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CREDIT MARKETS, PROPERTY RIGHTS, AND THE COMMONS

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ABSTRACT

Credit markets and property rights are fundamental for modern economies, but they also have implications for the commons. Using a dynamic model of competitive resource extraction, we show that improving property right security unambiguously increases conservation incentives, but the effect of credit markets on resource extraction effort hinges on the security of property rights. We test these predictions using data on global fisheries, credit markets, and the largest-ever marine property rights assignment. We find that property right security reduces resource extraction, while credit market development increases resource extraction under insecure property rights but reduces resource extraction under secure property rights.

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1 Introduction

Well-functioning credit markets and secure property rights are widely regarded as fundamental for efficient investment and economic development. But because these market fundamentals affect the cost of capital and effective discount rates, they may also affect incentives for resource extraction in the commons. In this paper, we examine how credit markets and property rights interact to affect the sustainability of common pool resources.

The economics literature has contributed immensely to our understanding of the role of secure property rights in driving economic development (Besley and Ghatak, 2010) and efficient resource extraction (Bohn and Deacon, 2000; Costello et al., 2008; Copeland and Taylor, 2009; Ayres et al., 2021; Behrer et al., 2021). The basic insight that emerges from this literature is that property right security confers a dynamic benefit to the owner; by reducing the risk of loss or expropriation, an additional unit of conservation today pays a larger dividend tomorrow. Not only does this tend to raise the value of natural resource stocks to the owner, it also rationally incentivizes resource conservation. For this reason, improving property right security is regarded as both a means of economic development and environmental sustainability. Testing this theoretical insight empirically, however, is complicated by the fact that exogenous variations in property rights over resources are rare. In this paper, we leverage the property rights shock caused by the implementation of the Exclusive Economic Zones (EEZs) that assigned property rights over most marine resources within a relative short time period. We use the heterogeneity of this property rights shock across resources with different levels of mobility to causally estimate the impact of property rights on resource extraction.

Credit markets play an equally important role in modern economies. Credit market development reduces the cost of borrowing and is widely though to be essential for efficient investment and modern economic growth (Rajan and Zingales, 1998; Beck et al., 2000b; Levine, 2005; Popov, 2018). We note that these features of credit markets may affect resource extraction incentives for at least two reasons. First, to the extent that credit market development lowers the cost of capital, resource extraction that relies on capital (such as fishing vessels, logging equipment or water wells) may accelerate. Second, and working in the opposite direction, is the effect of credit market development on effective discount rates. As credit markets improve, discount rates tend to decline,[1] thus incentivizing resource conservation (Clark, 1973). Despite the importance of credit markets for economic development, we are unaware of any paper that asks how credit market development affects environmental sustainability. In this paper we show that the response of resource harvesting to exogenous credit market shocks depends critically on the level of property rights security over the resource.

While credit markets have developed rapidly around the world (Beck et al., 2010), common pool resources such as groundwater, forests and global fish stocks are still used beyond sustainable limits (Stavins, 2011; Blakeslee et al., 2020) causing billions of USD in economic losses annually (Costello et al., 2016; Arnason et al., 2017). Have credit market expansions fueled resource overexploitation through lower capital costs? Or is it precisely in the areas with credit market expansions that we have seen resource recovery motivated by lower discount rates? Can improved property rights halt the degradation of common pool resources? We tackle these questions by developing a theoretical model of dynamic resource extraction with both credit markets and insecure property rights. We then test the model's predictions with an in-depth empirical analysis designed to draw causal inference about the effects of credit market development and property right security on resource extraction in the global commons. Our empirical strategy relies on the largest property rights assignment in history: the implementation of the exclusive economic zones (EEZ) following the United Nations Convention on the Law of the Sea (UNCLOS) that assigned property rights over almost half of the global oceans, encompassing 90 % of global fish stocks. However, the impact of EEZs on property right security over fish stocks was compromised by the ability of fish to move between EEZs of different countries and the high seas (the ocean outside of the EEZs). This threat to property right security differs across all species; some fish are more mobile, and traverse more EEZs, than others. We exploit these differences in property right security in our empirical analysis. Similarly, we use exogenous shocks to domestic credit markets to test their impact on resource extraction, taking potential interactions with property right security into account.

[1] Throughout the text, we assume that the market interest rate equals the discount rate for non-credit constrained firms because of arbitrage.

A key insight that emerges from our simple theoretical model concerns the interplay between credit market development and property right security in determining natural resource extraction. Intuitively, altering credit markets, for example by increasing the borrowing limit or lowering the discount rate,[2] affects incentives to extract. Perhaps the most obvious effect works via the cost of capital. As the cost of extraction capital declines, the ability to rapidly extract a common pool resource increases - this effect implies that credit market development could accelerate the tragedy of the commons. But a countervailing effect arises via the discount rate. As credit market development lowers the discount rate, the incentive to preserve the stock for future periods is enhanced. This second effect implies that credit market development could lead to resource stock recovery, effectively reversing the tragedy of the commons. We find that property rights are pivotal in determining which effect dominates. Most notably, the conservation effect is present only when property rights are relatively secure; when property rights are insecure, little conservation incentive exists regardless of the discount rate. In the extreme case of a sole owner with perfectly secure property rights, a reduction in the discount rate increase the value of future resource extraction, and therefore the value of the resource stock, resulting in increased conservation incentives. We also show how these conclusions can hinge on domestic management effectiveness; even if property rights are perfectly secure, ineffective management within a country can still erode the resource stock. Overall, the theoretical model comes to the conclusion that credit market development will accelerate resource extraction when property rights are insecure, but can lead to resource conservation when property rights are sufficiently secure.

The second half of the paper is devoted to an empirical test of our theoretical predictions. Empirically testing the impact of credit market development on resource extraction in relation to property right security is complicated by at least three factors. First, resource extraction often depends on the size of the stock; resource degradation can cause declining extraction despite increasing extraction effort. Using extraction levels alone to measure resource extraction

[2]Getting access to credit markets can be interpreted as an increase of the borrowing limit from zero to any positive number. Further, increasing the borrowing limit has a similar effect on the investment decisions as a reduction in the discount rate because it reduces the current marginal value of capital or income relative to its future marginal value.

is therefore a misleading measure of the economic incentives that drive extraction behavior. Second, property right security may respond to the status of the resource stock if regulators try to halt resource degradation by increasing property right security. Ignoring this endogenous response of property rights to the resource status leads to biased estimates and may give rise to misleading conclusions. Third, credit market development is potentially endogenous and the consequence of increased credit demand from a growing economy. Observed changes in resource extraction may simply result from the increased resource demand of a growing economy and may not be the consequence of credit market development.

To conduct the empirical test, and to overcome these challenges, we compile a novel dataset on global fish catches, fish stocks sizes and property right security for the majority of the world's commercial fisheries. We combine these resource-level data with indicators of credit market development, financial networks and macroeconomic performance to estimate the impact of credit market development on resource use under different levels of property right security.

Three strategies help us overcome the challenges identified above. First, by matching extraction data with data on resource stock sizes, we normalize extraction relative to the resource stock (commonly referred to as *fishing mortality* in the context of the fishery). This is equivalent to the share of the resource stock that is extracted. It also conveniently corresponds to the "effort" devoted to resource extraction in bioeconomic models,[3] and is empirically advantageous because it controls directly for changes in resource abundance. Increasing fishing mortality therefore implies increasing fishing effort, regardless of the stock of the underlying resource. We leverage this insight in the empirical analysis.

Second, we use the introduction of each country's 200 nautical mile EEZ, in combination with biological differences in the range and mobility of each fish species, as an exogenous and heterogeneous shock to property right security over individual fishery resources. The implementation of EEZs was the largest assignment of property rights over marine resources in history. Although its focus was largely on minerals and energy resources, it also changed the

[3]For example, in the fishery, fishing mortality is proportional to fishing effort in the widely applied Schaefer harvesting model (Clark, 1990).

property right regimes for 90 % of global fish stocks (Ebbin et al., 2005; Englander, 2019). While the implementation of EEZs gave countries the legal right to establish property rights over marine resources, the species' mobilities and their distributional ranges limit the countries' secure control over their biological resources. The share of the resource stock in a country's EEZ varies considerably across species and countries, depending on a country's coastline (which determines the shape and location of a countries EEZ) relative to the global distribution of the species. In other words, species 1 could have a large share of its stock in the EEZ of country A and a small share in country B, while for species 2, this relationship could be reversed. A second source of variation comes from the mobility of species. Put simply, a country's EEZ will likely establish very secure property rights over immobile resources such as lobsters or oysters, but may do little to solidify property rights over a mobile stock such as tuna that regularly moves between EEZs of different countries and the high seas. We make use of these sources of variation to define our measure of property right security. The advantage of our property rights measure compared to other measures (such as the actual management of resource stocks) is that it is exogenous to the status and exploitation rate of the resource stock. Further, including the biology of fish species in our property rights measure allows us to exploit differences in property right security across species and over time within the same country to estimate the causal effect of property rights on resource extraction. While secure property rights can facilitate efficient resource use, they may require additional regulation if common pool externalities persist within the countries' jurisdictions. In the empirical part of this paper we show how government enforcement transforms property rights into effective resource management in line with the theoretical predictions of our model.

Third, to describe credit market development we use the volume of total credit to the private sector and the lending interest rate to the private sector in a robustness test. While the lending interest rate provides a direct measure of the opportunity cost of capital, increases in the volume of credit to the private sector are commonly seen as reductions in credit constraints and are one of the most common measures of credit market development (Levine et al., 2000; Beck and Levine, 2004; Aghion et al., 2010; Manova, 2013; Aghion et al., 2014; Leibovici, 2021). We recognize that credit market development could be endogenously driven by general economic development, which could simultaneously determine resource extraction. To partially address this concern, we control for GDP in linear and squared form in all specifications. To further strengthen our results, we introduce an instrumental variable (IV) approach using financial exports of financial partner countries to countries other than the focal country as an instrument for the volume of credit in the focal country. This instrument builds on the insight that credit shocks are transmitted through financial networks, a fact that largely contributed to the global financial crisis in 2007-08 (Glasserman and Young, 2016).

We present two sets of results. The first set concerns the impact of property rights on resource extraction effort, holding everything else constant. Our main specification suggests that increasing property rights from open access to secure property rights reduces resource extraction effort by 32 %. Using only the variation of property rights across species but within countries increases the estimate to 56 %. Restricting the data to a balanced panel and taking the dynamics effects of EEZ introduction into account (Callaway and Sant'Anna, 2021) results in a weighted average treatment effect of 59 %. This event study approach also suggests parallel trends in the pre-treatment period.

The second set of results presents our empirical findings on the impact of credit market development on resource extraction. Our main specification shows that a one percent increase in credit to the private sector *increases* the extraction rate of fish stocks subject to insecure property rights by 0.16 %. In contrast, the same credit increase actually *reduces* the extraction rate by 0.29 % for fish stocks with secure property rights. This finding is consistent with our theoretical result that secure property right security incentivizes resource conservation as the discount rate is reduced. These results remain qualitatively unchanged when using the IV approach for credit market development, but the magnitude increase to 0.94 % and 0.41 % respectively.

To better understand the mechanisms underlying our empirical results, we again lean on our theoretical model. It predicts that countries will respond to changes in property rights or credit markets by altering harvesting capital. In the context of fisheries, this suggests that the main mechanism linking credit markets and property rights to resource extraction is fishing capital. To test this mechanism directly, we make use of a novel, never utilized dataset on the construction date, location, and characteristics of the near-universe of large global fishing vessels in the world's oceans. These data arise from meticulous matching of automatic identification system (AIS) signals with a range of global vessel registries. The results based on these data not only underscore the main results of our paper, but help reveal the underlying mechanisms at play. Based on individual vessel information and movement patterns, we are able to match each individual vessel with the resources it is targeting. For example, we can calculate construction of Japanese vessels to target open access stocks and compare that against the construction of Japanese vessels to target stocks with secure property rights. Using these data within our regression framework, we find that a one percent increase of credit to the private sector increases the size of fleets that target open access fish stocks by 0.31 % globally, while the same credit increase has no impact on fleets that target resources with secure property rights. Similarly, increasing property rights over resources from open access to secure property rights reduces the size of the related fishing fleets by 38 %.

While these findings help illuminate an interesting interplay between property right security and credit market development, we are also interested in interpreting the empirical magnitude of these findings on the tragedy of the commons. To do so, we use our empirical estimates to simulate the impact on global fisheries of a hypothetical increase in credit volumes (to US levels) and an increase in property right security (to fully secure levels), all across the planet. This simulation reveals that credit market development alone (holding property rights at current levels) has only a modest impact on global fisheries, reducing the share of overfished stocks by 7 %. This lackluster environmental outcome arises because the positive and the negative effects of credit market development on resource extraction cancel out under current levels of property right security around much of the world. The places with secure property rights would enjoy large ecological benefits from credit market development, and the places with insecure property rights would suffer significant ecological losses from credit market development; at the end of the day, these effects more-or-less cancel each other out (resulting in a net improvement of 7 %). However, we find that upgrading property rights, or property rights and credit markets simultaneously, has a large effect on global fisheries by reducing the number of overfished stocks by about 13 % and 33 % respectively. The findings of our study therefore suggest that increasing property right security over resources can reverse the negative impact of financial development on global common property resources. They suggest further that increasing property right security under current credit market conditions has a much larger effect on resource conservation than would credit market development alone.

Our paper contributes to several strands of literature. First, our paper builds on the literature examining the impact of economic development on resource use under incomplete property rights. A seminal contribution is Copeland and Taylor (2009), who develop an elegant theory on how extraction technology, incomplete enforcement, and prices determines the sustainability of common pool resources. Taylor (2011) supports this theory with a careful attribution of causes of the 19th century American buffalo slaughter. This grand-scale, real-world tragedy of the commons nearly led to the extinction of one of the most populous large land mammals on earth, and arose as a consequence of technological progress, demand growth, and institutional failure. Testing predictions about the impact of property rights improvements and economic development on the environment empirically is challenging because variation in economic activity and institutions is rarely exogenous. Liang et al. (2021) use an instrumental variable approach to study the impact of economic growth on biodiversity in the United States. Although they address the endogeneity of economic activity, there is no variation in property rights over biodiversity. Balboni et al. (2020) partially overcome this challenge by studying variation of the extent of externalities from forest fires caused by differences in wind speed and direction and the enforcement of regulations on deforestation in Indonesia. Although this study also concerns the effect of internalizing externalities on resource use, it is only indirectly related to property rights. Our paper contributes to this growing literature by introducing exogenous variation in both credit market development and property rights security.

The second contribution of our paper is to establish the importance of financial development for resource sustainability. While we know of no paper that test the relationship empirically, a related, long-standing theoretical literature examines the role of discount rates in driving optimal resource management and environmental conservation. Faustmann (1849) showed in the 19th century that discount rates determine the optimal cutting age of forest, and nearly a century ago Hotelling (1931) formulated the rule for optimal non-renewable resource extraction, which depended crucially on the discount rate. Clark (1973) showed further that high discount rates render the extinction of slow growing animal populations economically optimal. These papers generally conclude that a reduction in the discount rate leads to resource conservation. Farzin (1984) challenges this conclusion and emphasizes the role of both resource stocks and capital requirements in driving resource extraction incentives. Our approach accords with these implications, and simultaneously accounts for the role of credit market development and property right security in driving discount rates and resource extraction incentives. In this way, our paper is also related to the empirical tests of the Hotelling rule that relate resource prices to discount rates.[4] This literature has, however, focused mainly on resource prices holding the discount rate constant and implicitly assuming perfectly secure property rights over the resource. Anderson et al. (2018) provides a new perspective on resource extraction incentives, but implicitly does so under constant discount rates and secure property rights. We conclude that while suggestive of some of the mechanisms at play, the existing literature is incomplete in its treatment of the role of property rights and credit markets in driving common pool resource extraction. Our study is designed to examine the independent contributions of, and interactions between, property right security and credit market development in driving the tragedy of the commons.

As described above, the reduction of discount rates as a result of credit market development could itself affect extraction incentives. But other pathways are also possible. For example, slackening credit constraints may affect resource extraction. Tahvonen (1998) and Tahvonen et al. (2001) show in a theoretical framework that the forest harvesting decision under credit rationing depends on the forest owner's preferences and is not determined by the prevailing discount rate.[5] Noack et al. (2018) show further that credit market development can reduce resource extraction under open access when increased investment in outside options raises the opportunity cost of resource extraction.[6] Our paper contributes to this discussion by showing

[4]For overviews see Gaudet (2007) and Slade and Thille (2009).

[5]See also Koskela (1989) and Kuuluvainen (1990) for theoretical treatments of the impact of credit rationing on forest management and Amacher et al. (2009) for a summary of the impact of credit market imperfections on forest management.

[6]See Barbier et al. (2016) for a theoretical treatment of economic growth, resource use and credit constraints.

that the effect of credit market development on resource extraction hinges critically on property right security. In other words, it is the interaction between credit market development and property right security that primarily drives the reversal or the acceleration of the tragedy of the commons.

While our theoretical results provide new insights into this interplay and help to clarify the intuition about the conditions under which credit market development should hasten, or reverse, resource depletion, we view the empirical findings as the main contribution. Compared to the large theoretical literature, we are aware of few studies that empirically examine the link between credit markets and resource conservation or the environment in general. While Andersen (2016, 2017) show that credit market development can increase investment in new technologies that offset the emissions from increased production, Assunção et al. (2019) show that loans tied to environmental standards are successful in reducing deforestation in the Brazilian Amazon. A study by Jayachandran (2013) focuses on the impact of liquidity constraints and consumption shocks on ecosystem service provision in Uganda while Fenichel et al. (2019) show that improved access to financial services can reduce the costs of ecosystem service provision.[7] Although these papers are also concerned with the environmental impact of credit market development, their proposed mechanisms, their environmental indicators, and their scale are fundamentally different than in this paper.

