

Credit Market Development, Property Rights and Resource Extraction: Evidence from Global Fisheries

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Abstract

While the rapid expansion of credit markets around the world has fueled significant economic development, it may also have accelerated the depletion of common pool resources. We examine the impact of credit market development on resource extraction by composing a dynamic model of resource extraction under property right insecurity and testing the model's predictions with new data on catches, stock sizes and property rights security of the world's commercial fisheries. As credit markets improve, our model predicts two main effects. First, the cost of capital diminishes - this tends to favor excessive resource extraction as harvesting capital is accumulated. But second, discount rates are lowered - this favors resource preservation because future harvests weigh more heavily in extractors' welfare. We find that which effect dominates depends crucially on the strength of property rights; insecure rights weaken the long-term incentives arising from a low discount rate. We thus show that when property rights are weak, credit market development is likely to lead to excessive harvest; but when property rights are strong, improved credit markets could actually lead to resource preservation. In our empirical application to the world's fisheries, we find that credit market development increases resource harvesting under insecure

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property rights but reduces resource harvesting under secure property rights. These results suggest a pivotal role played by property right institutions in determining whether credit market improvements will hasten, or reverse, the decline of common pool natural resource stocks.

1 Introduction

Improving credit markets is widely regarded as a necessary condition for efficient investment and is therefore fundamental for economic development. Indeed, evidence suggests that improved credit markets affects the investment behavior of households and firms (Beck et al. 2000; Kaboski and Townsend 2011; Banerjee 2013; Amiti and Weinstein 2018; Beck et al. 2018). But because improved credit markets can affect the cost of capital and discount rates faced by natural resource extractors, this approach to economic development may also change incentives for the pace of resource extraction potentially threatening environmental sustainability. In this paper we examine the effects of credit market improvements on natural resource extraction and show that whether these improvements hasten, or reverse, the decline of common pool resources hinges critically on the property right security governing resource ownership.

There has been a rapid expansion of credit markets over the past few decades improving the access to credit and reducing the cost of borrowing (Beck et al. 2010; Morduch and Cull 2017). Over the same time period, many of the same regions of the world have experienced significant declines in natural resource stocks, though this evidence is muddied by some notable exceptions where resource stocks seem to be rebounding.¹ Have credit market improvements fueled resource overexploitation? Or is it precisely in the areas with credit market improvements that we have seen resource recovery? We tackle these questions by developing and analyzing a new theoretical model of dynamic resource extraction incentives and testing the model's predictions with an in-depth empirical analysis designed to draw inference about the effects of credit market improvements on resource extraction.

A key insight that emerges from the theoretical model concerns the interplay between credit market improvements and property rights security in determining natural resource extraction incentives. Intuitively, altering credit markets, for example by increasing borrowing limits² or lowering

¹Examples for recovering resource stocks include fish stocks such as cod, plaice and hake in European waters (van Gemert et al. 2018). While recovering and declining resources are often spatially separated, renewable resources with opposite trends can also occur within the same country or region such as increasing forest resources but declining groundwater levels in areas of India and North America (Rodell et al. 2009; Scanlon et al. 2012; Song et al. 2018).

²Getting access to credit markets can be interpreted as an increase of the borrowing limit from zero to any positive

the interest rate, affects incentives to extract. Perhaps the most obvious effect works via the cost of capital. As the cost of harvesting capital declines, the ability to rapidly extract a common pool resource increases - this effect implies that credit market improvements could hasten resource over-exploitation. But a countervailing effect arises via the discount rate rate. Both higher borrowing limits and lower interest rates imply lower discount rates of the resource harvesters and as their discount rate declines, the incentive to preserve the stock for future periods is enhanced. This effect implies that credit market improvements could lead to resource stock recovery. Both of these incentives can be affected by the security of property rights. Most notably, the discount rate effect is present only when property rights are relatively secure; when property rights are insecure, little conservation incentive exists regardless of the interest rate. Thus, the theoretical model comes to the conclusion that credit market improvements will accelerate resource extraction when property rights are weak, but will lead to resource recovery when property rights are strong.

