{i,RA2}) := \frac{1}{1 - r_i}(\pi_i + \alpha_i \sum_{i \neq j}^{n} \pi_j)^{1-r_i} \tag{5}$$

The solution shows that the threshold level for α_i coincides with that for a risk-neutral individual, for any level of risk attitude (as the parentheses $(\pi_i + \alpha_i \sum_{i \neq j}^{n} \pi_j)^{-r_i}$ cancel out). Hence, risk attitudes do not change the cut-off value.

To summarize, cooperative attitudes of risk-averse individuals in a social dilemma, with other-regarding preferences entering linearly into their utility functions, are either unaffected or reinforced by uncertainty, depending on the way in which risk aversion enters their utility functions. A very similar logic applies to ambiguity attitudes if we assume that ambiguity aversion can be represented by a smooth function (Klibanoff et al., 2005). Ambiguity aversion will in this case add additional concavity to the utility function and, thus, intensify the effect of risk aversion whenever there is an effect on the cut-off level for cooperation.

We formulate our hypotheses in relation to the conceptual model illustrated in Figure 1. Given the theoretical results, and bearing in mind that the model choice is somewhat arbitrary and that empirical assessments seem desirable in order to establish stylized facts, our hypotheses stipulate null effects. All hypotheses are formulated as a comparison to a case with deterministic MPCR and assume that the MPCR remains in the range that implies a social dilemma.

HYPOTHESIS 1: Cooperative attitudes are not affected by natural uncertainty over the MPCR.

HYPOTHESIS 2: The distribution of contribution types remains unaffected by natural uncertainty over the MPCR.

HYPOTHESIS 3: Beliefs about other group members' mean contribution levels are not different under natural uncertainty over the MPCR.

HYPOTHESIS 4: The relative impact of attitudes and beliefs about contributions is unaffected by natural uncertainty over the MPCR.

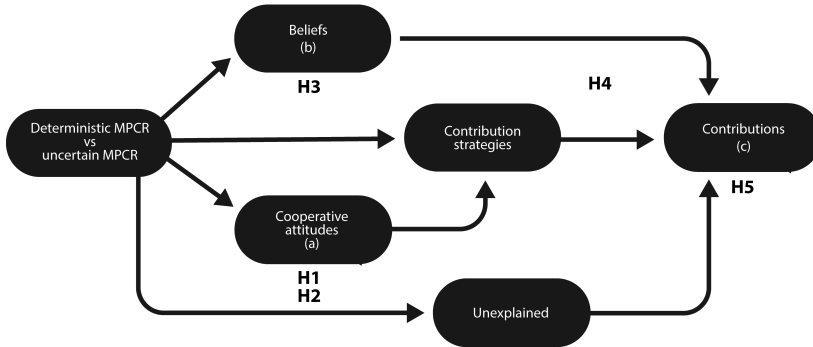HYPOTHESIS 5: Contribution behaviour is not different under natural uncertainty over the MPCR.

Figure 1: Conceptual framework. The abbreviations H1 - H5 represent our testable hypotheses.

3.2 Experimental design

Our experiment implements three conditions in a between-subject design: CONTROL, RISK and AMBIGUITY. Each session was divided into three parts as summarized in Table 1. Our basic experimental setting is a public goods game with a linear payoff function (i.e. a VCM) played in groups of four. All players played two versions of this game: a one-shot game (Part 1) in order to elicit cooperative attitudes, beliefs and unconditional contributions, followed by a 10-period repeated game (Part 2) in order to elicit cooperative behaviour in a repeated setting. Participants were informed in the initial instructions that the experiment consisted of three parts. The instructions for each part were distributed and read out loud prior to the start of the respective part (see Appendix II).

In Part 1, we followed the design by Fischbacher et al. (2001), and conducted a one-shot public goods game with elicitation of an unconditional contribution and a vector of conditional contributions (aka a contribution table). At the end of Part 1, without any knowledge of the outcomes, subjects were asked for their beliefs regarding the average contribution of their group members in the one-shot game. They were incentivized as in Gächter and Renner (2010).[9] All contribution decisions were incentivized as described in Fischbacher et al. (2001), and clearly described to the participants, using a random mechanism that made the conditional contribution payoff-relevant for one group member and the unconditional

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[9]If the guess was within 0.5 points of the actual average contribution, the subjects earned an amount equal to half of the endowment. If the guess was further off than 0.5 points, they earned a fourth of the endowment divided by the (absolute) distance between the guess and the actual average contribution. This task was not included in the instructions, i.e. it came as a surprise to the participants. A screenshot of the belief elicitation is included in Appendix I, Figure A1.

Table 1: Overview of the experimental design

	Condition		
	CONTROL	RISK	AMBIGUITY
Part I: Public goods game - One shot • Unconditional contrib. • Conditional contrib. • Beliefs	$m_{CONTROL} = 0.6$ $n * m_{CONTROL} = 2.4$	$m_{RISK} = 0.3; p = 50\%$ $m_{RISK} = 0.9; p = 50\%$ $n * m_{RISK} = 1.2; p = 50\%$ $n * m_{RISK} = 3.6; p = 50\%$	$m_{AMBIGUITY} = 0.3;$ *unknown p* $m_{AMBIGUITY} = 0.9;$ *unknown p* $1.2 \leq n * m_{AMBIGUITY} \leq 3.6$
Part II: Public goods game - Ten periods • Unconditional contrib.	$m_{CONTROL} = 0.6$ $n * m_{CONTROL} = 2.4$	$m_{RISK} = 0.3; p = 50\%$ $m_{RISK} = 0.9; p = 50\%$ $n * m_{RISK} = 1.2; p = 50\%$ $n * m_{RISK} = 3.6; p = 50\%$	$m_{AMBIGUITY} = 0.3;$ *unknown p* $m_{AMBIGUITY} = 0.9;$ *unknown p* $1.2 \leq n * m_{AMBIGUITY} \leq 3.6$
Part III: Lottery Risk attitudes Ambiguity attitudes	50 red, 50 blue chips 100 chips; red or blue	50 red, 50 blue chips 100 chips; red or blue	50 red, 50 blue chips 100 chips; red or blue
Number of observations	60	60	60

contribution payoff-relevant for the remaining group member. The amounts were denoted in experimental currency units (ECU), where 1 ECU = €0.10 in Part 1. The final payoffs for Part 1 were not announced until the end of Part 3. Thus, the participants did not know how much the other group members had contributed to the public good in Part 1.

In Part 2, participants were randomly assigned to a new group of four members with whom they had previously not interacted, and played a repeated linear public goods game for ten periods in fixed groups. After each period, players received feedback on the contributions of the other group members, the total contribution to the public good and the payoff of each group member including themselves. Subjects were informed that all ten periods were payoff-relevant, and the exchange rate was set to 1 ECU= €0.04.

Both in Part 1 and in each period in Part 2, each subject was endowed with 20 tokens and could choose how much of the endowment to contribute, c_i, to the public good while keeping the rest in an individual account.[10] Thus, the individual profit from the decision in every round was determined by:

$$\pi_i = (20 - c_i) + m_T \sum_{j=1}^{4} c_j \tag{6}$$

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[10]Fischbacher and Gächter (2010) did not find evidence of order effects in an experimental setup very similar to ours. Hence, since no feedback was provided between Parts 1 and 2, we do not expect any order effects between these parts.

where the public good is represented by the sum of all four group members' contributions; $\sum_{j=1}^{4} c_j$. The MPCR, m_T, was fixed at $m_T = 0.6$ in CONTROL and either high ($m_T = 0.9$) or low ($m_T = 0.3$) in the RISK and AMBIGUITY conditions, respectively. Each subject experienced only one of the three conditions. The MPCR in the two uncertainty conditions was realized at the end of each period with the condition-specific distribution of probabilities. By setting the probability of the high and the low MPCR to 50%, the expected MPCR in the risk condition equals 0.6, which is exactly the same as in CONTROL. The levels of m_T were calibrated such that the social dilemma structure of the game was kept, i.e. $m_T < 1$ and $nm_T > 1$, while at the same time maximizing the distance between the high and low realizations. In effect, this calibration ensures a Nash equilibrium of zero contributions for a (monetary) payoff-maximizing individual, since $m_T < 1$. Also, the social optimum of contributing the entire endowment remains unaltered across conditions because $nm_T > 1$. The marginal returns were determined through a 'chips-drawing' procedure introduced to the participants at the beginning of the first public goods game.

In the RISK condition, one opaque bag was filled with 100 chips (50 yellow and 50 white) in front of the participants at the beginning of Part 1. The realization of m_R was implemented by randomly selecting one participant who publicly drew one coloured chip, with replacement, for each group in the sessions. If the colour of the drawn chip matched the colour picked by the experimenters prior to the session (and written down on a piece of paper placed in a closed envelope), m_R was set to 0.9 for that group. If the colours did not match, m_R was set to 0.3. At the beginning of Part 2, ten bags were filled in front of the subjects (one for each period of the game), and the realization of m_R took place at the end of each period in the same way as in Part 1. Hence, during Part 2 participants knew the realizations after each period.

In the AMBIGUITY condition, prior to Part 1, subjects were asked to choose a 'decision colour', either yellow or white. The realization of m_A was implemented in a similar manner as described for the RISK condition. Instead of filling the bags in front of the participants, they were instructed that the bags had been filled beforehand with 100 chips from a large pool of chips containing an unknown distribution of yellow and white chips (we followed the procedure of Kocher et al., 2015; reasons for the specific setup are discussed there). If the colour of the drawn chip matched the colour chosen by a majority[11] of the group, m_A was set to 0.9 for that group; otherwise m_A was set to 0.3. In Part 2, subjects were shuffled into new groups and the majority colour was determined anew, based on the group members' initial choice of decision colour and the majority of the group. In both uncertainty conditions, subjects were invited to inspect the content of the bags at the end of the experiment.

Part 3 consisted of multiple choice lists to elicit attitudes to risk and ambiguity, following

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[11]In the case of a tie, the majority colour was determined by a random draw.

the design by Sutter et al. (2010). All amounts were expressed in euros (see Appendix II for an example of the lists). Participants completed a series of ordered choices on whether to take a safe or an uncertain payoff. In the first 20 choice problems, attitudes to risk were elicited. The safe payoff was increased in increments of €0.5 from 0 to €10 and the risky payoff was either €10 or 0, each with a probability of 50%. The second set of 20 decisions focused on attitudes to ambiguity. The safe payoff was identical to the first 20 choices, and the ambiguous payoff was either €10 or 0, each with an unknown probability. The payoff-relevant choice was determined by letting one randomly chosen participant draw a card form a deck of 40 cards, which represented the 40 decisions made. If the number of the card corresponded to a risky choice (1-20), the participant drew one chip from a bag filled with 50 red and 50 blue chips in front of all participants. If the number of the card corresponded to an ambiguous choice (21-40), the participant drew a chip from a bag with an unknown distribution of red and blue chips, filled as the bags in Parts 1 and 2 described for the AMBIGUITY treatment. The payoff from the risky/ambiguous choice was set to €10 if the colour drawn matched the colour chosen by the participant prior to Part 3, and to €0 otherwise. For participants who had chosen the safe amount in the choice problem determined by the card, the safe amount was paid out regardless of the colour drawn. It should be noted that we cannot exclude order effects from Part 2 to Part 3 due to the feedback information, in particular on profits in Part 2. Thus, the elicitation of uncertainty attitudes in Part 3 provides auxiliary data that do not affect our condition comparisons. Given this, our test of equality in uncertainty attitudes across conditions is a demanding test of successful randomization.

4 Empirical analysis and results

The experiment was carried out in the MELESSA laboratory at the University of Munich, Germany, and programmed using the z-tree software (Fischbacher, 2007). One hundred eighty participants were recruited with ORSEE (Greiner, 2015) from the laboratory's subject pool. In total, nine experimental sessions were run with 20 participants in each session. The sample was similar in socio-economic characteristics such as gender (Fisher's exact test, p=0.80) and academic field (χ^2 test, p=0.10) when comparing across the three treatments.[12] The experiment lasted 1.5 - 2 hours, depending on the condition. The average payoff was €24 (€23.4 in CONTROL, €24 in RISK and €24.4 in AMBIGUITY). The earnings were paid privately in cash at the end of the session together with a show-up fee of €4.

The risk attitude elicitation task in Part 3 of our experiment allows us to determine individual attitudes to risk and ambiguity (Figures A2–A3). We find no significant differences across conditions when looking at the number of risky and ambiguous choices

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[12]All tests throughout the paper are two-sided.

in a Mann-Whitney test (risk attitudes in Part 3: CONTROL=RISK: p=0.136; CONTROL=AMBIGUITY: p=0.679; RISK=AMBIGUITY: p=0.299; ambiguity attitudes in Part 3: CONTROL=RISK: p=0.530; CONTROL=AMBIGUITY: p=0.920; RISK= AMBIGUITY: p=0.679)[13], which we take as evidence that our randomization worked.

4.1 Cooperative attitudes

The conditional contribution schedules from Part 1 allow us to elicit cooperative attitudes. By conditioning decisions on other group members' average contributions, the decision becomes (from a game-theoretic perspective) sequential and does not exhibit any strategic uncertainty. Do contribution schedules differ across our three treatments, which feature different types of natural uncertainty? A quick glance on Figure 2 indicates that there are very small differences between the treatments.
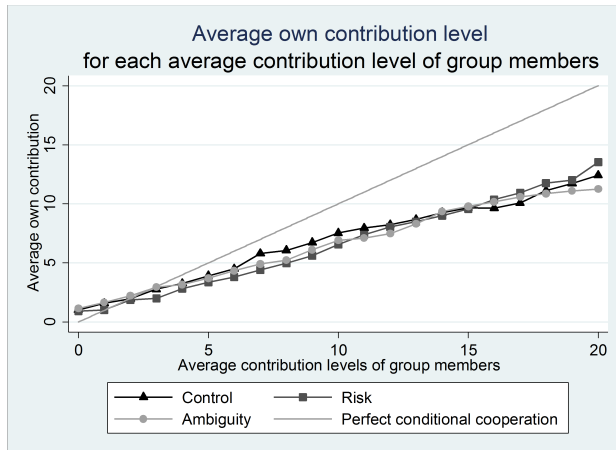

Figure 2: Average conditional contribution schedule

In a more detailed analysis of the conditional contribution patterns, we investigate individual heterogeneity. Following Fischbacher and Gächter and Renner (2010), we fit a linear regression for each individual. We can then compare different attitudes by plotting the relation between the individual slope coefficient (x-axis), which shows how much an individual increases her contribution if the others on average increase theirs by one unit, and the average

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[13]We find similar results when using the switching point as a proxy for risk and ambiguity attitudes, respectively. The great majority of our subjects are consistent in their choices. 100%, 96.6% and 95% of those in the CONTROL, RISK and AMBIGUITY treatments, respectively, show consistent choice behaviour in the risk attitudes elicitation in terms of a maximum of one switching point in the direction risky-to-safe. The corresponding numbers for the ambiguity attitudes elicitation are 98%, 97% and 93%.

individual contribution in the schedule (y-axis), represented by a circle (Figure 3). The circles are scaled such that a larger size represents higher relative frequency of the average individual contribution. It is useful to use perfectly conditional cooperators (people who match the others' average contributions perfectly for all levels) and free riders as reference points when interpreting the figures. A perfect conditional cooperator will have a mean contribution level of 10 and a slope of 1. For a free rider, both the mean contribution and the slope will be zero. Most subjects have positive slopes, meaning that they increase their contributions as the group's average contribution increases. Although there is considerable heterogeneity in cooperative attitudes within our three treatments, there are no significant differences across conditions (F-test, p=0.798).[14] This can also be seen more clearly when combining the fitted slopes, which relate the individual slopes from the contribution schedules to the individual average contributions in the contribution table, into one graph (Figure 3, bottom right).
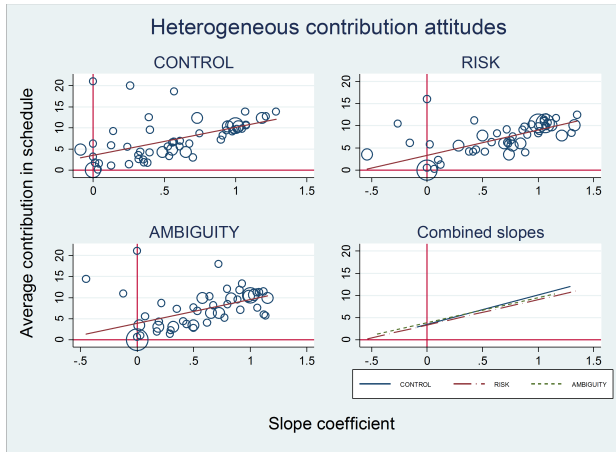

Figure 3: Heterogeneous contribution attitudes

RESULT 1: Cooperative attitudes are not affected by natural uncertainty.

Findings from numerous replications of the Fischbacher et al. (2001) design are conclusive in that attitudes to cooperation differ across individuals. The most common categorization, based on the full contribution schedules, is to form four types of groups. *Free riders* are the subjects who never contribute anything, irrespective of the contributions of others. *Conditional cooperators* are subjects whose contributions monotonically increase with the average

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[14]Nor is there any statistical difference in terms of purely altruistic contributions, defined as positive contributions conditional on the average contribution in the group being zero (Mann-Whitney tests: CONTROL=RISK, p=0.229; CONTROL=AMBIGUITY, p=0.674; RISK=AMBIGUITY, p= 0.424; proportion test: CONTROL=RISK, p=0.207; CONTROL=AMBIGUITY, p=0.658; RISK=AMBIGUITY, p= 0.408).

contribution of the other group members, or for whom the Spearman rank correlation coefficient between own and others' contributions is positive and significant at the 1% level. *Hump-shaped* is the term for those who increase their contributions up to a certain point, after which they decrease their contributions (creating a 'hump' in the contribution schedule). Finally, the remaining subjects are classified as *others*.

Figure 4 shows the distribution of types. By far, conditional cooperators are the most frequent type in all conditions: 82% in CONTROL, 72% in RISK and 70% in AMBIGUITY. Overall, the frequency of contribution types does not differ statistically across conditions (Pearson's χ^2: p=0.551; Fisher's exact test: p=0.574). The conditional contribution schedules of the different types are also similar in the three treatments (see Appendix I, Figure A4). The distribution of types is consistent with previous findings in the literature (Chaudhuri, 2011).
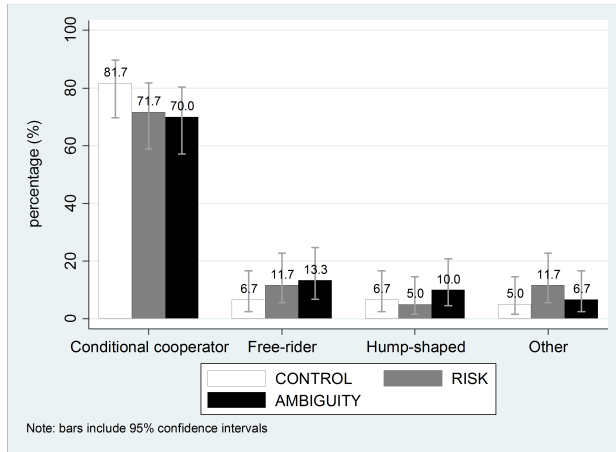
Figure 4: Distribution of contributor types

RESULT 2: The distribution of contribution types is unaffected by natural uncertainty.

4.2 Beliefs

Are beliefs in the RISK and AMBIGUITY conditions different from those in the CONTROL condition? Overall, subjects do extremely well in guessing the average contribution of their group members in all three conditions. We find no significant difference between the average one-shot contributions in Part 1 (Appendix I, Figure A5) and the average beliefs about group members' mean contributions, as shown in Table 2. Average beliefs are somewhat

Table 2: Mean beliefs and unconditional contributions (std. dev in brackets)

	Belief	Contribution (one-shot)	H_0: Belief=Contribution Wilcoxon signed-ranks test
CONTROL	9.25	9.42	p=0.97
	(4.47)	(6.42)	
RISK	8.57	7.87	p=0.39
	(3.40)	(5.96)	
AMBIGUITY	8.09	8.12	p=0.90
	(5.02)	(6.90)	

	Mann-Whitney U-test	
H_0: CONTROL=RISK	p=0.57	p=0.21
H_0: CONTROL=AMBIGUITY	p=0.15	p=0.21
H_0: RISK=AMBIGUITY	p=0.36	p=0.92

lower in both uncertainty conditions, and so is the average contribution in the one-shot public goods game in Part 1. Particularly, when looking at the cumulative distribution of beliefs (Appendix I, Figure A6), it seems that a higher share of participants in the RISK and AMBIGUITY conditions believe that the other group members' contributions are low: 75% and 72%, respectively, of the subjects believe that the average contribution is 10 or less; the corresponding number in the CONTROL condition is 65%. However, the difference in belief distribution is too small to be significant (Kolmogorov-Smirnov: CONTROL=RISK, p=0.660; CONTROL=AMBIGUITY, p=0.660; RISK=AMBIGUITY, p= 0.509). Our null result also holds if we break down the analysis into types (see Appendix I, Table A1). Although there are indications of lower beliefs in the uncertainty conditions, we cannot reject our null hypothesis of equal beliefs across conditions.

RESULT 3: There are no differences in beliefs about other group members' mean contribution levels under natural uncertainty, compared with the deterministic situation.

4.3   Effect of attitudes and beliefs on contributions

Table 2 reveals that one-shot unconditional contributions are not significantly different from each other in the three treatments using pairwise tests. If at all, average contributions to the public good are lower in RISK and AMBIGUITY than in CONTROL (in contrast to both theoretical utility specifications put forward in Section 3), even though the differences fail by far to reach conventional levels of significance in pairwise tests. Remember that we have a comparatively large sample (N=60) and that all absolute differences are small in economic terms. Section 4.5 provides some additional power analyses for our main results.

The elicitation of beliefs in Part 1, together with the unconditional and conditional con-

tributions, allows us to analyse how beliefs relate to actual average contribution decisions at the individual level. We use the belief from Part 1 and the respective conditional contribution from the contribution schedule in Part 1 to see how they can explain the unconditional contributions from Part 1.

Following Fischbacher and Gächter (2010), we predict the unconditional contribution, $\hat{c}_i$ as: $\hat{c}_i = a_i(b_i)$. That is, we take the belief of a subject, look up her conditional contribution for the specific belief and see how the 'predicted unconditional contribution' matches the actual unconditional contribution in Part 1. If we define subjects who deviate within two units from the predicted contributions as consistent, as in Gächter et al. (2014), we have 50% consistent decision makers in CONTROL, 65% in RISK and 58% in AMBIGUITY (Pearson $\chi^2 : p = 0.414$; Fischer's exact: p=0.452, for the comparison across treatments), which is similar to the finding in Gächter et al. (2014), where 64% are classified as consistent. Moreover, on average there are no significant differences across treatments in terms of the magnitude of deviations from the predicted contribution (Mann-Whitney test; CONTROL=RISK: p=0.438; CONTROL=AMBIGUITY: p=0.197; RISK=AMBIGUITY: p=0.533).

The next step is to explain the impact of attitudes and beliefs on unconditional contributions. We use OLS to run a regression of contributions as a function of beliefs and predicted contributions:

$$c_i = \alpha + \beta \hat{c}_i + \gamma b_i + \epsilon_i \tag{7}$$

The predicted contribution captures how well beliefs about others' behaviour correlate with attitudes to cooperation. If attitude is the only thing that matters for decisions, the coefficient of $\hat{c}_i$ should be 1, i.e. $\beta = 1$. If both attitudes and beliefs matter, and there is nothing else explaining contribution behaviour, the sum of their coefficients should be 1, i.e. $\beta + \gamma = 1$, assuming no problem related to multi-collinearity between attitudes and beliefs (see further Fischbacher and Gächter, 2010, footnote 17).

The regression results are presented in Table 3. Panel A includes the whole sample of subjects, whereas panel B is restricted to subjects categorized as conditional cooperators. The sample is restricted to conditional cooperators because beliefs are expected not to affect the behaviour of free riders, while they play the most important role for conditional cooperators. For both panels, we estimate one regression per treatment in order to simplify readability compared with a regression with interaction effects of the main variables with the treatment dummies. Consistent with previous findings (Gächter et al., 2014; Gächter and Renner, 2010), both beliefs and predicted contributions are positive and significant in explaining the first period contribution in both panels. The F-test in Table 3 shows that the sum of the coefficients is not statistically different from one in either of the conditions. This implies

that the magnitude of the coefficients is similar across the three treatments. Table A3 in Appendix I introduces the independent variables separately to give an indication of possible multi-collinearity. Our conclusions remain unchanged.

Looking at the whole sample (Panel A), the regression results indicate that beliefs are playing the most important role in explaining contributions in all conditions, particularly so in the RISK condition. This result is further supported when looking at the R^2 in the regression in the Appendix, which uses only one of the independent variables at a time. F-tests on the equality of the coefficients reveal no significant difference across the three treatments. Note, however, that in the RISK treatment, the influence of the beliefs on cooperation is on average a bit higher than in the two other treatments.

RESULT 4: The relative impact of attitudes and beliefs on contributions is unaffected by natural uncertainty.

Table 3: The explanatory power of attitudes and beliefs for first period contribution decisions

VARIABLES	CONTROL (1)	RISK (2)	AMBIGUITY (3)	CONTROL (1)	RISK (2)	AMBIGUITY (3)
$\hat{c}$	0.455***	0.398***	0.437**	0.537***	0.440**	0.426*
	(0.136)	(0.116)	(0.175)	(0.158)	(0.167)	(0.232)
Belief	0.554***	0.763***	0.577**	0.393*	0.629**	0.522*
	(0.201)	(0.158)	(0.231)	(0.225)	(0.253)	(0.297)
Constant	0.965	-1.161	0.571	2.512*	-0.059	1.829
	(1.254)	(1.129)	(1.121)	(1.377)	(1.573)	(1.501)
F-test: $\hat{c} + Belief = 1$	p=0.933	p=0.181	p=0.899	p=0.559	p=0.681	p=0.703
F-test: $\hat{c} = Belief$	p= 0.761	p=0.150	p=0.725	p=0.700	p=0.634	p=0.854
Observations	60	60	60	49	43	42
R^2	0.672	0.641	0.665	0.687	0.576	0.618

Note: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

4.4 Repeated contributions

Our findings indicate that outcome uncertainty does not significantly change the relative importance of beliefs and attitudes for contribution decisions. However, in a repeated setting other factors such as learning, reputational concerns and dynamics in the beliefs might play an important role. It these factors play a different role when interacted with natural uncertainty, contribution behaviour could change. We thus conclude our empirical assessment by looking at Part 2 of the experiment, i.e. the 10-period repeated VCM in fixed groups.

In Figure 5 we average over group contributions for each period and condition. Indeed, the contribution levels in the AMBIGUITY condition seem to be somewhat lower until period 7. However, the difference in absolute levels is small and the mean level of group contributions over all ten periods does not differ significantly across the three treatments (Kruskal-Wallis text, p=0.392).
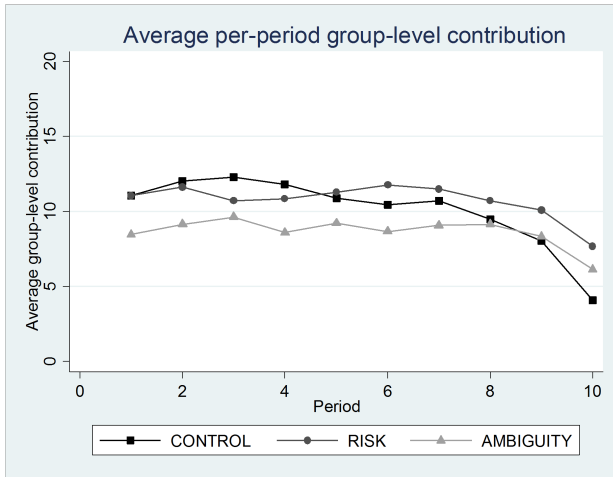

Figure 5: Repeated contributions across conditions

Going beyond the non-parametric comparison, we look at an individual random-effect panel regression that can take the dynamics of contributions into account. The most parsimonious way of looking at individual contributions is to model them as a function of the treatment and a time trend.

We also modify our base model by adding the positive and negative deviations in own contributions from the average contribution of the other group members in the previous period, $c_{i,t-1}^{devPos}$ and $c_{i,t-1}^{devNeg}$, respectively, and a dummy, $HighMPCR_{i,t-1}$, indicating whether the realization of the MPCR was high or low in the previous period, as well as the interactions, $\sum I$. The econometric specification is:

$$c_{it} = \alpha + \gamma_{RISK} RISK + \gamma_{AMBIGUITY} AMBIGUITY + \beta_1 c_{i,t-1}^{devPos} + \beta_2 c_{i,t-1}^{devNeg} + \\ \beta_3 HighMPCR_{i,t-1} + \delta' Period + \sum I + \epsilon_{it} \qquad (8)$$

The deviations from group members' previous decisions are introduced to capture the

dynamics within the group. For conditional cooperators, the contributions of others relative to their own contributions matter by definition. The dummy for the realization of the previous period's marginal per capita return is introduced to get a grasp of whether individuals adhere to simplifying decision heuristics (gambler's fallacy or hot hand fallacy), and how this differs between risk and ambiguity. In effect, the realization of the marginal per capita return is independent across periods. Nevertheless, the latest realization might be used, deliberately or subconsciously, as some sort of guide for the next decision. We run the model as a pooled OLS with errors, ϵ_{it}, clustered at the group level.[15] As a robustness check we also run a random effects Tobit model where the contributions are censored at 0 (lower limit) and 20 (upper limit). Such censoring is ignored in an OLS framework, which might lead to inconsistent and downward-biased estimates (Merrett, 2012). The results do not affect the interpretations of the effects at play (results in Appendix 1, Table A4).

The results from our most basic model (Table 4), confirm the impression from Figure 2. Average contributions are lower in the AMBIGUITY condition and higher in the RISK condition. However, the dummy variables for the conditions are not significant. When adding deviations from group members' average contributions in the previous period, and their interaction with the condition dummies (Column (2)), we find, not surprisingly, that subjects respond the most to negative deviations. A one-unit increase in the average negative deviation is matched with a -0.43 contribution response, irrespective of condition. In other words, the large share of conditional cooperators identified in Part 1, base their contribution decisions on the other group members' previous contributions. However, their reactions are stronger to negative than to positive deviations.

The results hold when we introduce dummies for the realization of the high MPCR level in the previous period (Column (3)). To this end, we run a regression using only the observations from the AMBIGUITY condition, using RISK as reference condition. The results do not provide any support for subjects using last period's realization as a simplifying heuristic for the current period's contribution decision. This finding is interesting in light of the findings in Köke et al. (2015), where the experience of a loss event triggered people to start cooperating in the next period despite the fact that realizations of losses were independent.

RESULT 5: There is no difference in contribution behaviour to a public good over time under natural uncertainty, compared with a deterministic situation.

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[15]We tested whether we could use GLS. However, a Hausman test applied to the base model, suggested choosing a fixed effects over a random effects specification ($\chi^2 = 16.46$, P < 0.001). As we want to capture time-invariant explanatory variables, we specified a pooled OLS with clustered standard errors at the group level.

Table 4: Regression results from pooled OLS for individual contribution decisions

VARIABLES	(1)	(2)	(3)
RISK	0.645	1.406	Reference
	(1.726)	(2.613)	
AMBIGUITY	-1.443	-0.851	-2.249
	(2.033)	(2.914)	(2.655)
$c_{i,t-1}^{devPos}$		0.091	-0.051
		(0.206)	(0.200)
$c_{i,t-1}^{devPos} * RISK$		-0.213	Reference
		(0.251)	
$c_{i,t-1}^{devPos} * AMBIGUITY$		-0.088	0.225
		(0.285)	(0.292)
$c_{i,t-1}^{devNeg}$		-0.430**	-0.499**
		(0.201)	(0.232)
$c_{i,t-1}^{devNeg} * RISK$		-0.102	Reference
		(0.283)	
$c_{i,t-1}^{devNeg} * AMBIGUITY$		-0.241	-0.025
		(0.291)	(0.317)
$HighMPCR_{i,t-1}$			0.956
			(0.889)
$HighMPCR_{i,t-1} * AMBIGUITY$			-0.139
			(2.045)
$HighMPCR_{i,t-1} * c_{i,t-1}^{devNeg}$			-0.069
			(0.196)
$HighMPCR_{i,t-1} * c_{i,t-1}^{devNeg} * AMBIGUITY$			-0.254
			(0.333)
$HighMPCR_{i,t-1} * c_{i,t-1}^{devPos}$			-0.161
			(0.208)
$HighMPCR_{i,t-1} * c_{(i,t-1)}^{devPos} * AMBIGUITY$			-0.198
			(0.313)
Constant	10.48***	12.53***	13.31***
	(1.214)	(2.237)	(1.649)
Period FE	✓	✓	✓
Observations	1,800	1,620	1,080
R-squared	0.047	0.111	0.111

Note: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

4.5 Power test

This paper provides a set of statistical null results. Moreover, the economic magnitude of the differences between different treatments in our experiment is very small. Taken together, we firmly believe that these statistical and economic null results are informative, especially since the theoretical priors are unclear. A statistical null result from an experiment is either due to a true representation of behavior or it is a false negative result, i.e., a Type II error, where we failed to detect a true difference. In contrast to a Type I error, i.e., false positive meaning that the significant difference found is due to random sample variation and related to chosen significance level, Type II error depends on several interacting factors. A common way to assess Type II error is by using a power test and focus on required sample size. The data input needed for such analyses are: (i) differences between the treatments and (ii) variance in the treatments. The non-existence of previous comparable results to derive test statistics from made an a priori test plan unobtainable since any results on required sample size would be directly affected by our numbers chosen.

However, to get a sense of the sample sizes that would have been necessary to obtain significant results, we conduct an ex-post assessment of statistical power. Clearly, this is an ad-hoc exercise in the sense that it uses the observed means and variances obtained in this study (for a critical discussion of the usage of post-experimental power tests, see Hoenig and Heisey (2001) and O'Keefe (2007)). Still, it puts perspective on the obtained results, and more importantly this should be used as an indication of required sample sizes for future experiments on uncertainty in linear public goods.