Lastly, our paper is related to the growing literature on the impact of property right security on resource conservation (see for example Besley (1995), Bohn and Deacon (2000), Jacoby et al. (2002), Goldstein and Udry (2008), Copeland and Taylor (2009), Hornbeck (2010), Costello and Grainger (2018), Isaksen and Richter (2019), Englander (2019)). A principal finding from this literature is unambiguous; stronger property rights increase resource conservation incentives. We echo this finding, and extend it by demonstrating the crucial role of property rights in determining the consequences of credit market development on the tragedy of the commons. We also contribute empirically to this literature by constructing an exogenous measure of prop-

[7]Quaas et al. (2012) and Teh et al. (2015) infer from observed extraction rates the implicit discount rates of fishermen or the fishing industry, but they do not relate these observations to property right security or changes in observed market interest rates.

erty right security based on the legal framework of the EEZs and the propensity of species to stay within the jurisdiction.

The paper proceeds as follows. Section 2 develops a theoretical framework to derive testable predictions. Section 3 provides the empirical background, Section 4 introduces the data, Section 5 specifies the empirical model, Section 6 presents the results and discusses their robustness, and Section 7 concludes.

2 Theoretical framework

Here we present a simple model of resource extraction capital in a context of insecure property rights. The stylized setting builds on the classic fish war model developed by Levhari and Mirman (1980), and is designed to highlight the interplay between credit markets and property rights in driving common pool resource extraction.

Consider resource extraction by a single player or country "c" who competes against N fringe countries "f". As $N \to \infty$ this characterizes a dominant firm and competitive fringe where the fringe can be interpreted as extracting under open access (Costello et al., 2017), whereas $N = 1$ depicts a classic two player game. We will focus on the incentives and behavior of country c, but because c competes with the fringe, we will also need to pay close attention to their incentives, and the equilibrium behavior across all countries. Country c controls fraction $\gamma_c \in [0,1]$ of the resource stock in every period, so γ_c can be thought of as the extent of country c's property rights over the resource stock. Each of the fringe countries controls $\gamma_f = \frac{1-\gamma_c}{N}$ of the stock. This *partial* ownership could arise, for example, because the stock is mobile, it straddles the EEZs of multiple countries, or because each country can only effectively enforce part of its jurisdiction (Englander, 2019). The aggregate resource stock in period t is X_t, so country c has access to stock $\gamma_c X_t$ and representative fringe country f has access to $\gamma_f X_t$. We will interpret γ_c as a measure of property right security in country c; small values of γ_c represent insecure property rights while γ_c closer to unity resemble the sole owner case of highly secure property rights. Note also that as N gets large, the property rights to any individual fringe country approaches zero. We loosely refer to this situation as the "open access" fringe.

Each period, country i must acquire costly capital k_{it} in order to extract the stock, where i's extraction is given by $h_{it} = \gamma_i X_t k_{it}$ and $0 \leq k_{it} \leq 1$.[8] This homogeneous production function is standard in renewable resource extraction models and implies that doubling any input (property right security, resource abundance, or capital) will double extraction, holding other inputs fixed. The choice variable k_{it} can also be thought of as extraction "effort," an interpretation that is common in natural resource models; we will use "captial" and "effort" interchangeably. Country i derives concave utility from extraction equal to $\log(h_{it})$ and incurs a cost of capital of $r_i k_{it}$, where we can interpret r_i as a per-period rental price of capital for country i, which may vary across countries. Like most bioeconomic models, we do not explicitly model an agency's budget, which could affect parameters like enforcement, resource stock assessment, and other important features of the problem. We do note, however, that i's discount factor, δ_i, is inherently linked to the cost of capital, r_i, such that in a well-functioning market, we expect $\delta_i = \frac{1}{1+r_i}$ (see e.g. Gollier (2012)). This assumption underpins the fundamental rationale for discounting, and it also allows us to capture the two important mechanisms through which credit markets affect resource extraction: the cost of extraction capital and the present value of future extraction. We adopt this relationship for the remainder of this analysis, so the rental cost of capital can be written $r_i = \frac{1-\delta_i}{\delta_i}$.

The resource stock grows according to the concave equation of motion:

$$X_{t+1} = (X_t - h_t)^{\alpha} \tag{1}$$

where $h_t = h_{ct} + N h_{ft}$ is the total extraction in period t, $\alpha \in (0,1)$ determines the rate of growth of the resource,[9] and the implied ecological carrying capacity of the resource is 1. Thus, the extraction h_t and resource stock X_t are measured relative to its carrying capacity.

Putting all of this together, the focal country c and N fringe countries f face different incentives and we will show that each country's payoffs hinge on the other countries' actions. While each country would like to steward the stock (to facilitate future extraction), each country

[8] We abstract from capital adjustment costs to keep the model tractable and refer the reader to Clark et al. (1979) and Singh et al. (2006) for a treatment of capital adjustment costs in resource use.

[9] The interpretation of α may be counterintuitive because a large α implies slow growth, while a small α implies fast growth. For example, $\alpha \to 0$ depicts a resource that jumps immediately to its carrying capacity.

also recognizes that it controls only part of it, so is partly at the mercy of the other countries' extraction decisions. In what follows we will characterize and analyze the solution to this dynamic game to determine the effects of property right security and credit market development on the countries' extraction effort.

2.1 Country c's problem

In time period t, country c takes the state X_t as given and chooses capital k_c to maximize the discounted utility from extraction over an infinite horizon, accounting for both the behavior of the resource stock and the response of its N competitors. This defines c's infinite horizon dynamic programming equation (DPE) as follows:

$$V_c(X) = \max_{k_c} \left[\log(\gamma_c k_c X) - \frac{1-\delta_c}{\delta_c} k_c + \delta_c V_c\left((X-h)^{\alpha}\right) \right]. \tag{2}$$

The first term on the right hand side is c's period-t utility from extraction. The second term is the cost of capital. The final term is the discounted continuation value, which depends on c's extraction and on the extraction of all N competitors. In Appendix (A.1) we derive the explicit form of this infinite horizon value function and show that it is $V_c(X) = A_c \log(X) + B_c$, for suitable constants A_c and B_c.[10] This solution allows us to derive c's first order condition as only a function of model parameters:

$$\frac{1}{k_c} - \frac{1-\delta_c}{\delta_c} - \frac{\delta_c \alpha A_c \gamma_c}{1-\gamma_c k_c - (1-\gamma_c)k_f} = 0. \tag{3}$$

The first term is the contemporaneous marginal payoff from applying more capital. The second term is the marginal cost of capital. The third term is the discounted marginal future cost, which arises because increasing capital today impacts future stocks; this dynamic marginal cost depends on property rights (γ_c), credit markets (δ_c), the behavior of c's competitors (k_f), and on the growth of the stock (α), and is related to the shadow value of the resource stock.[11] This first order condition reveals that k_c depends on the fringe's choices (k_f) through the dynamic marginal cost, but not explicitly on the resource stock, X. The second order condition

[10] In particular, we will make use of the result that $A_c = \frac{1}{1-\alpha\delta_c}$.

[11] The shadow value is $\frac{\partial V_c(X)}{\partial X} = \frac{A_c}{X}$, which, unlike the third term in Equation 3, depends on the stock, X.

is straightforward to verify (see Appendix A.2). It is intuitive, and we will show below, that a similar result obtains for each of the fringe countries.

2.2 Country f's problem

Each of the N fringe countries must solve a dynamic problem similar to c's, but with incentives that differ because of the cost of capital and property right security. Let the infinite horizon value function for country f be given by $V_f(X)$. Perhaps unsurprisingly, f's value function takes a form similar to c's, but with different parameters: $V_f(X) = A_f \log(X) + B_f$, where $A_f = \frac{1}{1-\alpha\delta_f}$. Letting $\bar{k}_f$ denote the capital applied by each of the *other* $N-1$ fringe countries, and noting the dependence of γ_f on N, a single country f's first order condition is:

$$\frac{1}{k_f} - \frac{1-\delta_f}{\delta_f} - \frac{(1-\gamma_c)\delta_f \alpha A_f}{N\left(1 - \frac{1-\gamma_c}{N}k_f - \frac{(N-1)(1-\gamma_c)}{N}\bar{k}_f - \gamma_c k_c\right)} = 0 \tag{4}$$

The larger is the pool of fringe countries (N), the less secure are a fringe country's property rights. In our model, this turns out to increase extraction pressure by each fringe county. To see this intuitively, inspect country f's first order condition (Equation 4), where the third term represents a dynamic marginal cost; it is the cost that is internalized by country f that accounts for the effects of its current extraction capital on future payoffs. When $N = 1$, this dynamic marginal cost is relatively large because the single fringe country is the residual claimant of a large fraction of the stock. Instead, suppose $N \to \infty$. Then the dynamic marginal cost goes to zero and the first order condition simplifies to:

$$k_f|_{N\to\infty} = \frac{\delta_f}{1-\delta_f}, \tag{5}$$

which we refer to as the open access level of fringe capital (see Appendix A.3). Our model predicts that when the fringe is under open access, capital choices by the fringe become large. If capital is relatively inexpensive in fringe countries,[12] then open access fringe capital will bind at its maximum value ($k_f = 1$). If capital is relatively expensive, corresponding, e.g., to less developed credit markets, then extraction capital will be less than maximal ($k_f < 1$).

[12]The precise condition is that $\delta_f \geq 0.5$, which corresponds to a cost of capital of $r_i \leq 1.0$.

2.3 The pure effect of property rights

The conditions in Equations (3) and (4) characterize the equilibrium behavior of all $N+1$ countries. These allow us to investigate the role of property right security on extraction effort. Focusing on country c, how will an exogenous increase in country c's property right security affect its equilibrium extraction behavior? Answering this question requires understanding how both c and f respond to changes in γ_c. Totally differentiating Equation 3 with respect to γ_c and k_c and simplifying gives the comparative static:

$$\frac{dk_c}{d\gamma_c} = \frac{\left(\frac{\alpha\delta_c}{1-\alpha\delta_c}\right)\left(\frac{1-k_f}{(1-\gamma_c k_c-(1-\gamma_c)k_f)^2}\right)}{SOC} \leq 0$$

where SOC is the second order condition (shown to be negative in Appendix A.2). The numerator is weakly positive, so the expression is weakly negative. This shows that for any value of k_f, c's choice of k_c declines with an increase in γ_c. In other words, c's best response function shifts down with an increase in γ_c (see Figure 9B). Since γ_c also affects f's best response function, we must calculate the comparative static for f. Totally differentiating Equation 4 and simplifying gives:

$$\frac{dk_f}{d\gamma_c} = \frac{\left(\frac{\alpha\delta_f}{N(1-\alpha\delta_f)}\right)\left(\frac{k_c-1}{1-\gamma_c k_c-(1-\gamma_c)k_f)^2}\right)}{SOC} \geq 0$$

The numerator and denominator are both negative, so the expression is weakly positive: As c's ownership of the stock increases, f's ownership decreases, which causes f to apply greater extraction effort. This shifts f's best response function to the right. Because f's best response function is steeper than c's, both shifts reinforce the decline in k_c (see Figure 9B). The end result is a decline in equilibrium extraction capital by c (k_c^*) arising from an increase in its property rights (γ_c). We regard this as the pure effect of property rights on extraction effort.

2.4 Credit markets and extraction

We model credit market development in country c by exogenously increasing the parameter δ_c. This affects country c's incentives in two ways: It lowers the cost of extraction capital, and it lowers the discount rate. The former effect suggests that credit market development could increase extraction effort, and the latter effect suggests that credit market development could decrease extraction effort. Thus, more careful analysis is required to draw conclusions about the ultimate effect of credit market development on resource extraction.

We proceed in a manner similar to above, except that we note here that only country c's best response function depends directly on δ_c (country f's best response function depends on δ_f but not directly on δ_c). Totally differentiating Equation 3 with respect to k_c and δ_c gives the comparative static:

$$\frac{dk_c}{d\delta_c} = \frac{\frac{\alpha\gamma_c}{(1-\gamma_c k_c-(1-\gamma_c)k_f)(1-\alpha\delta_c)^2} - \frac{1}{\delta_c^2}}{SOC} \lesseqgtr 0 \tag{6}$$

The sign of the denominator is negative, but the sign of the numerator is not immediately clear. Note, however, that as c's property rights approach zero, this expression becomes:

$$\frac{dk_c}{d\delta_c}|_{\gamma_c \to 0} = \frac{-1}{(\delta_c^2)(SOC)} > 0$$

When c's property rights are sufficiently insecure, credit market development leads to an increase in c's extraction effort.

When c's property rights are secure, this result can reverse. While proving this requires significant algebra (see Appendix A.6.3 and A.6.4), we provide some intuition here. Credit market development both lowers the cost of capital and raises the dynamic marginal cost of extraction. Property rights interact only with the second set of incentives; the more secure the property rights, the larger is the dynamic marginal cost of extraction. In the limit, when property rights are extremely insecure, we showed above that the first set of incentives always dominates, so credit market development increases extraction effort. Instead, as property rights improve, the dynamic cost of extraction also increases. When property rights are sufficiently secure, this effect can dominate, in which case credit market development can decrease extraction effort. Sufficient conditions for this to arise are shown in Appendix A.6.3 and A.6.4.

The results above suggest that credit market development in country c can either raise or lower c's extraction effort, depending on the security of property rights in c. Importantly, though, while credit market development in c will affect f's equilibrium extraction effort, they do not directly affect country f's best response function. This implies that the consequences of an increase in δ_c on equilibrium k_c^* can be ascertained directly from the comparative static on c's extraction effort. Appendix Figure 9C shows this result graphically.

2.5 Management effectiveness

We have shown that property right security, credit market development, and the interaction of these variables have important implications for natural resource extraction. It is also reasonable to think that the effectiveness of resource management, which aims to control domestic extraction directly, could also play a role. This raises the possibility that secure property rights may be necessary, but not sufficient, to efficiently manage a natural resource stock. To investigate the role of management effectiveness in the presence of property right insecurity and credit markets, we borrow an idea from Quaas et al. (2016) who conceptualize the effectiveness of resource management as a multiplicative factor on the shadow price. To operationalize that idea in our model, let μ denote the management effectiveness in country c. For example, we could think of each country being populated by an infinite number of resource extractors. In that setting, μ could be interpreted as how effectively those extractors are managed. When $\mu = 0$, these within-country extractors are effectively open access, so act as-if there is no future. When $\mu = 1$, these extractors are perfectly managed within the country, so extract according to the incentives derived above.

To formalize this idea, let μ denote the fraction of dynamic costs that are accounted for by resource extractors in country c. $\mu = 1$ corresponds to the case in which country c is a perfect dynamic optimizer who fully accounts for the consequences of its period-t choices on its period-$t+1$ payoffs (of course, also accounting for the behavior of its competitors). $\mu = 0$ corresponds to the case in which country c fails to account for any the future consequences of its actions. And if $0 < \mu < 1$, country c accounts only for fraction μ of these dynamic costs. We can add this feature to our model of incomplete property rights. Under this generalization, country c's infinite horizon DPE becomes:

$$V_c(X) = \max_{k_c} \left[\log(\gamma_c k_c X) - \frac{1-\delta_c}{\delta_c} k_c + \mu \delta_c V_c\left((X-h)^{\alpha}\right) \right] \tag{7}$$

We show in Appendix A.5 that this value function has the form:

$$V_c(X) = \frac{\log(X)}{1 - \mu\alpha\delta_c} + M_c \tag{8}$$

where M_c is a constant that is independent of X. We can use this result to determine how management effectiveness alters country c's incentives, and how improvements in management affect equilibrium behavior. The relevant comparative static is:

$$\frac{dk_c}{d\mu} = \frac{\frac{\delta_c \alpha \gamma_c}{(1-\gamma_c k_c - (1-\gamma_c)k_f)(1-\mu\delta\alpha)^2}}{SOC} \leq 0 \tag{9}$$

Which means that for any value of k_f, country c will respond to an improvement in fishery management by (weakly) decreasing fishing pressure. Because k_f does not depend directly on μ, there is no shift in f's best response function. The shape of the best response functions ensures that equilibrium k_c^* also declines with an increase in μ. Thus, improving management effectiveness in country c lowers equilibrium extraction effort by c, even in the competitive environment examined here. As an aside, we note that such an increase in μ also raises the economic value of the resource for any level of resource stock.

2.6 Summary of theoretical predictions

Here we briefly summarize our main theoretical predictions.

Proposition 1. *In the dynamic competitive resource extraction game presented above, country c's equilibrium choice of extraction effort, k_c^*, has the following properties:*[13]

(a) An improvement in c's property right security decreases extraction effort in c: $\frac{dk_c^*}{d\gamma_c} \leq 0$. This result occurs for any level of credit market development.

(b) Development of c's credit market increases c's extraction effort, provided c's property rights are sufficiently insecure: $\frac{dk_c^*}{d\delta_c}|_{\gamma_c \to 0} \geq 0$.

(c) Development of c's credit markets can decrease c's extraction effort, provided c's property rights are sufficiently secure: $\frac{dk_c^*}{d\delta_c}|_{\gamma_c \to 1} \leq 0$.

(d) An improvement in c's resource management effectiveness decreases extraction effort in c: $\frac{dk_c^*}{d\mu} \leq 0$. This result occurs for any level of property rights or credit markets.

Ultimately we are interested in empirically testing: (1) the direct effect of property rights on resource extraction effort (Proposition 1a), (2) the interacting effects of credit markets and

[13] Most of our mathematical results involve weak inequalities. This is indicated by the mathematical results, but in the interest of brevity of the proposition, we suppress the word "weak".

property rights on resource extraction effort (Proposition 1b-c), and (3) the effect of management effectiveness on resource extraction effort (Proposition 1d).

3 Background on global fisheries

Global fisheries present an ideal setting in which to test our theoretical predictions for at least three reasons: (1) The stock is a globally-shared common-pool renewable resource, (2) property rights vary substantially across countries, fish species and through time, for both institutional and ecological reasons, and (3) credit markets could plausibly have significant impacts on extraction behavior. By building a first-of-its-kind global dataset on fisheries, property rights, and financial development, we are able to empirically test the predictions from the theoretical framework presented above. The dataset covers 4,692 fish stocks from 772 fish species (the majority of global fisheries) in 130 countries over a period of 53 years.