The second half of the paper is devoted to an empirical test of this credit market and property right hypothesis. 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 harvest is often resource stock size dependent. Resource degradation can therefore cause declining harvest levels despite increasing harvesting effort. Using harvest levels to measure resource extraction is therefore a misleading measure of the economic incentives that drive extraction behavior. Second, property rights security responds to the status of the resource stock as regulators may try to halt resource degradation by increasing property right security. Ignoring this endogenous response of regulators to the resource status leads to biased estimates. Third, measuring the impact of credit markets on resource use is confounded by the response of the whole economy to credit market development. Credit market development can spur investment and economic growth, which increases the demand for resources as well as the opportunity costs of resource extraction. Failing to control for changes in demand and the opportunity cost of resource use can further bias the estimates. We attempt to overcome these, and related challenges.

To conduct the empirical test, we compile a novel dataset on fish catches, fish stocks sizes and property rights security for the majority of the world's commercial fisheries over the period 1960 to 2015. We combine these resource-level data with indicators of credit market development and macroeconomic performance to estimate the impact of credit market development on resource use under different levels of property rights security.

number.

Three strategies help us overcome the challenges identified above. First, by matching harvest data with data on stock sizes, we normalize harvest relative to resource stock (commonly referred to as *fishing mortality* in the context of the fishery). This conveniently corresponds to the “effort” devoted to resource extraction in bioeconomic models, and is empirically advantageous because it controls directly for changes in resource abundance.³ 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 timing of the introduction of each country’s 200 mile Exclusive Economic Zone (EEZ) combined with a rule of law index to measure property right security over fish stocks. While the implementation of the EEZs gave countries the legal right to establish property rights over marine resources, the rule of law index measures the ability of countries to enforce these rights. Since the EEZs resulted from the United Nations Convention on the Law of the Sea and they cover all marine resources including minerals and fossil fuels, the timing of their implementation can be viewed as exogenous to the status of individual fisheries. The ability to establish property rights over a resource does not only depend on the legal rights and ability to enforce these rights but also on the distribution of the resource stock across territories of different resource users and the mobility of the resource within its distributional range. Returning to the earlier example of forests and groundwater in North America and India, while it is easy to establish property rights over trees that do not move between properties it is notoriously difficult to establish property rights over aquifers or rivers that stretches between many properties and in which the resource is at least partially mobile (Ayres et al. 2017; Leonard and Libecap 2016). We therefore weight our property rights indicator by the share of the fish stocks’ distributional range that falls into a country’s EEZ and the mobility of the fish species within its range in a robustness check. Since our measure of the species’ range and mobility is purely exogenous to the harvest decision, the measure allows us to exploit differences in property rights security across species within individual countries.

Third, to describe credit market development we use the lending interest rate to the private sector and, following for example Levine et al. (2000) and Manova (2013), the volume of total credit to the private sector as an alternative measure of credit market development. While lending interest rates measure the opportunity costs of capital directly, changes in the volume of credit to the private sector can be interpreted as changes in borrowing constraints. However, even an

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

experimental setup could not separate the direct effects of credit market development on resource harvesting from its indirect effects through economic development or the economic opportunities of resource users (see e.g. Galor and Zeira (1993)). Further, credit market development may respond to economic development which may also drive demand for fish and the opportunity cost of fishing. To address the concern of omitted variable bias, we control for GDP in linear and squared form in all specifications and introduce the unemployment rate and changes in the total factor productivity as further controls in a robustness check. Although these controls reduce the risk of omitted variable bias we explore the relationship between credit and resource extraction further in a robustness test using sector specific credit as explanatory variable while controlling for the total volume of credit to the private sector.