As input data in our post-experimental analyses of required sample size, we use the figures presented in Table 2. To obtain the required sample size given the specified differences and variances, we need to set the significance level, i.e., the probability of a false positive, and the power, i.e., the probability of detecting the specified effect. We set these parameters to the figures normally used in the literature namely significance level of 5 % and power of 80 %, where latter means a 20 % probability of a false positive. Table 5 shows the required number of observations needed for the figures discussed above using a two-sided test of independent means. The results show that our null results are very robust and that the sample size would have to be much larger to come close to significant differences between the treatments. It should be noted that we have 60 independent observations for each treatment in Part 1 of the experiment. This is a comparatively high number for experimental public goods games. In any respect, the economic magnitude of the differences between treatments is very small and fundamental to our main conclusions.

Table 5: Post-experimental power test on required sample size

	Belief	Contribution
CONTROL and RISK	N=536	N=251
CONTROL and AMBIGUITY	N=264	N=413
RISK and AMBIGUITY	N=1,253	N=10,440

Note: We use mean and variance from Table 2 and we set the significance level to 5 % and power to 80 %.

5 Conclusion

The objective of this paper was to investigate the effect of uncertainty regarding the MPCR on contributions to public goods. Many, if not most, real-life public goods have the feature that the relationship between contributions to and the return from the public good is uncertain. Meanwhile, most knowledge about cooperative behaviour from public goods experiments conducted in the laboratory is based on purely deterministic returns. By conducting both a one-shot public goods experiment using the strategy method and a 10-period public goods experiment with deterministic, risky and ambiguous return conditions in a between-subject design, we can separate the effect of natural and strategic uncertainty. Our main finding is that the standard results with deterministic return hold in the presence of uncertainty.

We do not observe significant differences between the three treatments CONTROL, RISK and AMBIGUITY. These null results hold for cooperative attitudes (contribution schedules), beliefs, one-shot contributions, the type distribution and the repeated interaction. While null results are often considered less interesting in economics, we think that we provide a very relevant null result here. First, theoretical predictions are ambiguous and do not give clear guidance regarding what to expect. Second, our null result holds consistently in related domains (attitudes, beliefs and contributions) and thus seems systematic rather than idiosyncratic. Third, our power analysis shows convincingly that the null results are robust to a strong increase in sample size, despite the fact that we already use a comparatively large sample in our experiment. Hence, we believe that we provide a very informative null result in the domain of research on social dilemmas.

Our results lend themselves to some relevant methodological implications and to apparent implications for the world outside the laboratory. It seems that existing empirical evidence based on deterministic public goods games can be taken as good indicators for situations outside the laboratory that involve natural uncertainty. Hence, the existing research has

not neglected an important dimension in the provision of public goods so far. Our findings also have more general implications for uncertainty in the provision of public goods. Our results are consistent with the interpretation that strategic uncertainty overshadows natural uncertainty in social dilemmas and that the focus when designing cooperation-enhancing mechanisms should be on reducing strategic uncertainty rather than natural uncertainty. Given that the latter is often not possible by the very nature of the problem, this is good news for the solving of real-world social dilemmas. A natural extension of our research is to study the external validity of our main findings directly in the field, but this will be left for future research.

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Appendix I

Table A1: Summary statistics of unconditional contribution, conditional contribution, and belief by type

Type	Average conditional contribution			Pairwise Mann-Whitney		
	CONTROL	RISK	AMBIGUITY	A=C	R=C	A=R
Conditional cooperator	7.60	7.72	7.91	p=0.187	p=0.526	p=0.482
	(6.69)	(6.46)	(6.53)			
Free rider	0	0	0	-	-	-
Hump-shaped	4.92	4.59	6.21	p=0.046	p=0.795	p=0.089
	(5.43)	(4.29)	(5.31)			
Other	6.52	7.13	6.51	p=0.278	p=0.914	p=0.505
	(3.76)	(5.86)	(5.44)			

Type	Beliefs			Pairwise Mann-Whitney		
	CONTROL	RISK	AMBIGUITY	A=C	R=C	A=R
Conditional cooperator	9.71	8.55	9.06	p=0.449	p=0.333	p=0.905
	(4.65)	(3.43)	(5.31)			
Free rider	6.5	6.5	3.75	p=0.225	p=0.634	p=0.520
	(3.11)	(6.02)	(2.17)			
Hump-shaped	7.25	6.5	6.42	p=0.592	p=0.593	p=0.999
	(3.80)	(4.09)	(3.67)			
Other	8	11.64	9	p=0.697	p=0.059	p=0.181
	(1.73)	(3.84)	(2.82)			

Type	Unconditional contribution			Pairwise Mann-Whitney		
	CONTROL	RISK	AMBIGUITY	A=C	R=C	A=R
Conditional cooperator	10.51	8.56	9.88	p=0.572	p=0.169	p=0.510
	(6.31)	(5.50)	(7.02)			
Free rider	2.5	2.86	0.5	p=0.514	p=0.773	p=0.845
	(5)	(7.56)	(1.41)			
Hump-shaped	5.75	4.66	6	p=0.828	p=0.589	p=0.513
	(5.56)	(4.04)	(5.83)			
Other	5.67	10	8.25	p=0.138	p=0.190	p=0.848
	(1.15)	(5.60)	(2.36)			

Table A2: Switching points

Number of switches	CONTROL		RISK		AMBIGUITY	
	Ambiguity	Risk	Ambiguity	Risk	Ambiguity	Risk
0			2	2	1	1
1	59	60	56	56	55	56
2			2		1	
3	1				1	
4						1
5				2	1	1
6					1	
9						1

Table A3: The explanatory power of attitudes and beliefs for first period contribution decisions

VARIABLES	CONTROL (1)	CONTROL (2)	RISK (3)	RISK (4)	AMBIGUITY (5)	AMBIGUITY (6)
$\hat{c}$	0.771***		0.769***		0.827***	
	(0.078)		(0.102)		(0.084)	
Belief		1.120***		1.121***		1.089***
		(0.118)		(0.129)		(0.110)
Constant	3.783***	-0.936	3.053***	-1.739	2.668***	-0.692
	(0.763)	(1.210)	(0.846)	(1.216)	(0.777)	(1.044)
Observations	60	60	60	60	60	60
R^2	0.629	0.608	0.493	0.566	0.628	0.628

Note: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table A4: Regression results from random effects Tobit. Dependent variable is the per period individual contribution decisions.

VARIABLES	(1)	(2)	(3)
RISK	0.522	0.602	
	(1.071)	(1.091)	
AMBIGUITY	-1.677	-1.598	-2.193**
	(1.073)	(1.093)	(1.113)
$c_{i,t-1}^{devPos}$		-0.094**	-0.149***
		(0.040)	(0.0475)
$c_{i,t-1}^{devNeg}$		-0.201***	-0.235***
		(0.045)	(0.056)
$HighMPCR_{i,t-1}$			0.595**
			(0.298)
Period FE	✓	✓	✓
Observations	1,800	1,620	1,080

Note: Robust standard errors in parentheses.
The results are reported at the means of the marginal effects on the expected value of the censored outcome.
*** p<0.01, ** p<0.05, * p<0.1.

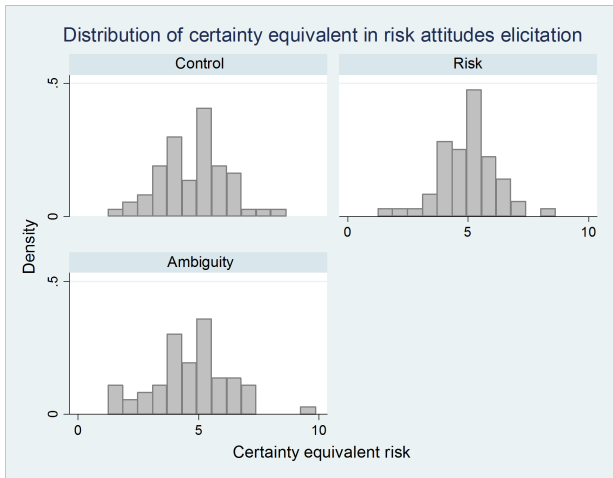Figure A1: Screenshot belief elicitation

Figure A2: Distribution of certainty equivalents in the risk attitudes elicitation across treatments
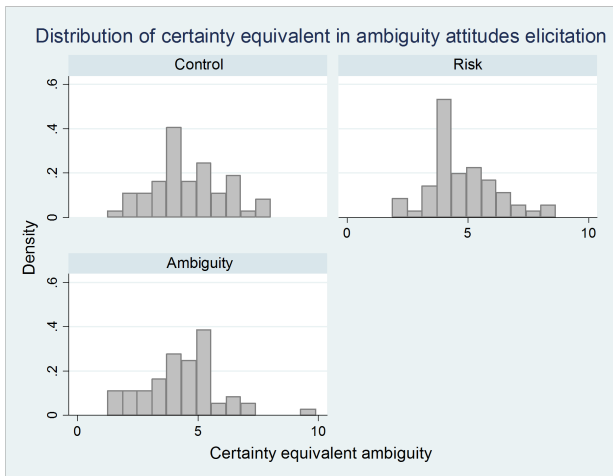

Figure A3: Distribution of certainty equivalents in the ambiguity attitudes elicitation across treatments
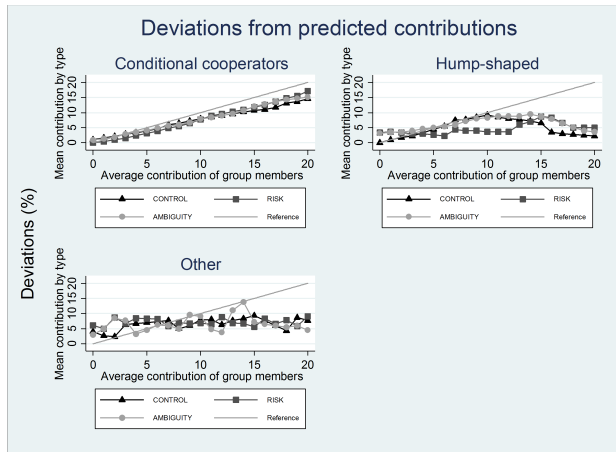
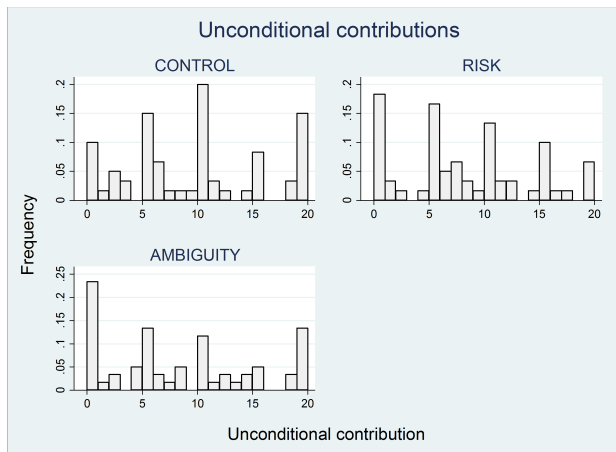Figure A4: Conditional contribution across types

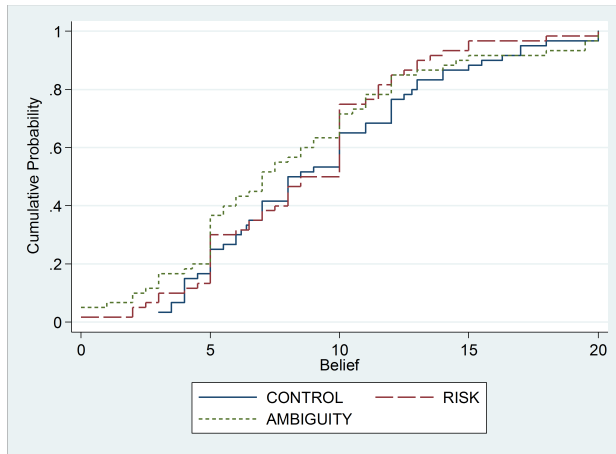Figure A5: Average unconditional contribution across conditions

Figure A6: Cumulative distribution function of beliefs across conditions

Appendix II

Experiment Instructions*

* The presentation of instructions are here limited to the AMBIGUITY treatment. Alterations of these were used for the RISK respectively CONTROL treatments, making sure to preserve as much resemblance as possible between the three instruction sets.

Welcome to the experiment and thank you for participating!

Please do not talk to other participants.

General

This is an experiment on decision making. You receive 4 Euro for showing up on time. During the experiment you can earn more money that will be paid out to you in cash at the end of the experiment.

The experiment will last approximately 120 minutes. If you have any questions, please raise your hand, and one of the experimenters will come to you and answer your questions privately. You are not allowed to communicate with any other participants during the experiment. If you do so, you shall be excluded from the experiment as well as from all payments. During the experiment, your earnings will be calculated in **experimental points**. At the end of the experiment, all points that you earn will be converted into Euro at the exchange rate announced at the beginning of each part.

Anonymity

You will learn neither during nor after the experiment, with whom you interact(ed) in the experiment. The other participants will neither during nor after the experiment learn how much you earn(ed). Your decisions will be anonymous. At the end of the experiment you will be asked to sign a receipt regarding your earnings which serves only as a proof for our sponsor.

Means of help

You will find a pen at your table which we ask that you, please, leave on the table when the experiment is over. While you make your decisions, a clock at the top of your computer screen will run down. This clock will inform you regarding how long we think that the decision time will be. However, if you need more time, you may exceed the limit. The input screens will not be dismissed once time runs out. However, the output/information screens (here you do not have to make any decisions) will be dismissed after time is up.

Experiment

The experiment consists of three parts. You will receive instructions for each part after the previous part has ended. These instructions will be read to you aloud. Then you will have an opportunity to study them on your own. The three parts are independent of each other.

Decision colour choice

Before we continue with the instructions, you will choose a decision colour – either yellow or white. The decision colour will be relevant later on, and we will describe in detail how it will be relevant.

Part 1

The basic decision situation

The basic decision situation will be explained to you in the following. Afterwards you will find some questions on the screen that will help you better understand the decision making environment.

You will be a member of a group consisting of **4 members**. Each group member will be endowed with 20 points and has to decide on the allocation of these 20 points. You can put these 20 points into your **private account** or you can put them **fully or partially** into a **group account**. Each point you do not put into the group account will automatically remain in your private account.

Your income from the private account:

You will earn one point for each point you put into your private account. For example, if you put 20 points into your private account (and therefore do not put anything into the group account) your income will amount to exactly 20 points out of your private account. If you put 6 points into your private account, your income from this account will be 6 points. No one except you earns something from your private account.

Your income from the group account:

Each group member will profit equally from the amount you put into the group account. Similarly, you will also get a payoff from the other group members' allocation into the group account. The individual income for each group member out of the group account will be either Option A or Option B:

OPTION A
Individual income from group account =

Sum of all group members' contributions to the group account $\times 0.3$

OR

OPTION B
Individual income from group account =

Sum of all group members' contributions to the group account $\times 0.9$

Option A and Option B become relevant with unknown probability; how the relevant option is determined will be explained below.

Examples

If, for example, Option A is relevant and the sum of all group members' contributions to the group account is 60 points, then you and the other members of your group each earn 60×0.3=18 points out of the group account. If instead the four group members contribute a total of 10 points to the group account, you and the other members of your group each earn 10×0.3=3 points out of the group account.

If, for example, Option B is relevant and the sum of all group members' contributions to the group account is 60 points, then you and the other members of your group each earn 60×0.9=54 points out of the group account. If instead the four group members contribute a total of 10 points to the group account, you and the other members of your group each earn 10×0.9=9 points out of the group account.

Relevant option

How do we determine whether Option A or Option B is relevant? Remember the decision colour choice in the beginning of this experiment. First, we determine the majority colour in your group. If three group members chose yellow, yellow is the group decision colour. If one chose yellow, white is the group decision colour, etc. If two group members chose yellow and two chose white, the decision colour is selected randomly.

This opaque bag has already been filled with exactly 100 coloured chips before the experiment. These chips are either yellow or white. The distribution of the colours is unknown to you: A student assistant has randomly drawn 100 chips from a bigger bag that contained far more than 100 chips – only yellow and white ones. Thus, you do not know how many of the 100 chips are yellow or white. At the end of the experiment, one randomly selected participant will draw one chip without looking into the bag for each of the groups in this room, starting with group 1, group 2, group 3, … (each time returning the chip into the bag). If the colour of the drawn chip for your group does not match your group decision colour, Option A is relevant for your group; if the colour of the drawn chip matches your group decision colour, Option B is relevant for your group. You are allowed to inspect the content of the bag at the end of the experiment if you want to.

Total income:

Your total income is the sum of your income from your private account and that from the group account:

Income from your private account (= 20 – contribution to group account)

EITHER

+ Income from group account (= 0.3 × sum of contributions to group account)

if OPTION A is relevant (if chip colour ≠ group decision colour)

OR

+ Income from group account (= 0.9 × sum of contributions to group account)

if OPTION B is relevant (if chip colour = group decision colour)

= Total income

Before we proceed, please try to solve the questions on your screen. If you want to compute something, you can use the Windows calculator by clicking on the calculation symbol on your screen.
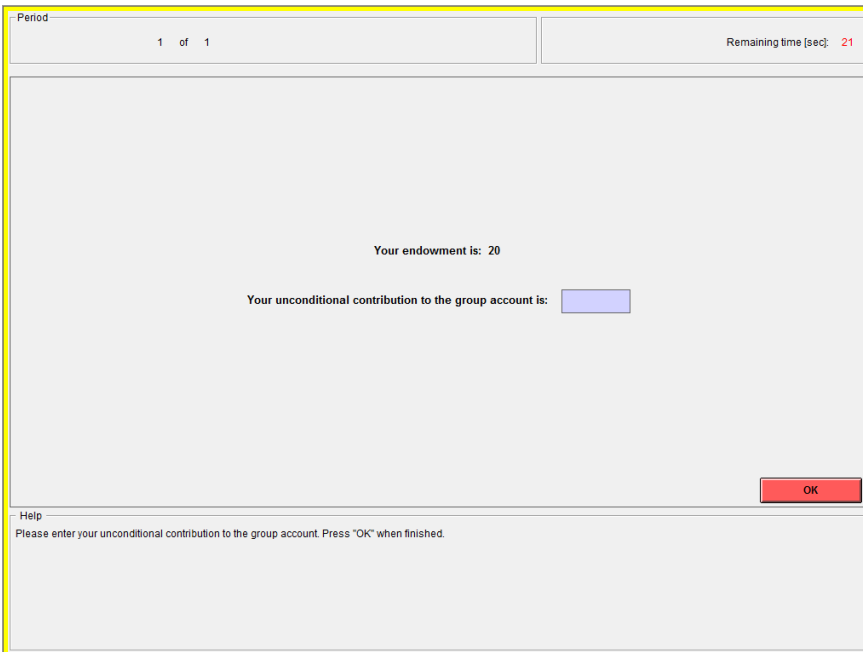
Procedure of Part 1

Part 1 includes the decision situation just described to you. The decisions in Part 1 will only be made **once**.

On the first screen you will be informed about your group membership number. This number will be of relevance later on. If you have taken note of the number, please click "OK".

As you know, you will have 20 points at your disposal. You can put them into your private account or you can put them into the group account. Each group member has to make **two types** of contribution decisions which we will refer to below as the **unconditional contribution** and the **contribution table**.

- In the **unconditional contribution** case, you decide how many of the 20 points you want to put into the group account. Please insert your unconditional contribution in the respective box on your screen. You can insert integers only (e.g. numbers like 0, 1, 2…). Your contribution to the private account is determined automatically by the difference between 20 and your contribution to the group account. After you have chosen your unconditional contribution, please click "OK".

Period		
1 of 1		Remaining time [sec]: 21

Your endowment is: 20

Your unconditional contribution to the group account is: [   ]

OK

Help
Please enter your unconditional contribution to the group account. Press "OK" when finished.

- On the next screen you are asked to fill in a **contribution table**. In the contribution table you indicate **how much <u>you</u> want to contribute to the group account for each possible average contribution of the <u>other</u> group members** (rounded to the nearest integer). Thus, you condition your contribution on the other group members' average contributions. The contribution table looks as follows:

Your conditional contribution to the group account (contribution table)

0		7		14	
1		8		15	
2		9		16	
3		10		17	
4		11		18	
5		12		19	
6		13		20	

OK

Help
Please enter your conditional contribution to the group account. You can condition your contribution on the average contributions of the other members in your group (given left to the input box). Press "OK" after you have completed the table.

The numbers in each of the left columns are the possible (rounded) average contributions of the **other** group members to the group account. This means, they represent the average amounts of the other group members' allocations into the group account. You simply have to insert into the input boxes how many points you will contribute to the group account. **You have to make an entry into each input box**. For example, you will have to indicate how much you contribute to the group account if the others contribute 0 points to the group account on average, how much you contribute if the others contribute 1, 2, or 3 points on average, etc. You can insert any whole number from 0 to 20 into each input box. You can of course insert the same number more than once. Once you have made an entry into each input box, please click "OK".

After all participants of the experiment have made an unconditional contribution and have filled in their contribution table, a random mechanism will select one group member from every group. **The contribution table** will be the only payoff-relevant decision for the **randomly determined participant** in this part. The **unconditional contribution** will be the only payoff-relevant decision for the **other three group members** not selected by the random mechanism in this part. You obviously do not know whether the random mechanism will select you when you make your unconditional contribution and when you fill in the contribution table. **You will therefore have to think carefully about both types of decisions because both can become relevant to you.** Two examples should make this clear.

<div align="center">

Examples

</div>

Example 1: Assume that Option A turns out to be relevant in the end (chip colour unmatches your group decision colour). Assume further that **the random mechanism selects you. This implies that your relevant decision will be your contribution table**. The unconditional contribution is the relevant decision for the other three group members. Assume they made unconditional contributions of 0, 3 and 6 points. The average rounded contribution of these three group members, therefore, is 3 points ((0+3+6)/3=3).

- If you indicated in your contribution table that you will contribute 1 point to the group account, keeping 20-1=19 in your private account, if the others contribute 3 points on average, then the total contribution to the group account is given by 0+3+6+1=10 points. All group members, therefore, earn 0.3×10=3

points out of the group account plus their respective income from the private account. You would then earn (20–1)+3=22 points.

- If, instead, you indicated in your contribution table that you would contribute 16 points to the group account, keeping 20-16=4 points in your private account, if the others contribute 3 points on average, then the total contribution of the group to the group account is given by 0+3+6+16=25 points. All group members therefore earn 0.3×25=7.5 points out of the group account plus their respective income from the private account. You would then earn (20–16)+7.5=11.5 points.

Assume instead that Option B turns out to be relevant in the end (chip colour matches your group decision colour) and again that **the random mechanism selects you. This implies that your relevant decision will be your contribution table**.

- If you indicated in your contribution table that you will contribute 1 point to the group account, keeping 20-1=19 in your private account, if the others contribute 3 points on average, then the total contribution to the group account is given by 0+3+6+1=10 points. All group members, therefore, earn 0.9×10=9 points out of the group account plus their respective income from the private account. You would then earn (20–1)+9=28 points.
- If, instead, you indicated in your contribution table that you would contribute 16 points to the group account, keeping 20-16=4 points in your private account, if the others contribute 3 points on average, then the total contribution of the group to the group account is given by 0+3+6+16=25 points. All group members therefore earn 0.9×25=22.5 points out of the group account plus their respective income from the private account. You would then earn (20–16)+22.5=26.5 points.

Example 2: Assume that Option A turns out to be relevant in the end (chip colour unmatches group decision colour). Assume further that **the random mechanism did not select you,** implying that **the unconditional contribution is taken as the payoff-relevant decision** for you and the other two unchosen group members. Assume that your unconditional contribution to the group account is 14 points and that of the other two unchosen group members is 10 and 18 points. The average unconditional contribution of you and the other group members, therefore, is 14 points (=(14+10+18)/3).

- If the group member whom the random mechanism selected indicates in her contribution table that she will contribute 3 points to the group account if the other three group members contribute, on average, 14 points, then the total contribution to the group account is given by 14+10+18+3=45 points. All group members will therefore earn 0.3×45=13.5 points out of the group account plus their respective income from the private account. You would then earn (20-14)+13.5=19.5 points.
- If, instead, the randomly selected group member indicates in her contribution table that she will contribute 18 points to the group account if the others contribute, on average, 14 points, then the total contribution to the group account is given by 14+10+18+18=60 points. All group members will therefore earn 0.3×60=18 points out of the group account plus their respective income from the private account. You would then earn (20-14)+18=24 points.

Assume instead that Option B turns out to be relevant in the end and again that **the random mechanism did not select you,** implying that **the unconditional contribution is taken as the payoff-relevant decision** for you and the other two unchosen group members.

- If the group member whom the random mechanism selected indicates in her contribution table that she will contribute 3 points to the group account if the other three group members contribute, on average, 14 points, then the total contribution to the group account is given by 14+10+18+3=45 points. All group members will therefore earn 0.9×45=40.5 points out of the group account plus their respective income from the private account. You would then earn (20-14)+40.5=46.5 points.
- If, instead, the randomly selected group member indicates in her contribution table that she will contribute 18 points to the group account if the others contribute, on average, 14 points, then the total contribution to the group account is given by 14+10+18+18=60 points. All group members will therefore earn 0.9×60=54 points out of the group account plus their respective income from the private account. You would then earn (20-14)+54=60 points.

Random mechanism

The random selection of the participants will be implemented as follows: One participant will be randomly select to throw a four-sided die – **after** all participants have made their unconditional contribution and have filled in their contribution table. The die throw will determine a number – 1, 2, 3, or 4. The thrown number will then be compared with the group membership number, which was shown to you on the first screen. If the **thrown number equals** your group membership number, then your **contribution table is payoff-relevant** for you and the unconditional contribution is payoff-relevant for the other three group members. **Otherwise**, your **unconditional contribution** is the relevant decision for you.

After the end of Part 1 you will get the instructions for Part 2. How much your group members contributed, and how much you earned in Part 1 will be revealed at the end of the experiment.

Part 2

Any point earned in Part 2 will be converted into Euro at the following exchange rate:

1 point = 0.04 Euro

Periods

The second part of the experiment will last 10 periods. The 10 periods are identical. **You are randomly matched anew into groups of 4 at the beginning of this part.** The group composition does not change over the 10 periods. **That means your group consists of the same people in all 10 periods**. You may now have a new group decision colour, depending on the individual colour choices of your group members at the beginning of the experiment. **Again, the majority within the group determines the decision colour.** Each group member receives a random identification number from 1 to 4. This number will also remain fixed in all 10 periods.

The basic decision situation

The basic decision situation is the same as the one described in the instructions for the previous part. In every period, each member of the group has to decide upon the allocation of the 20 points. You can put these 20 points into your private account or you can invest them fully or partially into a group account. Each point you do not invest into the group account is automatically placed into your private account. *The only difference to the first part is that you can only provide an unconditional contribution*. There is no contribution table in this part. Every member's payoff in each period depends on all members' unconditional contribution decisions.

Your income from the private account:

As in Part 1, you will earn one point for each point you put into your private account. No one except you earns something from your private account.

Your income from the group account:

The per period individual income for each group member out of the group account will be either Option A or Option B as in Part 1:

OPTION A
Individual income from group account =

Sum of all group members' contributions to the group account $\times 0.3$

OR

OPTION B
Individual income from group account =

Sum of all group members' contributions to the group account $\times 0.9$

Option A and Option B become relevant with unknown probability; how the relevant option is determined exactly will be explained below.

Total income:

Your per period total income is determined in the same way as in Part 1:

Income from your private account (= 20 – contribution to group account)

EITHER

+ Income from group account (= 0.3 × sum of contributions to group account)

if OPTION A is relevant

OR

+ Income from group account (= 0.9 × sum of contributions to group account)

if OPTION B is relevant

= Total income

The decision screen, which you will see in every period, looks like this:

Period			
1 of 10		Remaining time [sec]: 26	

Your group number is: 1

Your endowment is: 20

Your unconditional contribution to the group account is:

OK

Help

Please enter your unconditional contribution to the group account. Press "OK" when finished.

As you can see, there is no conditional contribution table. You only need to decide on your unconditional contribution in every period. At the end of every period, each participant receives feedback on the results of the period, including the individual contributions made by each group member, the total amount contributed to the group account, and the participant's own earnings from the period.

Option A or B?

These 10 opaque bags have already been filled with exactly 100 coloured chips before the experiment and labelled Period 1, Period 2, Period 3, …, Period 10. These chips in the bags are either yellow or white. The distribution of the colours is unknown to you: A student assistant has randomly drawn 100 chips for each bag from a bigger bag that contained far more than 100 chips – only yellow and white ones. Thus, you do not know how many of the 100 chips in each bag are yellow or white. At the end of every period, one randomly selected participant will draw one chip from the appropriate bag (bag "Period 1" after period 1, bag "Period 2" after period 2 ,…) without looking into the bag for each of the groups in this room, starting with group 1, group 2, group 3, … (each time returning the chip into the bag). If the colour of the drawn chip for your group does not match your group decision colour, Option A is relevant for your group; if the colour of the drawn chip matches your group decision colour, Option B is relevant for your group. You are allowed to inspect the content of the bag at the end of the experiment if you want to.

At the end of every period, each participant receives feedback on the results of the period, including the individual contributions made by each group member, the total amount contributed to the group account, the relevant option (A or B) and the participant's own earnings from the period.

Your earnings from Part 2 will be determined by the sum of earnings from all 10 periods.

At the end of part 2, we will ask you to choose a colour. This colour will later be used in part 3.

Part 3

Part 3 consists of two sub-parts: Part 3a and Part 3b. All payoffs are stated in Euro. Either Part 3a or Part 3b is paid out for real.

Part 3 is composed of two sets of **individual decision problems**, and they are presented on two subsequent screens. You are not matched to any person; you decide for yourself. In each of those 40decisions you can chose between **two alternatives**. Your decision is valid only after you have reached a decision for all problems on one screen and have clicked on the OK-button at the bottom of the screen. Take enough time for your decisions, because one of your choices will determine your payoff in Part 3, as we describe below.

The first 20 decisions (Part 3a) concern Bag A. **Bag A is filled with 100 chips. Exactly 50 chips are red, and 50 chips are blue.** In the 20 decisions you will have to decide whether you want to bet on the draw from the bag (Option X) or take an increasing amount of money for sure (independent of the draw) (Option Y).

If part 3a is payoff-relevant, a randomly selected participant will blindly draw a chip out of the opaque bag A, at the end of Part 3. **If you have chosen Option X for the payoff-relevant decision problem, and the colour of the chip matches your personal decision colour for Part 3, you receive 10 Euro. If instead you have chosen Option X and the colour does not match your personal decision colour for Part 3, you receive nothing. If you have chosen Option Y, you will receive the corresponding sure payoff, independently of the colour drawn.** This is how Part 3a will look like:

	Part 3a. Please indicate wich alternative, X or Y, you prefer:			
	Option X		**Option Y**	
1.	Draw from bag A	or	0.5 € for sure	X ○ ○ Y
2.	Draw from bag A	or	1 € for sure	X ○ ○ Y
3.	Draw from bag A	or	1.5 € for sure	X ○ ○ Y
4.	Draw from bag A	or	2 € for sure	X ○ ○ Y
5.	Draw from bag A	or	2.5 € for sure	X ○ ○ Y
6.	Draw from bag A	or	3 € for sure	X ○ ○ Y
7.	Draw from bag A	or	3.5 € for sure	X ○ ○ Y
8.	Draw from bag A	or	4 € for sure	X ○ ○ Y
9.	Draw from bag A	or	4.5 € for sure	X ○ ○ Y
10.	Draw from bag A	or	5 € for sure	X ○ ○ Y
11.	Draw from bag A	or	5.5 € for sure	X ○ ○ Y
12.	Draw from bag A	or	6 € for sure	X ○ ○ Y
13.	Draw from bag A	or	6.5 € for sure	X ○ ○ Y
14.	Draw from bag A	or	7 € for sure	X ○ ○ Y
15.	Draw from bag A	or	7.5 € for sure	X ○ ○ Y
16.	Draw from bag A	or	8 € for sure	X ○ ○ Y
17.	Draw from bag A	or	8.5 € for sure	X ○ ○ Y
18.	Draw from bag A	or	9 € for sure	X ○ ○ Y
19.	Draw from bag A	or	9.5 € for sure	X ○ ○ Y
20.	Draw from bag A	or	10 € for sure	X ○ ○ Y

Please note:

There are 50 red and 50 blue chips in bag A.

OK

The second 20 decisions (Part 3b) concern Bag B. **Bag B is filled with 100 chips. The chips are either red or blue. The distribution of the colours is unknown to you**: A student assistant has randomly drawn 100 chips from a bigger bag that contained far more than 100 chips – only red and blue ones. Bag B was filled with 100 chips just before this session began. **Thus, you do not know how many of the 100 chips are red or blue**. In the 20 decisions you will have to decide whether you want to bet on the draw from the bag (Alternative X) or take an increasing amount of money for sure (independent of the draw) (Alternative Y).

If part 3b is payoff-relevant, a randomly selected participant will blindly draw a chip out of the opaque bag B at the end of Part 3. **If you have chosen Option X for the payoff-relevant decision problem**, and the colour of the chip matches your personal decision colour for Part 3, you receive 10 Euro. If instead you have chosen Option X and the colour does not match your personal decision colour for Part 3, you receive nothing. If you have chosen Option Y, you will receive the corresponding for sure payoff independently of the draw. This is how Part 3b will look like.

	Part 3b.	Please indicate wich alternative, X or Y, you prefer:		
	Option X		**Option Y**	
21.	Draw from bag B	or	0.5 € for sure	X ○ ○ Y
22.	Draw from bag B	or	1 € for sure	X ○ ○ Y
23.	Draw from bag B	or	1.5 € for sure	X ○ ○ Y
24.	Draw from bag B	or	2 € for sure	X ○ ○ Y
25.	Draw from bag B	or	2.5 € for sure	X ○ ○ Y
26.	Draw from bag B	or	3 € for sure	X ○ ○ Y
27.	Draw from bag B	or	3.5 € for sure	X ○ ○ Y
28.	Draw from bag B	or	4 € for sure	X ○ ○ Y
29.	Draw from bag B	or	4.5 € for sure	X ○ ○ Y
30.	Draw from bag B	or	5 € for sure	X ○ ○ Y
31.	Draw from bag B	or	5.5 € for sure	X ○ ○ Y
32.	Draw from bag B	or	6 € for sure	X ○ ○ Y
33.	Draw from bag B	or	6.5 € for sure	X ○ ○ Y
34.	Draw from bag B	or	7 € for sure	X ○ ○ Y
35.	Draw from bag B	or	7.5 € for sure	X ○ ○ Y
36.	Draw from bag B	or	8 € for sure	X ○ ○ Y
37.	Draw from bag B	or	8.5 € for sure	X ○ ○ Y
38.	Draw from bag B	or	9 € for sure	X ○ ○ Y
39.	Draw from bag B	or	9.5 € for sure	X ○ ○ Y
40.	Draw from bag B	or	10 € for sure	X ○ ○ Y

Please note:

There are 100 red and blue chips in bag B, but the composition is unkown.