An ideal experiment for testing the impact of credit market development on resource extraction under varying levels of property right security would randomly assign different levels of credit market development and property right security to otherwise identical fisheries. We would then observe extraction effort and test whether credit market development increased, or decreased, resource extraction effort, and how that result depended on property right security.

Although property right security is not randomly assigned to fish stocks in the real world, we exploit the country level implementation of exclusive economic zones (EEZs), which dramatically changed the institutional setting of more than 90 % of global fish stocks (Ebbin et al., 2005; Englander, 2019). The establishment of each country's EEZ arose out of an international agreement and altered property rights for all marine resources, not just specific fisheries. In fact, much of the discussion around the introduction of the EEZs focused on energy and mineral resources (Bailey, 1984).[14] We therefore argue that the timing of the roll-out of EEZs can be considered exogenous to the status of individual fisheries, though our approach does not

[14] A comment from US Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs on the implementation of EEZs illustrates the debates around the implementation of EEZs during the early 1980s: "We are discussing an institution that would exert supreme control over the deep oceans and their mineral wealth representing over 60% of the resource potential of planet Earth" (cited in Robertson (2008)).

hinge on this assumption.

The implementation of EEZs did not assign secure property rights to all fisheries alike. Even a single country's control varies substantially across the species residing in its EEZ. There are two basic reasons for this. First, fish swim. They move in and out of EEZs, and the mobility varies across species; for example, a single shark can easily traverse thousands of kilometers over its lifetime, while a clam may move just meters. This would suggest, for example, that a country's property right would be more secure for clams and less secure for sharks. Second, even holding mobility constant, the geographic distribution relative to countries' EEZs differs across species. For example, tuna tend to reside far from land (and thus are more likely to traverse EEZs), while snapper tend to reside in the rocky nearshore habitat (and are thus less likely to traverse EEZs). Additionnaly there is variation in property rights within the same species across countries. While a one species could have the majority of its range (the geographical distribution) in one country's EEZ, it may only extend marginally in a second country. The reverse may be true for a different species because species differ in their ranges (e.g. tropical versus polar species). The country with the marginal share of the species' range in its EEZ has limited control over the resource stock compared to the other country that hosts the majority of the fish stock in its EEZ. We exploit these biological differences across species by combining measures of the mobility of species with the share of the species' distributional range that lies within an EEZ to define the share of the resource stock controlled by an individual country. Thus, following the implementation of its EEZ, a country's property right security will differ across all species residing in its waters. Our property rights measure is directly related to the parameter γ_c in the model presented above (recall, γ_c is the fraction of the stock controlled by country c).

Even assigning perfectly secure property rights over resources may not solve the problem of over-extraction. Resource economist have long recognized the importance of resource management for efficient resource extraction (Clark, 1990; Arnason, 2012). In recent empirical tests, Costello et al. (2008) and Birkenbach et al. (2017) for example, show that the introduction of individual transferable quotas for fisheries management reversed the collapse of global fisheries and slowed the race to fish. Here, we argue that the introduction of individual transferable quotas was only possible because of the previous introduction of EEZs. Similar to Isaksen and Richter (2019), we take the view that resource management is likely to be endogenous and depends crucially on property rights and the ability of governments to enforce those rights. This idea that governance, in addition to secure property rights, plays a role in extraction incentives is captured by the parameter μ in the theory part of this paper. In our empirical test, we employ governance indicators to capture the notion of regulation and enforcement.[15]

Recalling our ideal experiment, we observe that changes to credit markets are also not randomly assigned to fisheries around the world. Rather, credit markets vary in response to policies (such as rural credit subsidies or banking regulations), technological progress (such as microfinance and mobile money), and general economic development and the demand for capital. Indeed, credit market development may be either driven by economic development or may drive economic development (Levine et al., 2000). To address concerns about endogeneity of credit markets, we exploit the interconnectedness of financial markets with an instrumental variable approach, predicting domestic credit market contraction and expansions with export shocks of international financial trading partners. Further, overall credit markets may characterize the financial environment of resource users only imperfectly, we conduct a robustness test where we use credit to the resource sector while controlling for general financial development.

In the next sections, we describe our data in detail before we introduce our estimation strategy and results.

3.1 The status of global fisheries

Global fisheries generate over 100 billion USD in revenue annually (Arnason et al., 2017) and employ about 57 Million people directly (FAO, 2016). In addition to their importance in terms of resource rents, they are the major source of protein, essential fatty acids, and nutrition for

[15] Some international agreements exist to jointly manage fisheries, though with mixed success. The most prominent agreements are the regional fishery management organisations (RFMOs) that help manage fisheries in the high seas. A full treatment of RFMOs is beyond the scope of this paper. They have, however, few implications for the empirical strategy because they mostly came into force decades after EEZ implementation (Li et al., 2021; Pons et al., 2018) and cover only a limited set of species.

many of the global poor (FAO, 2016; Costello et al., 2020). Despite their importance, many global fisheries are depleted below the level that maximizes long-run extraction (Figure 1), and it is widely agreed that an important cause of overfishing is over-investment in extraction capital (Clark, 2006; Kelleher et al., 2009). Resource economists often point to insecure property rights over the resource as the major driver of overfishing, but the theoretical model above suggests a more nuanced and economically rich interplay between credit markets, property rights, and institutions. Our empirical test aims to evaluate this hypothesis.

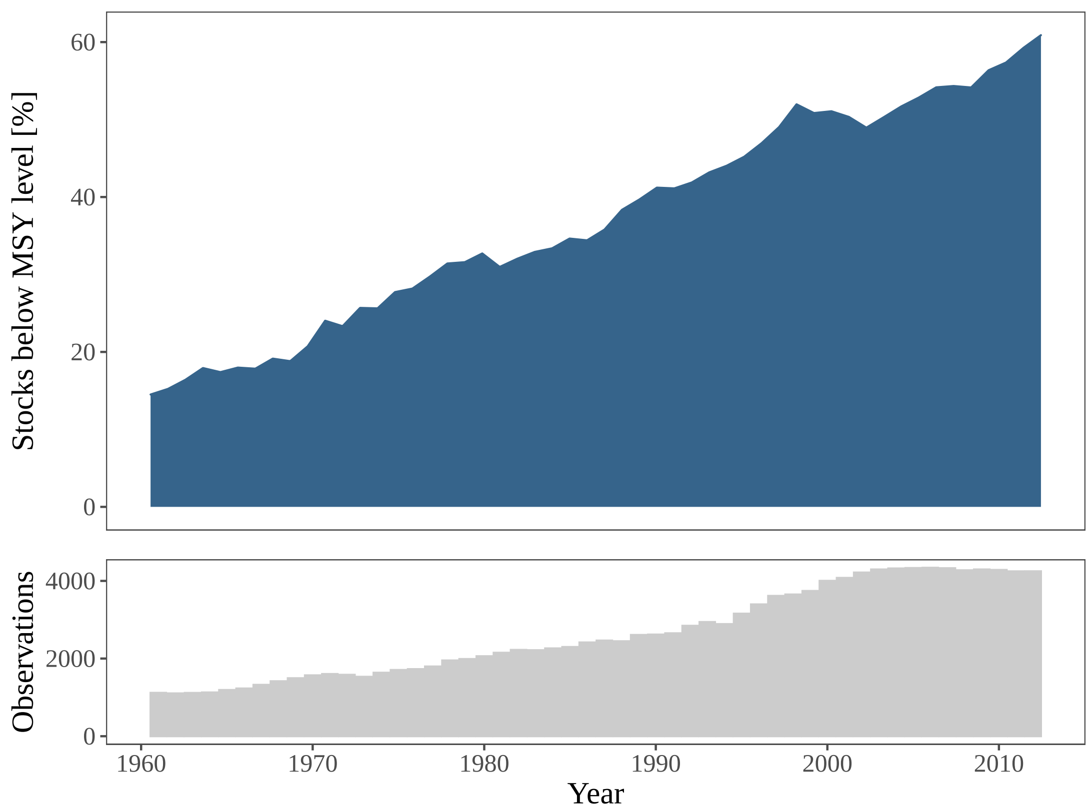

Figure 1: The figure shows the share of global fish stocks with biomass levels below the level that would maximize long-run extraction (MSY level) in blue and the number of observations in our panel in gray. The data are from (Costello et al., 2016).

Overfishing can cause large economic losses when resource stocks are driven to levels that compromise fish catch. Current estimates of the annual global inefficiency from mis-managed fisheries ranges from 53 Billion USD (Costello et al., 2016) to 86 Billion USD (Arnason et al., 2017), or even 90 Billion (Sanchirico and Wilen, 2007); most of the losses from overfishing occur in the developing world. This literature implies that improvements in institutions that allow fish stocks to rebuild and facilitate the capture of resource rents would deliver large global gains that would accrue disproportionately to the poor.

4 Data

In this section we describe the data used to measure resource extraction, property right security and credit market development. Further data to control for the gross domestic product (GDP) in constant 2010 USD are taken from the World Bank World Development Indicators.

4.1 Resource extraction in the fishery

We measure resource extraction using a panel of fish stocks and fish catches that covers 4,692 fish stocks from 130 countries over the period from 1960 to 2012. The sample includes the vast majority of all commercially exploited fish stocks globally, but small-scale fisheries in developing countries are likely underrepresented due to the paucity of data.

We adopt the convention of measuring the resource extraction rate relative to the extraction rate that would achieve maximum sustainable yield (MSY) and express the value in percent.[16] For example, an extraction rate of 150 indicates that the current extraction rate is 50 % higher than the extraction rate that would achieve MSY. In that case, the fish stock would decline over time, ultimately yielding less total extraction than MSY. There are several advantages of this measure. First, it makes resource extraction comparable across all stocks (e.g. the value 150 has the same interpretation whether the stock is a small coastal fishery or a large industrial one). Second, it facilitates interpretation. A resource extraction level above 100 indicates an extraction rate that would lead to a long-term decline (and if large enough, a collapse) of the resource stock.[17] The data on catches and stock sizes are from Costello et al. (2016) who

[16]Fishing mortality, F is the ratio of extraction to biomass. The convention is to scale F by the value of F that would return MSY, so the resource extraction rate is F/F_{MSY}. We multiply by 100 for ease of interpretation, giving a final statistic of $F/F_{MSY} \times 100$.

[17]However, a temporary extraction level above 100 could be economically optimal for an under-exploited fish

compiled fish catches from the RAM Legacy Stock Assessment Database (Ricard et al., 2012) and the Food and Agriculture Organization (FAO). The data for fish stocks sizes are either from stock assessments (stocks from the RAM database) or from data-poor empirical models Costello et al. (2016). In one robustness test, we restrict our analysis to the raw data from the most recent RAM Legacy Stock Assessment Database.[18] This recent dataset covers over half of global fish catches. However, as stocks in the RAM database (i.e. those with formal stock assessments) tend to be concentrated in countries with both secure property rights and high levels of credit market development, we use the complete data set for our main specification in order to increase the external validity of our results.

We further clean the data in the following ways: First, we exclude all resource stocks not identified to the species level (such as "tuna-like fishes"). Second, we exclude all stocks with fewer than ten years of observations since, for these stocks, we cannot distinguish between newly exploited or newly recorded species which could potentially bias our results. Figure 1 suggests that new stocks are added to the data over time. To test for potential bias arising from the non-random addition of stocks, we use only the balanced panel of fish catches in a further robustness test.

Figure 2 provides the summary statistics for the extraction rate by country over the entire time period. Although the figure visualizes the variation in our data, it is not reflective of current extraction since it is based on the complete time series. Current extraction rates are summarized in Appendix A.13. In the next subsection, we show how the introduction of EEZs fundamentally altered property rights over these resources.

4.2 Property rights over fish stocks

Until the mid-1900's the ocean fisheries of the world had limited scope for economically rational exploitation. Before the 1982 United Nations Convention on the Law of the Sea (UNCLOS), countries' legal rights to marine resources extended only 12 nautical miles (nm) (22.2

stocks, emphasizing the importance of understanding the underlying stock of fish. We therefore include the lagged estimated stock size (again, relative to the stock size at MSY) as a control in a robustness test.

[18]RAM Legacy Stock Assessment Database, Version 4.495, released 2021-05-27

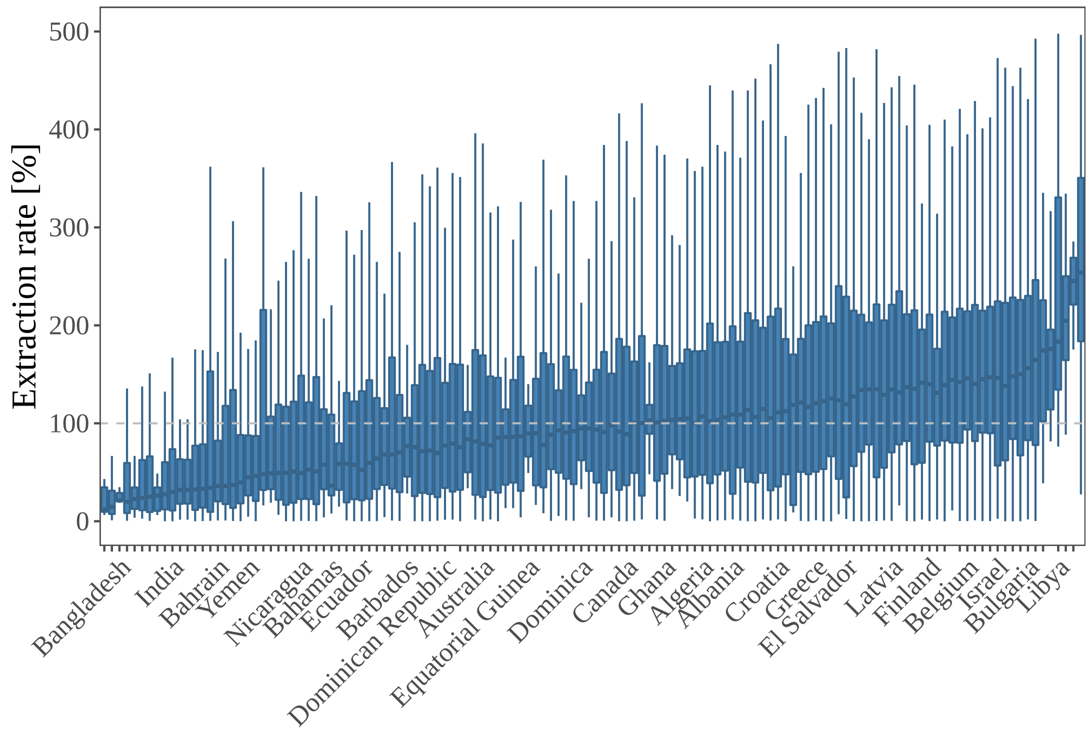

Figure 2: The boxplots show the median, the 25th and 75th percentiles as well as the minimum and maximum (excluding outliers) of the extraction rates by country over the complete time period (1960 to 2012). Extraction is expressed relative to the extraction that maximizes long-term extraction (=100). The grey dashed line is the MSY level (100 %).

km) from their coastlines. And even within this zone, countries rarely took firm steps to enclose the commons. This left the majority of fish stocks under open access. Fisheries regulations were further hampered by the fact that most fish stocks' ranges extended beyond 12 nm, so domestic management was often thwarted by other nations. This situation changed dramatically with the adoption of UNCLOS because it granted an EEZ of 200 nm (370 km) to each coastal nation and therefore established de jure property rights over marine resource in the most productive zones of the oceans.[19] The agreement assigned the exclusive property right to all marine resources within a country's EEZ. UNCLOS was widely regarded as a blanket assignment of property rights including nearly all productive coastal waters, amount to about 90 % of global fish stocks (Ebbin et al., 2005). Although all countries generally agreed to the EEZs, the implementation and the enforcement of the law differed significantly between countries. While some countries implemented EEZs unilaterally even before UNCLOS (for example India and Norway had implemented their EEZ by 1977), others implemented their EEZs much later. The delay of the implementation is largely unrelated to the economic development of the country but rather driven by conflicts about overlapping EEZ claims (for example, many countries bordering the Mediterranean Sea including Italy or Tunisia did not implement their EEZ until the mid 1990s or early 2000s due to overlapping EEZ claims). We extract the year of implementation of EEZs from the Sea Around Us Project (Pauly and Zeller, 2015). For the purposes of this study, we will interpret the implementation date as marking the date of transition from open access to spatial property right over the stocks that reside in a country's EEZ.

Fish are mobile and move within their distributional range. While some of these ranges are small and completely contained within an EEZ other ranges are large, encompassing several oceans. Thus, even the implementation of EEZs did not bestow full ownership of all fish stocks to individual countries; ownership depends on the share of the species' range that falls within the country's EEZ. To quantify this biological dimension of property right security, we use the share of the total distribution range of a species that falls into a specific EEZ. The data on the distribution of species is based on the habitat requirements and is therefore exogenous to the status of the stock.[20] Figure 3 shows the distribution of all species' ranges that are contained within EEZs. The variation in the species' ranges that are contained within EEZs over time is caused by the EEZ implementation. Within a year, variation across species is determined by the differences in the species' ranges and their overlaps with all EEZs.

[19]The areas of the EEZs often exceed the land mass of the associated country. For example, the EEZ of the US is about 2.6 times larger than the total land area of the US; the EEZ of New Zealand is 15 times larger than its land area.

[20]The data and methods are from Molinos et al. (2016).