While fishermen may respond to credit market development through investment in harvesting capital under open access, it may be the government that sets the harvesting limits under secure property rights over resources. In that case, we might expect extraction to be completely insulated from credit market improvements. However, Costello and Grainger (2018) show that resource extractors have many pathways to “capture” or otherwise influence regulatory decisions in their favor. In addition, optimal management of resources depends on the harvesting costs and is often modeled as the solution to the problem of a sole owner of the resource stock facing harvesting costs determined by competitive markets. In that sense, our approach can be interpreted as the questions if governments regulate their resources optimally.

Our empirical results on the impact of credit market development on resource harvesting generally confirm the theoretical predictions. A one percent increase in the credit to the private sector *increases* the harvesting rate of fish stocks under open access by 0.29 %. In contrast, the same credit increase actually *reduces* the harvest rate by 0.49 % for fish stocks with secure property rights. This finding is consistent with our theoretical result that strong property right security allows the resource user to act more conservatively as the discount rate is lowered. We obtain qualitatively similar results when we use the private sector lending interest rate as a measure of credit market development. A one percent reduction of the private sector interest has a negative but statistically insignificant impact on the harvesting rate of fish stocks under open access but reduces the harvesting rate of stocks with secure property rights by 0.32 %. Our results show further that increasing property rights security from open access to fully secure property rights reduces resource harvesting by more than 50 %. Taking the biological differences across species into account increases the effect further to 83 %.

All of these findings are consistent with the prediction that credit market development increases resource harvesting under open access and that it reduces resource harvesting under secure property rights. While these findings help illuminate an interesting interplay between property right security and credit market development, we are also interested in interpreting the magnitude of the impact of credit market improvements on resource health. To do so, we use these estimates to simulate the impact on global fisheries from a hypothetical increase of credit volumes to US levels and an increase of property rights security to fully secure levels, all across the planet. The results of the simulation show that raising the level of credit to the private sector to US levels has only a negligible impact on global fisheries. The reason is that the result is muted because the positive and the negative effects of credit market development on resource extraction in some sense cancel out under current levels of property rights security around much of the world. 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 30 % and 55 % respectively. The findings of our study therefore suggest that increasing property rights security over resources can reverse the negative impact of financial development on global common property resources.

What has the previous literature concluded about the role of discount rates and property right security on resource extraction? Resource economists have long considered discount rates an important factor for determining optimal resource management and environmental conservation. Faustmann (1849) showed as early as the 19th century that interest 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 interest rate. Clark (1973) showed further that high interest rates render the extinction of slow growing animal populations economically optimal. Our study is therefore related to the empirical studies of the Hotelling rule that relates the resource prices to the interest rates.⁴ This literature has, however, focused mainly on resource prices holding the interest rate constant while at the same time assuming secure property rights over the resource. The recent study by Anderson et al. (2018) that relates oil production to oil prices is no exception in this respect. However, the findings are not easily transferable to many global resources that are exploited under insecure property rights and in countries with rapidly developing credit markets. Our study contributes to that literature in that it takes both property rights security and changes in discount rates due to financial development into account.

Our study is further related to a distinct stream of literature that focuses on capital investment

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

and resource harvesting (Clark et al. 1979; Singh et al. 2006; Nøstbakken 2012) and its contribution to resource degradation (Clark et al. 2005; Beddington et al. 2007). However, as far as we know, the literature has related their findings neither to financial development nor property rights security. We contribute to this literature by showing how changes in capital costs or access to capital affect overharvesting of resources and further, how this impact depends on the property rights security over the resource.

Compared to the large literature on capital investment in resource harvesting, few studies consider the impact of credit constraints on 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 interest 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 fishing.⁶ The current paper contributes to this discussion on the impact of credit market development on resource management by showing a) that increasing borrowing limits and declining interest rates have qualitatively similar effects on resource extraction and b) that the effect of credit market development on resource extraction depends critically on property rights security.

While our theoretical results provide new insights and help clarify intuition about the when credit market improves 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 only very 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. (2013) show that loans that are 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

⁵See 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.