OK

If you want to perform calculations, just click on the **calculator symbol** at the bottom right area of the screen, which will start the Windows calculator (Note: be aware of the order of operations, multiplication before addition!).

Profit from Part 3

Your profit will be determined as follows: When all participants have completed the 40 decisions, a randomly selected participant will blindly draw a card from a deck of 40 cards. The cards are numbered 1 to 40. The number on the drawn card determines which of the 40 decision problems is payoff-relevant (it determines indirectly whether it is Part 3a or Part 3b). Then, he or she draws one chip from either Bag A (if the number is between 1 and 20) or Bag B (if the number is between 21 and 40).

If you have chosen Alternative Y you receive the sure outcome. If you have chosen alternative X, you receive 10 or 0 depending on whether your personal decision colour matches the drawn chip from the relevant bag.

Examples

For example, imagine that decision number 4 is chosen by the card draw and that you preferred alternative X. Then the randomly selected participant draws one chip to determine one of the two outcomes of alternative X. If your decision colour matches the colour drawn, you receive 10 Euro (with a probability of 50%), if not you receive nothing (with a probability of 50%) as payoff for Part 3. If you instead had preferred alternative Y you would have got 2 Euro as payoff for Part 3, independently of your decision colour.

Imagine instead that the number on the card corresponds to decision number 27 and that you preferred alternative X. The randomly selected participant draws one chip to determine the outcome. Again, if your decision colour matches the colour drawn, you receive 10 Euro (with an unknown probability), if not you receive nothing (with an unknown probability). If you instead had preferred alternative Y you would have got 3.5 Euro as payoff for Part 3, independently of your decision colour.

All 40 decisions in Part 3 are made only once. At the end of Part 3, you will be asked a number of questions. Remember, all answers in our experiment remain anonymous. After you have completed the questionnaire page on the screen, the experiment ends. You will be informed about your earnings in each of the three parts of the experiment, and will receive your payoff from the experiment individually and in cash.

Chapter II

Coordination effects of common pool resource management - empirical evidence from the Swedish shrimp fishery[*]

Lisa Björk [†1]

[1]*University of Gothenburg, Sweden*

Abstract

The effect of property rights on incentives for restoring resource value in common pool settings is well established. However, given the case-specific nature of socio-ecological systems, there is little empirical evidence of the comparative advantage of different sets of rights. This study uses a quasi-natural experiment in the Swedish shrimp fishery to evaluate two co-existing property rights regimes: territorial user rights in fisheries (TURF) and co-management, respectively. By linking dock-side harvest prices with trip data and exploiting the spatial and temporal variation, I establish the causal effect of the regimes on revenues and tease out underlying mechanisms. The results show that the TURF regime has a large and positive effect on revenues whereas the co-management has a slight negative effect. Differences in effort coordination and investments in sustainable practices are the main mechanisms behind the results. All measures constructed, as well as all data exclusions and manipulations, are reported in the study.

Keywords: common pool, TURF, co-management, coordination, shrimp

JEL classification: Q5, Q22, D7, L2

1   Introduction

Under which institutional arrangements are individuals able to collaborate so as to sustain the productive capacity of shared natural resources?

Many natural resources accessed and daily used by people are shared. In Sweden, "Allemansrätten" (i.e., the right of public access) gives everyone the right to access forest lands and to harvest, e.g. mushrooms and plants, for private consumption. Farmers and herders use communal irrigation structures and grazing lands, and fishers harvest wild stocks. These types of resources, for which the exclusion of unwanted users is costly and the regenerative capacity of the system is prone to overexploitation, are referred to as common-pool resources (Ostrom, 1994). Garrett Hardin (1968) coined the term "the tragedy of the commons" in a seminal paper demonstrating the, given his theoretical model, unavoidable path towards overexploitation in these types of regimes. His work has spurred a major research area in social sciences engaged in mapping existing and potential governance structures for common pool resources that promote cooperation and allow users to make short-term sacrifices to increase future productivity (van Laerhoven and Ostrom, 2007).

Evidence from decades of empirical, theoretical, and experimental studies shows that property rights are key to successful governance of common pool resources (Saunders, 2014; Anderies et al., 2011; Cardenas, 2011). The point of departure in most studies is a mismanaged system, and success is measured as the relative revenue gain from reducing common pool problems. The major divide in this literature is whether property rights over natural resources should be collective or individual (Baland and Platteau, 1996). Whereas there are several examples of successful policy interventions aiming at establishing property rights systems for common pool resources, there are at least as many examples of unsuccessful ones (Saunders, 2014). Scholars have requested a more systematic and empirically grounded generation of knowledge of the effects of various governance arrangements, in particular of key issues such as the interdependence between ecological dynamics and temporal scales, the social and historical context, uncertainty, and information flows (van Laerhoven and Ostrom, 2007).

This study responds to this call by analyzing a quasi-natural experiment introducing two distinct management regimes in the Swedish shrimp fishery. The results contribute to the small but important set of empirical studies aiming at quantifying the effects of collective rights resource management regimes on value-maximization (Smith, 2012; Abbott and Wilen, 2011). A systematic evaluation would require a whole spectrum of management regimes, from open access to complete ownership and for different numbers of rights holders. Lacking such an ideal empirical setting, this study compares a collective regime involving a group of 27 fishers and regulatory agencies, referred to as *co-management*, and a territorial user rights in fisheries (*TURF*) regime that grants exclusive harvesting rights to five fishers, using the status

quo fishery as control. The setting is interesting for three main reasons: Firstly, fisheries constitute one of the most canonical examples of common pool resources problems. Around 90 % of the world's fish stocks are either fully fished or over-fished (FAO, 2014). This implies that the great majority of global stocks are on or have surpassed, the biomass level that is necessary to sustain the stock at its most productive level (MSY) given recruitment, natural mortality, and growth. Secondly, shrimp is fairly immobile, which makes the study setting comparable to other non-moving common pool resources. Moreover, the six-year life span of the shrimp implies that inter-generational potential revenues created under the different regimes will be captured during the time period of study. Thirdly, collective rights types of management regimes have received renewed focus in recent policy discussions and literature. One driver of this is the development towards focusing on ecosystem-based management, in which the interdependence between species, space, and the larger ecosystem is brought forward, bringing the focus beyond the single-species approach to regulations (Möllmann et al., 2013).

One of the most straightforward measures in evaluating the effects of a regime shift is the effect on revenue generation compared with the status quo (Wilen, 2006). This is evaluated in two steps. Firstly, a location-specific panel data set capturing harvest activities and related prices between 1997 to 2013 is constructed. In a difference-in-differences set-up, the effects of the TURF and co-management regimes are evaluated using the regulated open access (ROA) fishery as a control. Given a set of time and individual fixed effects and control variables, this approach provides causal and comparable estimates of the regimes' effect on gross and net revenues, as well as on harvest composition and efficiency. Secondly, the intensive margin behavioral changes in terms of timely harvest are examined. An extended panel-data set, involving realized and potential trip-date pairs, is constructed to study the decision-making nature. By exploiting changes in expected revenues and weather, the relative importance of these variables for the daily decision to fish is evaluated.

The main results show that the establishment of the TURF has led to an average increase in revenues for participants by 26-28 %. This is partly explained by an overall improved ability to target days on which expected revenues are high. In contrast, the co-management regime is shown to on average decrease gross revenues by 4-5 % for participants. This result is a combined effect of increased within-group competition, a change in harvest composition, and lower harvest efficiency.

The paper is organized as follows. Section 2 discusses previous literature, the study setting, and the hypothesis. Section 3 presents the empirical strategies for the analysis. Section, 4, discusses the data, and the results and robustness checks are presented in Sections 5 and 6. Section 7 concludes the paper. All figures are constructed by the author. All prices and costs in the study have been converted to 2013's prices using the consumer price index provided by Statistics Sweden. The average exchange rate in 2013 was SEK 8.65 = €1.

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2 Background

2.1 Fisheries management

The recognition of the interdependence between economic incentives of fishers and the status of fish stocks and other marine ecosystems is arguably the most important development in fisheries management in recent decades (Beddington et al., 2007). Weak or non-existing property rights induce fishers to enter the fishery and compete for catch as long as the individual net revenues are positive (Gordon, 1954; Scott, 1955). The resulting bioeconomic equilibrium is often associated with excess capital, low stock levels, and minimal economic rents. The World Bank (2009) estimates that the total economic waste across the world's fisheries, in terms of the difference between potential and realized net rents, is US$50 billion a year.[1]

A sustained reduction in fishing effort requires incentive-based management, also referred to as rights-based management (RBM). Ostrom and Schlager (1992) proposed a framework for categorizing bundles of rights, which is useful in conceptualizing different RBMs (Fig. 1). In short, RBM refers to regimes that extend the rights of fishers beyond *access* and *withdrawal* of the resource. The additional rights include internal *management*; the establishment of rules regarding *exclusion* of others and mechanisms for future *transfer* of rights; and finally *alienation*, i.e. the ability to sell or lease rights. These bundles of rights should be interpreted as additive. As fishers are allowed more rights (and responsibilities), the regime is regarded as stronger in terms of creating incentives for collective action. In contrast to RBM regimes, open access or regulated open access (ROA), where access to the resource is determined through licenses and in which harvest is restricted by total allowable catches (TAC) enforced by seasonal closure, does not incentivize fishers to reduce racing behavior (Grafton et al., 2006; Costello and Deacon, 2007). Homans and Wilen (1997) show that ROA can even worsen the situation compared with open access. If the TAC is set such that the stock is brought back to biologically sustainable levels, the fishery might attract additional fishers and capital investments, which increases the race to catch and shortens the season.

Despite a long tradition of focusing on exclusivity and transferability as the main condition for successful governance, recent literature and policy developments point at the importance of fisher participation in management decisions (Grafton et al., 2006; Smith, 2012; Möllmann et al., 2013). This development has spurred a renewed focus on management regimes that involve collective rights. TURFs and co-managements are some of the oldest and most common forms of fisheries management (Christy, 1982). TURFs encompass a broad category of regimes that allocate exclusive user rights to a group of fishers within a spatially confined water column. Co-management regimes are arrangements of power sharing between resource

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[1]These estimates should be interpreted as a lower bound as they exclude all activities related to the processing and distribution of fish, the environmental externalities, and recreational fisheries.
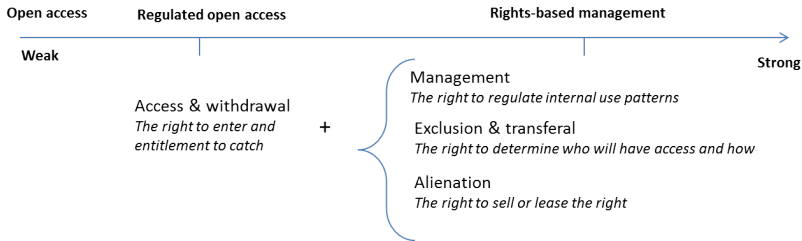
Figure 1: Re-interpretation of Ostrom and Schlager (1992). The scale is read from left (weakest) to right (strongest), where the strength depends on the combination of the bundles of rights.

users and government/the local jurisdiction to regulate internal use patterns for a specific area (Carlsson and Berkes, 2005). The various configurations of TURFs and co-managents in terms of scope and scale make them hard to compare. This is one of the factors explaining why they up until now have received little attention in the literature compared with the work focusing on individual transferable quota systems (ITQs).

The two regimes studied here can be classified according to Ostrom and Schlagers' framework. The right of internal management is allocated to the fishers in both regimes. In the TURF the fishers are also granted the exclusive right to harvest, while there is a barrier to entry, but not full exclusivity, in the co-management. Thus, based on these differences in rights allocation and according to said framework, higher level of coordination is expected among the fishers in the TURF compared to the co-management.

2.2 The Swedish shrimp fishery

The shrimp (*Pandalus borealis*) fishery is important in Sweden, accounting for 12 % of the total annual landings value of commercial species (SCB, 1997-2013). Fishers from Sweden, Norway, and Denmark commercially exploit the same shrimp stock in the Norwegian Deep Sea and Skagerrak areas (ICES divisions: IIIa, and IVa east).[2] Shrimp is harvested year-round. Total landings decrease during the coldest months November-February which are associated with an increased likelihood of high wind speed, which complicates hauling of nets and onboard processing of shrimp. July, which corresponds to the month of Swedish general industry vacation, is also correlated with low harvest. The highest catchability of shrimp coincides with the spawning period in the fall (Fig A1). The fishery can be divided into two main, and partly overlapping, segments: the coastal fishery and the offshore fishery.

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[2]Recent findings suggest that there might be very small, yet significant, genetic differences between the coastal fjord and offshore shrimp populations (Knutsen et al., 2014). However, such difference is currently not recognized in the management of the *Pandalus borealis* stock.

Larger vessels, with crews of 3-4 people, more frequently carry out extended fishing trips in the offshore areas, whereas smaller vessels, operated by 1-2 fishers, carry out day-trips in the coastal parts of western Sweden. A fish retention tunnel (120 mm mesh) is allowed provided the vessel has a quota permit for the species caught. In general, fishers combine the shrimp fishery with other fisheries.

The overall fishery is managed as a regulated open access (ROA) in which an annual national share of the biologically determined total allowable quota (TAC) for the Deep Sea-Skagerrak stock is allocated to the Swedish shrimp fishers. In the rare case that the quota is reached before the end of the season, a seasonal closure is imposed.[3] In 2008, a license was introduced limiting participation to vessels with a minimum yearly shrimp landing of 1,000 kg.[4] The license requirement led to a decrease in the number of vessels participating in the fishery, from about 90 in 1997 to 61 in 2013. Part of this decrease is attributable to a general trend of migration from the fisheries sector to industries with higher wages. The number of Swedish fishers decreased by 70 % from 1973 to 2003 (Eggert and Tveterås, 2013).

In contrast to many other shrimp species with annual life cycles, *Pandalus borealis* can live up to six years. The shrimp harvest is sold for direct consumption or to the processing industry depending on size. Large shrimp, defined as a maximum of 160 specimens per kg., are boiled directly on board and sold for consumption at any of the three auctions operating on weekdays.[5] Small shrimp, defined as a maximum of 245 specimens per kg, is iced onboard and sold collectively to the processing industry through a cooperative driven by the shrimp fishers. The price obtained for small shrimp is practically constant, around €1.60 per kg, throughout the week and the year due to the large supply from Swedish, Danish, and Norwegian vessels. In contrast, the prices for large shrimp exhibit seasonal patterns and can vary daily depending on supply and quality (Fig. 2). On average, the price is eight times higher than for small shrimp and the revenues from large shrimp constitute 80-85 % of the total sales value of shrimp (SFR, 2007).

The annual TAC for shrimp does not differentiate between specimen for industrial use and consumption.[6] However, since the 1930s, the Swedish shrimp-fishing industry has upheld a voluntary system of weekly size-based rations proportional to vessel size to avoid flooding the market with large shrimp which would erode its high market value. The agreement also

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[3] This happened once during the period of study, in December 2012. This is dealt with in the analysis by excluding the observations from this month.

[4] This license was suggested by the producer organization to limit an anticipated increase in participation in the shrimp fishery as an indirect consequence of the introduction of the ITQ system in the pelagic fishery in 2009 (Mathias Ivarsson, pers. com.).

[5] Although this study only includes Swedish auctions, fishers might also sell their harvest at Norwegian or Danish auctions. Since around 95 % of the shrimp catch is landed at Swedish auctions (SCB, 1997-2013), this is of little concern for my analysis.

[6] In contrast, in Norway the minimum allowable carapace length is 15 mm. When 10 % of the catch is undersized the fishing ground is closed.
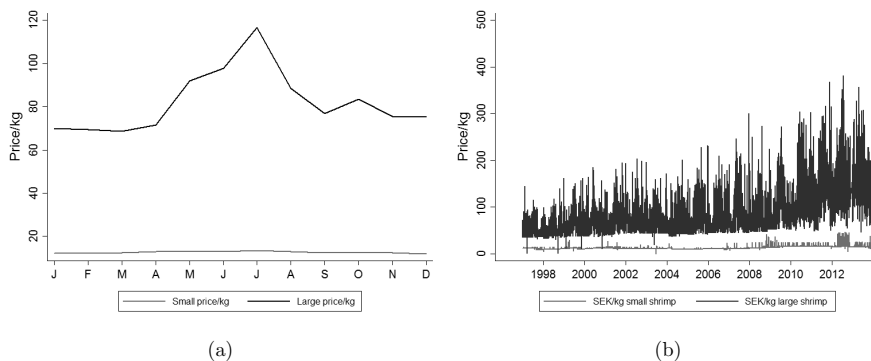
Figure 2: Monthly average price (SEK/kg) of large and small shrimp in *a)*. Time series of prices (SEK/kg) for large and small shrimp over the period of study *b)*.

incorporates a voluntary quota limiting fishing activity to a maximum of three days a week (SFR, 2007). Since 2009, there is a ban on sorting out smaller specimens in the harvest in favor of larger ones, so called high-grading, in Sweden and Denmark (Ziegler et al., 2016). Still, Swedish discards of small shrimp, as a proportion of total landings, are estimated to be in the range of 17-30 % (Munch-Petersen et al., 2013). The discards of small shrimp has received considerable attention and spurred a debate about overcapacity in the fishing fleet (Ziegler et al., 2016).[7]

Swedish policies changed in the 1990s in line with EU-wide common fisheries policy. The former narrow focus on stock management shifted to a more integrated approach recognizing the connections between the fishing industry, the wider ecosystem, and the coastal communities. More emphasis was put on the importance of communal income generation related to coastal fisheries communities, and on the preservation of marine areas with rich biodiversity (Swedish Environmental Objectives, 1997). The establishment of the co-management and the TURF regimes was clearly influenced by this new policy focus. Important to note is that the annual national TAC for the shrimp stock was unaltered by the regime shifts.

The co-management regime agreement for the Koster-Väderöfjord area was reached in 2000 (Fig. 3). In a joint response to findings of adverse impacts of shrimp trawling on the seabed fauna, the Regional County Board, the Swedish Agency for Marine and Water Management (SwAM), and the fishers agreed to limit trawling to areas at least 60 meters

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[7]These estimates are partly informed by comparing the share of kg landed large shrimp in Sweden with the Danish counterparts. The shrimp vessels in Denmark are tied to important processing plants, which mitigates their incentive to high-grade. In 2013, the average share of large shrimp landed by Swedish trawlers was 47 %. The corresponding figures in Norway and Denmark were 45 % and 25 %, respectively (SINTEF fiskeri og havbruk, 2015; Ministry of Food, Agriculture, and Fisheries of Denmark, 2015).
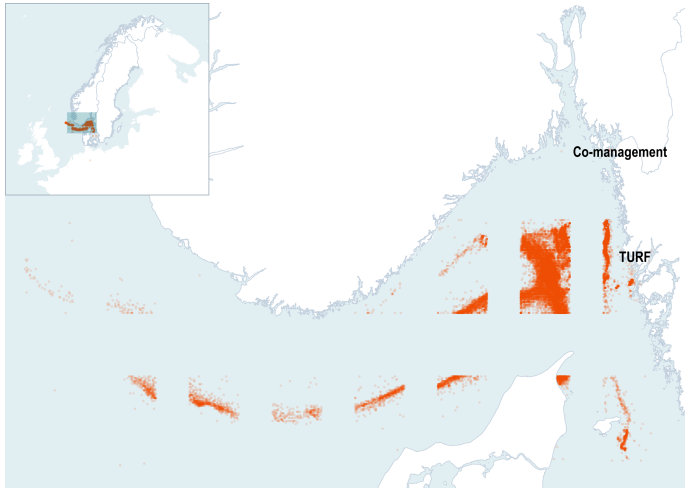
Figure 3: A map of the study area representing the geographical starting position of the initial tow for each trip recorded 1997-2013. The labels 'Co-management' and 'TURF' show the areas where the regimes were introduced in 2000 and 2004, respectively.

deep and to only use a specific species-selective trawl in the Koster-Väderöfjord. The gear restriction imposed a barrier to entry but the management regime did not impose any explicit exclusivity measures. Since the fishers wanted to avoid to be shut out from potential future fishing areas undergoing regulatory changes, they opted for a barrier to entry instead of area exclusivity (Kerstin Johannesson, pers. com.). Around 27 vessels, all with a history of fishing within that area, regularly participate in the co-management fishery. The fishers have set up voluntary rules limiting trawling activity to a maximum of three days per week and 15 hours per trip (Erland Lundqvist, pers. com.).

The TURF was established in The Gullmar Fjord in 2004 (Fig. 3). The fjord is one of the areas with the oldest documented history of shrimp fishing dating back to the early 20th century. In the 1990s, all trawling in the fjord was banned in order to study the effect of prolonged trawling on unique marine fauna (Jonsson, 2007). No adverse impact was proven and the area was reopened in 1999 for a total of 100 days per year for vessels of up to 15 meters employing a species and size-selective grid together with otter boards (cf. Eggert and Ulmestrand (2007)). In the first two years, nine vessels competed for the 100 days. In the first year the days were exhausted in September, and in the second year already in June. Faced with this race to catch, the fishers agreed on distributing the 100 days across the quarters and weeks in 2002 and 2003 to prolong the season. They also initiated a dialogue

with SwAM about future management plans in which they brought forward ideas of exclusive harvesting rights. During this period, two fishers exited the shrimp fishery completely. In 2004, SwAM allocated user rights to the six vessels with the most frequent fishing history in the fjord. The one vessel not granted exclusive harvesting rights re-allocated most fishing activity to the co-management area. In 2005, one of the six TURF vessels retired from the shrimp fishery. The five remaining fishers had a long history of shrimp fishing in the fjord (SFR, 2007). Figure A2 shows the time line of all important events in the shrimp fishery.

2.3 Mechanisms and hypothesis

The introduction of management regimes that alter the fishery from regulated open access to rights-based regimes is expected to have a direct impact on rent-generation, via the realized level of coordination of activities. Two main incentives are expected to arise, although they are not so easily separable: a collective interest in securing the resource value of the biological stock and an individual interest in maximizing net revenues from harvesting (Costello and Grainger, 2015). The key margins along which fishers can respond to the management shifts are distribution of effort, across and within seasons, and technology adjustments (Fig. 4).

The distribution of effort is an important channel of coordination. Effort, in terms of days fished or hours trawled, can be coordination through delayed *start of the season*, avoidance of negative *congestion* effects (Huang and Smith, 2014), and *timely* exploitation of intra-seasonal price variations (Scheld and Anderson, 2014).

Delay of the season is a type of voluntary public good investment. By abstaining from harvesting in early spring, fishers allow a greater share of the larvae to hatch and specimens of year class 2 and above to grow. The perceived quality, and hence the price, of consumption shrimp is strongly correlated with its size. This implies that there are marginal rents to be captured from any measures taken to delay the capture of shrimp. The TURF fishers have formally agreed to delay the beginning of the season to April. There is no corresponding agreement among the co-management fishers (Fig. A3).

Congestion effects are dealt with under the co-management regime through a voluntary agreement restricting individual fishing activity to a maximum of three days per week for a total of 15 hours per trip. Within the TURF fishery, there is an agreement of carrying out fishing a maximum of one day per week and that trips should be planned such that there are never more than two vessels fishing simultaneously in the area. Several continuous days of trawling have an adverse impact on the catch per unit effort as the shrimp specimens rise from the seabed and disperse in the water body.

Timely harvest allows fishers to capture intra-seasonal price variations related to weather, season and day of the week. Although fishers are price takers, there is some predictability in the price variation that the fishers can exploit by means of timely harvest. Adverse weather
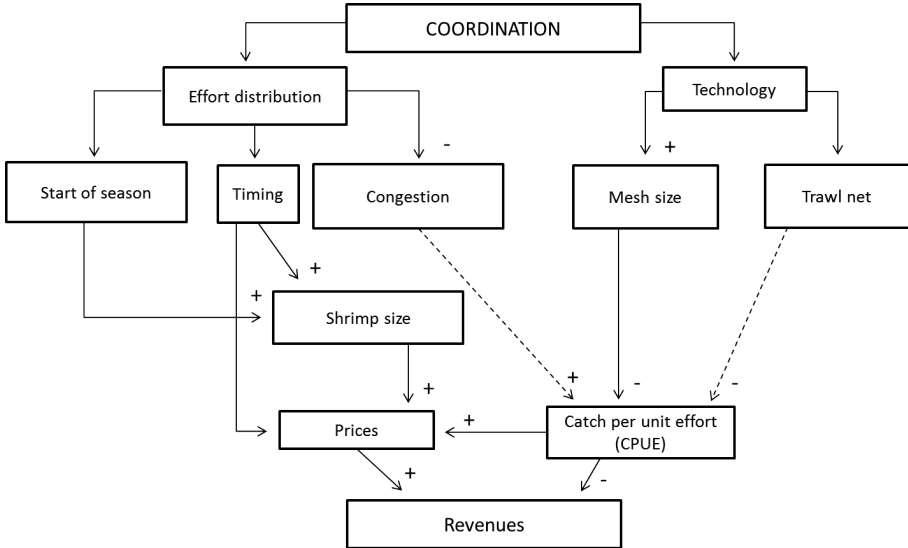
Figure 4: Coordination mechanisms. The expected directions of change are illustrated with + and - signs, and arrows indicate the chains.

implies that fewer vessels carry out fishing, which results in lower market supply and higher prices. Seasonal festivities in the summer months and around the turn of the year increase the demand and thus lead to higher prices. The industry-wide voluntary agreement of not fishing on weekends implies that the harvest sold on Mondays is, or is perceived to be, old and fetches a lower price than later in the week. The quantity of landed shrimp and the average dock-side prices obtained at the auction, are made available on the auction webpages.

Whereas the distribution of effort operates through the individual incentive of maximizing revenues, technology adjustments rather represent the collective incentive to conserve the long-term value of the stock. Within both regimes, the right to fish is conditioned on the use of specific species-selective gear. In 2003, the TURF fishers agreed on using a 43 mm mesh size. In 2006, the size was increased to 45 mm, or 10 mm larger than the legal requirement. In the same year, the co-management fishery agreed on using a 37 mm mesh size. A larger mesh size is expected to decrease the harvest quantity since it reduces the catch of smaller specimens, as well as bycatch. It may also improve the quality of the harvest since the reduced weight implies that fewer shrimp get crushed in the net.

3   Empirical strategies

3.1   Revenues and harvest

The empirical strategy for identifying the causal effect of the management regimes on revenues and harvest relies on a difference-in-difference (DiD) framework. In this strategy, the mean effect of the regime shift on an outcome variable is estimated by comparing observations before and after the regime shift in a group affected by the change, to before and after observations in a control group unaffected by the change. Since the vessels participating in the respective management regimes have self-selected into treatment, the difference-in-difference estimator measures the average treatment on the treated (ATT) effect (Bertrand et al., 2004). The sample include all vessels with a registered shrimp trawl, which implies that there is no need to randomly select vessels from the treatment and control groups.

A fisher with user rights to the TURF regime does not carry out fishing exclusively within that area. Similarly, a fisher participating in the co-management is also free to harvest outside that fjord. Hence, the categorization of observations into treatment and control groups is based on the geographical location of the trip. Trips are sorted based on the geographical coordinates indicating the starting position for each tow, using SwAM's administrative definition of the TURF and co-management areas. Trips carried out in the TURF area, before and after its introduction, constitutes one treatment group. Similarly, trips carried out in the co-management area, before and after its introduction, constitutes another treatment group. All trips carried out elsewhere are grouped into a control group. This way of categorizing treatment and control groups is also motivated by the assumption that fishing behavior is principally influenced by the institutional setting under which the fishing is carried out (Smith et al., 2009). For a clean analysis, all trips carried out within multiple treatment areas (e.g. one tow located in the TURF area and another in the ROA) are excluded from the analysis. By making use of all trips, underlying trends in shrimp demand and stock can be controlled for, as well as potential spillover effects between treatments.

The identifying assumptions for causal interpretation of the DiD estimates are strong and cannot be taken for granted. Firstly, the introduction of the management regimes should not be systematically related to unobserved drivers of the outcome variables of interest (Wooldridge, 2010). This implies that if factors that explain participation also directly explain the outcomes of the treatment, these factors must be controlled for in the estimation (Abbott and Wilen, 2011). The respective processes leading to the regime introductions were partly initiated by the fishers in response to the prospect of losing the fishing opportunity in the areas. To control for other underlying trends potentially explaining the management shifts, I include location-specific time trends. Secondly, for unbiased estimates, the control and treatment groups should be comparable (Abadie, 2005). Factors that vary between the

groups before and after the shift in management regimes must impact the groups similarly, or be controlled for using exogenous variables, to avoid that the treatment effect is confounded with time-varying factors. Because all vessels fish on the same stock and land their catch on the same market, they are similarly affected by system-wide shocks. The differences in unobservable characteristics are controlled for in the main analysis using vessel fixed effects. This is possible since there is an overlap in the distribution of characteristics such as kW and length across all three regimes (Fig A4). Thirdly, the most crucial assumption is the parallel trends assumption. That is, conditional on a vector of covariates that control for systematic differences between groups, the change in average outcomes in the absence of the regimes would have been similar. Parallel trends assure that the untreated trips in the control group can be used to estimate the counterfactual outcome. An absence of parallel trends would cause biased estimates without causal interpretation. Graphical and empirical tests of this assumption are carried out and discussed in Section 5.3.

3.2 Timely harvest

To disentangle the main effects on revenues, a reduced form model of individual daily decisions of carrying out a fishing trip is specified. A successful regime is expected to change the behavior of fishers in terms of increasing engagement in timely harvest. In contrast to many studies where these types of models are used to control for selection bias in the main regressions, I am interested in the selection of days per se. A shift in participation towards days with higher expected revenues would explain changes in revenue outcomes.

To control for changes in timing of harvest caused by factors unrelated to the area-specific management regimes, a DiD estimation on the probabilities of carrying out a trip is carried out on the full sample. The decision is assumed to be a latent variable linearly related to a set of observables and estimated using a linear probability model (LPM). The choice of LPM over a non-linear specification such as a probit or logit is motivated by the relevance of including interaction effects. In non-linear models, the standard DiD identifying assumption of common trends is violated since the counterfactual outcome, i.e. the imputed change in the treatment group should the management shift not have happened, is restricted to between 0 and 1 (see Puhani (2012) for a discussion).[8]

The participation decision is evaluated using a slight refinement of the treatment and control groups. When evaluating the effect of the TURF regime on timely harvest, the treatment group consists of all fishers with user rights to the TURF area, and the control group the rest of the fishery. Similarly, when evaluating the effect of the co-management regime, fishers carrying out at least 40 % of their trips in the fjord over the whole period of study constitute the treatment group, and the rest of the fishery the control group. This is

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[8]The results from a logistic specification are similar and available on request.

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done to avoid having to estimate the chosen location of the trip in addition to the binary choice of whether to fish or not, which likely would have decreased the precision of the results as the majority of the trips are carried out within the area of the regime being evaluated.

4   Data and summary statistics

This study exploits logbook data and trip tickets collected by the Swedish Agency of Marine and Water Management (called the Swedish Fishery Board prior to 2011) from 1997 to 2013.[9] The two sources are merged using a unique trip ID to construct trip-level panel data on catch and dock-side prices for all trips carried out with shrimp trawl in the selected period. The unique and personal fishing license enables me to follow the same license holder throughout the whole period of study as it is always transferred to the vessel in current possession.

The merged data-set constitutes an unbalanced panel of 158 individual license holders and 47,014 unique trip observations. Fourteen percent of the observations are not possible to match through the trip ID. These unmatched observations most likely result from reporting errors without systematic patterns (Jarl Engquist, pers. com.). The panel is complemented with input data on wind speed, stock index, and fuel prices. Daily wind speed is collected from two weather stations by the Swedish Meteorological and Hydrological Institute (SMHI). These two stations represent a good proxy for the weather conditions in the area of study (Mats Ulmestrand, pers. com.). The annual stock index, defined as shrimp biomass in tons per nautical mile, is collected from the Institute of Marine Research in Norway (Fig. A5) and captures the overall availability of shrimp (the index is not differentiated by size). Long-term marginal stock effects of the management regimes are not explicitly examined in this study. Available stock assessments show that predators, such as cod, haddock, and various flatfishes, account for twice as much of the mortality of shrimp as the fishery (Ulmestrand et al., 2014). The high natural mortality implies that stock dynamics are driven mostly by factors unrelated to the shrimp fishery (however, not to other fisheries targeting predators). Monthly fuel prices are collected from the Swedish Petroleum and Biofuels Institute (SPBI) and used to construct trip-level fuel costs using speed and fuel consumption (trawling and steaming) approximations for three vessel segments combined with trip level distances. The vessel classes are based on the same length segment division as that used by SwAM, i.e. small vessels <15 meters, medium vessels 15-24 meters, and large vessels >24 meters. Steaming fuel consumption is constructed using the sum of geodetic distances between departure and landing ports and the distance(s) between haul location(s) divided by steaming speed and multiplied by fuel consumption during steaming. Trawl fuel consumption is obtained by

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[9]1997 is chosen as the start year of the time series as it is the first year for which dock-side prices can be matched to individual trips. 2013 is chosen as the end point as it is the last year before the shrimp fishery underwent a regulatory change imposing individual non-transferable vessel-specific quotas.

multiplying the number of hours trawled by the fuel consumption during trawling.[10] The total trip-level fuel cost is calculated by multiplying the trip-level fuel consumption by the monthly data on diesel prices. Since the distance is trip-specific, this measure is a proxy for variable costs.[11] The average consumption is in line with previous findings that fisheries targeting high-value species like shrimp, tuna, and swordfish consume in excess of 2 liters of fuel per kg of landings (Tyedmers, 2001; Tyedmers et al., 2014). The estimated fuel costs are used to construct net revenues. Estimates from studies on fuel and energy consumption suggest that trip-level fuel costs account for 40 - 50 % of the total annual costs of a trawler (Basurko et al., 2013). Thus, trip-level fuel costs is a good proxy for the variable costs during the fishing activity. Hence, net revenues in this study are restricted since they do not include labor and fixed costs.