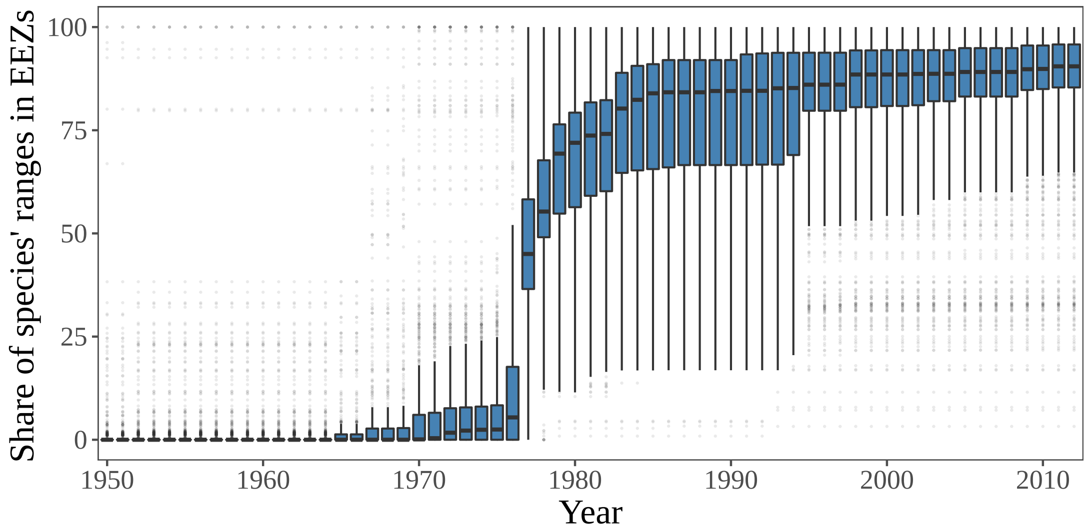

Figure 3: Distribution of the share of fish species' ranges contained within EEZs. The boxplots show the 25th, 50th and 75th percentiles of the distribution in each year. The bars show the minimum and the maximum of the distribution (excluding outliers). The dots are observations outside this range (outliers).

The share of a stock inside each EEZ only partially captures the security of property rights to the stock because it fails to account for the mobility of each species within its range. While some species such as tuna move constantly within their distributional range, other species such as shellfish are largely immobile. We therefore introduce a mobility parameter that we use to account for the mobility of a species within its total distribution range. Accounting for these components, our measure of property right security is defined as follows:

$$PR = \text{EEZ} \times \text{R}^{\text{M}}, \tag{10}$$

where "EEZ" is a dummy variable that indicates whether a country has established an EEZ, 'R' is the share of the species total distribution that falls into the EEZ of a country and "M" is the mobility parameter. The mobility parameter determines the importance of the distribution range for establishing property rights over a fish stock. For immobile species (for which M$=0$), such as many shellfish, property right security is completely determined by the implementation of an EEZ.[21] Other highly mobile species such as tuna or sharks constantly move within large

[21] Here, we abstract from the dispersal of eggs and larvae to simplify the biological dimension of property rights.

parts of their distributional range, and we set the mobility parameter to M= 0.2, based on the empirical results from a large tracking study of pelagic species by Block et al. (2011). We set the mobility parameter to M= 0.1 for all other species.

While resource management plausibly depends on property rights, it may also depend on the institutions to enforce those rights. In a robustness check, we introduce the Rule of Law Index (ROL) from the Worldwide Governance Indicators of the World Bank (Kaufmann et al., 2011) as well as the Property Rights Protection Index (PRP) from Ouattara and Standaert (2020) as measures of property right enforcement. Both indices are directly related to the enforcement of property rights. The ROL index was calculated every two years between 1996 and 2002 and then every year from 2002 onward for 193 countries. The PRP index covers 191 countries every year between 1994 and 2014. We interpolate the indices for missing values at the country level using Stineman interpolation (Moritz and Bartz-Beielstein, 2017) and carry the last observation backward until the EEZ introduction. We then normalize the index between 0 and 1 in line with the parameter μ in the theoretical section of this paper. The process is illustrated in Appendix A.7. However, we use Equation (10) for our main specification of property rights to avoid endogeneity and data quality concerns and use $PR = \text{EEZ} \times \text{R}^{\text{M}} \times ROL$ only in a robustness test.

Table 1 illustrates the components of our property rights measure for two common commercial species, yellowfin tuna (Thunnus albacares) and Caribbean spiny lobster (Panulirus argus), in the United States and Mexico and for the year 2012. Both species have considerable economic importance but while the tuna is a pelagic species with a large range and high mobility within its range, the lobster is a shellfish with a relatively small range and limited adult mobility. The first column of Table 1 indicates that both countries had implemented their EEZ in 2012. The ability to establish secure property rights over the fish stocks is, however, mediated by the distribution of the stocks across multiple EEZs and the high seas. Although the share of the lobster's range in both EEZs is about ten times larger than the share of the tuna's range with the EEZs, the range parameter (R) is in fact very small in both cases. In column (3), we account for mobility by introducing the parameter $M \in [0,1]$ which we set equal to $M = 0.2$ for yellowfin tuna and $M = 0$ for spiny lobsters. One interpretation of these calculations is that yellowfin tuna stay about 39 % (R^M=0.39) and 42 % (R^M=0.42) of their time in the EEZ of the US and Mexico respectively, which is in line with the findings of Block et al. (2011). Column (3) is the definition of property right security that we use in our main specification. It suggests that property rights over these two species are very similar across the two countries, but very different across species. However, this measure neglects different abilities of countries to enforce property rights. Columns (4) and (5) introduce the enforcement component of property rights. These indices suggest a difference between countries' abilities to enforce property rights. The last two columns combine the biological and the enforcement components of property rights. Both columns agree that the tuna stocks in Mexico have the least secure property rights, while the lobster stocks in the United States enjoy the most secure property rights. We use these specifications in robustness tests.

Table 1: Property right security for yellowfin tuna and Carribean spiny lobster in the US and Mexico, 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EEZ	EEZ × R	EEZ × R^M	EEZ × ROL	EEZ × PRP	EEZ × R^M × ROL	EEZ × R^M × PRP
Mexico							
Yellowfin tuna	1.00	0.01	0.42	0.44	0.41	0.18	0.17
Spiny lobster	1.00	0.10	1.00	0.44	0.41	0.44	0.41
United States							
Yellowfin tuna	1.00	0.01	0.39	0.90	0.87	0.35	0.34
Spiny lobster	1.00	0.16	1.00	0.90	0.87	0.90	0.87

Notes: "EEZ" indicates whether a country has established an EEZ , "R" is the share of the species' range within an EEZ relative to the total distribution of a species, "M" is the mobility parameter, "ROL" is the Rule of Law Index, and "PRP" is the Property Rights Protection Index.

4.3 Credit market development

Fundamentally this study is about credit markets and how they affect resource extraction under different levels of property right security. To measure credit market development, we use domestic credit to the private sector relative to GDP as well as the country average interest rates charged by banks for loans to the private sector. The lending interest rate measures the cost of capital, and we directly relate it to the discount factor in Section 2. However, the comparison of interest rates across countries is complicated by the differences in conditions attached to the loans. We therefore use the volume of private credit relative to GDP levels as our main indicator of credit market development. This is one of the most common indicators of credit market development in the financial literature (Levine et al., 2000; Beck and Levine, 2004; Aghion et al., 2010, 2014; Leibovici, 2021).

Data on domestic credit to the private sector are from Beck et al. (2000a) and are updated by the World Bank. Data on lending interest rates are provided by the International Financial Statistics from the International Monetary Fund (IMF).

However, we acknowledge that the volume of credit and the private sector interest rates may be imperfect measures of credit market conditions facing fishermen. We make use of an FAO dataset on the total volume of credit to the agriculture, fisheries, and forestry sector as well as the volume of total credit to the private sector. The data cover the period from 1991 to 2015 and include 101 countries. Although the spatial and temporal extent of this dataset is not as extensive as our fishery data, it allows us to test the robustness of the results by using sector specific credit data while controlling for the volume of credit to the rest of the economy.

Inflation affects interest rates directly and through financial policies. We therefore control for inflation using the consumer price index from the World Bank financial development indicators. Still, the recorded interest rates become unreliable in periods of hyperinflation. We therefore exclude all periods of hyperinflation with inflation rates exceeding 30 % per year when we use the interest rates to describe credit market development.

Figure 4 illustrates the dynamics of credit market development. We highlight five countries from different continents and with different levels of economic development. Panel A) shows domestic credit to private sector relative to GDP and panel B) depicts the development of the lending interest rates over time. There are substantial differences in the volume of credit and interest rates across countries and within countries over time. The figure also shows that the credit data (panel A) include more countries (Norway is missing in the interest data) and span longer time periods than the interest rate data (panel B).

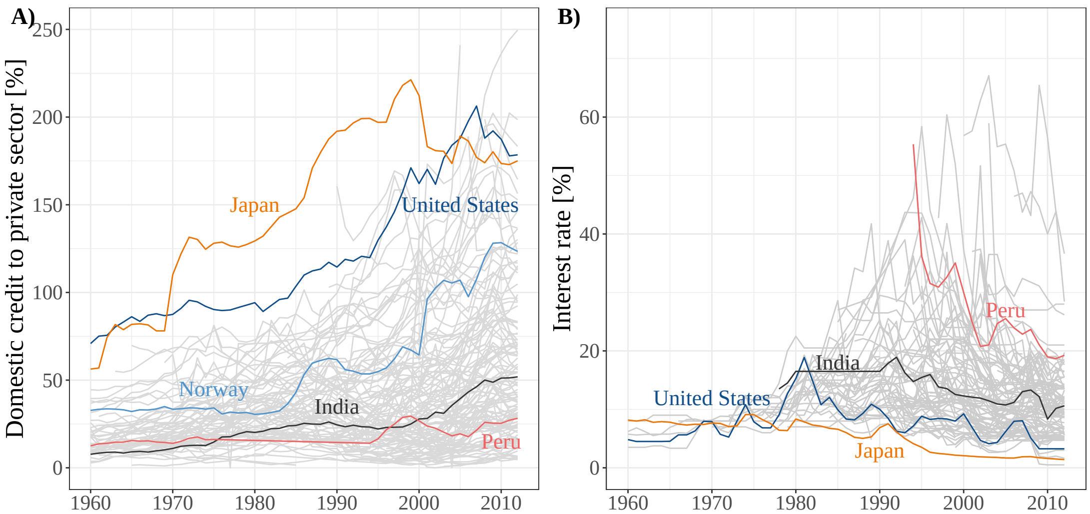

Figure 4: Panel A) shows the development of domestic credit to the private sector relative to GDP by country. Panel B) shows the development of the nominal lending interest rates by country. Each line represents a different country.

The figure also suggests that countries with high volumes of credit such as Japan or the United States tend to also have low interest rates, while countries with low volumes of credit such as Peru or India tend to have high interest rates. Figure 5 plots country level time series of interest rates and the volume of domestic credit to the private sector against each other. We highlight the same countries as in the previous figure and add fitted lines from selected country level linear regressions. The figure suggests that the negative relationship between the volume of credit and the level of interest rates holds both across countries and within countries over time.

To facilitate interpretation of the results and to directly relate them to the model presented above, we transform the interest rate into a discount factor i.e. $\delta = \frac{1}{1+r}$. Similarly, we transform the inflation rate into an inflation factor.

4.4 Financial networks

Economic development and technological progress could drive credit market development as well as resource extraction, giving rise to omitted variable concerns. To address this, and other

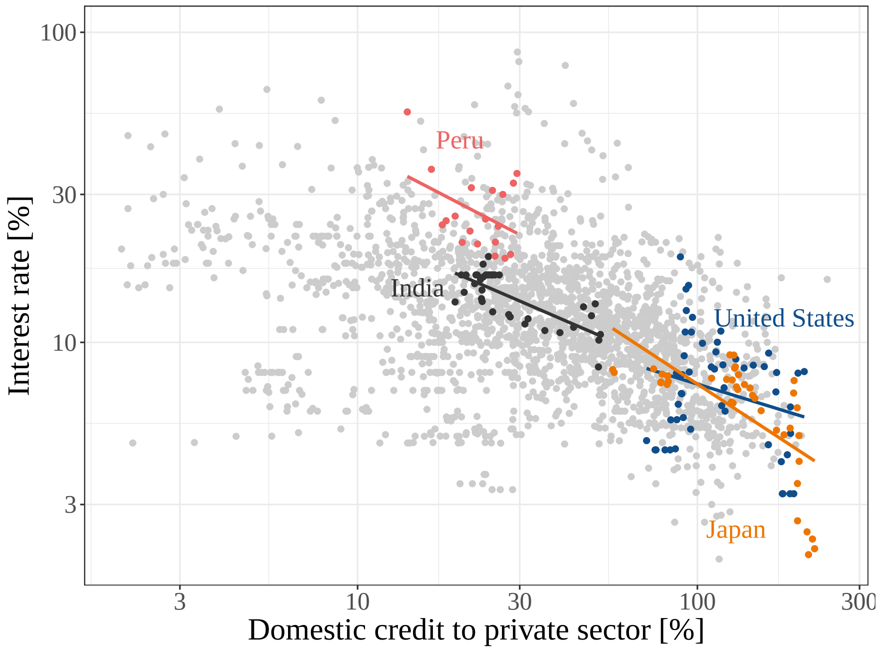

Figure 5: Nominal lending interest rates and domestic credit to the private sector relative to the GDP level by country and year. The lines visualize country level linear regression models.

endogeneity concerns about credit markets, we introduce an instrument for the volume of credit based on the interconnectedness of global financial markets. We combine credit export shocks of financial partner countries with a measure of financial dependency using the Locational Banking Statistics (LBS) of the Bank for International Settlements (BIS). The LBS records financial flows of banks located in 48 reporting countries to counterparties residing in more than 200 countries (including constituent countries) between 1977 and 2021. It comprises 95 % of all cross-border claims of all banks worldwide.[22]. The main purpose of the LBS is to measure the risk exposure of banks to international financial shocks, which is the central idea of our instrument (see Section 5.1 for a description of the instrument). This novel instrument is inspired by shift-share instruments (Adao et al., 2019), and is composed of two elements, an *exposure* and a *shock*. However, unlike traditional shift-share instruments, our shock component differs across countries. In the following, we define the export of financial services from country k to

[22] `https://www.bis.org/statistics/about_banking_stats.htm?m=6_31`

country j as the total cross-border claims of country k to all economic sectors in country j.

Exposure: We calculate the exposure of country j to a financial shock in country k using the export of financial services from country k to country j relative to the sum of financial exports from all countries to country j. We then use the mean over the complete time period to construct a time-invariant weight. Repeating this step creates a matrix of weights that measure the dependence of all importing countries (the counterparty countries in the LBS) to shocks in all exporting countries (the reporting countries in the LBS).

Shock: We measure financial export shocks of country k to importing country j as the sum of financial exports from country k to all other countries, excluding country j. We exclude country j to avoid reverse causality. This step creates a matrix of shocks for each year that are unique to all possible pairs of importing (the counterparty countries in the LBS) and exporting countries (the reporting countries in the LBS). We discuss the construction of the instrument and its validity in Section 5.1.

5 Estimation strategy

Here, we describe our empirical strategy for estimating the impact of property right security and credit market development on resource extraction. In our main specification, we estimate

$$\text{Extraction}_{ijt} = \beta_1 \, \text{PR}_{ijt} + \beta_2 \, \text{Credit}_{jt} + \beta_3 \, \text{PR}_{ijt} \times \text{Credit}_{jt} + X_{jt}\varphi + \nu_{ij} + \theta_t + \varepsilon_{ijt} \qquad (11)$$

using ordinary least squares (OLS) estimation. Here "Extraction_{ijt}" denotes the extraction effort of stock i in country j at time t relative to the MSY rate measured in percent (as explained above). The variable "PR_{ijt}" indicates the level of property right security as defined by equation (10), and is equivalent to the parameter γ_c in Section 2. The variable "Credit_{jt}" captures the total volume of credit to the private sector. The term "$\text{PR}_{ijt} \times \text{Credit}_{jt}$" captures the interaction between property rights and credit (which will allow us to test Propositions 1b-c). The vector of variables "X_{jt}" contains GDP and GDP^2 to control for the general development of a country. Lastly, "ν_{ij}" are country and fish stock fixed effect, "θ_t" are year fixed effects, and "ε_{ijt}" is the error term.

We transform all variables except the property rights variable (and the fixed effects) using inverse hyperbolic sine (IHS) transformation (Burbidge et al., 1988). The interpretation of the coefficients as elasticities is similar to log transformed variables, but the transformation is also defined for zeros, which are common for extraction rates.[23] The transformation reduces the skewness of the distributions but also implicitly assumes an isoelastic relationship between credit market development and the extraction rate. Although isoelastic relationships often result from isoelastic production functions such as Cobb-Douglas or CES we cannot tie this assumption directly to Proposition 1. We leave the property rights index untransformed in line with our theory and to facilitate interpretation.

Differences in levels of credit market development across countries are absorbed by country level fixed effects. However, cross-country differences in the levels of credit market development affect estimates of the interaction effects, even if country level fixed effects are included (Balli and Sørensen, 2013). We therefore demean the credit market development indicators at the fish stock-country level. This has important implication for the interpretation of the parameters. While β_2 measures the impact of credit market development under open access, the sum $\beta_2 + \beta_3$ represents the impact of credit market development under secure property rights. The parameter β_1 reflects the impact of property rights on extraction rates under mean fish stock-country specific levels of credit market development. A short note on the order of the transformations: The variables are first IHS transformed, then demeaned and then squared (if applicable).

The variables in our dataset are likely to be correlated within groups such as countries, fish species or years. To account for the correlation of errors, we cluster our standard errors at the year, country and species level using multi-way clustering.[24]

[23]The interpretation is only correct for sufficiently large values of the transformed variables. Bellemare and Wichman (2020) suggests a threshold of 10. The mean value of the dependent variable is 147 % while the mean values of our credit market indicators are 62 % and 11 % for the volume of credit and the interest rates respectively.