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

⁷Quaas et al. (2012) and Teh et al. (2015) infer from observed harvesting rates the implicit discount rates of fishermen or the fishing industry but they do not relate these observations to property rights security or changes in

impact of credit market development their proposed mechanisms, their environmental indicators and their scale are fundamentally different than in this paper. Our paper is further related to the growing literature on the impact of property rights security on investment and resource management (see for example Besley (1995), Bohn and Deacon (2000), Jacoby et al. (2002), Copeland and Taylor (2009), Liscow (2013) and Costello and Grainger (2018)). While previous empirical studies including Costello et al. (2008) and Isaksen and Richter (forthcoming) have focused on the impact of quota systems on fisheries management we use a more fundamental approach to property rights security defined by the legal rights over resources and the ability to enforce these rights over mobile resources.

The paper proceed as follows. Section 2 uses the theoretical framework to derive testable predictions. Section 3 presents the data, specifies the empirical model, presents the results and discusses their robustness. Section 4 concludes.

2 Theoretical framework

Here we develop a simple model to predict the impact of credit market development on resource use under arbitrarily insecure property rights. The model captures the effect of credit market development on the opportunity cost of capital and on discounting the income stream from future resource use. We introduce depreciable harvesting capital following Clark et al. (1979) and Singh et al. (2006) to capture the effect of credit markets on the opportunity costs of amassing harvesting capital. To model credit market development we take a simple and parsimonious approach. Stylized facts hold that developing countries often have low borrowing limits (in the absence of credit market these would be zero) and high interest rates (see Banerjee and Duflo (2010) and the summary statistics of this article). We therefore assume that credit market development can be characterized by increasing borrowing limits as in Deaton (1991) and declining interest rates. Both aspects of credit market development lead to lower discount rates as we will show below.

We model the resource user as an infinitively lived representative household that uses a common pool resource to generate income in an economic environment with market imperfections. We focus here on property right and credit market imperfections but assume well functioning markets for other production factors and consumption goods. This setting may describe the typical economic environment of rural areas in developing countries where households buy and sell goods in

observed market interest rates.

well-functioning markets but where property rights over resources are neither clearly defined nor perfectly enforced and where financial markets may malfunction.

The household maximizes a time separable utility function of consumption, as follows

$$\max \sum_{t=0}^{\infty} u(c_t)\beta^t. \quad (1)$$

Consumption is constrained by income from resource harvesting, investment in a harvesting technology and borrowing from imperfect credit markets. To simplify the model we assume that the household supplies labor inelastically such that resource harvesting depends only on the capital k_t and on the resource stock, x_t . In the example of a fishery, k_t may represent the boat or fishing gear and x_t may represent the biomass of fish; similar mappings exist for other natural resources. Investment in harvesting capital at time t is denoted by i_t and can either be positive or negative. Negative investment implies that the household is selling harvesting capital. The household exists in a small open economy and takes all prices as given. The resource-derived income is given by

$$y_t = ph(k_t + i_t, x_t) \quad (2)$$

where the harvest function $h(k, x)$ is increasing in both arguments, concave, continuous and twice differentiable. This formulation of the harvesting function assumes first, that the investment happens before the harvest; second, that the household employs all harvesting capital; and third, that the harvesting capital acts as the numeraire. The second assumption is an outcome of the optimizing behavior of the household (see Clark (1990, ch. 4.5.) for details). The resource stock grows after harvest according to the increasing and concave function

$$x_{t+1} = f(x_t - h_t). \quad (3)$$

Two other variables that describe the state of the system are harvesting capital and net assets of the household. Harvesting capital evolves over time in the standard fashion:

$$k_{t+1} = (k_t + i_t)(1 - \delta) \quad (4)$$

where $\delta \in [0, 1]$ is the capital depreciation rate. As newly invested harvesting capital is immediately employed it depreciates after the first harvesting cycle.