When evaluating the effect of management regimes on revenues and harvest outcomes, 1,090 trips during which fishing is not exclusively carried out within one of the management areas are excluded. All fishing activity in December 2012, i.e. 23 observations, is excluded as the shrimp fishery was shut down due to an expected quota shortage for all areas except for the TURF. The restricted sample includes 45,901 trips carried out by 158 individual license-holders. The summary statistics for this sample, including management-specific before and after comparisons, are presented in Table 1.

The dataset used to evaluating participation decisions, which is extended to include all (realized and potential) vessel-date pairs for the period 1997-2013, is described more closely in Section 6.

5   Revenues analysis

In essence, the DiD estimator uses differences in averages between groups before the management shift, including time-invariant, group-specific factors that might influence the selection process, and compares them with differences in averages after the shift. The effect of the respective regime shift on revenues can, given the assumptions discussed above, be estimated using the following specification (presenting the richest specification used in the analysis):

$$
\begin{aligned}
Y_{idmy} = \beta_0 + \beta_1(treatloc_i * post_{iy}) + \beta_2(simultloc_i) + \beta_3(simultloc_i * post_{iy}) \\
+ \tau_y + \alpha_i + \theta_i + \tau_m + \tau_d + \varepsilon_{idmy}
\end{aligned}
\tag{1}
$$

where Y_{idmy} is the outcome variables of interest for vessel i on trip date d in month m and

---

[10]The fuel consumption approximations are informed by Mathias Ivarsson (pers. com).

[11]During 1997-2000, the fuel prices are only collected on a yearly basis, thus limiting the variation in fuel prices for those four years.

Table 1: Summary statistics

Variable	TURF		co-management		ROA
	< 2004	⩾ 2004	< 2000	⩾ 2000	Full period
kW	177.9	197.04	**203.13**	**200.38**	380.1
	(47.81)	(66.78)	**(74.07)**	**(75.25)**	(187.4)
Length (m)	13.01	12.67	14.80	14.19	21.35
	(1.73)	(1.59)	(3.87)	(3.47)	(6.33)
Trip effort (hours trawled)	9.72	10.49	10.06	9.18	26.31
	(3.59)	(3.56)	(5.86)	(4.14)	(15.46)
Large price (SEK/kg)	86.37	155.72	60.78	101.03	77.07
	(31)	(68.04)	(19.86)	(46.51)	(38.37)
Shrimp only gross revenue (SEK/h)	980.15	1,599.31	**1,314.43**	**1,317.49**	1,570.37
	(767.79)	(1,582.07)	**(1,271.25)**	**(1,161.78)**	(1,566.86)
Gross revenue (SEK/h)	1,091.78	1,701.04	**1,509.93**	**1,441.97**	1,867.53
	(876.37)	(1,838.5)	**(1,369.22)**	**(1,344.19)**	(1,566.86)
Net revenue (SEK/h)	1,033.30	1,596.50	**1,428.33**	**1,254.70**	1,570.21
	(866.74)	(1,829.45)	**(1,354.71)**	**(1,316.82)**	(2,107.27)
Catch per unit effort (CPUE) (kg/h)	**14.91**	**14.22**	38.02	26.51	37.2
	(12.94)	**(13.92)**	(40.13)	(.26)	(33.67)
Share large	**.82**	**.80**	**.56**	**.56**	.54
	(.23)	**(.24)**	**(0.29)**	**(.32)**	(.23)
Share bycatch	.07	.04	.13	.05	.15
	(.18)	(.14)	(.19)	(.14)	(.20)
Hauls (number)	2.03	2.24	1.47	1.57	3.01
	(.98)	(.78)	(.91)	(.73)	(1.71)
Mesh size (mm)	37.7	44.8	35.87	36.94	35.77
	(4.27)	(1.06)	(1.75)	(2.84)	(2.09)
Trip fuel consumption (1/kg)	**2.89**	**2.57**	2.38	3.11	3.13
	(2.7)	**(2.27)**	(.21)	(5.39)	(9.53)
Share of trips within management area	.84	.67	.54	.62	-
	(.36)	(.47)	(.50)	(.49)	
Observations	268	686	1, 552	9, 675	33, 720

Note: Statistics divided into before and after for the TURF and co-management regimes. Entries in bold indicate that means are not statistically different at a 5 % level using a two-sample t-test.

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year y; the treatment variable $treatloc_i * post_{iy}$ is an indicator that equals one for the treated trips after the introduction of the regime and zero otherwise; and $simultloc_i * post_{iy}$ captures the potential spill-over effect of the regime shift on the other group. When evaluating the TURF regime, this variable equals one for trips carried out under the co-management regime after 2004 and zero otherwise. The co-management is evaluated correspondingly, using TURF trips after 2000 to control for spill-over effects. Inclusion of location, α_i, and year, τ_y, fixed effects allows for the interpretation of β_1, under the key assumption of parallel trends, as the average causal effect of the management regime on outcomes within the treated group.

The variable θ_i represents license holder fixed effects to capture unobservable time invariant characteristics such as skipper skill (cf. (Squires and Kirkley, 2011)). τ_m, and τ_d are month of the year and day of the week fixed effects, respectively, and capture seasonal variations in stock and corresponding price effects as well as variations in demand throughout the week.

The importance of using cluster-robust standard errors was pointed out in an influential paper by Bertrand et al. (2004). Failure to correctly control for error correlations within clusters might lead to biased standard errors and subsequently misleading inference. This is particularly true when the explanatory variable of interest does not vary within the same cluster, such as when policies are evaluated (Cameron and Miller, 2015). I use Cameron, Gelbach, and Miller 2006 standard errors clustered on day of departure and location in a two-way approach that allows for control of autocorrelation in both time and space. The reason to cluster on location rather than vessel is that location nests the vessel units. Departure date is included as there might be supply and demand factors that affect all vessels out fishing on that particular day. Standard errors clustered on vessel are included for comparison.

5.1 Revenues

Three different estimates for each of the two management regimes are presented in Table 2. The results represents the estimates from the preferred specification which includes a full set of fixed effects and time controls. The full set of results, including simpler specifications, are presented in Tables A1-A6. Panel A accounts for the average estimated effects of the TURF regime, whereas Panel B accounts for the average effects of the co-management regime. The outcome variables are logged to adjust for heteroscedasticity in the data and to prevent negative predictions. All three revenue variables are standardized by the hours trawled during a trip. The first column in each panel presents the effect on gross revenues per hour effort, the second presents gross revenues restricted to the shrimp share of the harvest per hour effort, and the third presents net revenues per hour effort. In all columns, the effect of the management on revenues for the treated group is identified by the variable $Treatloc * post$. Simultaneous changes in revenues that have occurred in the other regime are controlled for

Table 2: **Effects of the regimes on revenues**

| VARIABLES | A. TURF | | | B. co-management | | |
	(1)	(2)	(3)	(4)	(5)	(6)
Treatloc	0.103***	0.126***	0.095***	0.144***	0.068***	0.151***
	(0.091)	(0.090)	(0.089)	(0.040)	(0.042)	(0.041)
	[0.039]	[0.043]	[0.027]	[0.017]	[0.017]	[0.015]
Treatloc*post	**0.272***	**0.265***	**0.283***	**-0.049***	**-0.038***	**0.042***
	[0.108]	[0.109]	[0.116]	[0.055]	[0.058]	[0.060]
	[0.036]	[0.037]	[0.044]	[0.016]	[0.020]	[0.020]
Simultloc	-0.035***	-0.018	-0.068***	-0.875***	-0.924***	-0.820***
	(0.037)	(0.036)	(0.042)	(0.289)	(0.296)	(0.300)
	[0.013]	[0.022]	[0.017]	[0.099]	[0.105]	[0.127]
Simultloc*post	0.153***	0.063***	0.282***	1.250***	1.314***	1.197***
	(0.053)	(0.054)	(0.061)	(0.297)	(0.304)	(0.312)
	[0.021]	[0.024]	[0.030]	[0.088]	[0.098]	[0.133]
Constant	5.255***	5.081***	5.175***	6.124***	6.065***	5.933***
	(0.310)	(0.315)	(0.327)	(0.094)	(0.095)	(0.118)
	[0.202]	[0.192]	[0.187]	[0.188]	[0.188]	[0.187]
Year FE	✓	✓	✓	✓	✓	✓
Vessel FE	✓	✓	✓	✓	✓	✓
Month and day of the week	✓	✓	✓	✓	✓	✓
Location linear trend	✓	✓	✓	✓	✓	✓
Observations	40,944	40,828	39,931	46,896	46,726	45,793
R^2	0.365	0.342	0.311	0.354	0.339	0.303

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

by the interaction $Simultloc*post$. In all columns, the two-way clustered standard errors are smaller than the ones obtained when clustering on the vessel only. As noted by Cameron and Miller (2015), this might follow from errors being negatively correlated, or, if the errors are similar in expectation, may simply be an effect of noise.

The results in Panel A show that the TURF regime has led to a significant increase in revenues for trips carried out within the area. All estimates are highly significant. On average, gross revenues per hour effort have increased by 26.5-27 percentage points depending on whether gross revenues are restricted to only shrimp or total harvest. This effect is also consistent with the 28 percentage point average increase in net revenues per hour effort. The similarity of the three measures of revenues indicate that shrimp is really the main target species and that the distance traveled during a trip remains fairly stable over time. As shown in Tables A1-A3, in absence of any controls, the effect is much smaller in magnitude and insignificant. Specifically, the inclusion of vessel fixed effects has a positive effect on the explanatory power of the model as indicated by the increase in the R^2. This implies that the observed changes in revenues after the regime shift are driven by changes in revenues within

observations of the same fisher.

The results for the co-management, presented in Panel B, tell a different story. Here, gross revenues per unit effort have on average decreased by 5 percentage points, and shrimp gross revenues as well as net revenues by 4 percentage points. The results presented in Tables A4-A6 demonstrate the importance of including vessel fixed effects and location specific time trends in the regression. In absence of any control, the average negative effect on revenues is estimated to 36-47 percentage points. This effect is reduced substantially when including vessel fixed effects, particularly in combination with the location specific time trend. Again, this suggests that the observed negative effect on revenues for the co-management in Table 2 is attributable only to the regime shift.

5.2 Effort coordination

To analyze the drivers behind the changes in revenues in the respective regimes, changes in harvest composition and efficiency are examined. Under the assumption of no behavioral spillover effects between management regimes, the trips carried out outside the regime locations can be used as a control group to estimate the effects of the regime on shrimp catch per unit effort (CPUE), and share of large shrimp in a DiD estimation using the same set of controls and fixed effects as specified in equation 1. Changes in CPUE identify the effect of the agreed restrictions on trawl gear and mesh size, while changes in share of large shrimp identify the effect of effort coordination in terms of seasonal delay and congestion avoidance. The results are presented in table 3. Again the variable $Treatloc * post$ identify the estimated treatment effect.

The estimated results for the TURF regime are presented in Panel C. Average CPUE (column 1) has increased by 34 percentage points. This effect is remarkable; despite the large increase in mesh size shown in fig 5, CPUE has increased. This indicates that effort coordination, in terms of delayed start of season and avoidance of congestion within the fjord, has improved catch rates such that this effect by far exceeds the harvest loss brought about by a larger mesh size.

However, the 18 percentage point average negative effect of share of large shrimp in the harvest (column 2) complicates the interpretation. A larger mesh size should intuitively increase the share of large shrimp in the harvest. There are three potential explanations for this opposite estimated effect of the regime shift on share of large shrimp. Firstly, the regime shift has brought about a new, perceived or realized, level of monitoring. High-grading is an industry-wide problem that has been under scrutiny for decades. It is likely that fishers under the TURF perceive to be monitored more carefully as a consequence of having been rewarded exclusive harvesting rights. Regardless of the realized degree of external monitoring, it is likely that the social control among the users has increased. In response, the fishers may

have decreased their level of high-grading inside the TURF area. Secondly, the fishers might try to reduce the share of large shrimp in harvest as a strategy to uphold the high price premium on large shrimp harvested within the TURF. Thirdly, fishing activity in the fjord might affect the shrimp stock locally. In that case, upon re-opening the Gullmar fjord for fishing in 1999, the share of large shrimp in the fjord would be relatively higher than compared to the overall stock. Comparisons between fishing trips in the area prior to and after the regime introduction in 2004, all else equal, would then result in a negative estimate of the effect of the TURF on share of large shrimp. Overall, it is not possible to rule out changes in location-specific stock abundance and size distributions. However, such stock effects should be captured by the location specific time trend. Thus, it is more likely that the negative effects on share of large shrimp is attributable to behavioral changes of the TURF fishers.

Taken together, the 27 percentage point increase in gross and net revenues in the TURF fishery is partly explained by higher harvest efficiency. Potentially, part of this increase is also attributable to the deliberate strategy mentioned above of delivering a lower share of shrimp to the auction, in order to sustain high prices.[12] Since the trip tickets do not distinguish the harvest at any finer level than classifying it into large and small shrimp, I cannot determine whether the quality of the harvest has changed. However, prices obtained on the auction can be used as a proxy for quality. Figure 6, depicts the average price development for large shrimp over the years separately for each of the three regimes. The TURF fishery experienced a small price premium already prior to the introduction of the regime. The price gap is widened after the management shift, with the exception of the year 2009, indicating that the price premium drove the increase in revenues.

Panel D in Table 3 presents the results for the co-management fishery. On average, the shrimp catch per unit effort has increased by 20 percentage points (column 3), and the share of large shrimp in the harvest has decreased by on average by 17 percentage points (column 4). The positive effect on CPUE is particularly interesting given that the fishers are experiencing increasing competition in the area. After the introduction of the co-management, the average share of days fished in the area increased by 8 percentage points (Table 1). The increase in harvest efficiency suggests that trips carried out within the co-management area are coordinated in terms of time and effort. Alternatively, the increase in fishing effort within the fjord have positive impacts on revenues since it reduces search cost (Huang and Smith, 2014). In terms of the reduced share of large shrimp, the same arguments as those for the TURF apply for the co-management regime. Since trips in the co-management area are carried out by an almost constant group of fishers under the period of study, social monitoring is facilitated, and it is likely that part of the decrease in share of large shrimp in harvest for this regime is explained by this. Since the trips carried out within the co-management

---

[12]The fact that there has been a voluntary rationing system in the Swedish fishery for decades speaks in favor of such a strategy being implemented.

Table 3: **Effects of the regimes on harvest composition**

VARIABLES	C. TURF		D. co-management	
	(1)	(2)	(3)	(4)
Treatloc	-0.272***	0.184***	-0.065***	0.051***
	[0.035]	[0.019]	[0.015]	[0.011]
Treatloc*post	**0.337***	**-0.180***	**0.197***	**-0.171***
	[0.031]	[0.030]	[0.015]	[0.017]
Simultloc	-0.127***	0.016*	-1.153***	0.338***
	[0.012]	[0.009]	[0.054]	[0.047]
Simultloc*post	0.278***	-0.139***	1.217***	-0.333***
	[0.015]	[0.011]	[0.048]	[0.084]
Constant	2.234***	-0.726***	3.117***	-0.766***
	[0.246]	[0.123]	[0.211]	[0.062]
Year FE	✓	✓	✓	✓
Vessel FE	✓	✓	✓	✓
Month and day of the week	✓	✓	✓	✓
Location linear trend	✓	✓	✓	✓
Observations	40,827	39,086	46,725	44,791
R^2	0.369	0.169	0.349	0.163

Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.
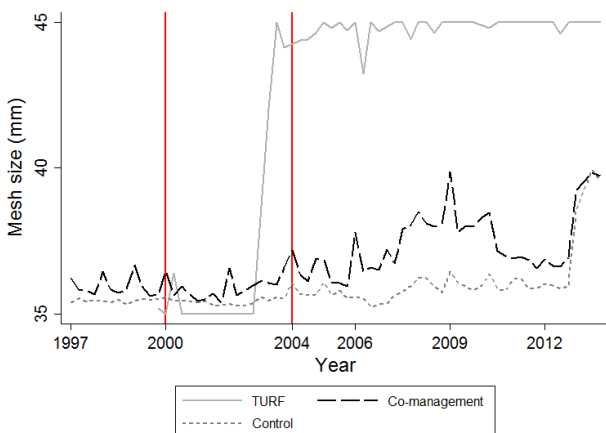
Figure 5: Mesh size by trip location and year. Vertical lines indicate the introduction of the co-management (2000) and TURF (2004).
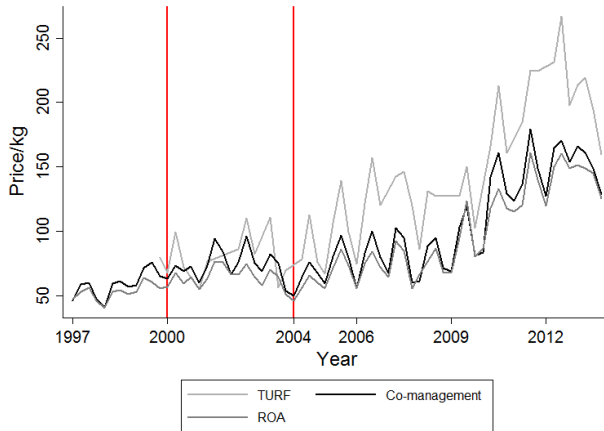
Figure 6: Prices for large shrimp by trip location. Vertical lines indicate the
introduction of the co-management (2000) and TURF (2004).

have not generated an increased price premium for large shrimp (Fig 6), the decrease in the
average share of large shrimp explain a large part of the modest increase in revenues for this
regime.

5.3   Robustness checks

The parallel trends assumption would be violated if the distribution of shrimp size would
differ across locations for other reasons than the introduction of the management regimes,
or if the shrimp stock would respond differently across locations to an adverse shock on the
stock.[13]

A first approach to verify the parallel trends assumption is to plot the outcome variables
from the trips carried out under the respective regimes and visually inspect the trends. Such
plots are shown in Figures A6 and A7. Ideally, the graphs would show a stable differential,
if any, in the outcome variables, and then a clear shift after the introduction of the TURF
and the co-management, respectively. The data on revenues is noisy throughout the whole
period of study. Since revenues are adjusted per unit effort, this is expected. However, the
parallel trends for revenues and CPUE (subfigures (a)-(d)) seem reasonable for the TURF.
The discrepancy in trends starts after the introduction of the regime. However, for the large

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[13]An indicative, although very crude measure of stock changes is the changes in stock composition across
years. A regression on catch of large shrimp per trawl hour using year, treatment area and treatment area time
trends, and license holder fixed effects as explanatory variables reveals no differences across years. Results are
available upon request.

share, the drop seems to occur already in 2003.

As for the co-management, the parallel trends for revenues are even more noisy. It is hard to visually determine whether there is a downward trend in 1997 and 1998 or not. However, the closer to the regime shift, the more parallel the trends seem to be, which is reassuring.

Also, Figure 6 is reassuring. The graph shows no evident trends in prices for large shrimp prior to the regime shifts for either management area.

Placebo-tests offer a second approach to verify potential problems of pre-trends (see Bertrand et al. (2004) for a critical assessment). The test consists of re-estimating the DiD specification (Eq. 1) on the pre-treatment years under the assumption that the regime shift occurred at an earlier date. Such tests are carried out for all outcome variables, using the same treatment groups as outlined in Section 3.1. Placebo effects for the TURF regime are estimated using 2000-2002 as fictive treatment years, and a single placebo effect for the co-management is estimated using 1998 as the fictive year of treatment.[14] All placebo tests are centered on a zero effect, which is reassuring as it does not give support for pre-trends in the main outcome variables. Results are shown in Figures A8 and A9.

A third approach makes use of an event study allowing for direct estimation of any differences in trends. The treatment indicator is interacted with the years prior to (leads) and after (lags) the regime shift, using the same set of time trends and vessel fixed effects as in the main specification (Eq. 1). As the time trends pick up any trend common to all fishers and the treatment group variable captures the difference between groups, the estimated coefficients of the leads and lags should be close to zero and insignificant if there is no difference in trends between groups. The results are displayed in Figures A10 and A11. Apart from 1999, in which the TURF was re-opened for shrimp fishing, and a slight deviation in 2001, all leads are centered on zero for the TURF. For the co-management, the suspicion of a downward trend in gross revenues is confirmed. This is controlled for in the main regression using a location-specific time trend.

6   Timely harvest analysis

A higher degree of coordination within the fishery is expected to improve engagement in timely harvest. Decreased competition could enable fishers to better exploit price variations due to seasonality, demand and weather. By extending the dataset to include all vessel-date pairs for the period 1997-2013, I can use the daily variation in fishing participation to evaluate choices made before and after the shift in management regimes. Rather than trying to include all the potential factors influencing the decision, the proposed model is a simplified version

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[14]The test requires to use pre-treatment years for which there is at least one year prior to and one year after the placebo introduction of the regime. Only 1998 satisfies this condition for the co-management regime, as the regime was introduced in 2000.

that focuses on, arguably, two of the most important factors: revenues and weather. This allows me to evaluate whether the likelihood of carrying out a fishing trip when expected revenues are high, or in adverse weather, has changed as a consequence of the regime shifts.

Assuming profit maximization, the underlying model of participation on a given day is modeled as a function of expected hourly gross revenues and weather.[15] In essence, the decision process is thought of as taking place on a daily basis. Each morning, the fisher makes the participation decision based on the expected hourly revenue that day. The trip is carried out when the expected gross revenue per unit effort of fisher i on day d is higher than some (unobserved) reservation level. Under the assumption that this reservation level is changed by the regime shift, this is represented by:

$$
\begin{aligned}
&P(fish_{i,d} = 1|W_{i,d}, S_d) = \\
&\Phi(\alpha + \beta_1\widehat{expW_{i,d}} + \beta_2 post + \beta_{12}(\widehat{expW} * post) + \beta_3 S_d + \beta_{32}(S_d * post)),
\end{aligned}
\tag{2}
$$

where *fish* is an indicator variable of the fishing decision that is linearly related to expected gross revenue per unit effort, $\widehat{W_{id}}$, an indicator variable of adverse weather on the day of departure, S_d, and their interaction. Adverse weather, defined as a day on which the average wind speed is above 12 m/s[16], makes it riskier and more difficult to fish (Pfeiffer and Gratz, 2016). Note that although there is seasonality in wind speed, there is substantial variation between years and seasons. The annual share of stormy days varies from 5 % to 23 % during the period our study (Fig A12). This unpredictability in weather supports the assumption that fishing decisions are being made on a day-to-day basis.

Expected revenue per unit effort is modeled as a function of expected price/kg and expected catch of shrimp per unit effort:

$$
\widehat{expW_i} = \widehat{expPrice_i} * \widehat{expCPUE_i},
\tag{3}
$$

where expected price and shrimp catch per unit effort are estimated from the data.

6.1   Construction of variables

The expected price is specified using two different approaches, one assuming myopic and the other rational decision makers. Firstly, the expected price is estimated assuming myopic

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[15]Theoretically, a profit maximizing fisher would consider changes in net revenues. However, that would require an estimation of the expected cost of each unit effort, which would reduce the precision of the estimates. Hence, gross revenues are used as a proxy.

[16]Defined as strong winds (equivalent to *gale*) by the Swedish Meteorological and Hydrological Institute.

fishers. That is, they update their price beliefs based on yesterday's prices. There are two reasons for this assumption; experimental evidence shows that individuals who make income-determining decisions for a short period of time in the near future, such as a fishing trip, are myopic (Ran et al., 2014); and the average price obtained at the previous day's auction is made public every day on the auction websites. Since small shrimp fetches a fairly constant price, it is the large shrimp that drives fishers' price expectations. Consequently, the mean price of large shrimp on the previous auction day is used as expected price in the model. A simple regression of the previous day's auction on the present day's price yields an $R^2 = 0.91$, revealing the high relevance of this myopia assumption.

Secondly, the myopia assumption is relaxed and the formation of price expectations is assumed to be a more elaborated process. I assume that the fisher use the following heuristic to form price expectations:

$$
\begin{aligned}
expPrice_{igdmy} = \alpha_i &+ \beta_1 windspeed_d + \beta_2 meshsize_i + \\
&+ \beta_3 quotause_i + \beta_4 group_g + T_{my} + \varepsilon_{igmdy},
\end{aligned}
\tag{4}
$$

where $windspeed$ captures weather effect on prices; $meshsize$ accounts for quality effects due to the planned mesh size; $quotause$ captures the total quota use in the overall fishery as an indication of the current weekly supply[17]; $group$ refers to the regime-specific group that the vessel belongs to and captures potential variations in prices at the auction, and T_m is a set of month, day of the week, and year indicators that captures seasonal effects and inter-temporal demand. Estimates are presented in Table A7. The explanatory variables are jointly significant (F-test, p<0.001) and of the expected sign. On average, the price increases positively with wind speed and mesh size and negatively with quota use. Compared with the TURF fishers, the expected price is lower for the co-management and the ROA fisheries. The average expected prices are higher during the summer months and late in the week. The year dummies show how the average price expectation increases over time, particularly from 2010 and later. Part of the price increase is explained by the exceptionally cold winters in 2009 and 2010 that affected early spring spawning negatively and hence had a negative effect on stock development in the subsequent years. The estimates are used to create individual expected prices for all potential trip-date pairs in the sample.

Fishers' heuristics of expected catch of shrimp per unit effort are assumed to be a process similar to the rational expected price formation. When forming beliefs, I assume that fishers

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[17]This is based on the industry-wide voluntary weekly three-day limit, assuming perfect information sharing among fishers and that the market clears on weekends. Own weekly quota use is captured as the difference between the voluntary limit of three days and the number of days fished during the week: $d_i = d_i^{max=3} - d_{iw}$. The sum of all other license holders is: $D_j = \sum_1^T d_{jt}$. Thus, a smaller D_j indicates that more fishers have been using up their (voluntary) quotas.

take into account scientific estimates of the stock, the location of their planned trip, weather conditions, and previous fishing behavior of others:

$$expCPUE_{imy} = \alpha_i + \beta_1 stockindex_y + \beta_2 area_i + \beta_{12}(area_i * stockindex_y)$$
$$+ \beta_3 meshsize_i + \beta_4 quotause_i + \beta_5 length_i + \beta_6 kW_i + T_{my} + \varepsilon_{imy},$$

(5)

where $stockindex$ is a function of the biomass in ton per nautic mile during a given year; $area$ classifies the location of the planned trip (TURF, co-management, or ROA); the interaction term $area * stockindex$ captures the fishers' assessment of area-specific catchability; $meshsize$ accounts for the expected effect of the mesh size; $quotause$ is defined as above; $length$ and kW capture individual vessel capacity, and T_m is a set of month indicators capturing seasonal effects. All estimates are presented in Table A8. The explanatory variables are jointly significant (F-test, p<0.001) and of the expected sign. On average, the catch of shrimp per unit effort is higher in both the co-management and the ROA fishery than in the TURF fishery. Mesh size has a negative effect on catch per unit effort, whereas length, kW, and sum of others' quota use are positively, albeit with a small effect size, affecting the shrimp CPUE. Again, the negative supply shock on the stock in 2009 and 2010 is reflected in the negative estimate of the stock index in 2011. The monthly dummies show how catch per unit effort fluctuates over the year, taking January as the reference month, with August-October being the months associated with the highest shrimp CPUE. The estimates are used to create individual expected catch per unit effort estimates for all potential trip-date pairs in the sample.[18]

Finally, expected revenues for all trip-date pairs and vessels are constructed by multiplying expected price with expected shrimp CPUE. The participation decision is estimated according to equation 2 using a sample of only TURF fishers, only co-management fishers, or the full sample of vessels. In estimating the effects on the whole sample of fishers, group-specific interactions are added to the base model 2.

Not all vessel-date pairs are relevant to include in the fishers' choice set. Exclusion of irrelevant observations is determined following two rules: firstly, the first date a vessel carries out a trip is taken as the start date and all previous dates are excluded. Secondly, periods of inactivity, defined as the 90th percentile of a consecutive period of days with no recorded shrimp fishing, are also excluded. In addition, all date-vessel pairs in December 2012, and 136 dates for which wind speed information is lacking, are dropped. Given these exclusions, the total sample consists of 670,431 vessel-date pairs and 144 decision makers for varying

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[18]Note that, despite the similarities, the constructions of expected shrimp CPUE and expected price should not be thought of as an instrumental variable approach. Rather it should be interpreted as a way of modeling the decision variables entering the fisher's decision making process.

time periods depending on the exclusion criteria defined above. On average, there are 360 vessel-date pairs.

The level of participation differs between the groups. For the TURF fishers, the mean level of participation was 5 % prior to the regime shift and 7 % after. For the co-management fishers, the mean level of participation was 14 % prior to the regime shift and 16 % after. In the ROA fishery, the mean level of participation is 5 %. The low number of shrimp fishing days is due to that most fishers combine shrimp with other types of fisheries.

6.2 Timing results

In estimating the effects of the regimes on timely harvest, I specify a linear probability model using the same DiD set-up as specified previously (Eq. 2). Greene (2010) proposes to use graphical representation of the marginal effects for continuous variables such as the expected revenues per unit effort. Thus, the estimated results are presented in Table A9, and the marginal effects are represented graphically in Figures 7 – 10. The figures are constructed by plotting the marginal effect of the probability of carrying out fishing for different levels of revenues, and in stormy (wsp > 12) or calm weather, before and after the respective regime shift. Figure 7 shows the predictive margins of carrying out fishing for myopic TURF fishers, adjusted to different levels of expected revenue and with separate lines for days when the average wind speed is above, or below, 12 m/s. Figure 8 represents the predictive margins for rational fishers. The pattern in both figures indicates the same behavioral mechanism: prior to the introduction of the TURF, the probability of carrying out fishing was unaffected by the level of expected revenue per hour. Instead, the difference in fishing activity on stormy days and days without heavy winds, suggests that fishers' decisions were mainly driven by the weather and not by expected marginal revenues. This is in line with the fact that the TURF fishers competed with each other as well as with other fishers during the 100 days shrimp fishing was permitted in the fjord. The open access fishery prevented fishers from capturing some of the high expected prices by planning their harvest. In contrast, after the introduction of the TURF, the fishers are more likely to carry out fishing on days with high expected revenues.[19] This effect is statistically significant for all expected revenue levels above the mean (the average expected revenue is SEK 1,165 (st.dev. SEK 555). The negative effect of stormy weather on fishing probability is reduced as a consequence of the TURF introduction, which suggests that TURF fishers actively target the fjord during stormy days as it lies more protected from high waves. In sum, the results indicate that part of the revenue increase in the TURF fishery is explained by a better ability to target days on which expected revenues of shrimp per unit effort are particularly high.

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[19]This effect is not driven by any single user rights holder; the probabilities of carrying out fishing are similar to those obtained when including fisher fixed effects and estimating probabilities for each vessel separately. Results available upon request.

Figure 7: Predictive margins of carrying out fishing for varying levels of expected revenues, during high and low wind speeds, for myopic TURF fishers. The error bars indicate 95 % confidence intervals.

Figure 8: Predictive margins of carrying out fishing for varying levels of expected revenues, during high and low wind speeds, for rational TURF fishers. The error bars indicate 95 % confidence intervals.

Figure 9: Predictive margins of carrying out fishing for varying levels of expected revenues, during high and low wind speeds, for myopic co-management fishers. The error bars indicate 95 % confidence intervals.
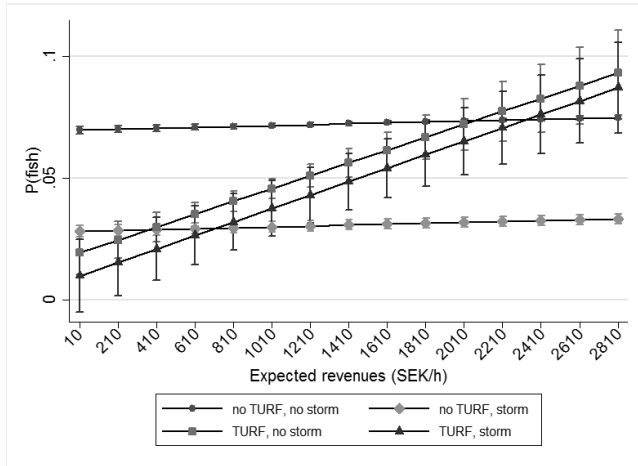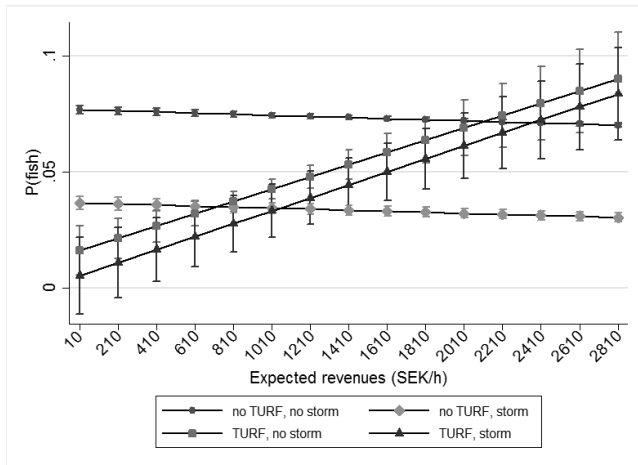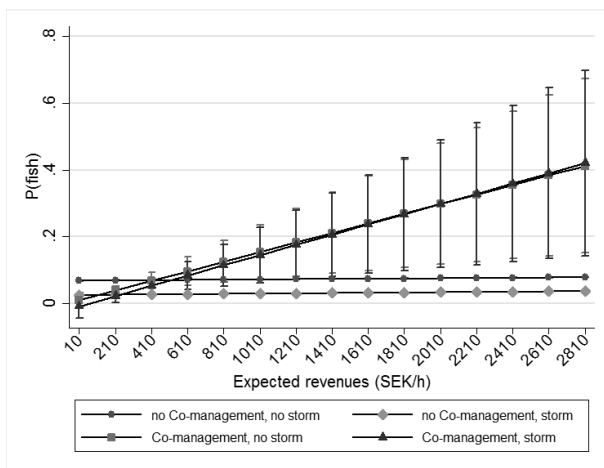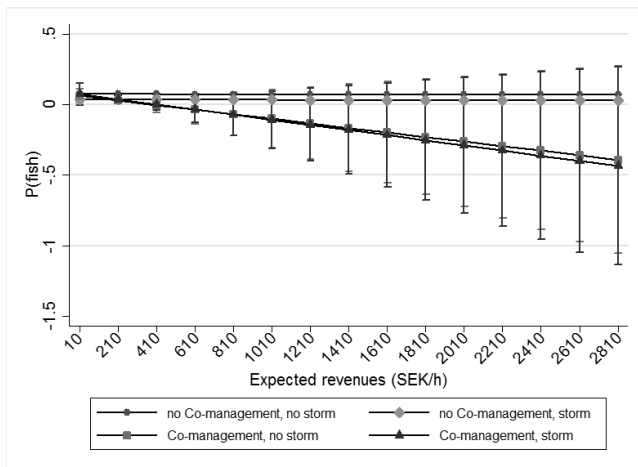

Figure 10: Predictive margins of carrying out fishing for varying levels of expected revenues, during high and low wind speeds, for rational co-management fishers. The error bars indicate 95 % confidence intervals.