[24]In contrast to many studies, our data do not consist of a random sample, but rather of the majority of commercial fishing activities over the relevant time period. Missing observations may be systematically different (e.g. small scale fisheries in developing countries) and we do not claim external validity of our results for those missing fisheries. Abadie et al. (2017) suggest that accounting for correlations between residuals within clusters is not necessary if the correlation of errors is not the result of the sampling procedure, but rather coming from the structure

Unobserved variables related to economic development or technological progress could determine credit market development as well as resource extraction. Including GDP as control in our regression specifications addresses the problem only partially. In a second approach, we additionally include country level time trends to capture additional trends of these confounding variables. However, this only addresses the problem if the growth rates of the confounders are constant (note that our variables are IHS transformed). We therefore test the robustness of our result with an instrumental variable approach, described below.

Property rights are characterized by a combination of biological features (geographic range and mobility of species) and the EEZ implementation. Above, we argued that they are exogenous to the extraction status of individual resource stocks. To address concerns about the endogeneity of the EEZ implementation, we add a robustness test with country by year fixed effects that uses only the property rights variation across stocks within one country to estimate the impact of property right security on resource extraction. However, country by year fixed effects absorb the variation in credit markets in this specifictaion such that we are unable to use it for our main results. A second concern is that fish stocks with eventually high and low property right security follow different trends. We address this concern in our event study approach (see below).

In any given year, resource abundance may itself affect extraction. To partially address this, our outcome variable expresses extraction relative to the contemporaneous resource stock size, thus taking changes in the resource base directly into account. In addition, we add the lagged resource stock as a control in a robustness test to address concerns of direct interactions between countries via the resource stock. But it is possible that changes in extraction by other countries (the fringe) may affect the incentives of the focal country not only through resource abundance itself but also through prices; if country j extracts more, perhaps this reduces the output price for country i. For two reasons, we believe this price channel is unlikely to pose a problem in this empirical setting. First, fish are extensively traded around the world (nearly

of the population as is the case for our data. However, we follow the convention and cluster our standard errors at the year, country and species level using three-way clustering. As a result, our standard errors are rather on the conservative side.

40% of fish are exported), so prices are largely harmonized. Second, while hundreds of different species are commercially extracted, there is a great deal of demand substitution across them. So while each of these species is considered a "fishery", their output prices are largely set in a common market. Indeed, a recent study treats all wild-caught marine fish as market substitutes (Costello et al., 2020).

Our measure of domestic credit to the private sector is likely an imperfect measure of credit available to fishers. Further, total credit could stimulate the whole economy, with indirect consequences for extraction either through output demand or the opportunity cost of extraction. In a further robustness test, we therefore use credit to the renewable resource sector (agriculture, forestry, and fisheries) as our main independent variable while controlling for total credit to the private sector. Although we prefer this approach generally, data on resource credit is available only from 1991 onward, allowing us to estimate the impact of credit on extraction only after the most significant changes in property right security (see Figure 3). A related concern is that small-scale fishers may have little access to official credit. In a robustness test, we restrict our data to OECD countries that are dominated by medium to large-scale commercial fisheries.

Although using data on all global fisheries has important advantages, it also presents some challenges. First, the data quality differs across countries and fish stocks; for example, stock assessments are undertaken annually for some species, but only periodically (or not at all) for others. Second, because it contains all harvested species, we need a way to distinguish target catch from economically less important fish species that are mainly caught as bycatch. Third, not all fish stocks are observed over the whole time period, partly because new fish stocks were exploited and partly because overharvested stocks sometimes collapse (and thus become unfished). We address these challenges by including robustness tests that restrict the data to 1) countries with generally high data quality (OECD countries), 2) fish stocks with formal stock assents and high data quality (RAM stocks), 3) a balanced panel of fish stocks that are present throughout the whole time period and 4) economically important species excluding bycatch species (top 10 % of species by value during the period from 2000 to 2012).

A rapidly growing literature on difference-in-differences methods suggest that estimates based on the differences in the timing of treatment (staggered adoption) are potentially biased

(Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; Sun and Abraham, 2021). Although the implementation year of EEZs varied across countries, for the vast majority of global fish stocks it occurred over a narrow time window (see Figure 3), thus limiting the extent of the potential bias. However, to address this possible concern, we discuss the dynamic effects of property rights on resource extraction and correct for staggered adoption based on Callaway and Sant'Anna (2021) before we introduce our main results. To do so, we convert our continuous property rights variable into a dummy that is one for a property rights value larger than 0.5 and is zero otherwise.

5.1 Instrumental variable approach

Credit markets do not develop in a vacuum. Instead, they are likely driven by general economic development and technological progress with potentially direct implications for resource extraction. Including GDP and GDP^2 as controls or adding linear time trends may help, but only partially solve the problem. To strengthen our results further, we use an instrumental variable (IV) to predict credit market expansions in a two-stage least squares (2SLS) approach. The main idea of our IV is that financial shocks are transmitted through financial networks, a mechanism that contributed to the global financial crisis in 2007-08 (Glasserman and Young, 2016). Our instrument combines financial shocks in partner countries with exposure to those shocks; in this way, it is similar to shift-share instruments Adao et al. (2019); Goldsmith-Pinkham et al. (2020); Borusyak et al. (2022). A key difference between our instrument and traditional shift-share instruments is that our shock variable differs across countries. We define the IV for the volume of credit in country j as the weighted sum of financial exports of all partner countries of country j to all countries other than country j. This shock variable differs across countries for two reasons. First, country i's partners may be different from country j's partners (e.g Chile may receive financial services from different countries than does Nigeria). Second, the focal country is omitted from the export shocks, making them exogenous to credit demand of country j. This shock exogeneity supports the validity of our instrument (Borusyak et al., 2022). Our two first-stage regressions are defined as

$$\text{Credit}_{jt} = \alpha_{11}\,\text{PR}_{ijt} + \alpha_{12}\,\text{IV}_{jt} + \alpha_{13}\,\text{PR}_{ijt} \times \text{IV}_{jt} + X_{jt}\alpha_{14} + \mu_{1ij} + \theta_{1t} + \varepsilon_{1ijt} \quad \text{and}$$

$$\text{PR}_{ijt} \times \text{Credit}_{jt} = \alpha_{21}\,\text{PR}_{ijt} + \alpha_{22}\,\text{IV}_{jt} + \alpha_{23}\,\text{PR}_{ijt} \times \text{IV}_{jt} + X_{jt}\alpha_{24} + \mu_{2ij} + \theta_{2t} + \varepsilon_{2ijt}$$

with

$$\text{IV}_{jt} := \sum_{k=1}^{N_j} \sum_{\substack{l_k=1 \\ l_k \neq j}}^{N_k} \omega_{jk} c_{kl_kt}.$$

Here, $k = 1,...,N_j$ are the financial partner countries of country j, $l_k = 1,...,N_k$ are the financial partner countries of country k, ω_{jk} is the weight of country k for country j and c_{kl_kt} is the export of financial services from country k to country l_k. The weight is defined as $\omega_{jk} = \overline{\left(\frac{c_{kj}}{\sum_h c_{hj}}\right)}$ where c_{kj} are the financial exports from country k to country j and $\sum_h c_{hj}$ are the total financial imports of country j. The weight is the defined as the mean of this ratio over the complete time period. While the credit variables are defined on country level, property rights are defined at the stock level. We therefore present an F-statistic in the following section that takes the correlation of errors into account.

The second stage is given by equation (11) but using the predicted instead of the actual values of Credit_{jt} and $\text{PR}_{ijt} \times \text{Credit}_{jt}$.

6 Results

This section presents the empirical results. We begin with our results on the impact of property right security on resource extraction and then turn to our main results on the interaction of property rights and credit markets.

6.1 Property rights and resource extraction

How does property right security affect resource extraction? We start by using only the most basic version of our property rights variable, and subsequently build to our aforementioned property rights index. Table 2 presents the results. The row "PR Definition" defines the property right variable for each specification. All specifications include fish stock, country, and year fixed effects as well as the volume of credit, GDP and GDP squared as controls (not shown). Standard errors are clustered at the country, year, and species level using multi-way clustering.

The first column uses only the EEZ dummy to measure property right security. This measure is uniform across all species within the EEZ of an individual country. Perhaps unsurprisingly, the results show that the establishment of an EEZ alone has no meaningful impact on resource extraction. However, interacting EEZ indicator with the share of the range of a species within a country's EEZ weighted by the species' mobility yields statistically significant results (column 2). Results suggest that increasing property rights from open access to complete property rights reduces extraction by 32 %. This is the main property right specification that we use throughout the remainder of this paper. The property rights variable in this specification varies both over time across countries and across species within a country. To demonstrate the importance of the variation in property rights across species, we introduce country by year fixed effects in column (3). These fixed effects absorb all country level variables including GDP and credit, as well as the differences in the timing of the EEZs across countries. However, the estimate for the impact of property rights on resource extraction amplifies in this specification, suggesting that the differences in the timing of the EEZ implementations are not driving our results. We obtain a similar result to our main specification when we interact the EEZ dummy with an indicator of the country's property rights enforcement, measured by the World Bank Rule of Law index (ROL) in column (4) or the Property Rights Protection index (PRP) in column (5). In column (6) we combine all three components of property rights. In this specification, both the coefficient estimate and the explanatory power (R^2) of the property rights index increase compared to all other specifications (noting that the explanatory power remains relatively small due to the stochasticity of fisheries). Column (7) introduces biological and enforcement components individually and interacted.[25] The result highlights the importance of institutions for resource regulation. It suggests that all three components of property rights (e.g. the legal framework, the biology as well as the enforcement) play important roles in effective regulation. Moving forward, to avoid complications related to endogeneity and enforcement data quality, we will use $PR = EEZ \times R^M$ as our main property rights definition.

[25] We demean all property rights components for this specification to facilitate interpretation.

We present results with $PR = EEZ \times R^M \times ROL$ as a robustness test in Apendix A.9.

Table 2: Resource extraction and property rights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Property right definition	EEZ	EEZ×R^M	EEZ×R^M	EEZ×ROL	EEZ×PRP	EEZ×R^M ×ROL	EEZ×R^M
Property rights	-0.062	-0.323***	-0.560***	-0.348***	-0.364***	-0.540***	-0.167*
	(0.061)	(0.104)	(0.201)	(0.098)	(0.102)	(0.129)	(0.098)
ROL							-1.98***
							(0.633)
Property rights × ROL							-1.58***
							(0.342)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes		Yes	Yes	Yes	Yes
Year FE	Yes	Yes		Yes	Yes	Yes	Yes
Country by Year FE			Yes				
Observations	151,979	151,979	151,979	151,961	151,686	151,961	151,961
R^2	0.573	0.575	0.623	0.575	0.575	0.576	0.579
Within R^2	0.013	0.017	0.004	0.017	0.017	0.020	0.026

Notes: The table reports the β_1 estimates of equation (11) without the interaction term of credit and property rights. The specifications differ only in their definition of property rights and the fixed effects. All specifications include GDP, GDP squared and the volume of credit as controls. All specifications include stock, country and year fixed effects. Specification (3) includes additionally country by year fixed effects (country and year fixed effects are absorbed). Standard errors are clustered at the country, year and species level using multiway clustering. All variables except for the property rights indicator and the fixed effects are IHS transformed. Independent variables are demeaned at the stock-country-level. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

Next, we discuss the dynamic impact of property rights on resource extraction while addressing the complications that result from the sequential introduction of the EEZs. Figure 6 compares event study graphs of two dynamic difference-in-differences estimations: 1) with a continuous but time constant property rights variable (R^M) and 2) a transformed binary property rights variable that is one for $R^M > 0.5$ and zero otherwise. The figure suggests that increasing property right security has a large and statistically significant impact on resource extraction effort. The figure shows further that the estimates are similar for the binary and the continuous property rights variable. However, the figure raises concerns about pre-trends, and fails to account for the problems arising from the staggered introduction of EEZs.[26]

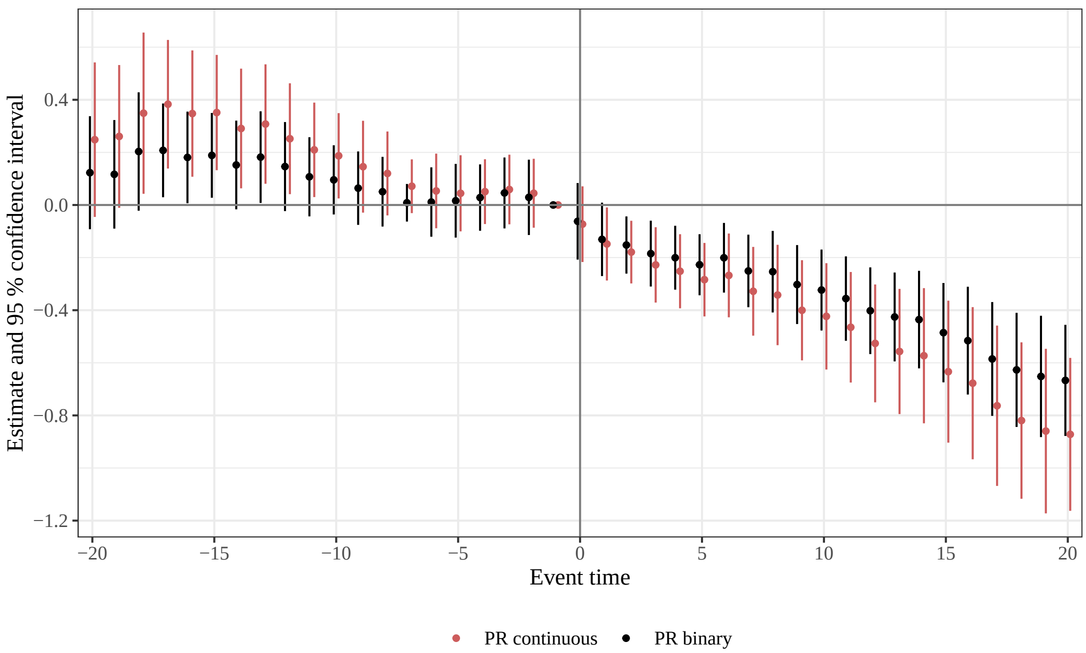

Figure 6: Event study of property rights and resource extraction with binary and continuous property rights. Event time indicates the time to the EEZ introduction. It is interacted with a time constant property rights variable which is R^M for the continuous specification and one if R^M>0.5 and zero otherwise for the binary specification. All specifications include stock, country and year fixed effects as well as GDP, GDP squared and the volume of credit. All variables except for the property rights indicator and the fixed effects are IHS transformed. Standard errors are clustered at the country, year and species level using multiway clustering. Estimates are based on an unbalanced panel that is restricted to 20 years or less from the event (n = 80,795)

To address these concerns, we re-estimate our dynamic difference-in-differences estimates with binary treatment using the method suggested by Callaway and Sant'Anna (2021) and a

[26]See e.g. Callaway and Sant'Anna (2021); Goodman-Bacon (2021); Sun and Abraham (2021) and Roth et al. (2022) for a recent overview of this rapidly growing literature.

balanced panel. Figure 7 presents the results of two specifications that differ only in their control groups. One specification (denoted "Never Treated") uses only those stocks that never receive highly secure property rights as the control group. The other specification ("Not Yet Treated") uses additionally those stocks that eventually receive high property right security as a control group. Importantly, the definition of the control and treatment group is exclusively defined by the biological component of our property rights variable. The standard errors are increased compared to Figure 6, largely because of the reduced number of observations, but the magnitude of the coefficients are similar. The figure further supports the parallel trends assumption. The weighted average treatment effect with weights proportional to group size is -0.59 (Standard Error 0.16). This estimate is very similar to the previous result which relied exclusively on the biological differences between resource stocks to estimate the impact of property rights on resource extraction i.e. Column (3) of Table 2.

We interpret these findings as strong support for our property rights measure and our theoretical predictions about the effects of property right security on resource extraction effort.

6.2 Main Results

This section presents our main results on the impact of credit market development on resource extraction under different levels of property right security. Here, we define credit market development as the volume of credit to the private sector; in the appendix we report results that instead use the private sector discount factor as the measure of credit market development.

Table 7 reports our main results. All regression specifications control for GDP, GDP^2 and include stock, country, and year fixed effects. Standard errors are clustered at the country, year, and species level using multi-way clustering.

The first column (Baseline) reports the result of our baseline regression specified in equation (11) but without the interaction between credit markets and property right security. This specification estimates the mean impact of credit market development on resource extraction across all levels of property right security. The results suggest that increasing the volume of credit to the private sector reduces resource extraction, although the estimate is small and not statistically significant. It further suggests, again holding all else constant, that increasing

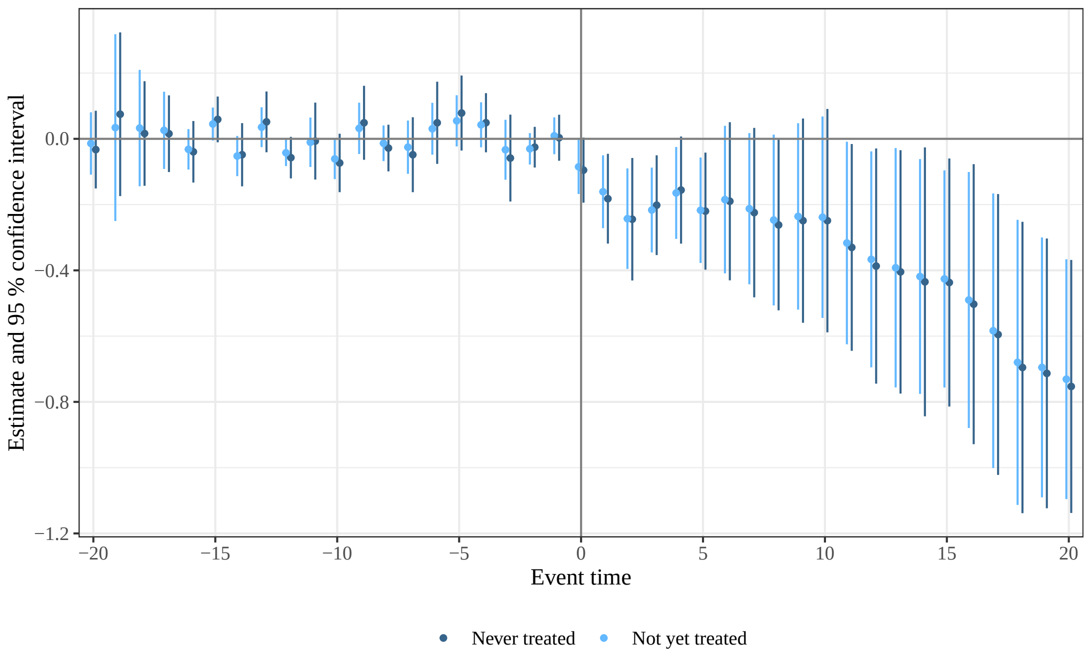

Figure 7: Event study of property rights and resource extraction using the method of Callaway and Sant'Anna (2021) for bias correction from staggered EEZ adoption. Event time indicates the time to the EEZ introduction. It is interacted with a time constant property rights variable, which is one if R^M>0.5 and zero otherwise. All variables except for the property rights indicator and the fixed effects are IHS transformed. Standard errors are clustered at the country level. Estimates are based on the complete balanced panel.

property right security reduces resource extraction by 32 %. This estimate repeats the result of specification (2) from Table 2.