Without credit market imperfections, the net assets (or debts) of the household develops according to

$$a_{t+1} = (1 + \rho)(y_t + a_t - i_t - c_t). \quad (5)$$

where $\rho \geq 0$ is the interest rate in the financial market. In this general formulation the interest rate is the same for borrowing ($a_{t+1} < 0$) and saving ($a_{t+1} > 0$), but nothing hinges on this assumption. In practice the interest rate is not necessarily constant but we will rely on the assumption that it is exogenously determined. We follow Bohn and Deacon (2000) and Costello and Grainger (2018) and model property right security, θ , as the probability of retaining the right to harvest in a given period, so $1 - \theta$ gives the probability of expropriation of that right.

The timing of events is as follows. First, the household observes whether it has the right to access the resource (this is binary), the asset level and the size of the resource stock. Second, it makes the investment decision, harvests the resource and consumes. After harvest and consumption, the resource stock grows and the interest payments for the next period are determined. Finally, at the very end of period t , expropriation of the resource either occurs, or it does not occur; this outcome is observed by the household at the beginning of period $t + 1$. Given the timing of events and the constraints, the household's optimization problem is to maximize expected utility from consumption by choosing investment in resource harvesting, taking the resource dynamics, the opportunity costs of capital and the security over future resource use into account. We take a dynamic programming approach and express the choice variables of the household, consumption and investment as functions of the future stocks of assets, harvesting capital and resources. The Bellman equation for the optimization problem therefore becomes

$$J(x_t, k_t, a_t; \theta) = \max_{k_{t+1}, a_{t+1}} u \left(y_t + a_t - \frac{a_{t+1}}{1 + \rho} - \frac{k_{t+1}}{1 - \delta} + k_t \right) + \beta E_t [J(x_{t+1}, k_{t+1}, a_{t+1}; \theta)]$$

where the uncertainty over future consumption stems from the risk of expropriation (captured above by the expectation operator, from the perspective of period t). The first order conditions for capital investment and borrowing are given by

$$\begin{aligned} u_{c_t}^t (p h_{k_{t+1}}^t - 1) + \beta E[(1 - \delta) J_{k_{t+1}}^{t+1} - J_{x_{t+1}}^{t+1} f_x^t h_{k_{t+1}}^t] &= 0 \\ -u_{c_t}^t + (1 + \rho) \beta E[J_{a_{t+1}}^{t+1}] &= 0. \end{aligned}$$

In the following we use superscripts to denote the timing of functions and subscripts to denote partial derivatives e.g. $u_{c_t}^t = u'(y_t + a_t - \frac{a_{t+1}}{\rho} - \frac{k_{t+1}}{\delta} + k_t)$ etc. Using the first order conditions together with the envelope conditions for borrowing ($J_{a_t} = u_{c_t}^t$) yields the Euler equation

$$\frac{u_{c_t}}{\beta E[u_{c_{t+1}}]} = 1 + \rho. \quad (6)$$

The term on the left hand side is the inverse consumption discount factor which plays a central role in the preceding analysis. We introduce the helpful notation $\phi_t \equiv \frac{u_{c_t}}{\beta E[u_{c_{t+1}}]}$ for consumption

discounting. Combining the first order conditions with the envelope conditions for capital ($J_{k_t} = u_{c_t}^t$) gives

$$\underbrace{(ph_{k_{t+1}}^t - 1)}_{\text{marginal profit}} + \underbrace{\frac{1}{\phi_t}}_{\text{discount factor}} \left\{ \underbrace{(1 - \delta)}_{\text{future capital stock}} - \underbrace{\frac{\beta E[J_{x_{t+1}} f_x^t h_{k_{t+1}}^t]}{\beta E[u_{c_{t+1}}^{t+1}]}}_{\text{future resource stock}} \right\} = 0 \quad (7)$$

The first term in 7 reflects the impact of one additional unit of capital on current profits from resource harvesting; terms in curly brackets reflect the impact of additional capital on discounted future value of the capital stocks and on the discounted future profits from resource harvesting through reduced resource stocks.