Figure 9 shows the predictive margins of myopic co-management fishers before and after the regime shift, whereas Figure 10 shows the results for the rational fishers. In contrast to the TURF fishery, the myopic and rational models yield different results. Assuming myopic fishers, the likelihood of fishing increases with expected revenues after the regime shift. The fishing probability is significantly different from the probability prior to the regime shift for all levels above the mean (average expected revenues in the group is SEK 1,764 with a st.dev. of SEK 764). Stormy weather is estimated as having a slight deterring effect on fishing probability. Instead, when assuming rational fishers, the probability of fishing is negatively related to expected revenues after the regime shift, although this effect is not statistically significant for any level of expected revenues. If we stick to the assumption of myopic fishers, the results indicate that the co-management fishers have increased their engagement in timely harvest relative to the level before the regime shift.

In sum, the myopic and rational models produce similar results for the TURF fishers, whereas they differ for the co-management. This indicates that the TURF fishers experience less volatility in dock-side prices for their harvest compared with the co-management fishers. However, assuming that the myopic assumption best describes fishers' decision-making, the estimates suggests that fishers engage more in timely harvest after respective regime shift.

7   Conclusion

In fisheries, rights-based management is increasingly used to provide incentives for fishers to coordinate their activities to restore and sustain the resource rent. Even though the effect of a management regime on coordination itself is difficult to measure, one straight-forward indicator is changes in revenues compared to the status quo, which often is a situation of open access. Given that most regimes in fisheries are introduced into systems that are already ill-managed, revenue changes measured over short time spans are likely to be very large. That is because such a comparison will capture revenues recovering from poor to "normal", and from "normal" to (potentially) improved. The average change in revenues over a longer period of time is arguably a more solid measurement of the effect of the regime shift on sustained rents.

In this study, I exploit a quasi-experimental setting in the Swedish shrimp fishery in which two spatially distinct management regimes altered the existing regulated open access regime. This setting allows for the construction of counterfactuals and evaluation of changes in revenues over a relatively long time period. The introduction of a co-management in 2000 and a TURF in 2004 was part of a broader ambition to strengthen the socioeconomic status of coastal communities and allow fishers to continue their activities within marine areas of high biological importance. The rest of the fishery was carried out under a regulated open access (ROA) regime. By constructing a panel that identifies revenues from fishing trips in each

of the three regime types, i.e., unaltered ROA, co-management, and TURF, I evaluate the effects on revenues using a difference-in-difference strategy. The results show that the TURF fishers on average increased their revenues by 27 %, whereas the co-management fishers on average experienced a 4 % increase. What explains this difference in outcomes?

Both the TURF and the co-management have clearly defined geographical boundaries, a stable set of resource users that are entitled to establishing internal management rules, and identical external monitoring enforced by the national agency of marine and water management. However, there is an important difference in terms of the strength of property rights. In the TURF, five vessels are granted exclusive harvesting rights. In contrast, 27 vessels are regularly fishing in the co-management area, to which the access is restricted by means of a mandatory gear type. The importance of a small number of players and the ability to exclude others from exploiting the resource for successful collective management is a well-established fact in the property rights literature.

Looking at the underlying mechanisms of revenue creation, it is clear that the smaller number of TURF-participants has a great impact. The estimated results of changes in harvest efficiency and composition show that the TURF fishers are able to coordinate their fishing activities in terms of effort distribution and gear choices and in so doing can increase the harvest efficiency and exploit the within-seasonal marginal rents. In addition, the reduced race to catch is demonstrated through an increased probability to carry out fishing when expected revenues are high. As for the co-management, there are indications of the same mechanisms, yet the obtained market price is not developing toward a price differential, as is the case for the TURF.

Is revenue creation the right indicator to measure the success of a management regime? The important link between revenue creation and long-term sustainability of the stock is well-established in the economics literature. However, sustainable management might also incur economic losses in the short- and medium-term as the resource users adjust their activities to the new equilibrium. Under the co-management regime, part of the shy decrease in revenues can be explained by a loss in the share of large shrimp in landed harvest. If the decrease is due to the fishers engaging less in high-grading, the fishers might increase the long-term value of the fishery. Short- and medium-term revenue measures fall short of accounting for such conservation efforts. Such perspectives on the right approaches for evaluating management regimes are increasingly brought up in the ecosystem-based literature and management policies.

Taken together, the findings in this paper are in line with property rights theory; well-defined property rights that effectively exclude others from using the resource create incentives for users to maximize revenues, particularly so when the number of resource users is small. The study provides compelling and unique evidence of the mechanisms underlying the revenue creation and points at the importance of enabling fishers to raise quality and engage in timely

harvest. Although the magnitudes of these results are particular for the case studied, they point at the important role TURFs can play in combining both conservation and socio-economic objectives.

Personal communication

Jarl Engqvist, administrator, the Swedish Agency for Marine and Water Management

Matthias Ivarsson, board member, National Association of Swedish Fishermen

Kerstin Johannesson, professor, Department of Marine Sciences, University of Gothenburg

Erland Lundqvist, project coordinator co-management, Strömstad

Mats Ulmestrand, environmental analyst, Department of Aquatic Resources, Swedish University of Agricultural Sciences

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8 Appendix
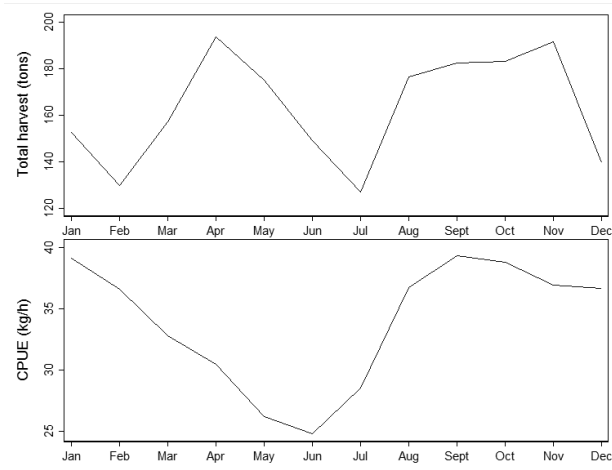
Figure A1: Average total catch per month in tons (top) and average catch per unit effort in kg/h (bottom).

Figure A2: Timeline of important events in the Swedish shrimp fishery management.

1983 — Gullmar Fjord declared marine reserve.

1992 — EU negotiations about TAC for Sweden. Sweden gets 19 % of *Pandalus borealis* stock in ICES divisions: IIIa and IVa east.

2000 — Co-management established with around 25 fishers. Agreement includes effort and input restrictions.

2004 — TURF established within Gullmar Fjord. Six vessels are granted exclusive access.

2008 — License requirement introduced for all shrimp fishery. Eligibility conditioned on yearly catch ≥ 1000 kg.

1999 — Gullmar Fjord is reopened for trawling. Max 100 days per year.

2002 — Gullmar Fjord fishers reach voluntary agreements on distributing days across quarters.

2005 — One vessel with territorial user rights retires from shrimp fishery. Five vessels remain in TURF.

Data availability 1997 - 2013

Figure A3: Distribution of trips within the areas by month before and after respective regime shifts.
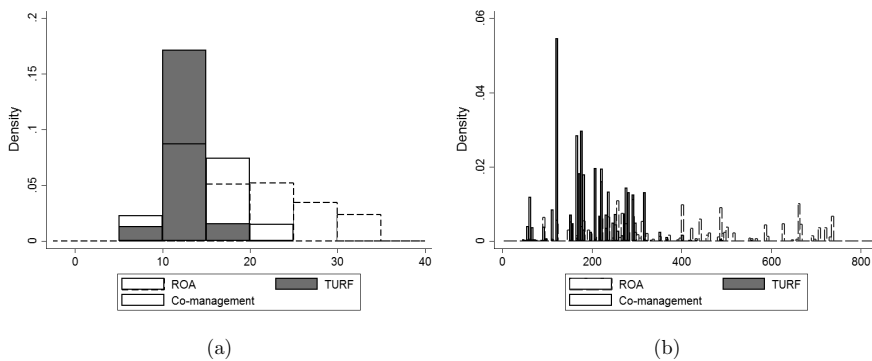
Figure A4: (a) Length (m) and (b) kW distribution of vessels carrying out trips in ROA, co-management, and TURF areas, respectively.

A3
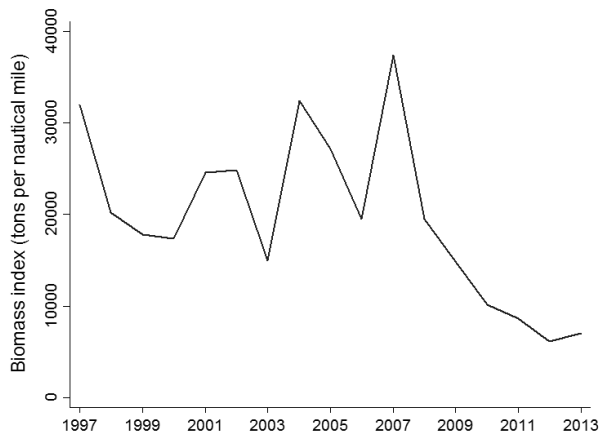
Figure A5: Biological index of stock, defined as number of species per nautical mile, over the period of study 1997-2013

(a) Gross revenues

(b) Shrimp gross revenues

(c) Net revenues

(d) CPUE

(e) Large share

(f) Bycatch CPUE
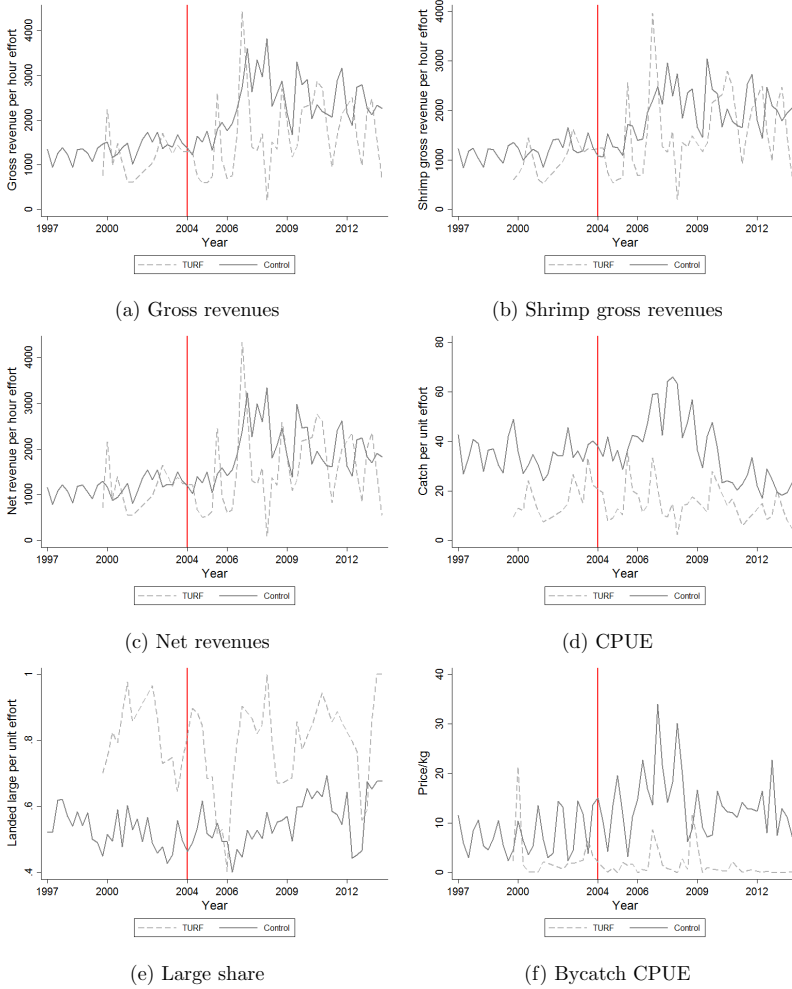
Figure A6: Parallel trends for the TURF. The vertical lines indicate the year in which the co-management and the TURF, respectively, were introduced.

A5

(a) Gross revenues

(b) Shrimp gross revenues

(c) Net revenues

(d) CPUE

(e) Share large

(f) Bycatch CPUE
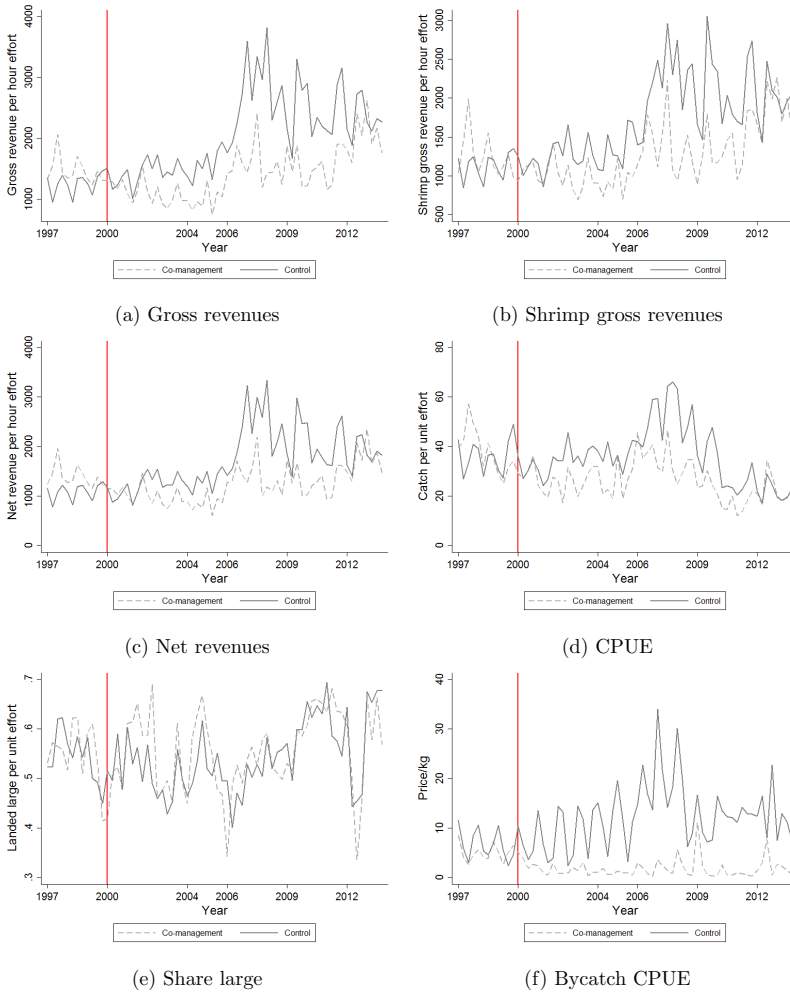
Figure A7: Parallel trends for the co-management. The vertical lines indicate the year in which the co-management and the TURF, respectively, were introduced.

(a) Gross revenues

(b) Shrimp gross revenues

(c) Net revenues

(d) CPUE

(e) Price for large shrimp
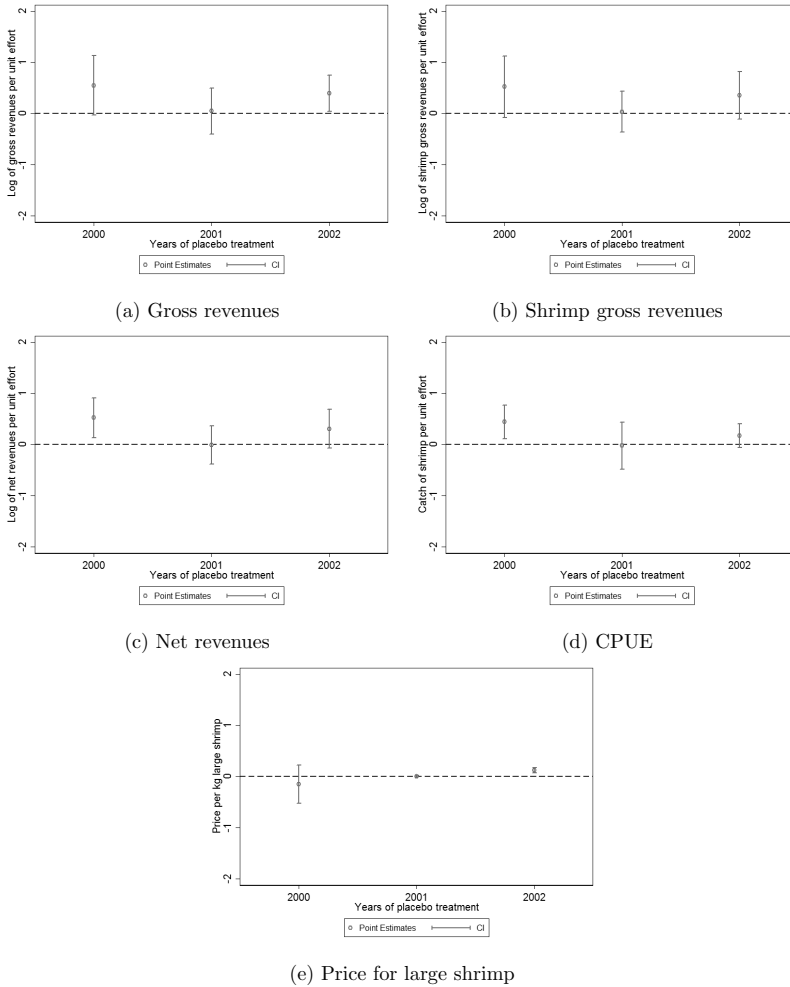
Figure A8: Placebo tests using 2000-2002 as fictive treatment years for the TURF and the same specification and samples as for the main analysis. The error bars indicate 99, 95, and 90 % confidence intervals.

A7

(a) Gross revenues

(b) Shrimp gross revenues

(c) Net revenues

(d) CPUE

(e) Price for large shrimp
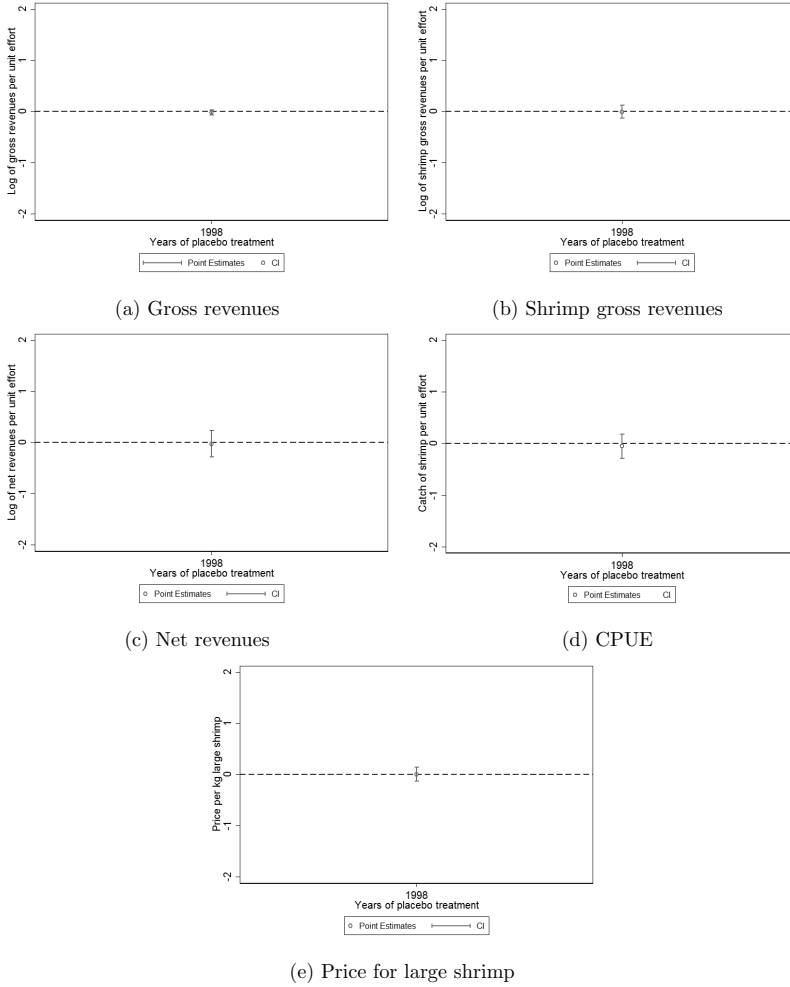
Figure A9: Placebo tests using 1998 as fictive treatment year for the co-management and the same specification and samples as for the main analysis. The error bars indicate 99, 95, and 90 % confidence intervals.

(a) Gross revenues

(b) Shrimp gross revenues

(c) Net revenues

(d) CPUE

(e) Price for large shrimp
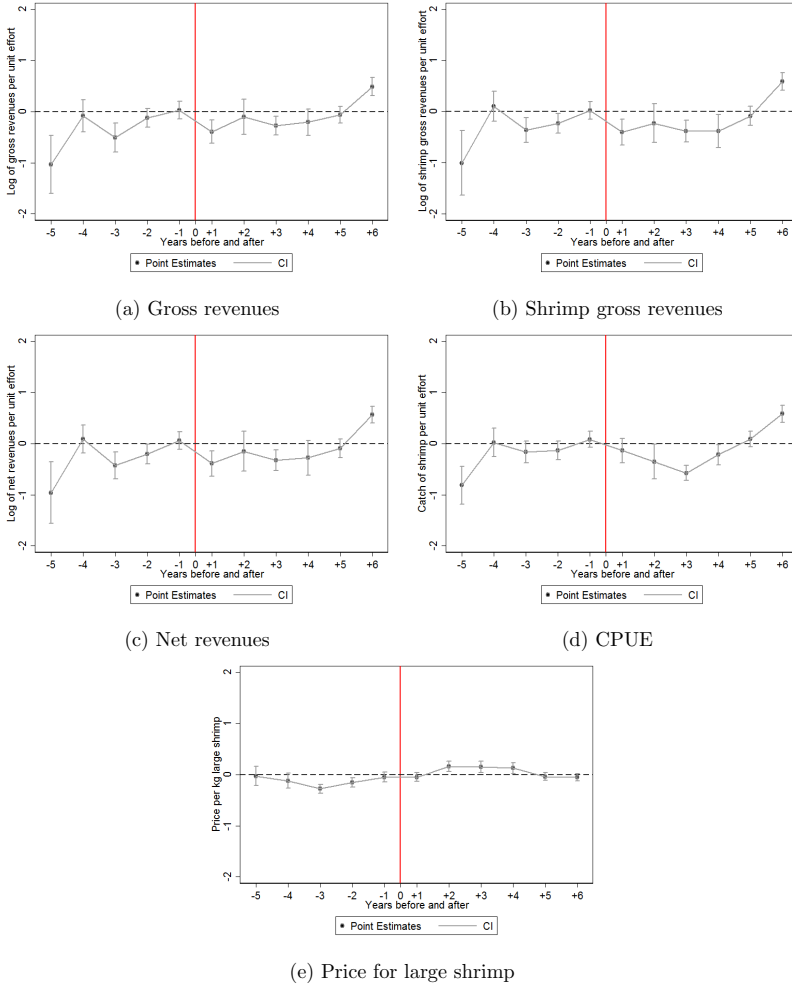
Figure A10: Point estimates and confidence intervals from event study for the TURF
using the same samples as for the main analysis. Leads and lags in relation to the
year of the regime shift, 2004, are used as a test of potential drivers and the
treatment effect after the regime shift. Vessel fixed effects are included.

(a) Gross revenues

(b) Gross revenues

(c) Net revenues

(d) CPUE

(e) Price for large shrimp
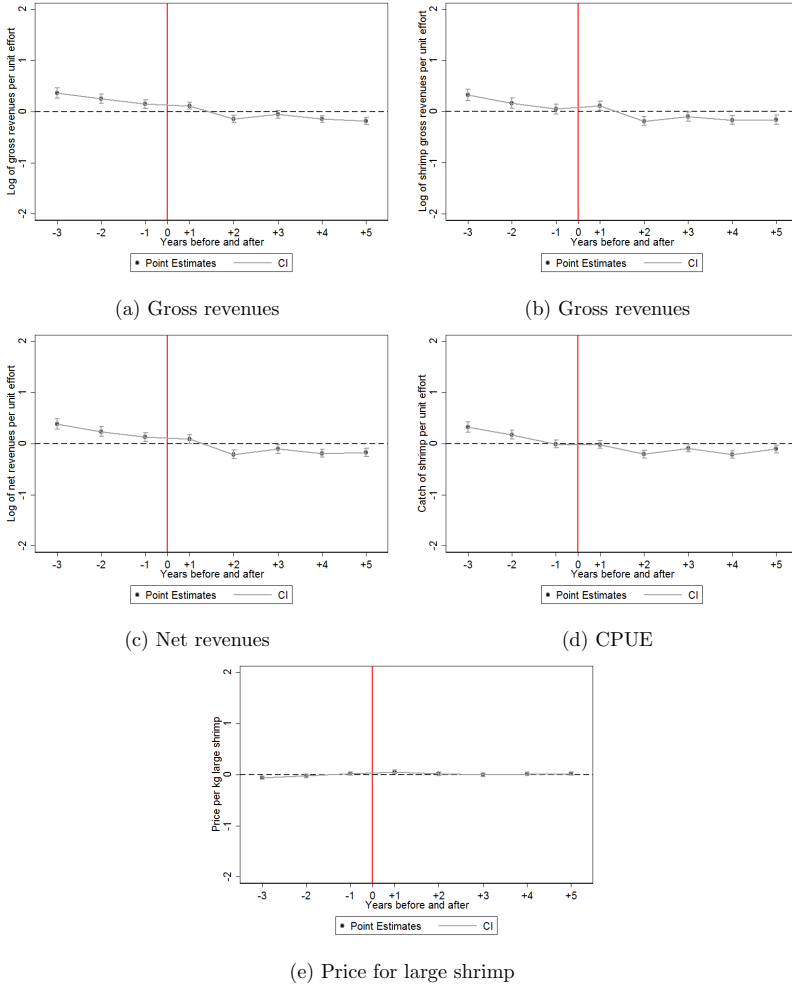
Figure A11: Point estimates and confidence intervals from event study for the co-management using the same samples as for the main analysis. Leads and lags in relation to the year of the regime shift, 2000, are used as a test of potential drivers and the treatment effect after the regime shift. Vessel fixed effects are included.
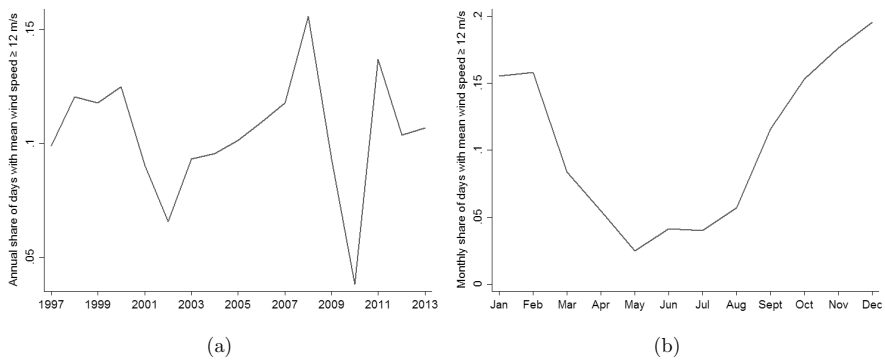
Figure A12: *a*) Annual share of days with average mean wind speed $\geqslant$ 12 meters per second. *b*) Monthly share of days with average mean wind speed $\geqslant$ 12 meters per second.

Table A1: Gross revenues, TURF treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	-0.336***	-0.306***	-0.097	-0.111	-0.079	-0.063	0.112	0.103
	(0.060)	(0.059)	(0.073)	(0.071)	(0.082)	(0.0851)	(0.089)	(0.091)
	[0.021]	[0.052]	[0.053]	[0.054]	[0.019]	[0.016]	[0.035]	[0.039]
Treatloc*post	0.068	0.055	0.141**	0.138**	0.169	0.208*	0.258**	0.272**
	(0.069)	(0.068)	(0.067)	(0.066)	(0.115)	(0.121)	(0.103)	(0.108)
	[0.024]	[0.022]	[0.039]	[0.036]	[0.025]	[0.028]	[0.029]	[0.036]
Simultloc	-0.173***	-0.180***	0.089***	0.066***	-0.292***	-0.309***	-0.00749	-0.0348
	(0.018)	(0.018)	(0.019)	(0.019)	(0.040)	(0.040)	(0.037)	(0.037)
	[0.004]	[0.004]	[0.012]	[0.010]	[0.005]	[0.005]	[0.007]	[0.013]
Simultloc*post	-0.164***	-0.180***	-0.093***	-0.094***	0.169***	0.154***	0.151***	0.153***
	(0.022)	(0.022)	(0.021)	(0.021)	(0.058)	(0.057)	(0.053)	(0.053)
	[0.014]	[0.006]	[0.011]	[0.010]	[0.005]	[0.006]	[0.014]	[0.022]
Constant	6.938***	7.024***	5.960***	6.194***	5.890***	5.948***	5.022***	5.255***
	(0.020)	(0.048)	(0.086)	(0.094)	(0.331)	(0.335)	(0.305)	(0.310)
	[0.045]	[0.021]	[0.179]	[0.202]	[0.019]	[0.022]	[0.220]	[0.202]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE		✓	✓	✓		✓	✓	✓
Month and day of the week		✓		✓				✓
Location linear trend					✓	✓	✓	✓
Observations	40,944	40,944	40,944	40,944	40,944	40,944	40,944	40,944
R^2	0.104	0.131	0.339	0.358	0.113	0.139	0.347	0.365

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A2: Shrimp gross revenues, TURF treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	-0.294***	-0.274***	-0.044	-0.082	-0.036	-0.031	0.159*	0.126
	(0.058)	(0.057)	(0.073)	(0.072)	(0.078)	(0.081)	(0.088)	(0.090)
	[0.015]	[0.013]	[0.053]	[0.055]	[0.014]	[0.006]	[0.037]	[0.043]
Treatloc*post	0.105	0.089	0.145**	0.140**	0.210*	0.240**	0.256**	0.265**
	(0.068)	(0.067)	(0.066)	(0.065)	(0.112)	(0.121)	(0.102)	(0.109)
	[0.018]	[0.015]	[0.033]	[0.030]	[0.023]	[0.025]	[0.027]	[0.037]
Simultloc	-0.169***	-0.192***	0.111***	0.066***	-0.269***	-0.306***	0.038	-0.018
	(0.018)	(0.018)	(0.019)	(0.019)	(0.039)	(0.039)	(0.037)	(0.036)
	[0.003]	[0.003]	[0.009]	[0.014]	[0.006]	[0.007]	[0.007]	[0.022]
Simultloc*post	-0.125***	-0.141***	-0.111***	-0.113***	0.144**	0.129**	0.061	0.063
	(0.023)	(0.022)	(0.022)	(0.021)	(0.056)	(0.059)	(0.056)	(0.054)
	[0.012]	[0.005]	[0.015]	[0.012]	[0.008]	[0.008]	[0.016]	[0.024]
Constant	6.797***	6.870***	5.902***	6.090***	5.681***	5.723***	4.909***	5.081***
	(0.023)	(0.049)	(0.087)	(0.095)	(0.323)	(0.326)	(0.312)	(0.315)
	[0.019]	[0.019]	[0.201]	[0.209]	[0.017]	[0.022]	[0.223]	[0.192]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE		✓	✓	✓	✓	✓	✓	✓
Month and day of the week		✓		✓		✓		✓
Location linear trend					✓	✓	✓	✓
Observations	40,828	40,828	40,828	40,828	40,828	40,828	40,828	40,828
R^2	0.100	0.143	0.306	0.335	0.109	0.151	0.313	0.342

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

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Table A3: Net revenues, TURF treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	-0.157***	-0.124**	-0.090	-0.114	0.091	0.113	0.111	0.095
	(0.058)	(0.057)	(0.073)	(0.072)	(0.079)	(0.082)	(0.087)	(0.087)
	[0.028]	[0.027]	[0.038]	[0.039]	[0.021]	[0.018]	[0.025]	[0.027]
Treatloc*post	0.019	0.009	0.113*	0.110*	0.154	0.195	0.266**	0.283**
	(0.069)	(0.068)	(0.067)	(0.066)	(0.121)	(0.128)	(0.110)	(0.116)
	[0.033]	[0.032]	[0.048]	[0.046]	[0.027]	[0.036]	[0.031]	[0.044]
Simultloc	-0.086***	-0.095***	0.091***	0.061***	-0.249***	-0.269***	-0.0302	-0.068
	(0.020)	(0.020)	(0.022)	(0.021)	(0.045)	(0.045)	(0.043)	(0.042)
	[0.005]	[0.003]	[0.017]	[0.012]	[0.007]	[0.005]	[0.013]	[0.017]
Simultloc*post	-0.186***	-0.205***	-0.076***	-0.081***	0.264***	0.246***	0.283***	0.282***
	(0.026)	(0.025)	(0.025)	(0.024)	(0.065)	(0.064)	(0.061)	(0.061)
	[0.017]	[0.009]	[0.017]	[0.013]	[0.013]	[0.013]	[0.020]	[0.030]
Constant	6.792***	6.902***	5.812***	6.045***	5.812***	5.894***	4.936***	5.175***
	(0.022)	(0.056)	(0.108)	(0.118)	(0.338)	(0.340)	(0.324)	(0.327)
	[0.046]	[0.017]	[0.173]	[0.204]	[0.020]	[0.037]	[0.218]	[0.187]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE		✓	✓	✓		✓	✓	✓
Month and day of the week		✓		✓	✓	✓		✓
Location linear trend					✓	✓	✓	✓
Observations	39,931	39,931	39,931	39,931	39,931	39,931	39,931	39,931
R^2	0.100	0.143	0.306	0.335	0.109	0.151	0.313	0.342