Column 2 (Main) of Table 7 presents the results of our main specification, which includes an interaction term of credit market development with property right security over the resource. Including this interaction term allows us to test whether the effect of credit markets on resource extraction is mediated by property rights, as our theoretical model predicts. Changing the property right security from open access to secure property rights reduces resource extraction by 38 % in our main specification. The results show further that under open access, a one percent increase in credit to the private sector *increases* extraction effort by 0.16 %. In contrast, under secure property rights, the same increase of credit to the private sector *decreases* extraction effort by 0.29 %.[27] These findings accord with our theoretical prediction that credit market development leads to increased resource extraction effort under open access, but decreased resource extraction effort under secure property rights. They also show that increased property right security reduces extraction, plausibly because the resource extractor or regulator places more weight on future payoffs.Including country level time trends (column 3) reduces the estimates, but leaves the results qualitatively unchanged. The reduced estimate for the impact of property rights on resource extraction effort is perhaps unsurprising, since we showed in the previous section that property rights change both the level and the trend of extraction, and the impact of property rights on the extraction trend is partially absorbed by the country level time trend.

To address the concern of endogenous credit market development further, we introduce the aggregate financial flows from trading partners to countries other than the focal country as an instrument for the volume of credit in the focal country. Results from the 2SLS (IV) approach are reported in column (4). The first stage cluster robust Wald statistic is 26 for the credit instrument and 121 for the interacted instrument. Although the estimate for the impact of credit on resource extraction is increased, the result remains qualitatively unchanged. The increase in magnitude could result either from a) endogeneity bias, b) the differences between the local average treatment effect and the average treatment effect or c) the change in the considered time period (the instruments are defined only after 1977). The change in the time period also explains the reduced estimate for the impact of property rights on resource extraction.[28]

Columns (5) and (6) use the same estimation equation as the main specification, but restrict the sample to OECD countries (OECD) and a balanced panel of resource extraction (Balanced). The results are qualitatively similar to the main specification, though the precision of the estimates declines, likely due to the reduced number of observations.

Our fisheries data cover the extraction of nearly all species in the ocean. Most of the volume and value of this catch is from targeted species. But some species are caught unintentionally as

[27] The marginal effect of credit market development on extraction effort under secure property rights is given by the sum of the coefficient on Credit and the coefficient on Credit $\times$ Property rights.

[28] Using only the observations after 1977 in our main specification also reduces the estimate for the impact of property rights on resource extraction.

bycatch, and we would not necessarily expect our property right and credit market hypothesis to apply to those species. Column (7) attempts to neutralize this concern by restricting the data to the 10 % most valuable species (76 out of 761 species) targeted by commercial fisheries. Although bycatch species may benefit indirectly from more secure property rights (Burgess et al., 2018), they are often not the main target of management interventions. The increase in the estimated impact of property rights on the most valuable species support this notion.

The final two columns introduce two different datasets. Column (8) uses the raw RAM legacy database to measure resource extraction. These data are based on formal stock assessments and have therefore the highest quality standards. The database also covers more recent years. The magnitude of the estimates is increased, but the results are otherwise qualitatively similar to the main specification. Column (9) uses data on the volume of credit to the agricultural sector (including fisheries) to measure credit market development while including total credit as a control. Data on credit to the agricultural sector is available only from 1990 onward, which restricts the analysis to the period after the introduction of most EEZs. The results remain, however, qualitatively unchanged, although most of them become statistically insignificant.

All specifications test multiple hypotheses simultaneously, which increases the chance of false positives. While the literature on multiple hypotheses testing has traditionally focused on multiple outcomes, the recent literature expands the discussion to multiple independent variables (List et al., 2019). We report the conservative Bonferoni and Holm corrections for the p-values in Appendix A.8. Our main estimates remain, however, statistically significant at the 10 % level.

Appendix A.9 reproduces the results using our enhanced property right security measure, which includes EEZ implementation, the species' range and mobility, and the Rule of Law Index ($PR = EEZ \times R^M \times ROL$). Using this specification further strengthens our results. To further test the robustness of our results, we reproduce the results from Table 7 with the resource stock in the previous period and the country level total factor productivity (from the Penn World Tables) as additional controls. The results are shown in Appendix A.10. They remain qualitatively unchanged.

Table 3: Resource extraction, property rights and credit market development

	Baseline	Main	Trend	IV	OECD	Balanced	Top10	RAM	Ag. Credit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Property rights	-0.323***	-0.382***	-0.183**	-0.236	-0.210*	-0.485***	-0.529***	-0.747**	-0.205
	(0.103)	(0.104)	(0.083)	(0.149)	(0.114)	(0.147)	(0.188)	(0.313)	(0.167)
Credit	-0.099*	0.164**	0.116*	0.942**	0.152	0.202*	0.089	0.796**	0.077
	(0.056)	(0.080)	(0.060)	(0.422)	(0.154)	(0.101)	(0.087)	(0.343)	(0.071)
Credit × Property rights		-0.449***	-0.233**	-1.35***	-0.206	-0.507***	-0.468***	-0.806***	-0.222**
		(0.115)	(0.096)	(0.384)	(0.142)	(0.157)	(0.164)	(0.294)	(0.104)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country trend			Yes						
Observations	152,145	152,145	152,145	125,362	101,634	56,514	58,122	16,955	32,259
R^2	0.575	0.578	0.607	0.574	0.537	0.630	0.661	0.644	0.680
Within R^2	0.017	0.022	0.002	-0.013	0.005	0.050	0.050	0.025	0.020

Notes: The table reports the estimates from equation (11) for β_1, β_2 and β_3. All specifications include GDP and GDP squared as controls as well as stock, country, and year fixed effects. Standard errors are clustered at the country, year, and species level using multiway clustering. All variables except for the property rights indicator and the fixed effects are IHS transformed and demeaned at the stock-country-level. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

To test alternative definitions of credit market development, we reproduce results using the private sector discount factor to describe credit market development in Appendix A.11. Results are qualitatively similar, though somewhat weaker than those shown above, likely owing to the reduced number of observations.

In the theory section, we suggest investment in harvesting capital as the main mechanism that links credit markets and property rights to resource extraction effort. Although the resource extraction rate is directly related to harvesting effort and therefore to harvesting capital, it remains to be shown that investment in harvesting capital fundamentally drives this relationship. To test these expectations, we build a unique dataset of the construction of the global fishing fleet based on the histories of 27,132 individual fishing vessels, comprising the majority of the global commercial fishing fleet. The detailed vessel information allows us to link individual vessels to groups of targeted species and therefore to their level of property rights security. We present the data, the methods and the results in Appendix A.12. The results are similar to the results on resource extraction presented above. A one percent increase of the volume of credit increases the number of vessels that target open access resources by 0.29 % in our main specification. This effect is reduced by 0.31 % for vessels that target resources with secure property rights. Introducing secure property rights for open access resources reduces the number of vessels by 40 %.

Overall, our empirical results are strongly consistent with our theoretical predictions that credit market development increases resource extraction under open access, but decreases resource extraction under secure property rights. Next, we interpret the magnitude of the estimated effects.

6.3 Simulations

How economically and ecologically significant are the effects of credit markets and property rights on natural resource extraction? Here we simulate the impact of changes in credit markets and property right security using parameter estimates from our main specification from

Table 7.[29] We show the aggregate results of these simulations in Figure 8 and report the disaggregated results in Appendix A.13. To assess the significance of these hypothetical scenarios for resource sustainability, we present the weighted means of global resource extraction using catches in 2012 as weights (Panel A). In Panel B), we show the share of unsustainable fished stocks (defined as an extraction rate above 100) for each scenario. The "Baseline" scenario reports the observed outcomes for current levels of property right security and credit market development (in 2012). It suggests that the mean extraction rate in 2012 was 132 % (exceeding the MSY level by 32 %) while 54 % of the global fish stocks were harvested beyond sustainable levels. This number is slightly lower than the share of stocks with biomass below MSY levels (see Figure 1). The "Credit" scenario simulates the distributions of resource extraction after a global increase in the volume of credit to US levels (178 % of GDP), holding everything else constant. The global average extraction declines to 119 % while 50 % of the stocks remain unsustainable in this scenario. While improving credit markets does lead to improved resource outcomes, the overall changes are modest. The main explanation for this modest effect of credit market development on resource extraction has to do with the distribution of property rights around the world. Some fisheries have relatively secure property rights, while others have extremely insecure property rights. Credit market development will decrease extraction in the former group and increase extraction in the latter group. In most countries, these effects roughly cancel each other out, leading to a modest overall effect.

In contrast, increasing property right security to its maximum level has a more meaningful effect on resource extraction than did credit market development alone. Increasing property right security to its maximum (scenario "Property Rights") would reduce global mean extrac-

[29] To compute resource extraction under different levels of credit market development and property right security we use the following approach:

$$\begin{aligned}\text{Extraction}_{ijs} = \sinh[\ &\text{ihs}(\text{Extraction}_{ijt}) + \beta_1(\text{PR}_{ijs} - \text{PR}_{ijt}) + \beta_2(\text{ihs}(\text{Credit}_{ijs}) - \text{ihs}(\text{Credit}_{ijt}))\\ &+ \beta_3(\text{PR}_{ijs} \times \text{ihs}(\text{Credit}_{ijs}) - \text{PR}_{ijt} \times \text{ihs}(\text{Credit}_{ijt}))]\end{aligned}$$

where the variable and parameter definitions are as in equation (11), the parameter values for β_1 to β_3 are from Table 7, s denotes the value of a variable after the shock, *ihs* is the inverse hyperbolic sine transformation and *sinh* is the hyperbolic sine function.

tion rates to 111 % and the share of fish stocks with unsustainable extraction rates to 46 %. What would be required to improve property rights to this level? Recall that for this simulation we use the definition of property rights that includes EEZ, fish home range, and fish mobility. Achieving a level of one would require that institutions are designed to completely internalize all spatial externalities of fishing (for example by forming international coalitions, changing EEZ delineations to capture a fish's biological range, or by assigning exclusive rights to fish in the high seas).

The last scenario (Credit & Property Rights) takes the further step of simultaneously improving credit markets and property right security. This scenario gives rise to the most significant reduction in resource extraction because increasing property right security amplifies the positive impact of credit market development on resource conservation. Extraction rates fall below MSY levels (87 %) and the share of unsustainable stocks declines to 36 % in this scenario. We discuss the economic implications of these changes in the next section.

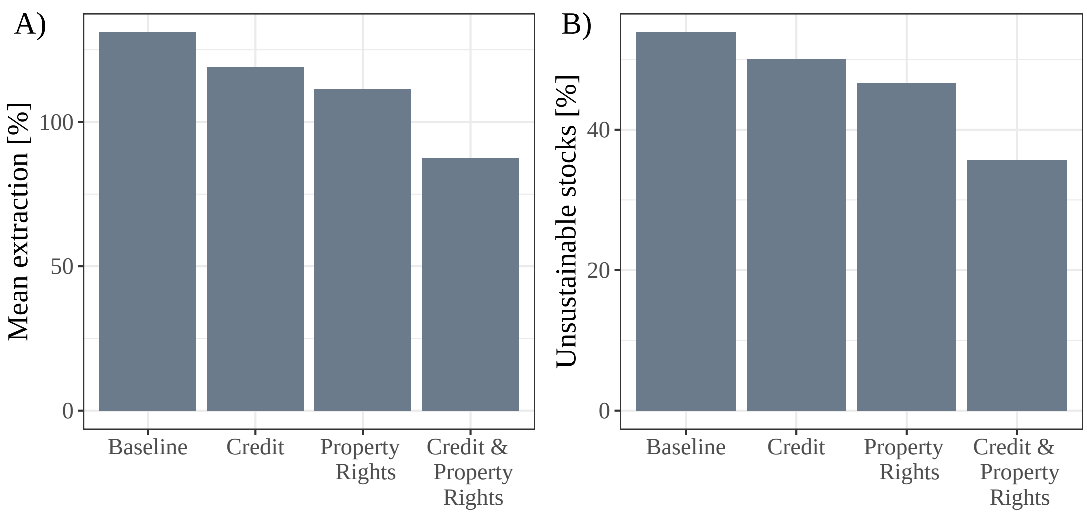

Figure 8: A) the weighted mean of resource extraction and B) the share of resource stocks with unsustainable extraction rates for four different scenarios: "Baseline" Actual data from 2012, "Credit" simulated outcomes raising the credit volume to US levels (178 % of GDP) globally, "Property Rights" simulated outcomes after increasing global property right security to unity and "Credit & Property Rights" simulated outcomes after simultaneously increasing the credit volumes to 178 % and property right security to unity.

7 Discussion and Conclusions

Credit markets are fundamental for economic development. Because credit market development affects economic primitives like discount rates and the cost of capital, we argue that they also affect incentives for resource extraction, and thus, the go-to tools for economic development have implications for the tragedy of the commons. To our knowledge, this is the first study to empirically estimate the impact of credit market development on resource extraction. In so doing, we uncover an inextricable link with property right security.

At first glance, there are two possible consequences of credit market developments on resource extraction. First, improving access to credit lowers the cost of capital. This effect may cause resource extractors to invest in more extraction capital (fishing boats, chainsaws, deeper wells), which would exacerbate the tragedy of the commons. But second, credit market development lowers the discount rate, which raises the intertemporal opportunity cost of extraction and could lead to enhanced resource conservation. We showed in a simple model that the ultimate consequence of improved credit markets on resource extraction is likely to hinge on the degree of property right security. To test the theory empirically, we make use of a new dataset on fish catches and fish stock sizes combined with data on property right security, financial development and economic performance covering the majority of commercial fisheries in the world. These novel data allow us to isolate empirically the impact of credit market development and property rights on resource extraction.

Our results show that both credit market development and property right security causally affect resource extraction. In an open access setting, we find that a 1 % increase in credit to the private sector *increases* extraction by 0.16 %, but that the same increase in credit to the private sector in a secure property rights setting actually *decreases* extraction by 0.29 %. We find similar effects for the private sector interest rate as credit market indicator. The results show further that increasing property right security from open access to complete property right security reduces resource extraction rates by 38 %.

To comment on the practical significance of these findings, we simulated the consequences of hypothetical credit market and property rights improvements around the world. These simulations suggest that holding property rights at their current levels, credit market development alone, has only modest effects on extraction or resource sustainability. This result is a consequence of the opposing effects of credit market development in the presence of secure vs. insecure property rights. However, the simulations show that in a world with secure property rights, credit market development can lead to large reductions in extraction, possibly bringing the average exploitation globally to a sustainable level.

The economic implications of these results are far-reaching. Arnason et al. (2017) estimate that the annual losses due to overfishing in 2012 were 86 Billion USD. Using figure 8B, our results show that improving property right security and promoting credit market development could reduce overfishing by 33 %. While quantifying the exact economic benefits of these improvements is beyond the scope of this paper, a simple proportional attribution using Arnason et al. (2017) suggests an annual benefit of 28 Billion USD, with concomitant ecological benefits. Using the results from figure 8A suggest even larger benefits.

We comment here on another, yet unexplored implication of credit market development. Our model suggests that the present value of resource rents of well managed fish stocks increases with credit market development due to lower discount rates. Resource managers therefore invest in resource stocks by reducing extraction rates. This finding implies that the opportunity cost of insecure property rights increases with financial development; credit market development amplifies the importance of effective natural resource management. This may help explain why resources in developed countries tend to be more aptly regulated.

Our theory applies beyond fisheries to other renewable resources such as timber, surface and groundwater, game, etc. In each of these settings, competitive extraction incentives will be affected by credit markets and the security of property rights to the underlying resource. For all such resources, credit market development will interact in important and economically significant ways with institutions that govern tenure and security of access to those resources to ultimately drive extraction. Our results suggest that as credit markets in these locales improve, we can expect to see a divergence of outcomes: For resources with secure property rights, credit market development is likely to drive resource recovery. But for resources with weak tenure or where property rights are otherwise insecure, credit market development could further exacerbate the tragedy of the commons.

Our model is intentionally stylized and does not explicitly tackle the challenge of enforcement. Even if property rights are well-defined, their security depends, in part, on effective enforcement; indeed, this is a central pillar of Copeland and Taylor (2009). In fisheries, while it has been shown that countries take actions to reduce extraction within their EEZs (Englander, 2019) additional regulations are needed to clearly define and enforce property rights for effective resource management (Costello et al., 2008; Birkenbach et al., 2017; Arnason, 2012; Barrett, 2019). Our theoretical model underscores the importance of effective management, and our empirical results show that rule of law can play an important role in effective property right security. This may be especially important for resources outside national jurisdictions, such as fish stocks in the high seas, where resource regulation relies largely on international agreements and intergovernmental institutions (Li et al., 2021; Pons et al., 2018).