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

Table A4: Gross revenues, co-management treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	0.139***	0.134***	0.260***	0.242***	-0.002	0.00302	0.158***	0.144***
	(0.028)	(0.027)	(0.028)	(0.028)	(0.043)	(0.042)	(0.041)	(0.040)
	[0.007]	[0.009]	[0.022]	[0.021]	[0.015]	[0.017]	[0.016]	[0.017]
Treatloc*post	-0.440***	-0.452***	-0.270***	-0.276***	-0.121**	-0.156***	-0.038	-0.049
	(0.030)	(0.029)	(0.029)	(0.028)	(0.060)	(0.059)	(0.056)	(0.055)
	-0.440***	-0.452***	-0.270***	-0.276***	-0.121***	-0.156***	-0.038**	-0.049***
	[0.011]	[0.009]	[0.014]	[0.017]	[0.014]	[0.016]	[0.015]	[0.016]
Simultloc	-1.069***	-1.089***	-0.797***	-0.829***	-1.098***	-1.116***	-0.852***	-0.875***
	(0.320)	(0.321)	(0.290)	(0.291)	(0.321)	(0.322)	(0.287)	(0.289)
	[0.040]	[0.083]	[0.102]	[0.111]	[0.015]	[0.049]	[0.107]	[0.099]
Simultloc*post	0.800**	0.844***	0.817***	0.835***	1.188***	1.264***	1.217***	1.250***
	(0.322)	(0.323)	(0.288)	(0.289)	(0.330)	(0.333)	(0.295)	(0.297)
	[0.037]	[0.080]	[0.092]	[0.094]	[0.021]	[0.063]	[0.098]	[0.088]
Constant	6.834***	6.896***	5.905***	6.108***	6.816***	6.878***	5.920***	6.124***
	(0.0228)	(0.046)	(0.087)	(0.093)	(0.024)	(0.047)	(0.088)	(0.094)
	[0.026]	[0.009]	[0.165]	[0.182]	[0.004]	[0.031]	[0.169]	[0.188]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE	✓	✓	✓	✓	✓	✓	✓	✓
Month and day of the week		✓		✓		✓		✓
Location linear trend			✓	✓			✓	✓
Observations	46,896	46,896	46,896	46,896	46,896	46,896	46,896	46,896
R^2	0.105	0.131	0.330	0.348	0.113	0.139	0.337	0.354

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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Table A5: Shrimp gross revenues, co-management treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	0.092***	0.072**	0.228***	0.190***	-0.100**	-0.107**	0.100**	0.068
	(0.029)	(0.029)	(0.028)	(0.027)	(0.048)	(0.047)	(0.042)	(0.042)
	[0.008]	[0.009]	[0.014]	[0.013]	[0.013]	[0.014]	[0.016]	[0.017]
Treatloc*post	-0.355***	-0.368***	-0.215***	-0.223***	-0.024	-0.068	-0.017	-0.038
	(0.032)	(0.031)	(0.029)	(0.028)	(0.065)	(0.064)	(0.059)	(0.058)
	[0.012]	[0.009]	[0.014]	[0.016]	[0.014]	[0.014]	[0.020]	[0.020]
Simultloc	-1.105***	-1.133***	-0.815***	-0.874***	-1.144***	-1.169***	-0.874***	-0.924***
	(0.313)	(0.312)	(0.299)	(0.297)	(0.314)	(0.312)	(0.297)	(0.296)
	[0.054]	[0.093]	[0.116]	[0.131]	[0.015]	[0.044]	[0.108]	[0.105]
Simultloc*post	0.907***	0.946***	0.891***	0.912***	1.318***	1.378***	1.285***	1.314***
	(0.315)	(0.313)	(0.296)	(0.294)	(0.324)	(0.324)	(0.304)	(0.304)
	[0.051]	[0.096]	[0.104]	[0.110]	[0.022]	[0.066]	[0.104]	[0.098]
Constant	6.756***	6.802***	5.908***	6.063***	6.733***	6.778***	5.912***	6.065***
	(0.024)	(0.046)	(0.087)	(0.094)	(0.025)	(0.047)	(0.088)	(0.095)
	[0.033]	[0.009]	[0.159]	[0.167]	[0.006]	[0.037]	[0.174]	[0.188]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE		✓	✓	✓	✓	✓	✓	✓
Month and day of the week				✓	✓	✓	✓	✓
Location linear trend				✓			✓	✓
Observations	46,726	46,726	46,726	46,726	46,726	46,726	46,726	46,726
R^2	0.099	0.141	0.304	0.332	0.108	0.149	0.311	0.339

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

Table A6: Net revenues, co-management treatment

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatloc	0.248***	0.243***	0.287***	0.263***	0.087**	0.095**	0.169***	0.151***
	(0.029)	(0.028)	(0.028)	(0.028)	(0.043)	(0.043)	(0.041)	(0.041)
	[0.010]	[0.010]	[0.019]	[0.020]	[0.015]	[0.018]	[0.014]	[0.015]
Treatloc*post	-0.477***	-0.494***	-0.276***	-0.288***	-0.072	-0.118*	0.065	0.042
	(0.032)	(0.031)	(0.030)	(0.029)	(0.064)	(0.063)	(0.060)	(0.060)
	[0.014]	[0.010]	[0.014]	[0.016]	[0.021]	[0.020]	[0.016]	[0.020]
Simultloc	-0.826**	-0.839**	-0.753**	-0.788***	-0.859***	-0.870***	-0.797***	-0.820***
	(0.330)	(0.327)	(0.304)	(0.300)	(0.331)	(0.328)	(0.303)	(0.300)
	[0.051]	[0.117]	[0.122]	[0.136]	[0.031]	[0.080]	[0.136]	[0.127]
Simultloc*post	0.698**	0.738**	0.759**	0.770***	1.103***	1.178***	1.168***	1.197***
	(0.332)	(0.329)	(0.301)	(0.298)	(0.344)	(0.342)	(0.313)	(0.312)
	[0.047]	[0.116]	[0.121]	[0.137]	[0.036]	[0.101]	[0.129]	[0.133]
Constant	6.643***	6.722***	5.721***	5.912***	6.620***	6.695***	5.741***	5.933***
	(0.026)	(0.055)	(0.108)	(0.117)	(0.027)	(0.055)	(0.109)	(0.118)
	[0.034]	[0.012]	[0.152]	[0.181]	[0.006]	[0.044]	[0.155]	[0.187]
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Vessel FE			✓	✓			✓	✓
Month and day of the week		✓		✓		✓		✓
Location linear trend					✓	✓	✓	✓
Observations	45,793	45,793	45,793	45,793	45,793	45,793	45,793	45,793
R^2	0.074	0.101	0.274	0.295	0.083	0.110	0.281	0.303

Note: Standard errors clustered on vessel in parentheses.
Two-way clustered standard errors on trip date and location in brackets.
Significance stars reflect the two-way clustered standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

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Table A7: Estimation results for expected price per kg harvested shrimp (SEK/kg)

VARIABLES	(1) Expected price
windspeed	2.434***
	(0.044)
meshsize	0.289***
	(0.057)
quotause	-0.120***
	(0.005)
co-management	-25.72***
	(0.822)
ROA	-29.98***
	(0.840)
Feb	-1.867***
	(0.622)
Mar	-0.687
	(0.583)
Apr	3.597***
	(0.577)
May	22.96***
	(0.577)
Jun	29.87***
	(0.597)
Jul	47.48***
	(0.599)
Aug	20.20***
	(0.595)
Sep	6.882***
	(0.599)
Oct	10.68***
	(0.604)
Nov	3.228***
	(0.594)
Dec	5.807***
	(0.646)
Mon	3.282***
	(0.992)
Tue	2.590***
	(1.001)
Wed	3.326***
	(1.014)
Thu	4.652***
	(1.056)
Fri	9.671***
	(2.033)
Sat	-2.187
	(2.693)
1998	-1.692**
	(0.659)
1999	8.227***
	(0.662)
2000	11.23***
	(0.661)
2001	17.14***
	(0.655)
2002	18.71***
	(0.664)
2003	11.81***
	(0.655)
2004	6.481***
	(0.639)
2005	20.94***
	(0.648)
2006	22.10***
	(0.663)
2007	22.01***
	(0.690)
2008	22.43***
	(0.680)
2009	39.08***
	(0.658)
2010	67.23***
	(0.688)
2011	83.09***
	(0.683)
2012	93.83***
	(0.730)
2013	89.50***
	(0.729)
Constant	43.96***
	(2.798)
Observations	43,605
R-squared	0.670

Note: Interaction terms omitted.
Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table A8: Estimation results for expected catch per unit effort

VARIABLES	(1) Expected shrimp CPUE
co-management	0.507***
	(0.070)
ROA	0.241***
	(0.077)
meshsize	-0.012***
	(0.002)
quotause	0.001***
	(0.000)
length	0.009***
	(0.001)
KW	0.001***
	(0.000)
Stockindex (1997)	0.361***
	(0.023)
Stockindex (1998)	0.403***
	(0.024)
Stockindex (1999)	-1.047***
	(0.199)
Stockindex (2000)	0.278*
	(0.152)
Stockindex (2001)	-0.360***
	(0.133)
Stockindex (2002)	0.212*
	(0.109)
Stockindex (2003)	0.516***
	(0.102)
Stockindex (2004)	0.242**
	(0.099)
Stockindex (2005)	0.385***
	(0.100)
Stockindex (2006)	0.232**
	(0.117)
Stockindex (2007)	0.153
	(0.108)
Stockindex (2008)	0.502***
	(0.010)
Stockindex (2009)	0.534***
	(0.093)
Stockindex (2010)	0.400***
	(0.010)
Stockindex (2011)	-0.288***
	(0.010)
Stockindex (2013)	0.395***
	(0.087)
Feb	-0.102***
	(0.017)
Mar	-0.131***
	(0.016)
Apr	-0.113***
	(0.015)
May	-0.274***
	(0.015)
Jun	-0.360***
	(0.016)
Jul	-0.209***
	(0.016)
Aug	0.028*
	(0.016)
Sep	0.088***
	(0.016)
Oct	0.032**
	(0.016)
Nov	0.019
	(0.016)
Dec	-0.036**
	(0.017)
Constant	2.488***
	(0.102)
Observations	45,496
R-squared	0.278

Note: Interaction terms omitted.
Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table A9: Effect of regimes on probability of fishing

	TURF		co-management	
	(1)	(2)	(3)	(4)
Treatloc	0.004	0.407**	-0.006	0.407**
	(0.083)	(0.198)	(0.010)	(0.198)
Post	-0.036***	-0.082***	-0.067***	-0.083***
	(0.003)	(0.003)	(0.002)	(0.003)
Treatloc*post	-0.073	-0.483**	-0.072***	-0.483**
	(0.083)	(0.198)	(0.011)	(0.198)
expW	0.000***	-0.000***	0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Treatloc*expW	0.001**	-0.001	-0.000	-0.002
	(0.000)	(0.001)	(0.000)	(0.001)
post*expW	-0.000***	0.000***	-0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Treatloc*post*expW	-0.001*	0.002	0.000***	0.002
	(0.000)	(0.001)	(0.000)	(0.001)
S	-0.072***	-0.061***	-0.050***	-0.061***
	(0.003)	(0.003)	(0.002)	(0.003)
Treatloc*S	-0.010	0.166	0.037***	0.166
	(0.071)	(0.105)	(0.013)	(0.105)
Post*S	0.035***	0.024***	0.012***	0.024***
	(0.003)	(0.003)	(0.002)	(0.003)
Treatloc*Post*S	0.038	-0.141	-0.005	-0.141
	(0.072)	(0.105)	(0.015)	(0.105)
Constant	0.083***	0.130***	0.112***	0.130***
	(0.003)	(0.003)	(0.002)	(0.003)
Year FE	✓	✓	✓	✓
Observations	670,431	670,431	670,431	670,431
R-squared	0.011	0.011	0.011	0.011

Columns (1) and (3) assume myopic fishers, and
columns (2) and (4) assume rational fishers.
Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Chapter III

Who do you know? Transaction relations in the Swedish pelagic ITQ system [*]

Lisa Björk [†1]

[1] *University of Gothenburg, Sweden*

Abstract

In fisheries, individual transferable quota (ITQ) systems are becoming an increasingly adopted management strategy to deal with fleet overcapacity. The system relies on transactions of the right to harvest a share of a capped fish stock between actors, to reallocate capacity from less to more efficient actors. If quota transactions are driven by factors other than differences in expected marginal rents, the system might lead to an inefficient redistribution of fishing capacity. This study examines the determinants of transaction volumes of permanent and lease quotas between actors using unique panel data on the Swedish pelagic ITQ system. The findings indicate that quota trade is highly spatially determined and that quota ownership becomes increasingly concentrated over time. In the lease market, more trade is carried out between actors who have occupied a central position in the quota market, or who share a common relation with a third party. The introduction of the landing obligation at the end of the period of the study, is associated with an increase in quota trade, which diversifies the choice of trading partners and hints at previous system inefficiencies. All measures constructed, as well as all data exclusions and manipulations, are reported in the study.

JEL classification: Q22, Q28, P48

Keywords: ITQ, fisheries, common pool, social networks

1 Introduction

Open access to renewable natural resources has shown to be detrimental to many ecosystems across the globe (Gordon, 1954). With fast population growth and technology development, natural resources are increasingly being used beyond their regenerative capacity (Rockström et al., 2009). In recent decades, public policies on both regional and global scales have contributed to the institutional reshaping of natural resource access away from unregulated toward property rights-based systems (Costello et al., 2008; Smith, 2012). As opposed to 'command and control' regulations, property rights regimes, if designed right, have the ability to align incentives of resource users with those of managers (Ostrom, 1994). In fisheries, the recognition of this interdependence between fishers' economic incentives and the status of biological fish stocks is one of the most important development in fisheries management (Beddington et al., 2007). Basically, fisheries managers face two main challenges, to restrict the amount of resource extraction to a sustainable level by combating excess fleet capacity, and to affect the way fishing is carried out. The traditional command and control strategies focusing on input restrictions and total allowable catch limits often result in 'effort creeping', i.e., fishers substituting for unregulated inputs with the undesirable effect that the total fishing capacity is *increased* rather than decreased (Kompas and Gooday, 2007). Instead, property rights-based management focus on reducing excess fishing effort by aligning economic incentives of fishers with the overall system development (Smith et al., 2009). Property rights in fisheries can be assigned in a variety of ways, including as territorial user rights (TURF) to harvest within a geographically determined area (Christy, 1982), co-management arrangements between fishers and other stakeholder groups (Carlsson and Berkes, 2005), and market-based individual transferable quota (ITQ) systems (Chu, 2009). If successful, such management systems provide an incentive for fishers as a group to act together and adjust the way fishing is carried out for the long-term benefit of their fishery (Arnason, 2012).

ITQs have been advocated by economists as the most efficient solution to combat excess fleet capacity and restore the resource rent (Grafton, 1996). ITQs are cap-and-trade systems that allow actors to, permanently or seasonally, sell and buy the right to fish a share of a capped fish stock.[1] The cap consists of a seasonal total allowable catch (TAC) which is updated each fishing season by the regulator in response to the most recent biological estimates of the status of the fish stock. Fishers are usually allocated harvest shares based on historical catch, a process referred to as 'grandfathering' (Anderson et al., 2011). The transferability characteristic of the right to fish makes ITQ systems one of the strongest rights-based management regimes in fisheries (Ostrom, 1994; Gibbs, 2009). Theoretically, ITQ systems provide an efficient mechanism for capital redistribution within the fleet if

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[1]Cap-and-trade systems for carbon-sequestration are perhaps the most well-known type. Such systems are being widely implemented in international climate policies (ICAP, 2015).

combined with an optimally set cap of the fish stock (Arnason, 2008). Such a result hinges on the existence of many heterogeneous buyers and sellers, freely available information of good quality, low transaction costs, and minimal wealth or income effects of the initial allocations of quotas (Grafton, 1996). Fishers who expect relatively lower marginal rents from harvesting their share will then obtain a higher marginal value by selling or leasing out their share to a fisher with higher expected marginal value (Kroetz and Sanchirico, 2010). Compared with an open access situation, permanent sales of shares implies that less profitable actors leave the fleet and the overcapacity is reduced, along with economically wasteful racing behavior. In addition, the requirement of accounting harvest against held quota increases the entry costs of new fishers.

Around a quarter of the world's harvest is produced under ITQ systems, mainly implemented in North and South America, Australia, New Zealand, and Northern Europe (Arnason, 2012; Costello et al., 2008). ITQs have been shown to improve rent generation and biological stocks compared with fisheries managed under other systems (Grafton et al., 2000; Wilen, 2006; Costello et al., 2008). Yet, whether such changes are brought about by the transferability characteristics of ITQs on the way fishing is carried out, for example by inducing ecological stewardship, or if it is rather an effect of a reduced fleet, is being debated (Grafton et al., 2000; Chu, 2009; Branch, 2009; Smith, 2012). The adoption of ITQs is politically sensitive. Fishers may opposed the management regime based on potential distributional consequences such as concentration of wealth and market power, which both may depend on the initial allocation of quota (Döring et al., 2016). Concentration effects are to be expected. If ITQs are successful in reducing fleet capacity, an indirect consequence may be a reduction of employment opportunities as fishing effort is reallocated (Squires et al., 1995). The design of an ITQ system and its expected impact on the distribution of economic benefits (and losses) realized within the system is consequently a highly political process.

Given that transactions are the central mechanism to reduce fleet overcapacity, as well as to determine capacity distributions, it is surprising that so little attention has been given to the micro-dynamics of ITQ markets (Thébaud et al., 2012). In reality, the assumption of frictionless ITQ markets is far from an established fact (Innes et al., 2014). Firstly, the initial allocation of quotas through grandfathering affects the costs of quota between actors if access to financial capital is heterogeneous (Emery et al., 2014). Secondly, in most systems quota prices are private information, i.e. there is no central market where prices are listed publicly. Quota prices play a critical role as they incorporate information on current and expected fish stock status, credibility of the system, liquidity availability, strategies, and preferences (León et al., 2015). Under private information of prices, market values must be learned by experience or by knowledge transfers between actors. Taken together, quota markets are likely to be associated with high transaction costs that affect the way quota trade is carried out (Innes et al., 2014). Transaction costs might be reduced by engaging in

trade with actors that are closer, socially or geographically (Pinkerton and Edwards, 2009). If that is the case, actors base their selling and purchase decisions on factors other than profit maximization which could imply that quota markets fall short of reducing overcapacity and incurring economic efficiency. The way transaction relations are created, destroyed, and maintained is consequently an important determinant of the long-run effectiveness of an ITQ system in terms of capacity redistribution (Ropicki and Larkin, 2014).

The present study aims at examining the drivers of quota transaction decisions. In doing so it relates to a small, but rapidly growing, number of studies seeking to relate economic and social networks to the outcomes of management regimes. In line with previous network studies on economic and social systems, the empirical approach rests on the assumption that fishers' structural position in networks of quota transactions may affect their decision making (Borgatti et al., 2009). The underlying hypothesis is that individuals acquire costly information about the value of quotas by interacting with others and that this process is influencing the overall development of the market structure. MacLauchlin et al. (2009) are, to the best of my knowledge, the first to analyze ITQ systems using network methods. They studied temporal evolution of the Florida spiny lobster traps license trading program by examining graphical representations of the network and identifying central individuals. The authors concluded their study by addressing the need to continue developing approaches to integrate network measures in empirical evaluations of ITQs to account for system complexity and learn about the mechanisms conducive to capacity redistribution. This call has been picked up in a few recent studies. Van Putten et al. (2011) study changes in the structure of the annual lease market network of the Tasmanian rock lobster ITQ system. The authors document the emergence of a small number of quota investors acting as brokers in the market by leasing out their entire shares to an increasing number of lease-dependent actors. Brokers are also found to impact the market structure in the Queensland Coral Reef Fin-Fish Fishery ITQ system (Innes et al., 2014). As a consequence of a large number of lease-dependent actors and high broker fees, 5-16 % of the annual quota were found to remain unused, causing unintended market inefficiencies. Ropicki and Larkin (2014) found that quota price dispersions in the red snapper ITQ fishery in the Gulf of Mexico were related to the fishers' position in the trading network as it determined information accessibility. Price dispersion diminished in the number of unique trading partners, indicating the importance of information access for bargaining power. More generally, Weisbuch et al. (2000) introduced networks in the analysis of trade among actors at the Marseille fish market. The empirical results showed how buyers maximize profit by being loyal to sellers in periods of high market demand and shopping around during periods of low market demand, thus stressing the importance of actors' past experiences in determining their future decisions.

The context of this study, the Swedish pelagic ITQ system introduced in 2009, provides an opportunity to study quota transaction markets. Detailed information on annual lease

and permanent transactions, and of the characteristics of the vessels associated with the participating actors, allows for the construction of a unique dataset on the Swedish pelagic ITQ system. The Swedish system shares two common characteristics with many other ITQ settings that motivates its use as a case study. Firstly, quotas were allocated using grandfathering based on own historic catch rates. Secondly, there is no central market place; quota transactions are initiated and negotiated by the quota holders themselves. Consequently, quota prices are private information and have to be learned through interaction with others. Given the European Union Common Fisheries Policy adopted in 2014, management systems allowing for transferability between actors are increasingly adopted, or are planned to be, in European countries. By identifying potential flaws in ITQs related to transaction inefficiencies, new systems might be designed to discourage such inefficiencies to arise in the first place. Hence, the findings related to transaction dynamics in the Swedish ITQ system are of general interest.

Two approaches are used to study the Swedish quota transactions network giving a detailed description of the development of the market and its effects on capacity distribution. Firstly, the determinants of volume flows between actors are analyzed separately for permanent and lease quota in a dyadic fixed effects regression framework. Secondly, changes in regional distribution of quota as well as concentration in quota holdings are examined to describe effects of the transaction decisions. The overall evolution of the lease transaction network is described using standard social network metrics. Measures of interaction patterns between individual actors in the ITQ market make it possible to compare it with other ITQ systems, allowing for deeper insights about similarities and differences in systems that share the same overall structure and objective (Schweitzer et al., 2009). The findings indicate that quota trade is highly spatially determined, with the Swedish west coast acting as a hub for quota ownership. On the lease market, more trade is carried out between actors who have occupied a central position of the quota market or that share a common relation with a third party. The introduction of the landing obligation at the end of the period of study, is associated with an increase in quota trade, which diversifies the choice of trading partners and hints at previous system inefficiencies. In sum, the results indicate that there may be actors who are restricted from trading to the extent that would be beneficial for them. This could be remedied by reducing transaction costs, for example by introducing a central market place with public prices.

The rest of the paper is structured as follows: Section 2 presents the data and discusses the Swedish ITQ system and its introduction and Section 3 introduces the concepts of transaction network analysis and discusses the empirical framework. The results of transaction decisions are discussed in Section 4, and Section 5 concludes the study.

2 The Swedish ITQ system

Pelagic species accounted for 50 % of the total annual landings value and 85 % of the landings volume in the Swedish fishery 2009-2013 (Statistics Sweden, 2016). The pelagic fishery is a multi-species fishery mainly targeting herring, sprat, sand eel, mackerel, and blue whiting.[2] The pelagic ITQ system was introduced in November 2009 for these five major species. Initial quotas were allocated to individual license holders in per mille through grandfathering based on actors' historical catch rates during the reference period 2002-2006.[3] The key reason for introducing the ITQ system was to enable a reduction of the fleet capacity by giving non-profitable license holders an opportunity to exit and obtain monetary compensation from quota sales rather than from publicly financed scrap subsidies. The status of the biological stocks was not considered a problem at the time, however, the fleet overcapacity was recognized as the driver of low economic rents, which could lead to overfishing and misreporting of harvest in the future (SwAM, 2014).

At the beginning of each year, the species-specific quota held by a license holder is converted to tons according to the annual species-specific TAC; $‰_{species} * TAC_{species}$. The TAC is negotiated every year within the EU based on biological advice from ICES. Quota shares can be permanently sold or temporarily leased over the year between license holders. All transactions are initiated and negotiated by the license holders themselves. Once the deal is made, the volume transacted is reported to, and must be approved by, the Swedish Agency of Marine and Water Management (SwAM) that governs the system. The prices of traded quotas do not need to be reported. Consequently, prices are private information for both fishers and SwAM. Before moving on, one important clarification needs to be made regarding the license holder. In this context, a license holder can be either a private or a juridical person with a license to carry out pelagic fishing professionally. The license is associated with a vessel, or a maximum of two vessels, and can be transferred to a new vessel in case of purchase. For consistency, in the rest of the paper I will use the term *actor* to refer to a license holder, regardless of whether the holder is a firm or an individual.

The Swedish system is designed in accordance to different policy ambitions - the achievement of economic efficiency through capacity reduction and the promotion of economically sustainable coastal communities. Consequently, a series of restrictions have been imposed on the system as is common in many ITQ systems (Kroetz and Sanchirico, 2010). Firstly, around 7 % of the Swedish TACs for pelagic fish is set aside from the ITQ system for regional fishing (Swedish Government, 2016).[4] Secondly, to avoid spill-over effects to other fisheries,

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[2]The fishing is carried out mainly with purse seine, and pelagic trawl, and to a lesser extent with bottom and semi-pelagic trawls.

[3]The system was extended to include Norway pout in 2013 and Atlantic horse mackerel in 2016. This study focuses on the five original pelagic species.

[4]The impact of these regional policies is studied by Waldo and Blomquist (2014), who show that the

actors holding leased or permanent quota for pelagic species are not allowed to fish for other species (with a few exceptions for actors combining pelagic and demersal fishery during a limited period each year (SwAM, 2014)). However, there is no restriction preventing fishers from selling their quotas and shift their fishing activity to other fisheries.[5] Thirdly, to avoid large ownership concentrations, any actor can hold a maximum of 10 % of the pelagic quotas made available within the ITQ system. This restriction was argued to prevent social and geographical imbalances (Swedish Government, 2008). Fourthly, the validity of quota shares has been restricted to the end of 2019, i.e., ten years from the system introduction. The main reason for the time limitation was that quotas, "by their nature", cannot be allocated for an indefinite future (Swedish Government, 2008). A ten year period was regarded as sufficiently long to provide a sense of stability in the system. Moreover, as most of the fleet reduction was expected to take place at the beginning of the system introduction, it was of little concern that quota prices may decrease towards the end of the ten years. On the other hand, the regulatory framework for ITQs is not time limited, and a potential extension of the system was suggested to be decided "in dialogue with the professional fishers" (Swedish Government, 2008). As noted by Stage et al. (2016), the ten year validity of quotas, in combination with a potential 'restart' of the system in 2019, may have made it more attractive for some excess fishers to remain in the system so as to be part of the next distribution of rights.

2.1 Data

The data used in this study is compiled from various records kept at SwAM. The primary record comprises information on the date and volume of, as well as actors involved in, each permanent and lease transaction carried out from 2009 (November) to 2016. Each actor is anonymized by SwAM and given a unique id. This makes it possible to combine the transaction data with three additional data registers: one on all initial allocations of quotas, a second containing information on vessel characteristics such as engine power in kW and home port, and a third with information on all pelagic catch, including the date, volume, price, buyer and landings port within and outside Sweden.[6] The unique identifier of each actor enables construction of a panel for each actor with information on current holdings, current vessel capacity and home port, volume and value of catch, as well as the ports used for landings. The two transactions among four actors that took place in December 2009 are merged with the records for 2010, yielding a panel for 2010-2016. Finally, to account for the spatial extent of the quota market, home and landings ports are matched with their

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regional set-asides have led to shortened fishing seasons in the affected fisheries as new vessels have been attracted to the areas.

[5]That such a shift could have happened was mentioned, but not looked into, in the half time evaluation of the ITQ system carried out by SwAM (SwAM, 2014).

[6]The latter record lacks information on 2016 as SwAM had difficulties compiling the data in time for this study.

geographical coordinates, allowing for the construction of beeline distances between actors. In the few cases where actors hold quota for two vessels, the mean value of the vessels, and the shortest distance between their home ports, are used.

2.2   Descriptives

Table 1 presents summary statistics for each year 2010-2016. Each year represents the full population of actors active in the pelagic ITQ system, through quota trade, pelagic fishing, or both.[7] There has been a net decrease in the number of actors within the Swedish ITQ system, regardless of how it is measured. In 2016, the number of actors holding permanent quota had decreased by 40 % from the beginning of the period, from 89 actors associated with 81 vessels, to 49 actors with as many vessels. The number of individuals participating in the lease market in any year decreased from 70 in 2010 to 39 in 2016. Taking all actors active in the transaction market into account, the number of actors has decreased by 44 % from 75 in 2010 to 42 in 2016. The number of vessels that actively participated in pelagic fishing decreased by around 25 %, from 39 vessels in 2010 to 29 in 2015. The extent to which this decrease in number of actors is a result of the ITQ system, or is part of a general trend of fleet reduction, cannot be determined in this study. However, it should be noted that the reduction of vessels in the entire fishing fleet over the period was smaller, around 10 % (SwAM, 2014).

In terms of capacity, if summing the average engine power (kW) over the number of transacting actors each year, the total fleet capacity fell by around 26 % in the 2010-2016 period. The vessel capacity actually used for pelagic fishing in 2010-2015 was reduced a bit less, by around 17 %. The number of trips per vessel decreased from an average of 72 to 67, although this is not adjusted for the number of days each trip lasted. Whether revenues in the pelagic fishery have increased is hard to determine, since I have no data on variable costs and the ex-vessel prices vary depending on the quality of the fish. Catch is sold in two main product categories. High-quality fish is sold fresh for direct consumption via the main fish auctions, mainly in Sweden, and frozen fish is sold to wholesalers for industry processing both in Sweden and abroad (Statistics Sweden, 2016). The number of buyers of pelagic catch in the landings market decreased from 24 in 2009 to 18 in 2015. On average, the five largest buyers in the landings market each year account for 65 % of the purchased volume and 50 % of its value. The average trip-level gross revenues shows an upward-sloping, albeit very small and highly fluctuating, trend from 2008-2015 (Fig. 1). There are many factors that may contribute to this trend other than the ITQ systems, and without comparisons to trends in

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[7]There is an ongoing discussion regarding the appropriate way to represent differences between years when the observations represent the entire population. One standpoint is to think of the population as one sample of many counter-factual populations. With that view, it is appropriate to report the standard deviations in the summary statistics, which I do here.

Table 1: Summary statistics

	2010	2011	2012	2013	2014	2015	2016
kW (actors transacting)	842.94	1,227.61	1,041.95	1,015.74	1,077.76	1,120.59	1,032.33
	(743.36)	(963.12)	(894.02)	(884.60)	(947.36)	(969.45)	(955.02)
kW (actors with reported landings)	1,136.74	1,165.22	1,087.44	1,108.39	1,159.80	1,261.90	-
	(818.88)	(870.79)	(880.49)	(897.65)	(914.41)	(963.34)	
# quota species	4.17	4.36	4.14	3.71	3.06	4.36	4.21
	(1.30)	(1.23)	(1.51)	(1.45)	(1.42)	(1.80)	(1.43)
# lease species	3.19	3.67	3.35	4.02	3.68	4.25	4.31
	(1.19)	(1.43)	(1.21)	(1.48)	(1.28)	(1.49)	(1.47)
Trip gross revenue	296,642.4	350,399.2	272,843.5	448,133.5	263,562.8	287,761.1	-
	(565,544)	(700,655.7)	(532,249.4)	(874,155.4)	(496,359.5)	(563,095.3)	
Trip weight (kg)	120,709.6	110,062.2	80,080.45	140,700.8	104,831.5	106,261.3	-
	(218,393)	(197,532.5)	(181,781)	(284,815.8)	(213,010.5)	(209,834.1)	
Trips/year	72.01	72.41	60.83	67.05	65.70	67.30	-
	(43.72)	(46.31)	(36.09)	(39.10)	(39.61)	(35.14)	
Actors with permanent quota	89	74	51	52	53	51	49
Actors transacting permanent quota	73	28	37	26	13	9	18
Permanent quota transactions	407	178	196	78	97	60	83
Permanent quota transaction dyads	116	71	83	29	14	6	13
Volume (ton) per permanent quota transaction	1,356.35	1,307.81	1,109.98	3,753.13	3,582.99	1,592.91	6,583.89
	(2,835.44)	(2,055.21)	(2,130.42)	(10,726.96)	(5,304.68)	(2,255.83)	(18,945.92)
Actors transacting lease quota	70	29	41	41	42	37	39
Lease transactions	106	166	239	267	296	412	343
Lease transaction dyads	48	63	121	127	153	179	126
Volume (ton) per lease transaction	333.35	244.99	162.06	181.24	219.08	142.41	400.27
	(481.69)	(405.26)	(351.59)	(309.15)	(479.94)	(280.63)	(818.51)
Total actors transacting quota	75	32	43	42	45	38	42
Distance between trading actors (km)	183.74	52.14	52.91	56.14	48.10	63.45	48.15
	(116.22)	(92.90)	(94.59)	(84.77)	(81.84)	(144.54)	(84.86)
Share international transactions	0.64	0.69	0.30	0.42	0.38	0.47	0.41
Vessels with positive quota holdings	81	77	54	52	50	52	49
Vessels with positive landings	39	38	34	35	30	29	-

Note: Values measured at the end of each year. Gross revenues are defined as total harvest landed times ex-vessel prices obtained.
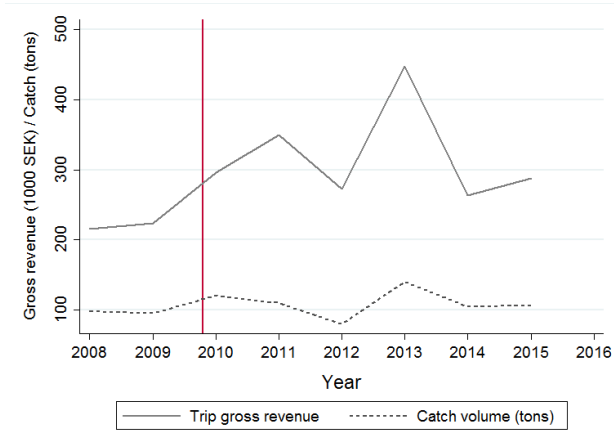All prices are adjusted to reflect 2015 using the CPI from Statistics Sweden.

Figure 1: Mean trip-level gross revenues (1,000 SEK) and catch (tons). Gross revenues are defined as total harvest landed times ex-vessel prices obtained. All prices are adjusted to reflect 2015 using the CPI from Statistics Sweden. The vertical line indicates the introduction of the ITQ system in November 2009.

other fisheries this is not an indication of a revenue effect. That said, the changes in harvest volume and revenues in 2013 are noticeable. They may reflect a response to expectations of a set of more constraining fishing regulations in the future, given the new European Common Fisheries Policy adopted in 2014.

In the descriptive statistics, as well as in the rest of the analysis of quota transactions, all species are collapsed into one category. The justification for this aggregation is that the majority of fishers engage in multi-species fishery. On average, actors hold quotas for four species over the period of study. The fishing seasons for pelagic species extend over the whole year, allowing for year-round harvest, with a seasonal low in July (Fig. A1). By combining different species, fishers are able to cope with fluctuations in the annually determined TAC, which is set in response to the latest estimates of underlying stocks by ICES (Fig. A2).

Figure 2 locates all unique pairwise transactions, both permanent and lease, carried out 2010-2016. Each node corresponds to the home port of the vessel held by the transacting actor, and each edge connects the transaction partners. Most activity takes place on the west coast, which mirrors the fact that a majority of pelagic vessels have their home ports there. Quotas can be annually leased, but not sold, to non-Swedish actors (SwAM, 2014). International leases have been carried out with Danish, German, Finnish, and Estonian fishers/firms.

The largest adjustment of permanent quotas took place during 2010 (see Fig. 3). Seventy-
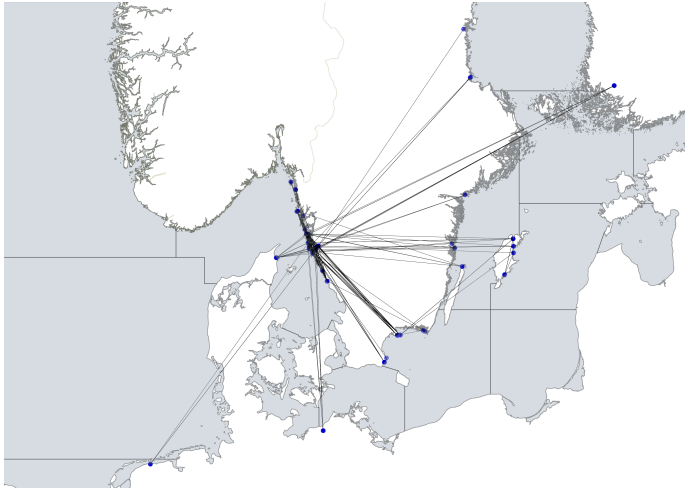
Figure 2: Map of transactions network. Each edge represents a permanent or lease transaction of pelagic quota between one seller node i and one buyer node j. All unique combinations of transaction pairs, y_{ij}, 2010-2016 are presented.
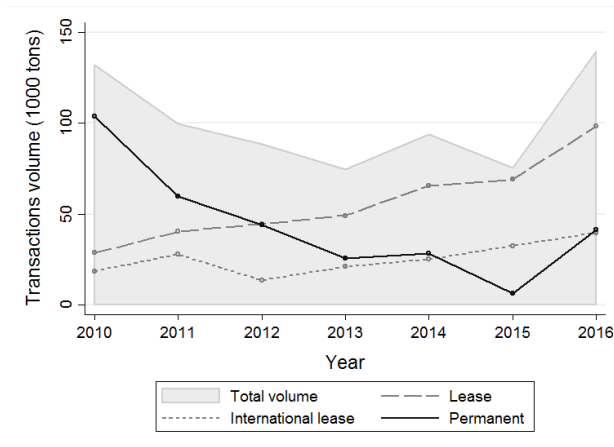
Figure 3: Volume of permanent and lease transactions. The total volume traded is represented by the grey area. The black line shows the total traded volume of permanent quota. The dashed line shows the total volume of lease transactions, with the dotted line representing the proportion of total annual lease transactions volume that was traded internationally.

three individual actors traded 16 times as much volume in 2010 as in 2015, which was the year of lowest activity of permanent transactions. The number of unique transaction dyads went from 407 in 2010 to 83 in 2016. The volume traded in the lease market shows the opposite pattern with a three times larger volume traded in 2016 than in 2010. The number of unique lease transaction dyads went from 48 in 2010 to 126 in 2016. On average, in both markets, the transaction pairs engage in one single transaction each year.[8] In 2010 and 2011, the share of leased quota volume that was traded internationally was 64 % and 69 %, respectively. In later years, around 40 % of the lease volume was traded internationally, with some variations across the years. Danish actors account for the largest share of international leases, which is not surprising since most of the fishing activity of Swedish and Danish actors is carried out in neighboring fishing waters. Around 60 % of the Swedish catch is landed in Denmark. Denmark has an important processing industry partly developed as a consequence of the fact that the Danish pelagic fishery has been managed under a full-scale ITQ system since 2007.[9] The average amount of quota traded in a single transaction has increased over time for both permanent and lease quota. The average volume of permanent quotas traded in 2016 was almost five times as large as in 2010. The average volume of lease quotas increased by 20 % over the same period. Taken together, the total volume of quotas traded peaked in 2010, driven by permanent transactions, and in 2016, driven by lease transactions.

Figure 4 depicts the timing of transactions. After the adjustment period in 2010-2012, permanent quotas is mainly sold at the end of the year, although trade in 2016 is more spread out. The lease transactions are more evenly spread out over the year, and the distribution reflects the fishing seasons with low numbers of quotas traded in July. Here too, transactions are more frequent at the end of the year, particularly up to 2015. In 2015, a landing obligation was introduced for fishing activity carried out in the North and Baltic Seas. In short, it requires that all specimens governed under TACs, regardless of size, to be brought to land and counted against held quotas. Prior to 2015, only specimens above a certain species-specific minimum size were allowed to be brought to shore (SwAM, 2016).[10] The landing obligation might be a reason behind the observed increase in trading partners for lease quotas in 2015 and 2016. This highlights an interesting feature of the Swedish ITQ system. Prior to 2015, actors who landed more fish than they held quota for had that amount subtracted from their quota allocation the following year, without any additional sanction imposed.[11] With the landing obligation, all landings in excess of the respective individual quota holdings may

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[8]However, the maximum number of transactions in a year within a dyad is 7 in the lease and 3 in the permanent market.

[9]The system was gradually implemented from 2003. See Andersen et al. (2010) for a summary.

[10]The landing obligation was one of the largest policy changes included in the European common fishery policy adopted in 2014. It was adopted to minimize discards and advance the development of selective tools. Due to its large consequences for the national regulatory agencies and national fleets, it was decided that the landing obligation should be gradually implemented 2015-2019.

[11]This only affected the individual holdings of that actor; not the national TAC.

be fined.[12] The higher frequency of lease transactions in 2015, suggests that the introduction of fines has given fishers an increased incentive to adjust quota holdings to landings.
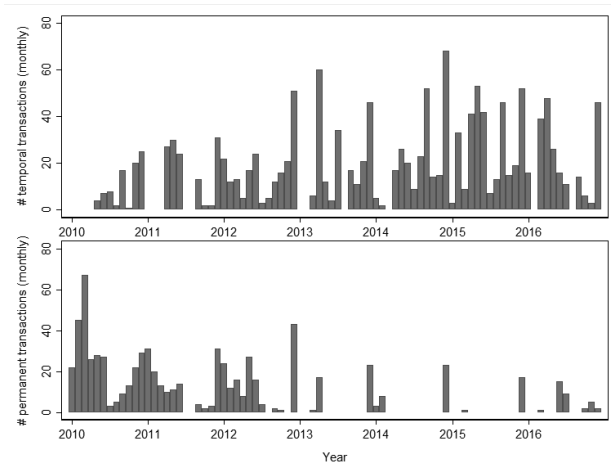

Figure 4: Timing of annual lease transactions (top) and
of permanent transactions (bottom) of all quotas per year.

3 Methods

3.1 Transaction networks

The representation of an economic system as a collection of actor nodes, N, with edges, E, representing their relations (of which Figure 2 is an example), has proven to be a useful tool for understanding various economic phenomena (Jackson, 2008). Studies of real world economic and social networks have revealed important empirical regularities. One such "rule" is the uneven distribution of interaction relations across actors, in which the number of nodes with very many, and very few, connections are found more often than would have been expected had they randomly formed. In these networks, coined "scale-free" networks by Barabási and Albert (1999), a few nodes act as hubs giving rise to clustering patterns (Ter Wal and Boschma, 2009). Such features have been documented in quota lease markets by Van Putten et al. (2011) and Innes et al. (2014). Preferential attachment, which refers to the relative importance of central actors compared with others when attracting new ties, might explain why such patterns are strengthened over time - friends of friends are likely to become friends

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[12]Fines are imposed if the infringement is deemed to have been intentional. They are case-specific and range from SEK 1,000-50,000, or €105-5,260 (Swedish Government, 2014).

as well (Barabási, 2012). Various proximity measures might explain the reason certain actors become central in the early stages of network formation (Boschma, 2005). The process of establishing partnerships more frequently with actors sharing similar attributes is referred to as homophily (see Fig. 5). While homophily can decrease search costs, it may induce economic inefficiency as it may restrict information and communication patterns in the system (Currarini et al., 2009). In a fisheries management context, Bodin and Prell (2011) studied communication paths between groups of fishers targeting different species in the Kenyan deep sea co-management fishery. They found that the failure of the co-management in restoring resource rents was largely related to the low number of communication paths between fishing groups, impeding a unified understanding of the ecosystem.
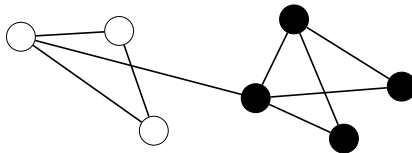
Figure 5: Relations are more common among nodes sharing the same color attribute, giving rise to homophily in the graph.

However, complementarity effects such as heterogeneous knowledge endowments among actors might also drive edge formation (Giuliani, 2007). Barnes et al. (2017) studied information exchange among socially fragmented fishing groups and found differences in how short-term and long-term information was spread. While short-term economically valuable information such as the current location of fish was not shared, information with long-term value such as technical innovations was shared more frequently across groups, possibly as a consequence of social prestige. Consequently, the way actors form and maintain ties at the Swedish ITQ market will have efficiency implications.

Several indicators have been developed to characterize features, or "topology", of networks allowing for comparison across time and systems (Schweitzer et al., 2009). Some of the most important features are summarized in Table 2.

Table 2: Network topological indicators

Indicator	Description
Average path length	Shortest path, σ_{ij}, between nodes in terms of edges between i and j.
Clustering coefficient	$C_i = e_i / d_i (d_i - 1)$ in which d_i is the number of neighbor nodes of i, and e_i is the number of connected paths between all actors and i.
Graph density	$\frac{E_g}{n(n-1)/2}$ in which E_g is the set of realized paths between nodes in the graph and $n(n-1)/2$ the theoretical maximum potential of edges between nodes n in the graph.
Betweenness centrality	$BC(i) = \sum j \neq I \neq k \frac{\sigma_{jk(i)}}{\sigma_{jk}}$ where σ_{jk} is the shortest path between j and k and $\sigma_{jk(i)}$ is the shortest path between j and k that i lies on.

The average path length in the network is the shortest path between two nodes, in terms of the shortest number of edges linking them, averaged over all node pairs. If all nodes would be placed on a line, the average path would be longer, whereas in a compact network the average path would be shorter. The extent to which a single node i is well-connected can be measured by its clustering coefficient, which measures the fraction of all linked pairs that are also linked to node i. The average clustering patterns in the network measure the local cohesiveness and gives an idea of the way information and norms are fostered in the network. The graph density is the proportion of possible edges that are present in the network. The lower the density, the less connected the average node in the network. The betweenness centrality of a node measures the number of shortest paths on which it lies (Fig. 6). In the quota transaction market, an actor with high betweenness centrality has access to a lot of information on the value of quota shares. For example, in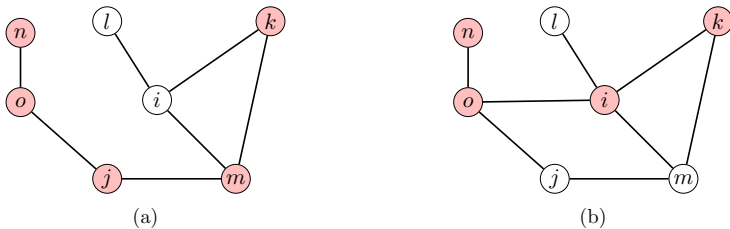 Figure 6 a) the shortest path between nodes k and n goes through m, j, and o. In b) the new edge between i and o reduces the shortest path between nodes k and n. Node i increases its betweenness centrality in b) compared with a) by linking to node o.

Given the results from previous studies on ITQ markets, I expect transactions between actors to depend on additional drivers beyond differences in marginal rents from fishing. Particularly, given that quota prices need to be learned by experience, I expect to find homophily patterns and clustering in the network. Two particular indicators will be used in the dyadic regression: the sharing of a buyer in the landings market as a driver of homophily and whether actors have had high betweenness centrality in the overall quota market in the

past. Both variables are indicators of information flows in the network. Ropicki and Larkin (2014) found a positive impact on obtained lease prices when actors shared processors in the landings market in the red snapper ITQ system in the Gulf of Mexico. Such price effects might be strategic, or driven by feelings of obligation - if you lease out to a beneficial price, I should reciprocate - which has been demonstrated as a driver of decisions that deviates from economic rationality in other highly networked markets, such as the garment industry (Uzzi, 1996). Actors with high betweenness centrality have access to many different sources of information which might impact on their, as well as others' decisions, to trade, particularly through preferential attachment effects (Innes et al., 2014).

Figure 6: Betweenness centrality. In a), the shortest path between nodes k and n goes through m, j, and o. In b), the new edge between i and o reduces the shortest path between nodes k and n.

3.2 Econometric specification

Here I outline the econometric approach used to study the determinants of transaction decisions between actors in the pelagic system. The analysis is carried out on annual dyadic flows of volume of quota between actors. The aggregation of data to the calendar level is motivated by the TAC, which caps the system one year at a time. To distinguish the determinants of permanent quota sales from annual lease transactions, the two markets are studied separately. The markets are of course not operating in isolation - at least some of the actors need to have permanent quota in order for lease transactions to take place - however the nature of the two transaction decisions differs. Whereas the permanent quota market is capturing long-term decisions, including decisions to exit the pelagic fishery completely, the lease market is reflecting short-term, and more often repeated, decisions. Such differences are captured by treating the markets for permanent and lease quota transactions separately.[13]

    I use an empirical set-up similar to Quillérou et al. (2013), who specify an adapted version of the gravity model to study how second-hand markets for fishing vessels influence the overall

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[13]However, one of the explanatory variables, betweenness centrality, is constructed using the full transaction network. That is to capture all potential information flows regarding quota values.

distribution of fleet capacity in France. In its most parsimonious form, the stochastic gravity equation for regional trade, Y_{ij}, between actor i and actor j is proportional to the product of their economic size, X_i and X_j, and inversely proportional to barriers of trade, T_{ij}, capturing geographical distance and other transaction costs between actors:

$$Y_{i,j} = \alpha X_i^{\beta_1} X_j^{\beta_2} D_{ij}^{\beta_3} \eta_{ij}, \tag{1}$$

where $\eta_{i,j}$ is a homoscedastic error term. In spite of its simple set-up, the gravity equation has shown to explain a remarkably large share of variation in regional trade (Head and Mayer, 2014). In later years the model has been extended to examine individual firm decisions (Koenig et al., 2010; Jienwatcharamongkhol, 2012) and other flow networks, particularly migration (Beine et al., 2016), tourism (Morley et al., 2014), as well as the already mentioned second hand market for fishing vessels. In empirical applications, the reduced form model of trade flows $Y_{i,j}$ between actors i and j is usually estimated in a log-linear regression with a stochastic error term, assuming that trade observations are independent conditional on a set of covariates and controlling for actor and dyad effects (Ward and Ahlquist, 2016).

Quillérou et al. (2013) use district vessel stock to capture size and geographical distance between districts to capture transaction cost related to trade of vessels. Their findings suggest that easier access to information within own regions is likely to drive the observed geographical concentration of vessel trade. The net increase in vessel capacity in certain regions illustrates the challenges of satisfying regional and national policy goals of fleet capacity reduction simultaneously: the efficiency of fleet reduction in some regions comes at the expense of a larger fleet in other regions. Here, adapting the set-up of Quillérou et al. (2013) to the current setting, a pelagic quota share is considered a homogeneous good that has different expected marginal return for the purchasing actor given differences in skipper skill, vessel characteristics, information access, financial capital costs, etc. Every year, each actor is assumed to choose the profit-maximizing volume of quotas to transact to every other actor. Given the decision nature of actors, the optimal decision may well be to transact zero volume. Another approach could have been to treat trade decisions as a two-step process in which extensive and intensive margins of trade are analyzed using a Heckman selection model (Helpman et al., 2007). In such set-ups, the decision to trade or not, and the level of trade are estimated as separate decisions. One of the main challenges of such an approach is that estimation of the extensive margin requires at least one exclusion variable that only affects the decision to trade but is unrelated to the level decision. Such an exclusion variable has been hard to find in many empirical applications. Wagner (2001) argues that this difficulty is driven by the fact that firms' decisions to trade are not a two-step process. Instead, with profit-maximizing firms, all relevant costs associated with trade, both fixed and variable, are taken into account. This reasoning applies well to the quota market - it is unlikely that the

decision of whether to trade quotas is independent of the decision of how much volume to trade. Hence, the zero trade flows observed in the data are regarded as being the result of a one-step decision process.

The presence of zero trade flows, which is common and usually high in trade data, implies econometric challenges that have been dealt with in different ways in the literature (Martin and Pham, 2015). In many applications, the "convention" of using a log-linear estimation equation for trade has implied that all zero trade flows are ignored, rendering estimates based on a restricted sample where $Y_{i,j} > 0$. If the process of zero trade flows is not random but a consequence of a decision-process as it is treated here, such estimates are biased and inefficient as a lot of information is being neglected.[14] Moreover, the assumption of a homoscedastic error term in the log-linear set-up is likely to be violated - it is often improbable that the error term is independent of actors' size and of the transaction costs between them. As shown by Santos Silva and Tenreyro (2006), the combination of ignored zero trade flows and heteroscedasticity in the residuals might lead to both inconsistent and inefficient estimates. They propose the use of a non-linear estimator which they refer to as a "pseudo Poisson maximum likelihood" (PPML) estimator, and which has some nice features. In the basic Poisson regression model, the outcome variable, given a set of explanatory variables, is assumed to follow a Poisson distribution. This assumption implies that the conditional mean and variance of the outcome variable are restricted to be equal, which is usually not what is observed in real-world data. Instead, the PPML estimator allows the ratio between the conditional mean and variance of the outcome variables to be any constant. If the constant is greater than one, it implies that the variance is greater than the mean, i.e., there is overdispersion, which is an empirically frequent situation, including in the data studied here. Moreover, consistent estimation of the conditional mean given the explanatory variables, is not determined by the nature of the outcome variable; it can be both *continuous* or count data (Wooldridge, 2010). However, given overdispersion, the standard errors of the estimated coefficients will be underestimated. This can, and should, be corrected and will be discussed below.[15]

Given the nature of the transaction decisions studied in this context, the PPML estimator is the preferred approach. This allows to specify the model with volume flows in levels and explanatory variables in logs, implying that the full set of potential transactions between actors, both positive and zero flows, can be included in the regression sample. Given that the assumption of equality between variance and means is relaxed, the standard errors are

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[14]One commonly used approach to deal with zero flows is to add a constant, usually one, to all observations of the dependent variable and estimate the gravity equation using OLS. However, in a log-linear regression the chosen constant influences the parameter estimate as it affects the distribution of the variable arbitrarily. Another approach is to use the Tobit estimator. However, this is only appropriate for censored outcome variables and not for a situation in which trade is bounded to be zero or positive.

[15]For an extended discussion of the PPML estimator, see Santos Silva and Tenreyro (2006, 2011).

corrected using multi-way clustering as suggested by Cameron and Miller (2012) and Egger and Tarlea (2015). The reduced form econometric model is given by:

$$Y_{i,j,t}^M = exp(\alpha + \beta_i^T X_{it} + \beta_j^T X_{jt} + \beta_{ij}^T X_{ijt} + \mu_i + \mu_j + \phi_t + e_{i,j,t}), \tag{2}$$

where $Y_{i,j,t}^M$ is the volume of quota, in tons, traded between actors i and j in year t on market M (permanent or lease), X_{it} and X_{jt} represent vectors of (*nodal*) covariates for selling actor i and buying actor j, X_{ijt} includes a set of dyadic variables particular to the pair of actors, and μ_i, μ_j, and ϕ_t are seller, buyer, and time fixed effects, respectively. For comparison, the model is also estimated using PPML and OLS on the restricted sample ($Y_{i,j,t}^M > 0$) with volume in levels respectively logs. Table 3 summarizes the explanatory variables.

The engine power, as measured in kW, of the vessel associated with actor i or j (hereafter denoted $i(j)$) proxies the fishing capacity of the actor.[16] Larger capacity is assumed to be associated with larger supply of quotas for selling actors and larger demand for quotas of buying actors. Actors associated with larger vessel capacity are also likely to raise financing at better cost. Previous findings from fishing has shown that small actors are more often capital-constrained (van Putten et al., 2012). kW replaces the use of district vessel stock in Quillérou et al. (2013) to reflect supply and demand, and more generally the use of GDP as a proxy for size in gravity equations for regional trade. Certainly, there are several proxies that could be used to capture vessel capacity. However, as kW is consistently measured for the vessels throughout the period of study, and a commonly used proxy in fisheries literature, it is the best candidate in this setting (see Quillérou et al. (2013) for a more extensive discussion of various capacity measures).

Transaction costs related to trade between actors i and j are captured by *Distance*, *Betweenness*, and *SharedBuyer*. Geographical distance is the most common variable to include in gravity settings as it captures how trade decay with distance (Martin and Pham, 2015). It is calculated as the bee-line distance in km between the home ports of the actors' vessels. Geographical distance between actors is assumed to increase transaction costs in line with the findings in Quillérou et al. (2013). Geographical distance might also reflect the nature of the pelagic fishery: given that fuel costs constitute a big share of the variable costs of fishing, it is likely that most actors carry out fishing close to their home ports (Opaluch and Bockstael, 1984). Since the optimal species quota mix might vary among different regional fishing grounds, it may be more likely for actors who fish within the same areas to trade.[17] Taken together, the volume of quota traded between actors is expected to decrease as the distance between them increases.

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[16]As usual in dyadic regressions, the nodal control variables are included twice, once for the selling actor and once for the buying actor (Cameron and Miller, 2012).

[17]I have no data on the location of the fishing trips, why I cannot verify this.

Table 3: Explanatory variables

VARIABLE	Description
Size	
$kW_{i(j),t}$	Logged nodal covariate of engine power (kW) of the vessel associated with the actor.
Transaction costs	
$Distance_{i,j,t}$	Logged dyadic covariate of distance (km) between actors.
$SharedBuyer_{i,j,t-1}$	Dyadic indicator variable of shared buyer(s) of harvest in the landings market in the previous year.
$Betweenness_{i(j),t-1}$	Nodal indicator variable equal to one if actors' betweenness centrality was positive in the previous year, and zero otherwise.
Nodal controls	
$Holdings_{i(j),t-1}$	Nodal indicator variable equal to one if actor held positive permanent quota at the end of last year, and zero otherwise.
$LandingsPos_{i(j),t-1}$	Nodal indicator variable equal to one if landings were positive last year, and zero otherwise.

Note: Main explanatory variables. Unobserved heterogeneity among actors, such as skipper skill, as well as time and location trends, are controlled for in the regressions using fixed effects.

Betweenness and *SharedBuyer* are specific to this context and included to reflect characteristics of the transaction network. *SharedBuyer* in the landings market captures actor similarity that might guide transaction choices. It is measured as an indicator variable equal to one if the actors share at least one buyer in the landings market, and zero otherwise. It is expected that the volume traded between actors is positively affected by sharing a buyer in the landings market, given the effect of homophily as discussed in Section 3.1. *Betweenness* is an indicator variable included to measure the degree to which an actor was acting like a hub in the overall transaction market in the previous period. The variable is equal to 1 if the betweenness centrality of an actor was above the mean in the past period, and zero otherwise, where the node specific betweenness centrality is calculated as described in Table 2, using the full transaction network. Since both permanent and lease quota transactions entail information on quota prices, and hence on the current market value of quota, both markets are regarded as being relevant for the measure. If there are tendencies of nodes acting like

"hubs", betweenness centrality will affect the volume traded positively. Two additional indicator variables are included to reflect drivers of trade (or no trade) between actors. *Holdings* is included as an indicator variable equal to one if the actor $i(j)$ has positive quota holdings at the beginning of the year, and zero otherwise. It captures differences in the potential supply of the selling actor and the potential demand of the buyer. Similarly, the indicator variable *LandingsPos* captures whether actor $i(j)$ is actively fishing and controls for differences in demand and supply of quotas between fishing and non-fishing actors. Given that the landings data in this study does not distinguish between fishing areas, both landings on the coastal quota not included in the ITQ system, and landings that should be counted against held pelagic quota are captured. Moreover, there are several reporting issues with respect to the volume of landings. Hence, the indicator variable is considered to be a less problematic measure of fishing activity, in spite of it containing less information.

There is a potential simultaneity bias in equation 2 with respect to *Holdings*, *LandingsPos*, *Betweenness*, and *SharedBuyer*. All variables can both be driving, and be a consequence of, the transacted volume of quota. This is dealt with by lagging these variables one year (Koenig et al., 2010).

To account for unobserved heterogeneity driving quota decisions, such as initial allocation of quota, skipper skill, and liquidity constraints, fixed effects for the selling actor and buying actor, respectively, are included (Feenstra, 2004). Time fixed effects are included to capture trends in trading opportunities between years as the quota market evolves.[18] To account for the regional differences in trade patterns, particularly the large amount of transactions concentrated to the west coast as identified in Fig. 2, I include an indicator variable equal to one when the selling or buying actor has a vessel with home port on the west coast, and zero otherwise. Standard errors are clustered at, and may be correlated within, seller, buyer, and year, as well as every combination of the three (Cameron et al., 2011).

3.3 Sample

In what follows, I describe the preparation of the dataset employed in the econometric analysis. Annual records of transaction volume between actors are constructed by summing all dyadic flows in a year for the lease and permanent transaction markets respectively. To ensure that the volume observations can be regarded as a result of a profit-maximizing decision, the transaction possibility set for each actor is limited to all potential dyadic combinations of *active* actors in each year. In the lease market, active actors are defined as those who have traded quotas at least once in the entire period of study. Actors recorded with zero permanent quota holdings at the end of the year and who never reappears in the data, are

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[18]Since the panel is short, the inclusion of time-varying fixed effects is not necessary in this setting (Olivero and Yotov, 2012).

treated as having exited from pelagic fishery and are excluded from the sample. In addition, quotas leased by non-Swedish actors are excluded since the data records lack information about size, holdings, home port, etc. The full set of seller-buyer pairs used in the lease market regression consists of 48,804 (out of 52,374 potential) dyads. In the permanent quota market, active actors are defined as those who were allocated quota when the system was introduced in 2009, or who have been trading permanent quota at least once. Similar to the lease market, actors who exited, i.e. had zero permanent quota holdings at the end of the year and never reappeared in the data, are excluded. The full sample for the permanent quota market consists of 12,265 dyads.

Table 4: Summary statistics of variables used in the regressions

	Permanent	Lease	Permanent $(Y > 0)$	Lease $(Y > 0)$
Volume (ton)	36.55	3.02	3,766.13	257.29
	(1,136.72)	(71.63)	(10,940.8)	(610.16)
kW	1,151.3	1,908.53	1,637.5	1,744.6
	(840.46)	(800.38)	(863.24)	(909.99)
Distance (km)	132.99	161.97	46.76	47.37
	(150.77)	(155.74)	(84.26)	(86.29)
Shared buyer	0.05	0.04	0.17	0.22
Betweenness	0.17	0.17	0.22	0.24
Positive holdings	0.27	0.24	0.54	0.64
Share positive landings	0.31	0.31	0.47	0.52
Sample	12,265	48,804	266	709

The summary statistics are presented in Table 4. The table also includes the summary statistics for the sample based only on the observed positive volume flows, that is on $Y > 0$. Overall, the permanent and lease transaction networks are sparse. Throughout the whole period of study, there are 266 dyads, or around 2 % of the total number of potential transaction pairs. The lease market is more active: 709 transaction pairs or almost 15 % of the potential transaction pairs are observed 2010-2016. In general, the volume transacted between actors is larger in magnitude in the permanent market compared to the lease market. Actors associated with vessels of larger capacity, as measured in kW, are on average more often involved in lease transactions. The rest of the variables are similar between the permanent and lease market. However, if looking at the sample including only positive trade flows, the lease market actors are on average shown to more often share a buyer in the landings market, have higher betweenness centrality, start the year with positive holdings, and carry out fishing.

4 Results

4.1 Econometric results

Tables 5 and 6 present the estimated effects of the explanatory variables on the conditional mean of traded quota volume, in the lease and permanent markets. The beta coefficients can be interpreted as elasticities of trade both in the log-linear OLS, and the PPML, cases. Hence, the coefficients report the approximate proportionate percentage change in the conditional mean of trade, for a proportionate change in the explanatory variable. In both tables, the first column shows OLS estimates using the restricted sample and the log of volume as dependent variable, the second column displays the results from a PPML regression using the restricted sample and volume in levels, and the third column presents the results from a PPML regression on the full sample and volume in levels. All regressions include seller and buyer fixed effects[19] (omitted from the output table) and standard errors clustered on seller, buyer, and year. In both tables, it is noticeable that some of the estimates change sign and significance when estimated using PPML on the full sample, compared to the restricted sample. This highlights the importance of accounting for heteroscedasticity in the residuals and the presence of zero-trade flows, as discussed in Section 3.2. Consequently, column (3) in both tables presents the estimates from the preferred specification. The discussion is limited to these results. The estimates are robust to different combinations of the explanatory variables. The full set of regressions are presented in Tables A1 and A2.

The transaction market for lease quota is discussed first. All else equal, the volume of lease quota traded between actors is significantly related to the vessel capacity of the buying actor. The elasticity is estimated to 0.86 and highly significant, implying that a ten percent increase in the engine power of the buyer's vessel increases the average volume traded by 8.6 percent. In contrast, the results do not suggest any association between the vessel capacity of the selling actor and the volume traded. Besides the fact that larger vessels are likely to need more quota, one driver could be that actors with larger vessel capacity face lower financial capital costs, as discussed above. The geographical distance between actors has a negative and largely significant effect on traded volume. A one percentage increase in the distance between trading actors reduces the volume traded with 0.4 percent. The corresponding effect of distance found in Quillérou et al. (2013) was a bit larger: 0.6 percent decrease in vessel trade between districts for a one percent increase in the distance between them.

Given that size and distance are controlled for, along with unobserved heterogeneity with respect to the actors, as well as time and regional dummies, the estimated positive effects related to the sharing of a buyer in the landings market and lagged betweenness centrality, are noticeable. The sharing of a landings buyer is estimated to increase the volume of lease

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[19]The reason the kW and $Distance$ variables are not dropped when including fixed effects is that some actors change vessel and home port between years.

Table 5: Estimated results for volume traded between actors in the quota lease market. Dependent variable is the annual dyadic volume of lease quota traded.

VARIABLES	(1) (OLS $Y > 0$)	(2) (PPML $Y > 0$)	(3) (PPML full)
kW seller	-1.257***	-1.211***	-0.257
	(0.27)	(0.12)	(0.46)
kW buyer	0.013	-0.464	0.857***
	(0.63)	(0.35)	(0.39)
Distance	-0.178***	-0.264***	-0.412***
	(0.06)	(0.03)	(0.07)
SharedBuyer	-0.033	0.146	0.528*
	(0.34)	(0.20)	(0.29)
Between seller	-0.236	-0.273***	0.433
	(0.18)	(0.08)	(0.41)
Between buyer	-0.155	0.186*	0.432**
	(0.26)	(0.11)	(0.21)
Holdings seller	0.100	0.109	0.271
	(0.19)	(0.21)	(0.33)
Holdings buyer	0.283	-0.166	-0.395
	(0.26)	(0.22)	(0.27)
LandingsPos seller	0.129	-0.004	0.555*
	(0.33)	(0.23)	(0.32)
LandingsPos buyer	0.486	0.422**	0.672*
	(0.31)	(0.21)	(0.35)
West coast seller	2.741***	2.065***	-1.195
	(0.55)	(0.67)	(1.06)
West coast buyer	-1.579***	-2.202***	-1.060
	(0.34)	(0.39)	(0.86)
2011	0.327	-0.104	0.041
	(0.48)	(0.42)	(0.53)
2012	0.077	0.368	1.164**
	(0.37)	(0.46)	(0.49)
2013	0.203	0.612	0.884
	(0.51)	(0.53)	(0.62)
2014	-0.230	0.213	1.134*
	(0.50)	(0.40)	(0.64)
2015	-0.513	-0.176	0.886
	(0.41)	(0.48)	(0.64)
2016	0.751	1.080*	2.143***
	(0.49)	(0.62)	(0.74)
Constant	112.519**	16.764***	-3.889
	(5.42)	(2.33)	(5.24)
Seller FE	✓	✓	✓
Buyer FE	✓	✓	✓
Observations	709	709	48,804
Adjusted R^2	0.15	0.71	0.10

Note: The dependent variable in the OLS regression is ln(volume). In the PPML regression, the dependent variable is volume. Results for the full and restricted sample are reported.
Multi-way clustered standard errors on seller, buyer, and year in parentheses.
Buyer and seller fixed effects are omitted from the output table.
*** p<0.01, ** p<0.05, * p<0.1.