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A Appendix

A.1 Confirm the form of the value function

Invoking the guess $V_c(X) = A_c \log(X) + B_c$ gives rise to first order condition in Equation 3. This implicitly defines $k_c(k_f)$, which is independent of X. Substituting $k_c(k_f)$ into Equation 2 and removing the max, gives:

$$\begin{aligned} V_c(X) &= \log(X) + \delta_c \alpha A_c \log(X) + B_c & (12) \\ &= (1 + \alpha \delta_c A_c) \log(X) + B_c & (13) \end{aligned}$$

where B_c is a constant that is independent of X. This confirms the form of the value function. Under the guess, the $\log(X)$ coefficient is A_c in period-t, and is $(1 + \alpha \delta_c A_c)$ in period $t-1$. This implies that the infinite horizon value of the coefficient is $A_c = \frac{1}{1-\alpha\delta_c}$. The infinite horizon value of B_c is immaterial for marginal incentives, so we omit it here.

A.2 Confirming the second order condition

The second order condition (SOC) is verified by taking the derivative of c's FOC with respect to k_c:

$$\frac{dFOC}{dk_c} = \frac{-1}{k_c^2} + \frac{-\delta_c A_c \alpha \gamma_c^2}{(1 - \gamma_c k_c - (1-\gamma_c)k_f)^2} < 0. \tag{14}$$

A.3 Fringe response to N

Totally differentiating Equation 4 with respect to N gives:

$$\frac{dk_f}{dN} = \frac{-\left[\frac{(1-\gamma_c)\delta_f \alpha A_f (1-(1-\gamma_c)\bar{k}_f)}{(N-(1-\gamma_c)k_f-(N-1)(1-\gamma_c)\bar{k}_f-\gamma_c k_c)^2}\right]}{SOC} \geq 0 \tag{15}$$

where SOC refers to the second order condition. The numerator and denominator are weakly negative, so an increase in N leads to an increase in extraction capital applied by each of the fringe countries. In the main text, we showed that as $N \to \infty$, f's capital choice approaches a constant ($\frac{\delta_f}{1-\delta_f}$), which we regard as the open access level of fringe capital.

A.4 Best response functions are downward-sloping

Equation 3 implicitly defines k_c as a function of k_f and Equation 4 implicitly defines k_f as a function of k_c. The equilibrium of these $N+1$ control variables is given by the intersection of the best response functions. Here we show that k_c is downward-sloping in k_f and vice-versa. Totally differentiating Equation 3 with respect to k_c and k_f gives:

$$\frac{dk_c}{dk_f} = \frac{\frac{\delta_c \alpha \gamma_c (1-\gamma_c)}{(1-\alpha\delta_c)(1-\gamma_c k_c - (1-\gamma_c)k_f)^2}}{SOC} \leq 0 \tag{16}$$

The numerator is positive and the denominator (the SOC) is negative (see above), which confirms that c's best response function is downward-sloping in k_f.

Totally differentiating Equation 4 with respect to k_f and k_c, and noting that $A_f = \frac{1}{1-\alpha\delta_f}$ gives:

$$\frac{dk_f}{dk_c} = \frac{\frac{\delta_f \alpha \gamma_c (1-\gamma_c)}{N(1-\alpha\delta_f)(1-\gamma_c k_c - (1-\gamma_c)k_f)^2}}{SOC} \leq 0 \tag{17}$$

the numerator is positive, and the denominator is negative, which confirms that f's best response function is downward-sloping in k_c.

Consider a graph of the best response functions with k_c on the vertical axis and k_f on the horizontal axis. Denote the equilibrium by k_c^* and k_f^*. Note that a stable interior equilibrium requires that $k_c(k_f)$ is steeper than $k_f(k_c)$, evaluated at (k_c^*, k_f^*). An illustration of these best response functions appears in Figure 9A.

A.5 Value function with management effectiveness

Guess the form of c's value function: $V_c(X) = L_c \log(X) + M_c$, which gives:

$$V_c(X) = \max_{k_c} \left[\log(\gamma k_c X) - \frac{1-\delta_c}{\delta_c} k_c + \mu \delta_c \alpha L_c (\log(X) + \log(1-\gamma k_c - (1-\gamma)k_f) + \mu \delta_c M_c \right] \tag{18}$$

This has first order condition:

$$\frac{1}{k_c} - \frac{1-\delta_c}{\delta_c} - \frac{\mu \delta_c \alpha L_c \gamma_c}{1-\gamma_c k_c - (1-\gamma_c)k_f} = 0 \tag{19}$$

By the same reasoning as in Appendix A.1, this confirms the form of the value function, and that $L_c = \frac{1}{1-\mu\delta_c\alpha}$. Total differentiation gives rise to Equation 9, so improved management effectiveness lowers k_c for any value of k_f. Note also that the best response function $k_f(k_c)$ is independent of μ. Since the k_c best response function shifts down in μ and the k_f best response function does not change, this implies that an increase in μ causes a decrease in k_c^*, so $\frac{dk^*}{d\mu} \leq 0$.

A.6 Proof to Proposition 1

A.6.1 Proposition 1a

The result was shown in Section 2.3. See also Figure 9B.

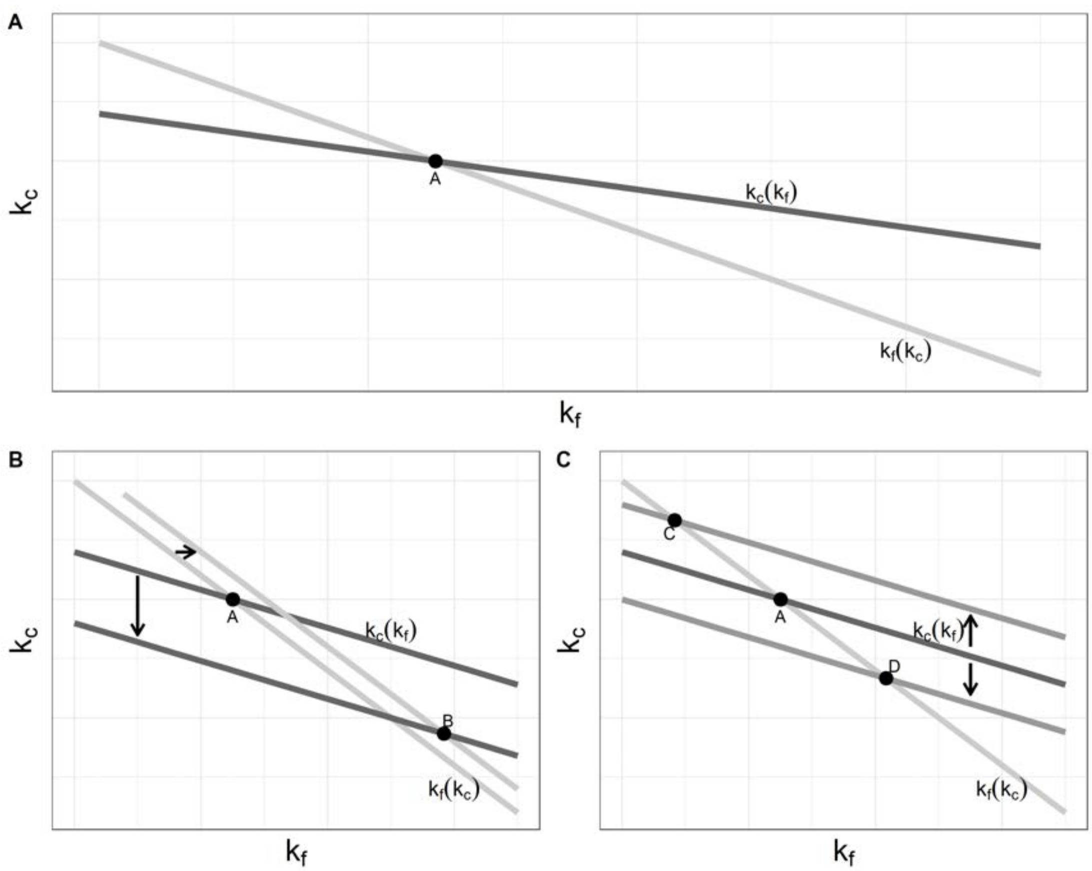

Figure 9: Stylized depiction of the best response functions between country c and f. Panel A: Equilibrium is at point A. Panel B: Shows how both best response functions shift with an increase in property right strength in country c (γ_c). Equilibrium shifts from A to B. Panel C: Show how c's best response function can shift with improved credit markets (δ_c). Equilibrium shifts from A to C under insecure property rights, but can shift from A to D under secure property rights.

A.6.2 Proposition 1b

The result was shown in Section 2.4. See also Figure 9C.

A.6.3 Proposition 1c

Invoking the comparative static in Equation 6, and evaluating as $\gamma_c \to 1$ gives:

$$\frac{dk_c}{d\delta_c}|_{\gamma_c \to 1} = \frac{\frac{\alpha}{(1-k_c)(1-\alpha\delta_c)^2} - \frac{1}{\delta_c^2}}{SOC} \lesseqgtr 0$$

The sign of this expression depends on k_c. For example, suppose $\gamma_c = 1$ and $\delta_c = 1$. Then c's first order condition can be solved explicitly for $k_c^* = 1 - \alpha$. Using this explicit solution, we obtain:

$$\frac{dk_c}{d\delta_c}|_{\gamma_c=1,\delta_c=1} = \frac{\frac{1}{(1-\alpha)^2} - 1}{SOC} < 0$$

where the sign is ensured because $\alpha < 1$. This provides a sufficient condition under which credit market development leads to a decrease in extraction effort, but only when property rights are secure. Other sufficient conditions are provided below.

A.6.4 Brief numerical vignette

Here we provide a brief numerical vignette to illustrate Proposition 1a-1c. We adopt the model from Section 2 and use biological growth parameter $\alpha = 0.5$. To keep things simple, we assume $N \to \infty$, so the fringe operates in open access. Suppose $\delta_f = .33$, which implies that equilibrium fringe capital is $k_f^* = 0.5$ (see Section 2.2). Then, for every possible combination of property right security (γ_c) and credit market development (δ_c), we solve c's first order condition in Equation 3, yielding k_c^*. The two panels of Figure 10 show this result. Panel A shows, for any combination of δ_c (horizontal axis) and γ_c (vertical axis), the extraction effort by country c, taking the fringe extraction as given at the open access level (consistent with the model). Curves on Panel A show level sets of extraction effort.

While Figure 10A suggests a monotonic relationship between property right security and extraction effort (moving vertically reduces k_c^*, per Proposition 1b), the effect of credit markets on extraction effort also clearly depends on property right security (moving horizontally gives an ambiguous sign). Figure 10B highlights this interplay. It shows how optimal extraction effort (vertical axis) depends on credit markets (horizontal axis), for two different levels of property right security. Secure property rights are indicated by the $\gamma_c = .95$ curve and insecure property rights are indicated by the $\gamma_c = .4$ curve.

Proposition 1a can be seen as the vertical distance between the curves (more secure property rights lead to lower extraction effort). Proposition 1b is seen as the positive slope of either curve when credit markets are weak (left side of figure). Proposition 1c is seen as the negative slope of either curve when credit markets are strong (right side of figure). Finally, the shaded region indicates the range of credit markets over which credit market development increase extraction effort when property rights are insecure, but decrease extraction effort when property rights are secure.

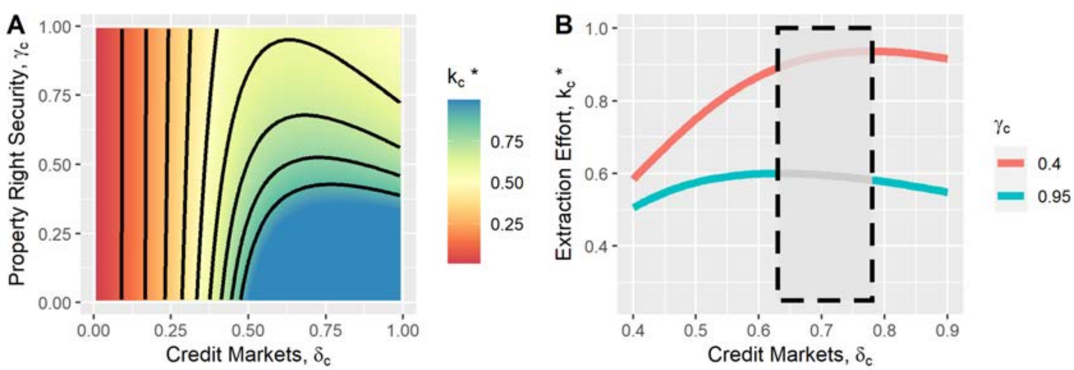

Figure 10: Panel A: Optimal extraction effort as a function of credit markets (horizontal axis) and property rights (vertical axis). Panel B: Optimal extraction effort as a function of credit markets, holding property rights fixed. Shaded region shows cases for which credit market development leads to increased extraction effort when property rights are insecure, and decreased extraction effort when property rights are secure.

A.6.5 Proposition 1d

The result is proven in Section 2.5.

A.7 Governance

The following figures show the observations and the extrapolated values of the Rule of Law Index of the World Bank and the Property Rights Protection Index of Ouattara and Standaert (2020) interacted with the EEZ dummy for a selection of countries. The points are the observed values, the lines show the extrapolated values that we use in our analysis. The sudden decline to zero marks the EEZ implementation year.

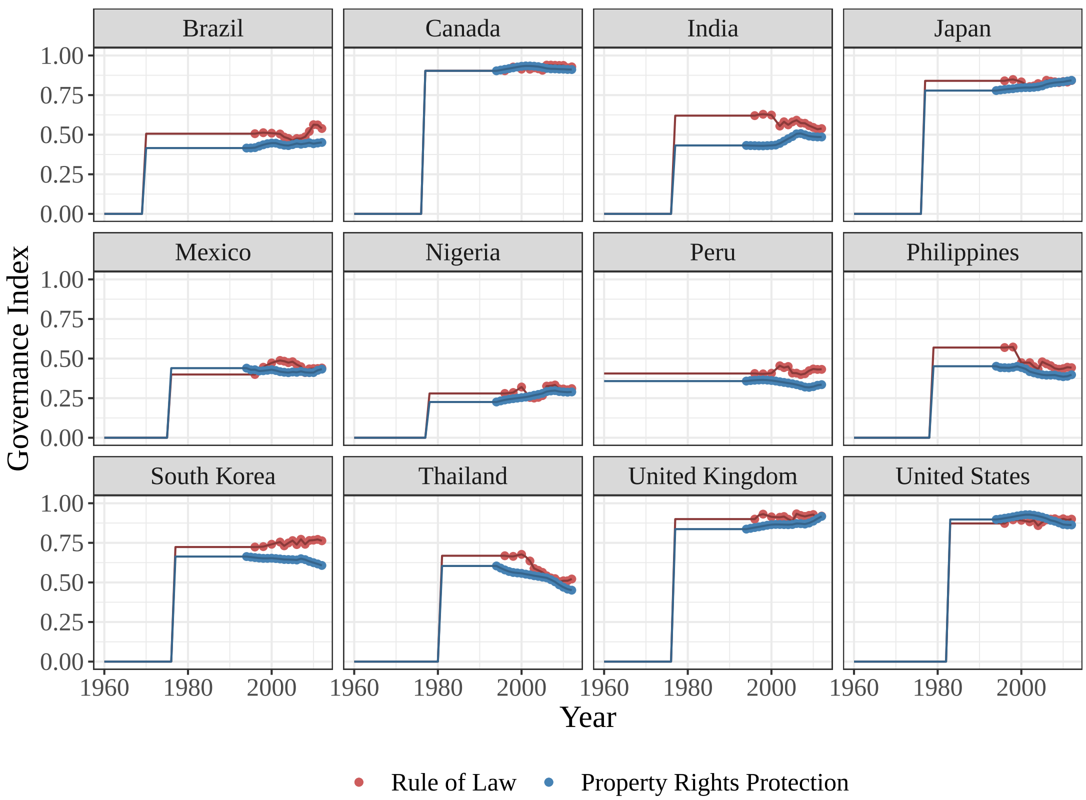

Figure 11: Observations (dots) and extrapolated values (lines) of the Rule of Law Index (red) and the Property Rights Protection Index (blue) interacted with the EEZ dummy.

A.8 Holm and Bonferroni p-values for the main results

Table 4 and Table 5 present the Holm (Holm, 1979) and Bonferroni corrected p-values for our main results presented in Table 7.

Table 4: Holm corrected p-values

	Baseline (1)	Main (2)	Trend (3)	IV (4)	OECD (5)	Balanced (6)	Top10 (7)	RAM (8)	Ag. Credit (9)
Property rights	0.01	0.001	0.06	0.12	0.22	0.01	0.02	0.04	0.46
Credit	0.08	0.05	0.06	0.06	0.33	0.05	0.31	0.04	0.46
Credit × Property rights		0.001	0.06	0.004	0.31	0.01	0.02	0.03	0.14

Table 5: Bonferroni corrected p-values

	Baseline (1)	Main (2)	Trend (3)	IV (4)	OECD (5)	Balanced (6)	Top10 (7)	RAM (8)	Ag. Credit (9)
Property rights	0.01	0.002	0.10	0.37	0.22	0.01	0.02	0.07	0.70
Credit	0.16	0.14	0.18	0.10	1.00	0.15	0.92	0.08	0.88
Credit × Property rights		0.001	0.06	0.004	0.47	0.01	0.02	0.03	0.14

A.9 Property rights and the Rule of Law

The following table presents our main results from Table 7 but using a property rights indicator that combines the EEZ and the range and mobility of species with the interpolated Rule of Law index from the World Bank (ROL) i.e. $PR = EEZ \times R^M \times ROL$.

Table 6: Resource extraction, credit market development, property rights and the Rule of Law

	Baseline	Main	Trend	IV	OECD	Balanced	Top10	RAM	Ag. Credit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Property rights	-0.540***	-0.600***	-0.219**	-0.495**	-0.283**	-0.709***	-0.529***	-0.750**	-0.975
	(0.129)	(0.124)	(0.105)	(0.183)	(0.136)	(0.166)	(0.188)	(0.339)	(0.579)
Credit	-0.081	0.147**	0.088	0.883**	0.134	0.216**	0.089	0.625*	0.074
	(0.053)	(0.064)	(0.053)	(0.422)	(0.131)	(0.086)	(0.087)	(0.314)	(0.063)
Credit × Property rights		-0.525***	-0.255**	-1.75***	-0.198	-0.641***	-0.468***	-0.605**	-0.309*
		(0.144)	(0.117)	(0.469)	(0.141)	(0.182)	(0.164)	(0.276)	(0.149)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country trend			Yes						
Observations	151,961	151,961	151,961	125,186	101,634	56,414	58,122	16,955	32,236
R^2	0.576	0.579	0.606	0.566	0.538	0.632	0.661	0.642	0.681
Within R^2	0.020	0.027	0.002	-0.031	0.005	0.059	0.050	0.021	0.024

Notes: The table reports the estimates from equation (11) for β_1, β_2 and β_3 with Property rights defined as $EEZ \times R^M \times ROL$. All specifications include GDP and GDP squared as controls as well as stock, country, and year fixed effects. Standard errors are clustered at the country, year, and species level using multiway clustering. All variables except for the property rights indicator and the fixed effects are IHS transformed and demeaned at the stock-country-level. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

A.10 Total factor productivity and the resource stock

The following table presents our main results from Table 7 with the country level total factor productivity (TFP) from the Penn World Tables and the lagged fish stock relative to its MSY level as additional controls.

Table 7: Resource extraction, credit market development and property rights with additional controls

	Baseline	Main	Trend	IV	OECD	Balanced	Top10	RAM	Ag. Credit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Property rights	-0.173*	-0.228**	-0.199**	-0.128	-0.167	-0.315**	-0.529***	-0.761**	-0.225
	(0.088)	(0.088)	(0.085)	(0.115)	(0.102)	(0.143)	(0.188)	(0.310)	(0.172)
Credit	-0.013	0.237***	0.118*	0.435	0.180	0.271**	0.089	0.865**	0.145*
	(0.057)	(0.084)	(0.070)	(0.304)	(0.145)	(0.111)	(0.087)	(0.349)	(0.078)
Credit × Property rights		-0.404***	-0.214**	-0.743**	-0.208	-0.413**	-0.468***	-0.862**	-0.206**
		(0.107)	(0.105)	(0.289)	(0.140)	(0.154)	(0.164)	(0.316)	(0.098)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country trend			Yes						
Observations	137,511	137,511	137,511	114,303	99,005	51,459	58,122	15,092	29,164
R^2	0.578	0.580	0.602	0.589	0.544	0.634	0.661	0.634	0.687
Within R^2	0.032	0.037	0.008	0.026	0.014	0.090	0.050	0.034	0.044

Notes: The table reports the estimates from equation (11) for β_1, β_2 and β_3 with property rights defined as $EEZ \times R^M$. All specifications include the lagged resource stock, total factor productivity, GDP and GDP squared as controls as well as stock, country and year fixed effects. Standard errors are clustered at the country, year and species level using multiway clustering. All variables except for the property rights indicator and the fixed effects are IHS transformed and demeaned at the stock-country-level. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

A.11 Discount Factor

In Table 8, we present the results using the private sector discount factor, defined as 1/(1+lending interest rate), as the credit market development indicator. All regression specifications control for GDP and GDP^2 and include fish stock, country and year fixed effects. In addition, we include the inflation factor as control and exclude all observations in times of hyperinflation with annual inflation rates exceeding 30 %. Otherwise, all regression specifications are as described in Table 7.

Table 8: Resource extraction, property rights and the discount factor

Model:	Baseline (1)	Main (2)	Trend (3)	Balanced (4)	RAM (5)
Variables					
Property rights	-0.137	-0.164	-0.192**	-0.462**	-0.623**
	(0.091)	(0.111)	(0.080)	(0.190)	(0.275)
Discount factor	-1.68**	-1.12	1.97**	0.052	2.92
	(0.767)	(1.17)	(0.931)	(1.49)	(3.63)
Discount factor × Property rights		-1.39	-2.68**	-2.63	-2.93
		(1.42)	(1.30)	(1.92)	(3.51)
Stock FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Country trend			Yes		
Observations	75,399	75,369	75,399	27,488	12,895
R^2	0.590	0.590	0.612	0.593	0.644
Within R^2	0.011	0.012	0.003	0.037	0.013

Notes: All specifications include stock-country fixed effects, year fixed effects, GDP, GDP squared and the inflation factor i.e. 1/(1+inflation rate). All variables except for the property rights indicator, the discount factor and the inflation factor are transformed using inverse hyperbolic sine transformation. Independent variables are demeaned at the stock-country-level. Standard errors are clustered at the country, year and species level using multiway clustering. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

A.12 Fishing capital, property rights and credit market development

Our theory proposes harvesting capital as the main channel through which property rights and credit markets affect resource extraction. In this section, we test this prediction directly using data from the construction of global fishing fleets. Testing our predictions for capital directly is complicated by the fact that the impact of credit market development and the implementation of EEZs depends on the location of the fishing activity and the target species. While distant water fleets that mainly target fish in the high seas are not affected by the implementation of their own country's EEZ, the situation is different for coastal fishing fleets that mainly fish within their country's EEZ. A similar reasoning applies to the impact of credit market development on harvesting capital because of the interaction with property rights. Even for coastal fleets, the impact EEZs may differ by target species. For example, the results of Table 2 from the main text suggest that the introduction of EEZs had only a small and imprecise impact on overall resource extraction within countries' EEZs. However, the same table suggest also that extraction of immobile stocks or stocks that are completely contained within an EEZ declined significantly after the introduction of EEZs, while extraction of mobile species with large ranges remained largely unaffected. Our novel dataset allows us to distinguish between fleets that target species in the high seas and fleets targeting species in coastal waters. It also allows us to separate fleets that target mobile species from fleets that target immobile species. The data are based on the histories of 27,132 individual fishing vessels, comprising the majority of the global commercial fishing fleet.

Data

The fishing vessel information is a combination of the movement pattern of individual vessels and the global vessel registries. Both are provided by the Global Fishing Watch database[30]. The vessel information contains information on the construction year, the length, the tonnage, the flag (country) as well as the gear type for 27,132 fishing vessels.

Location and target species: We allocate individual vessels to fishing fleets based on their

[30] `https://globalfishingwatch.org/map-and-data/` downloaded in February 2022.

gear type. Purse seiners, squid jiggers and long liners are mainly active in the high seas, while trawlers are mainly active in coastal waters (Kroodsma et al., 2018; Sala et al., 2018). Taconet et al. (2021) suggest further that vessels using traps, dredges and gillnets are mainly active in coastal waters. While purse seiners, longliners, squid jigger, trawlers and gillnetters target mobile species such as fish and squid, vessels with dredges and traps catch mainly immobile shellfish. We therefore classify vessels based on their fishing location and the mobility of their target species as "high seas" (long liners, purse seiners, squid jiggers), "coastal-mobile" (trawlers, gillnetters), and "coastal-immobile" (vessels using traps and dredges). Lastly, we classify all vessels that fit into neither category as "other". Some vessels use several gear types. For example, Taconet et al. (2021) show that some vessels use gillnets during one season and trolling during a different season. We weight the contribution of each vessel to a fleet by the inverse total number of gear types that the vessel uses.[31]

The share of the resource that is contained within an EEZ differs across fleets. We call the share of the resource within EEZs γ, in line with the theoretical section of the paper. While resources of fleets that target "coastal-immobile" resources are completely contained within EEZs, the resources of "high seas" fleets are completely outside the EEZs. We therefore assign γ values of one and zero to these fleets respectively. Resources of "coastal-mobile" fleets are mainly contained within EEZs, but can also move in and out of EEZs. We therefore assign γ values of 0.5 to these fleets. The fleet category "other" contains a range of different fishing vessels. We set their γ value also to 0.5 but drop these observations in a robustness test. Table 9 summarizes the number of vessels within each fleet category, as well as their value of γ. We use different numerical values of γ in a robustness test (γ_{RT}) to test the impact of the numerical γ values on our results.

Fleets: We are mainly interested in the size of the gear and country specific fleets. We allocate individual fleets to countries according to their flag. We then use cumulative sums based on the construction year of the vessel to calculate the gear, country and year specific fleet size. We use the number of vessels and their tonnage (a standard measure of vessel size) to characterize the size of a fleet. Our main concern with the data is attrition, i.e. we only observe

[31] E.g. the weight is 1 if the vessel uses only one gear type and 0.5 if the vessels uses two gear types.

Table 9: Fishing fleets and property rights

Fleet	Number of vessels	γ	γ_{RT}
High seas	8435	0	0.25
Coastal-mobile	9578	0.5	0.5
Coastal-immobile	1034	1	0.75
Other	8378	0.5	0.5

vessels if they are still active in 2022. In other words, we observe more vessels that were built in recent years than vessels from older time periods due to capital depreciation. However, we address this problem by year fixed effects and in a further robustness test by country - year fixed effects to allow for country specific capital depreciation. Since our approach is based on the entry of new fishing vessels, our estimates are likely downward biased since they neglect the exit of fishing vessels in response to changes in property rights and credit market development.

Estimation

To quantify the impact of credit market development and property rights on fishing capital, we estimate our main regression equation (11) but with the IHS transformed total number of fishing vessels and in an alternative specification the IHS transformed tonnage of the fleet as dependent variable. All specifications include GDP and GDP^2 as controls. We further include fleet, country, and year fixed effects and in an alternative specification additionally year-country fixed effects. All variables except for the property rights indicator and the fixed effects are IHS transformed and demeaned at the country-level.

Results

Table 10 reports the results. The results suggest that property rights reduce fishing capital and that credit market development increase fishing capital for fleets that target open access resources. Columns (1) and (2) report the results for the main specification with the IHS transformed number of vessels and the IHS transformed aggregate tonnage of the fleet as the dependent variable. The results suggest that an increase of property rights from open access (0) to fully secure property rights (1) reduces the number of fishing vessels by 40%. This effect increases further to 149 % if we account for vessel size by measuring the fleet by its total tonnage. Increasing the volume of credit to the private sector by one percent increases fleets that target open access resources by 0.29 % but has no impact on fleets that target resources under secure property rights (the sum of the coefficients on "Credit" and "Property rights × Credit"). Using the different numerical values for γ i.e. γ_{RT} (Columns (3) and (4)) as well as removing the non-specific fleets ("other") from the sample (Column (5) and (6)) has no impact on the qualitative results. Lastly, adding country-year fixed effects (Column (7) and (8)) increases the impact of property rights on fishing fleets but leaves the results otherwise qualitatively unchanged (note that the credit is absorbed by the fixed effects).

Overall, we conclude that these results generally support the conclusion of the paper, and indeed point to the accumulation of fishing capital as a key component of the increase in extraction effort.

Table 10: Fishing fleets, property rights and credit market development

	Main		γ_{RT}		Specific fleets		Fixed effects	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Number	Tonnage	Number	Tonnage	Number	Tonnage	Number	Tonnage
Property rights	-0.396**	-1.49***	-0.389*	-1.57***	-0.396**	-1.49***	-0.633***	-2.18***
	(0.160)	(0.417)	(0.195)	(0.511)	(0.160)	(0.417)	(0.216)	(0.546)
Credit	0.286***	0.368**	0.352***	0.469**	0.286***	0.368**		
	(0.080)	(0.165)	(0.110)	(0.220)	(0.080)	(0.165)		
Credit × Property rights	-0.309**	-0.340	-0.480**	-0.602	-0.309**	-0.340	-0.305*	-0.288
	(0.130)	(0.278)	(0.201)	(0.412)	(0.130)	(0.278)	(0.154)	(0.336)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fleet FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE-Year FE							Yes	Yes
Observations	12,933	12,933	12,933	12,933	12,933	12,933	12,933	12,933
R^2	0.617	0.588	0.616	0.585	0.617	0.588	0.676	0.635
Within R^2	0.011	0.014	0.008	0.008	0.011	0.014	0.014	0.021

Notes: The two dependent variables are the number of vessels and the total tonnage of fleet f in country j at time t. There are four fleets: "high seas" (long liners, purse seiners, squid jiggers), "coastal-mobile" (trawlers, gillnetters), "coastal-immobile" (vessels using traps and dredges), and"other". The regression specifications are: "Baseline" with property rights defined by $\gamma \times EEZ$ and using the full sample. "γ_{RT}" with property rights defined by $\gamma_{RT} \times EEZ$ and using the full sample. "Specific fleets" with property rights defined by $\gamma \times EEZ$ but excluding the non-specific (other) fleets. "Fixed effects" is as the "Baseline" specification but includes country-year fixed effects. All specifications include GDP and GDP squared as controls, as well country and year fixed effects. Standard errors are clustered at the country and year level using multiway clustering. All variables except for the property rights indicator and the fixed effects are transformed using inverse hyperbolic sine transformation and demeaned at the country-level. Significance levels are: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

A.13 Simulation results by country

This section reports the disaggregated simulation results from Section 6.3. The blue boxplots in Figure 12 depict the actual within country distribution of resource extraction rates in the year 2012. The red boxplots simulate how these distributions would change under a hypothetical shock in credit market development and property right security. We simulate the effects of three alternative shocks. The red boxplots in panel A depicts the distribution of extraction effort after a global increase in the volume of credit to US levels (178 % of GDP), holding everything else constant. Panel B focuses instead on an increase in property right security to a level of one in all countries (but holding credit markets at their baseline values). Finally, panel C shows the impact of a simultaneous change of property right security (to a level of one) and an increase of the volume of credit to US levels on the within and across country distribution of resource extraction rates.

The country level results highlight an important difference between the impact of credit and property right security on resource extraction. While credit market development increases extraction rates for resource stocks with low property right security, it reduces extraction effort for stocks with high property right security. In panel A) this becomes visible when the blue distributions extend below and above the red distributions. In contrast, increasing property right security (weakly) reduces extraction effort for all fish stocks, although it has no impact on those stocks that start with secure property rights.

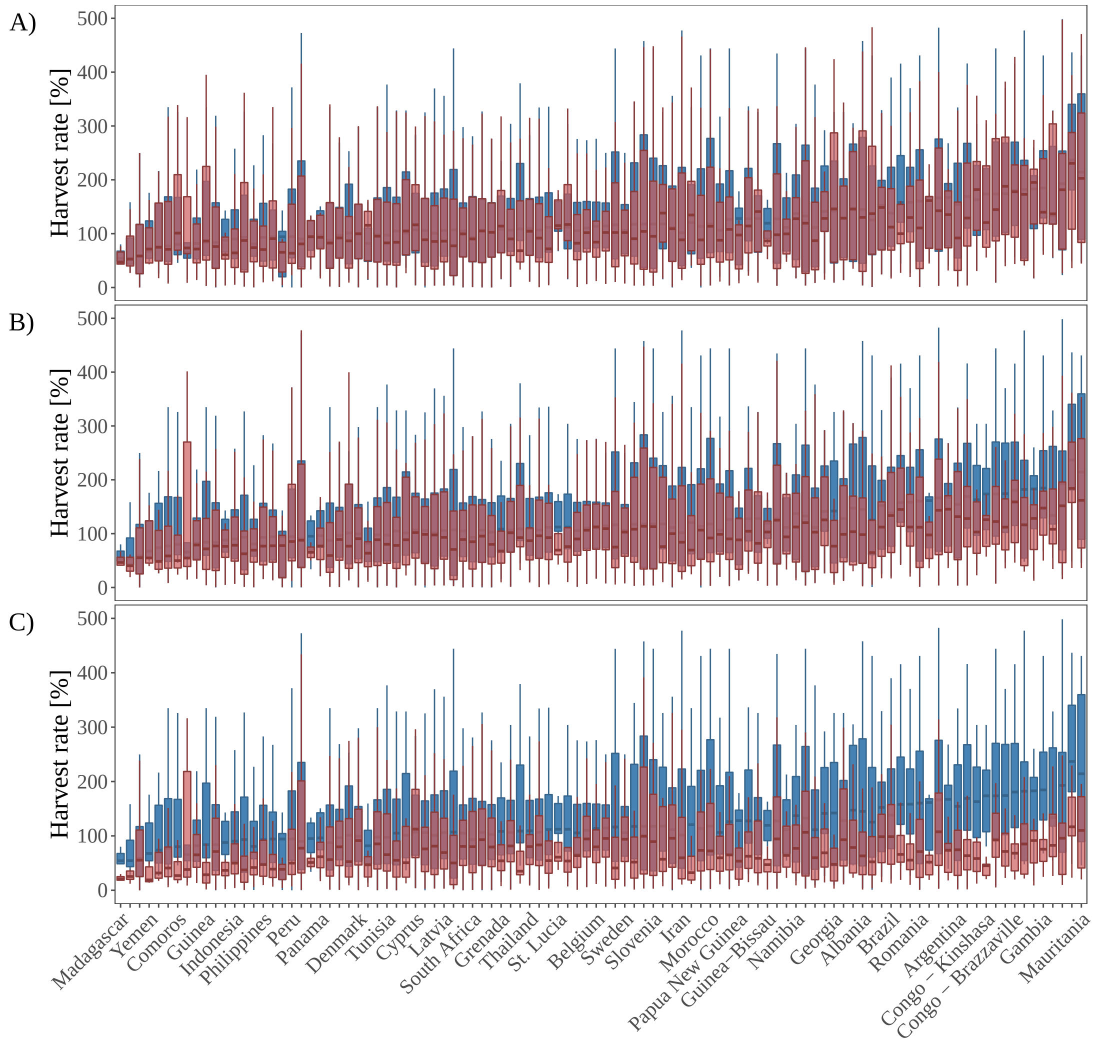

Figure 12: The figure shows the actual within country distribution of extraction effort in 2012 (blue) as well as the resource extraction that would result from three hypothetical scenarios (red boxplots). These scenarios are: A) a global increase of the credit volume to US levels (178 % of GDP) B) a global increase of property right security to unity and C) a simultaneous change of credit volumes to 178 % and property right security to unity.