Table 6: Estimated results for volume traded between actors in the permanent quota market. Dependent variable is the annual dyadic volume of permanent quota traded.

VARIABLES	(1) (OLS $Y > 0$)	(2) (PPML $Y > 0$)	(3) (PPML full)
kW seller	-0.626	-0.088	-0.079
	(1.12)	(0.76)	(0.54)
kW buyer	-0.147	-0.108	-0.881
	(0.79)	(0.45)	(1.13)
Distance	0.336*	0.117**	-0.383***
	(0.20)	(0.06)	(0.14)
SharedBuyer	-0.164	0.658***	-0.114
	(0.45)	(0.25)	(0.50)
Between seller	-0.799***	-0.797**	0.192
	(0.28)	(0.31)	(0.79)
Between buyer	-0.716	0.182	0.413
	(0.62)	(0.49)	(0.37)
Holdings seller	-1.094	-0.583	0.011
	(0.82)	(0.47)	(0.54)
Holdings buyer	-1.024	-0.719	-0.750
	(0.71)	(0.66)	(0.59)
LandingsPos seller	0.254	-0.205	-0.296
	(0.43)	(0.29)	(0.71)
LandingsPos buyer	-0.790	-1.989***	0.498
	(0.79)	(0.68)	(0.75)
West coast seller	7.603***	6.975***	16.112***
	(2.07)	(0.91)	(1.13)
West coast buyer	3.267	-0.732	12.099***
	(3.63)	(1.36)	(1.07)
2011	2.606**	0.826	-0.175
	(1.06)	(0.92)	(0.74)
2012	1.848**	0.511	-0.230
	(0.75)	(0.81)	(0.62)
2013	2.155*	3.205**	0.408
	(1.12)	(1.32)	(1.11)
2014	2.255**	0.799	-0.460
	(0.90)	(0.75)	(0.71)
2015	12.145***	9.471***	-1.819
	(1.98)	(1.39)	(1.21)
2016	1.884	1.161*	0.727
	(1.39)	(0.61)	(1.04)
Constant	3.699	-3.810	-43.580***
	(9.67)	(4.15)	(9.84)
Seller FE	✓	✓	✓
Buyer FE	✓	✓	✓
Observations	266	266	12,265
Adjusted R^2	0.18	0.78	0.09

Note: The dependent variable in the OLS regression is ln(volume). In the PPML regression, the dependent variable is volume. Results for the full and restricted sample are reported.
Multi-way clustered standard errors on seller, buyer, and year in parentheses.
Buyer and seller fixed effects are omitted from the output table.
*** p<0.01, ** p<0.05, * p<0.1.

quota traded between actors by about 69 %, although the effect is only significant at the ten percent level.[20] This effect might derive from beneficial lease prices as noticed in Ropicki and Larkin (2014). One factor that could be conducive to improved lease prices is that actors sharing a landings buyer are more likely to interact. Since the harvest is usually transported to different selling points by truck, fishers need to coordinate landings and transportation routes. This could facilitate the coordination of quota trade negotiations too. In any case, the result indicates that there are important homophily patterns at the lease market.[21] All else equal, the volume of lease quota traded between actors increase when the buyer's betweenness centrality in the previous period was equal to, or higher than, the average. Compared to a less central actor, the traded volume increases on average by 54 percent. This suggests that central buyers in the lease market remain central, at least for one more period. Again, the selling actor's previous position in the transaction network is not found to have a significant effect on quota trade, although the coefficient is positive. Together with the positive association between buyers' vessel capacity and the volume traded, the results suggest that the demand side is driving a large part of the volume dynamics in the lease market.

Whether or not actors hold quota at the beginning of the year is not shown to influence lease trade, although the sign of the coefficients, positive for sellers and negative for buyers, are as expected. The significance and magnitude of the estimated elasticities are neither changed much when holdings are excluded from the regression (Table A1, column (5)). Fishing activity is shown to have a large and positive effect on trade volumes. For a selling actor, fishing activity in the previous year is related to a 74 percent increase in traded lease volume. For a buying actor, the corresponding effect is 96 percent. Of course, this indicator does not distinguish between levels of fishing between actors. However, it does suggest that the majority of traders, and particularly the buyers, of lease quota are fishing at least at some point during the year. Finally, the regional dummies for the west coast are not shown to have any effect on the volume of traded quota. This indicates that most of the variation explained by the west coast indicator is picked up by the other regressors. The year fixed effects show that the average volume of trade is significantly higher in 2012, 2014, and 2016 compared to in 2010. That larger volumes are traded in 2014 and 2016 are consistent with the earlier observation of the potential effect of the landing obligation on behavior.

Turning to the permanent market, the estimates reveal different transaction dynamics compared to the lease market. The results suggest that the geographical distance between actors and whether they are located on the west coast or not are the only variables associated with trade volumes. The elasticity of trade with respect to geographical distance is very

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[20]The estimates of indicator variables is given by: $100(e^{b_i} - 1)$ where b_i is the estimated coefficient.

[21]The buyers in the landings market purchase on average three to four species of the five pelagic species included in the ITQ-system in a given year. This implies that the effect is not likely to be driven by a few landings buyers specializing in only one particular species.

similar to that in the lease market: a one percentage increase in the distance between actors is associated with a 0.38 percentage decrease in trade. However, what really explain permanent quota trade flows is whether actors are located on the west coast, as showed by the large coefficients of the west coast indicator. Hence, the closer the actors on the west coast, the larger volume of permanent quota they trade.

Summing up, the results indicate that the factors that drive decisions of permanent quota transactions are very different from those driving lease transactions. On both markets, geographical distance is affecting the volume of trade between actors negatively, implying geographical concentration of trade. On the permanent market, this concentration is clearly located to the west coast of Sweden. On the lease market on the other hand, trade is related to additional drivers which suggests the presence of network effects. That central actors remain central in the transaction network suggests preferential attachment patterns, and the positive effect on trade volume from sharing a buyer in the landings market suggest homophily effects.

4.2 Concentration and network topology

How have the flows of permanent quota between actors impacted the overall distribution of quotas over time? Ownership concentration of quotas is often used to assess ex-post socio-economic consequences of ITQ systems, as it indicates potential system inefficiencies related to market power (Döring et al., 2016). On the one hand, if the overall goal is fleet reduction, the fact that quota ownership is concentrated to a few actors, presumably with lower marginal operating costs, while others are leaving the fleet, may well be proof that the ITQ system works efficiently. On the other hand, if owners of permanent quota lease out their shares rather than use them for fishing, the way fleet capacity is affected is determined by the way the lease market operate (Emery et al., 2014; León et al., 2015).

The Gini coefficient is a standard measure used to evaluate concentration of wealth (Eq. A1). Here it is used to determine changes in quota ownership, in accordance to previous studies of quota markets. The initial allocation of quotas in 2009, already established a relatively high concentration of quota ownership; the Gini coefficient was 0.60 prior to any trade (Table 7). In the following years, the Gini coefficient ranged between 0.70 to 0.83 with a general development towards a higher ownership concentration.

Table 7: Gini coefficient by year for total share of pelagic quota made available through the ITQ system

	2009	2010	2011	2012	2013	2014	2015	2016
Gini coefficient (permanent holdings)	0.60	0.81	0.70	0.71	0.82	0.78	0.76	0.83

Note: The Gini coefficient is calculated in relation to total ownership of permanent pelagic quota for the actors remaining in the system each year.

If the population of quota holders in each year is ranked from the one owning the least quotas to the one owning the most, and they are divided into groups, the ownership distribution of quotas is captured on a finer level. Prior to trade in 2009, the top 10 percent of quota owners held 41 percent of the total permanent quotas in the system (Table A3). At the end of 2016, the top 10 percent held 68 percent of the total accessible permanent quotas.

The concentration levels of quota ownership are a bit higher than those found in the Australian Great Barrier Fin fishery in Innes et al. (2014), where the Gini coefficients ranged from 0.66 in the initial year to 0.78 eight years later. Without the 10 % cap on individual ownership of quota, which was introduced to prevent "imbalances" in the fishery (Swedish Government, 2008), concentration levels might have been higher. In the Tasmanian rock lobster ITQ system for example, where individual ownership levels are highly restricted, the Gini coefficient for ownership concentration was found to be 0.36 (Hamon et al., 2009). Regional effects related to quota redistribution was considered one potential system imbalance. In line with the regression results with respect to the permanent quota market, the geographical concentration of quota has been increasing over the years. If aggregating quota ownership over the home ports of the vessels associated with the actors, the two ports with the highest quota ownership accounted for 48 % of the total permanent quotas in 2009 (Fig. 7 a)). At the end of 2016, the two ports with the highest quota ownership accounted for 80 % of the total permanent quotas (Fig. 7 b)).

(a) 2009   (b) 2016
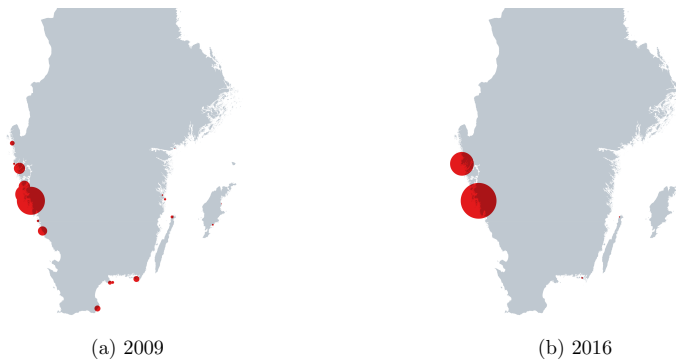
Figure 7: Share of total quota ownership by actor share of total initial allocation port in 2009, (a), and 2016, (b). The size of the circles corresponds to the share of total quota held in that port in that year.

At the same time, the importance of the west coast as a place for landings of the pelagic species included in the ITQ system, has decreased. In Figure 8, the shares of total landings

per port in 2009 and 2015 are depicted. The largest part of the landings is located to non-Swedish ports, particularly to Denmark. In 2009, 76 % of the total volume of harvest of the pelagic species included in the ITQ system was landed abroad. In 2015, the corresponding volume had risen to 87 %. While ownership of pelagic quota is highly concentrated to the west coast, the ports used for landings indicate a more diverse fishing activity, which may explain why the west coast is a less accurate predictor of volume of lease quota traded between actors than of permanent quota volumes.

<div align="center">(a) 2009   (b) 2015</div>
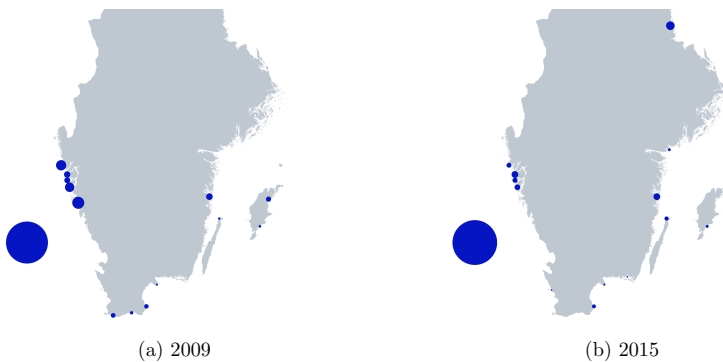
Figure 8: Share of total landings by port in 2009, (a), and 2015, (b). The size of the circles correspond to the share of total landings taking place in a port during that year.

In theory, initial allocation of quotas should not matter for the redistribution of quota ownership through trade (Coase, 1960). However, given that markets are not frictionless, initial allocation of quota may impact the evolution of quota ownership. The relationship between initial allocations and quota ownership is illustrated in Figure 9. The histograms depict owned quota percentiles for different initial quota allocation percentiles in 2010 and 2016, respectively. Although the impact of initial quota on ownership of permanent quotas in 2010 may not be that surprising, its effect on the ownership distribution in 2016 is more notable. The actors whose initial allocation of quota were in the top 20 %, owned almost five times as much quota as the average actor at the end of 2016. At the same time, actors that had no or small initial quota allocations, owned around 1.5 times as much quota as the average quota owner. Whether this development reflects that the grandfathering process was representative of actor efficiency, or it reflects barrier to trade among actors cannot be determined in this study. In any case, the strong association between quota ownership and initial allocation is noticeable. Such a relationship was also found in Innes et al. (2014).

(a) 2010   (b) 2016
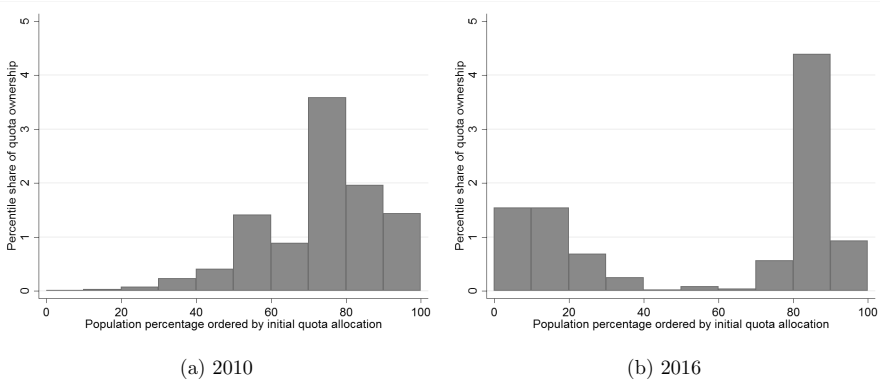
Figure 9: (a) Share of total quota ownership by actor share of total initial allocation port in 2010 and 2016.

Actors with permanent quota holdings are becoming increasingly involved in lease trans-actions over time. The volume of lease transactions as a share of permanent holdings increased in every year except 2014 (Fig. A3). In the initial year of quota trade, when the lease market was very thin, the share was almost zero. In 2016, the volume of lease quota traded by actors with permanent holdings was almost four times as big as their permanent holdings, on average. The overall lease market development is depicted in Figure A4. The development is best captured by studying the evolution path of the topological indicators described in Table 2 and summarized in Figure 10. The average path length is fairly stable over time and similar to the findings in Van Putten et al. (2011) and Ropicki and Larkin (2014). The average clustering coefficient increases over time, to levels about double the size of the ones documented for the Australian quota lease markets. This indicates that actors who are ac-tive in the market are increasingly trading among each other. Together with the stability of the average path length, it indicates that a few quota holders are highly connected. The average betweenness centrality of actors diminishes over time as the network becomes more fragmented. However, around half of the ten actors with the highest betweenness centrality in a year reappear every year. Taken together, this suggests that permanent quota holders are playing an important role as quota re-distributors in the market, actively engaged in both buying and selling lease quota. In 2016, there is a slight decline in the average clustering coefficient as the graph density increases in this year. This reflects that a greater share of the actors in the system are trading quota, which attenuates the role of actors acting like hubs. The effect is plausibly driven by the landing obligation, which led to an increased demand for lease quotas among active fishers. This indicates the important role that the landing obligation might have in the quota market. As monitoring increases and penalties for not

being able to account quota for catch are being introduced, trade is stimulated. In effect, this might lead to actors looking for new trading partners which leads to a more integrated market.
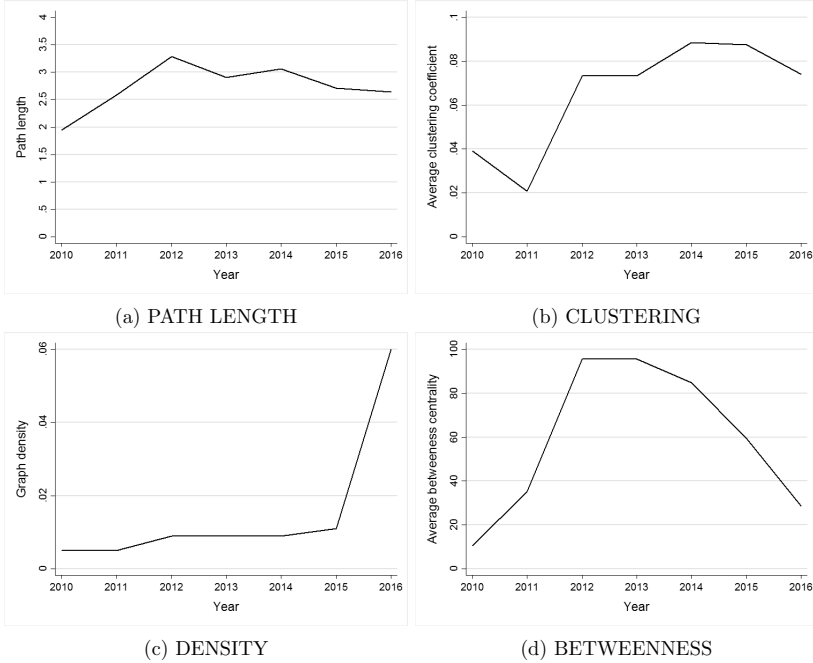
Figure 10: Evolution of network topology

5 Conclusion

ITQ systems are introduced to promote economic efficiency through a rationalization of the fishing fleet capacity (Arnason, 2012). To achieve such outcomes, the system requires a functioning market that facilitates trade between actors who face different marginal rents from fishing (Newell et al., 2005). In this study, I give a detailed description of the development of the pelagic ITQ market and its effects on capacity distribution, using a unique dataset on quota trade in the Swedish pelagic ITQ system 2010-2016.

The system is shown to be associated with a large reduction of the fleet size. The total vessel capacity held by actors active on the quota transaction market in 2016 was reduced

by around 26 %, and the vessel capacity actively used for fishing decreased by around 17 %. Further, the concentration of quotas among actors is shown to increase over time and space, with the Swedish west coast acting as a hub for quota ownership. However, it is not clear that this development fully reflects technical and economic fishing efficiency, instead it may partly be a consequence of the initial allocation of quota, which is shown to have a persistent effect on concentration levels and which may have affected the actors' relative financial capacity positively.

Concentration of quotas gives economies of scale in fishing operations. In 2016, 87 % of the total quotas was located to two ports on the Swedish west coast. However, if quotas are leased out, the fishing efficiency depends on the actor leasing in. The findings show that large quota owners play an important role in the domestic lease market, by taking part in a significant share of the total volume that is being traded. In 2016, the total volume of lease transactions that quota owners took part in, was on average four times larger than their owned quota volume. Lease trade is also larger between actors that share a common buyer in the landings market. This suggests that information asymmetries and other transaction costs are remedied by trading between actors who are more likely to interact frequently.

The quota market showed a higher level of activity, in terms of density, after the introduction of the landing obligation in 2015, both on the permanent and the lease market, which led to involve a greater share of the actors within the pelagic system in quota trade. This suggests that there was unrealized potential for trade in earlier years and that the harsher rules of counting harvest against quota stimulated trade. During this period the average betweenness centrality in the network decreased, suggesting that the importance of some actors acting like hubs in the network, became less important.

Taken together, the results also highlight the conflicting objectives in the current Swedish fishing policy. The reduction of fleet capacity and promotion of economic efficiency is inevitably reducing the economic opportunities for some actors (Kroetz and Sanchirico, 2010). In the Swedish ITQ system this is partly circumvented by ownership restrictions and regional set-asides. As pointed out by Arnason (2012), ITQs are not sufficient for achieving full efficiency in the fishery, an optimal use of ecosystems, and to harmonize conflicting uses of marine resources across time and space. ITQs are consequently likely to be adopted together with other regulations aiming at balancing different policy objectives. However, the results suggest that the introduction of ITQ systems considered by many European countries may be more likely to successfully promote economic efficiency given certain features of the system design. Firstly, quota prices should be reported and public. That would both increase the amount of information in the system and signal the value of quotas to potential financial actors, with the additional consequence of potentially reducing the financial cost for capital constrained actors. Secondly, it should be recognized that the common approach of allocating initial quota based on historical catches may have system implications in that it may not be

neutral to how the market evolves. Thirdly, too lax regulations with respect to fishing beyond held quota are less likely to stimulate market transactions, and hence the redistribution of capacity in the system. Finally, the understanding of trading behavior on quota markets, and how well they work in achieving policy goals relies on that such relevant data exists. Hence, a strategy for data collection should be part of the system design.

The findings in this study highlights the complexity of quota markets and that more work is required to identify drivers of quota trade. The joint ownership structure of fishing firms between Danish and Swedish individuals, and potential associations between fishing actors and landings buyers are potential factors affecting trade patterns that are not examined here, but that are of interest for further research. In addition, future development of the market as a consequence of the landing obligation, and the management responses in different European countries, is of great interest. Also, if price data was available, the price dispersions between different trading locations would reveal important information about the market efficiency.

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Appendix
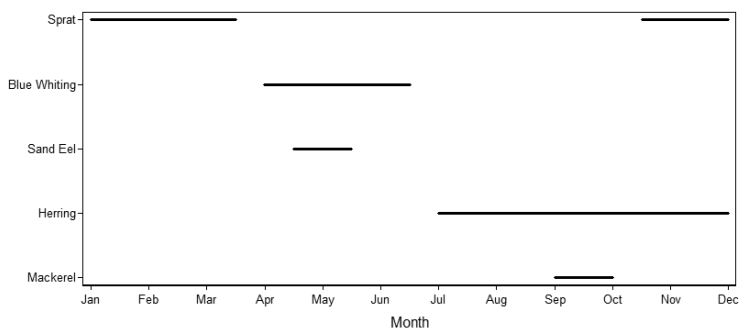
(a)
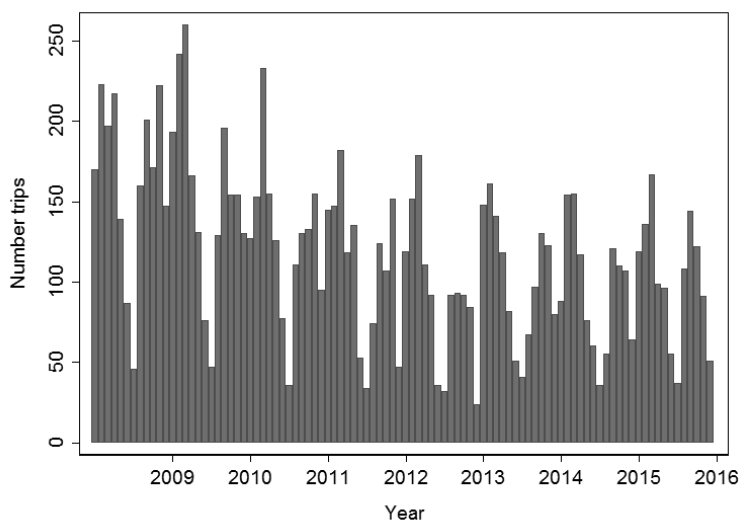
(b)

Figure A1: (a) The main fishing periods for the five major pelagic species.
Source: Swedish Agency of Marine and Water Management, author's adaption.
(b) Number of pelagic fishing trips carried out by month and year.

(a) (b)
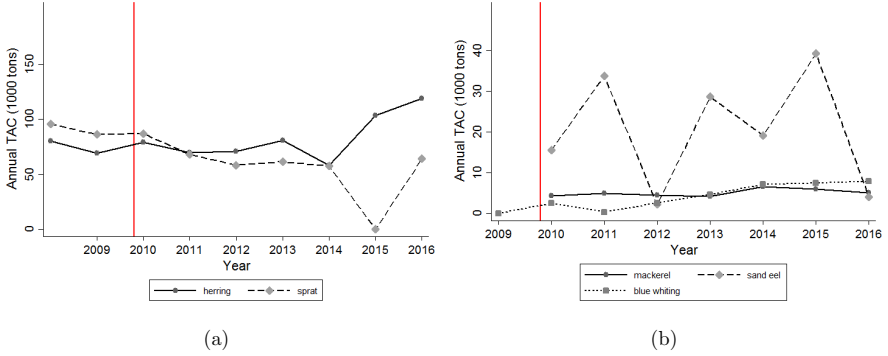
Figure A2: Total allowable catch made available for pelagic species within the transferable system expressed in 1,000 tons. Note the difference in scale on the y-axis, i.e., the TACs for herring and sprat, a), are much larger in magnitude than the TACs for mackerel, sand eel, and blue whiting, b). The TACs for herring and sprat include year 2008 for comparison. There were no available quotas for mackerel and sand eel prior to 2010. The vertical lines denote the introduction of the Swedish pelagic ITQ system. Source: Swedish Agency of Marine and Water Management, author's adaption.

The Gini coefficient is calculated as:

$$Gini = \frac{1}{n}(n + 1 - 2)\frac{\sum_{i=1}^{n}(n + 1 - i)q_i}{\sum_{i=1}^{n} q_i}, \tag{A1}$$

where actors are ranked in ascending order of quota holdings q_i (Gini, 1921). A Gini coefficient of 1 indicates maximum inequality, whereas 0 indicates complete equality.

Table A1: Estimated results for volume traded between actors at quota lease market. Dependent variable is the annual dyadic volume of lease quota traded.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
kW seller	0.000	0.005	-0.009	-0.124	-0.259	-0.257
	(0.40)	(0.16)	(0.17)	(0.13)	(0.47)	(0.46)
kW buyer	1.093***	1.100***	1.112***	1.000***	0.828**	0.857**
	(0.41)	(0.25)	(0.29)	(0.22)	(0.38)	(0.39)
Distance	-0.408***	-0.410***	-0.411***	-0.406***	-0.410***	-0.412***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
SharedBuyer				1.029***	0.532*	0.528*
				(0.33)	(0.29)	(0.29)
Between seller			0.508	0.498*	0.444	0.433
			(0.35)	(0.29)	(0.40)	(0.41)
Between buyer			0.411**	0.416***	0.441**	0.432**
			(0.19)	(0.15)	(0.21)	(0.21)
Holdings seller						0.271
						(0.33)
Holdings buyer						-0.395
						(0.27)
LandingsPos seller					0.563*	0.555*
					(0.32)	(0.32)
LandingsPos buyer					0.638*	0.672*
					(0.35)	(0.35)
West coast seller		-1.440	-1.546	-1.401	-1.327	-1.195
		(1.21)	(1.29)	(1.26)	(1.05)	(1.06)
West coast buyer		-0.724***	-0.777***	-0.687***	-0.667	-1.060
		(0.24)	(0.27)	(0.25)	(0.85)	(0.86)
2011	0.104	0.093	-0.161	-0.093	-0.061	0.041
	(0.43)	(0.06)	(0.14)	(0.12)	(0.42)	(0.53)
2012	0.864**	0.842***	0.753***	0.923***	1.064***	1.164**
	(0.35)	(0.07)	(0.08)	(0.09)	(0.40)	(0.49)
2013	0.903**	0.891***	0.711***	0.781***	0.830**	0.884
	(0.38)	(0.06)	(0.14)	(0.12)	(0.41)	(0.62)
2014	1.179***	1.168***	0.871***	0.987***	1.085**	1.134*
	(0.42)	(0.05)	(0.19)	(0.17)	(0.48)	(0.64)
2015	0.983**	0.972***	0.747***	0.791***	0.825*	0.886
	(0.41)	(0.05)	(0.11)	(0.09)	(0.42)	(0.64)
2016	1.551***	1.539***	1.367***	1.572***	2.079***	2.143***
	(0.53)	(0.05)	(0.13)	(0.14)	(0.62)	(0.74)
Constant	-9.649***	-7.567**	-7.214*	-5.793*	-3.862	-3.889
	(2.79)	(3.66)	(3.84)	(3.31)	(5.25)	(5.24)
Seller FE	✓	✓	✓	✓	✓	✓
Buyer FE	✓	✓	✓	✓	✓	✓
Observations	48,804	48,804	48,804	48,804	48,804	48,804
Adjusted R^2	0.06	0.07	0.08	0.08	0.09	0.10

Note: The dependent variable is volume of lease quota in levels. The full sample is used in all regressions. Multi-way clustered standard errors on seller, buyer, and year in parentheses. Buyer and seller fixed effects are omitted from the output table. *** p<0.01, ** p<0.05, * p<0.1.

Table A2: Estimated results for volume traded between actors at permanent quota market. Dependent variable is the annual dyadic volume of permanent quota traded.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
kW seller	-0.162	-0.124	-0.129	-0.124	-0.069	-0.079
	(0.56)	(0.55)	(0.57)	(0.57)	(0.54)	(0.54)
kW buyer	-0.924	-0.882	-0.948	-0.945	-1.005	-0.881
	(0.80)	(0.92)	(0.92)	(0.91)	(0.93)	(1.13)
Distance	-0.349***	-0.375***	-0.374***	-0.374***	-0.378***	-0.383***
	(0.13)	(0.14)	(0.14)	(0.14)	(0.13)	(0.14)
SharedBuyer				-0.076	-0.100	-0.114
				(0.53)	(0.49)	(0.50)
Between seller			0.102	0.108	0.189	0.192
			(0.79)	(0.77)	(0.80)	(0.79)
Between buyer			0.494	0.497	0.426	0.413
			(0.38)	(0.38)	(0.40)	(0.37)
Holdings seller						0.011
						(0.54)
Holdings buyer						-0.750
						(0.59)
LandingsPos seller					-0.311	-0.296
					(0.66)	(0.71)
LandingsPos buyer					0.442	0.498
					(0.77)	(0.75)
West coast seller		16.623***	16.215***	16.207***	16.151***	16.112***
		(1.17)	(1.15)	(1.15)	(1.12)	(1.13)
West coast buyer		12.927***	12.567***	12.563***	12.552***	12.099***
		(2.44)	(0.55)	(0.29)	(1.18)	(1.07)
2011	-0.689**	-0.449	-0.671**	-0.679**	-0.711*	-0.175
	(0.31)	(0.32)	(0.32)	(0.33)	(0.39)	(0.74)
2012	-0.869***	-0.644**	-0.694**	-0.703**	-0.699*	-0.230
	(0.31)	(0.32)	(0.32)	(0.33)	(0.36)	(0.62)
2013	-0.306	-0.077	-0.152	-0.155	-0.097	0.408
	(0.64)	(0.64)	(0.73)	(0.71)	(0.74)	(1.11)
2014	-0.905*	-0.671	-0.820	-0.828	-0.800	-0.460
	(0.48)	(0.47)	(0.53)	(0.53)	(0.52)	(0.71)
2015	-2.485**	-2.250**	-2.389**	-2.394**	-2.288**	-1.819
	(1.01)	(1.01)	(1.01)	(1.01)	(1.01)	(1.21)
2016	0.150	0.383	0.337	0.326	0.397	0.727
	(0.68)	(0.70)	(0.70)	(0.70)	(0.87)	(1.04)
Constant	-11.149	-43.975	-43.282	-43.329	-43.191***	-43.580***
	(.)	(.)	(.)	(.)	(8.11)	(9.84)
Seller FE	✓	✓	✓	✓	✓	✓
Buyer FE	✓	✓	✓	✓	✓	✓
Observations	12,265	12,265	12,265	12,265	12,265	12,265
Adjusted R^2	0.06	0.08	0.07	0.07	0.07	0.09

Note: The dependent variable is volume of permanent quota in levels. The full sample is used in all regressions.
Multi-way clustered standard errors on seller, buyer, and year in parentheses.
Buyer and seller fixed effects are omitted from the output table.
*** p<0.01, ** p<0.05, * p<0.1.

Table A3: Permanent quota ownership in bottom 50 %, mid 40 %, and top 10 %

	0-50	50-90	90-100
2009	0.09	0.50	0.41
2010	0.07	0.51	0.42
2011	0.10	0.51	0.39
2012	0.05	0.62	0.33
2013	0.04	0.33	0.63
2014	0.18	0.49	0.33
2015	0.03	0.71	0.26
2016	0.02	0.30	0.68
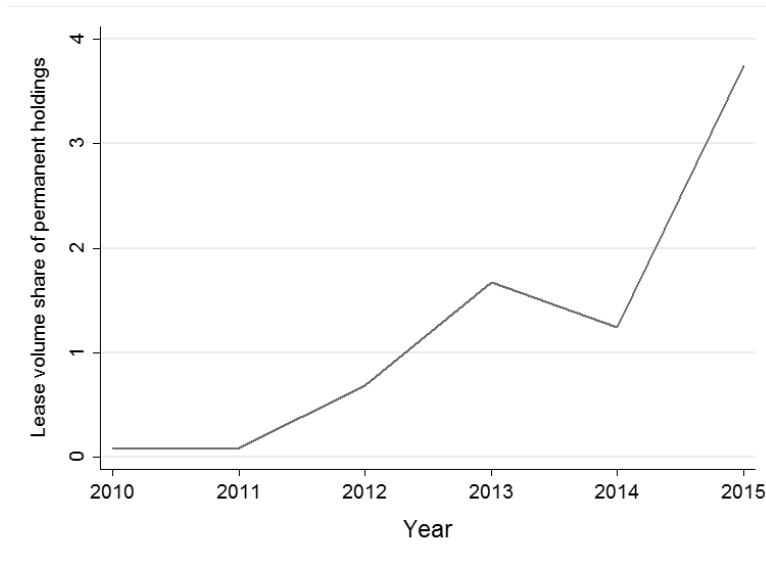
Figure A3: Annual average actor-specific volume of lease trade (both purchase and sale) as a share of permanent quota holdings.
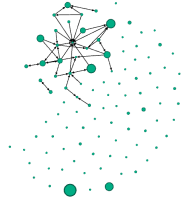
(a) 2010
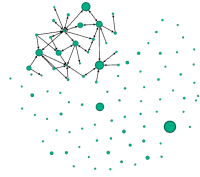
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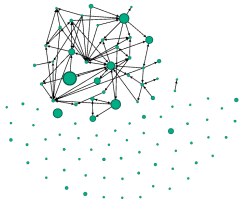
(c) 2012
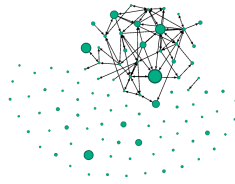
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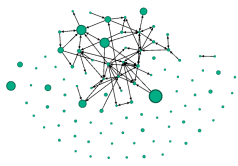
(e) 2014
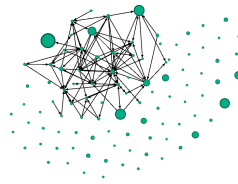
(f) 2015
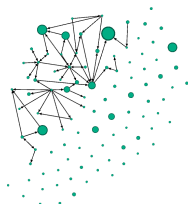
(g) 2016

Figure A4: Annual lease transactions network. The size of the nodes corresponds to the initial allocation of quotas. Unconnected nodes are actors that did not participate in any lease trade in the year.

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