An interesting special case arises under open access, when expropriation is certain (so $\theta = 0$), in which case condition 7 simplifies to

$$(ph_{k_{t+1}}^t - 1) + \frac{1}{\phi_t}(1 - \delta) = 0.$$

Under open access, the household takes only the returns on investment and the capital depreciation into account, neglecting its impact on the resource stock and future harvests. The first term in brackets is the instantaneous marginal profit from harvesting capital i.e. the marginal productivity of capital in resource harvesting minus the unit costs of capital. In the following, we denote the instantaneous marginal profit from harvesting capital evaluated at the optimal capital investment level, k^* , for a given level property rights security, θ , by

$$\pi^\theta \equiv (ph_{k_{t+1}} - 1)|_{k^*, \theta}.$$

The first order conditions reveal that the instantaneous profit is negative under open access as long as capital does not depreciate completely after one period. The intuition is that harvesting capital remains valuable in the next period such that the total cost of capital is the unit cost minus the discounted and depreciated future value of capital: $1 - \frac{1}{\phi}(1 - \delta)$. This condition implies that the household can shift consumption from the future to the present by reducing investment levels. With complete property rights over the resource and using the envelope condition for the resource stock, $J_{x_t} = u_{c_t}^t ph_{x_t}^t$, the first order condition for capital investment becomes

$$\phi(ph_{k_{t+1}}^t - 1) + (1 - \delta) - ph_{x_{t+1}}^{t+1} f_x^t h_{k_{t+1}}^t = 0.$$

As in the open access case, this condition is deterministic. But here, because the future is secure, the household takes its impact on future resource harvesting into account. Under secure property rights,

the instantaneous profit depends not only on the capital depreciation but also on the impact of the current harvest on future resource abundance. Intuitively, instantaneous profit is an increasing function of capital depreciation, δ . But profit also increases in the fourth term, $ph_{x_{t+1}}^{t+1}f_x^th_{k_{t+1}}^t$, which captures the marginal impact of capital investment on future harvest via the reduction of the resource stock. This term increases in the density dependence of the harvest, $h_{x_{t+1}}$, and in the impact of resource extraction on next period's resource availability (the negative of the regenerative capacity of the resource), f_x .

It is also interesting to note that the optimal instantaneous profit from capital investment under secure property rights can be either positive or negative. Consider the extreme cases. Under secure property rights, complete capital depreciation ($\delta = 1$), some resource dependence of the harvest ($h_{x_{t+1}} > 0$) and finite resource growth ($f_x > 0$), the instantaneous profit is positive and $\pi^{\theta=1} > 0$. The other extreme case under secure property rights with no capital depreciation ($\delta = 0$) and instantaneous regeneration of the resource ($f_x = 0$), $\pi^{\theta=1} < 0$. Thus, we find that the properties of the resource stock largely determine whether the household can shift more consumption to the present by increasing harvest.

Thus far, we have focused on the optimal dynamic decisions of the household, and how they depend on features of the problem such as resource growth, expropriation, etc. A key objective of this paper is to examine how credit market improvements will alter these decisions. To investigate the impact of credit rationing on resource extraction we introduce an exogenous borrowing limit, α , such that

$$y_t + a_t - i_t - c_t \geq -\alpha.$$

When this credit constraint binds, the household's demand for credit exceeds α and the discount factor is larger than the market interest rate such that condition (6) no longer holds. The intuition is that an unconstrained household borrows money until the marginal utility of current consumption equals the marginal utility from repaying the loan plus its interest in future. The borrowing limit binds if the consumption discounting exceeds the cost of borrowing at the point where the household borrows the maximum amount, α . Now consider the response of a household to an exogenous increase in the borrowing limit, α . A credit constrained household increases borrowing in response to an increase in α ; this increases the current consumption at the expense of future consumption. As a result of the increased borrowing, the future consumption becomes relatively more valuable and the consumption discount factor declines. If the borrowing limit increases further, the discount factor eventually reaches the market interest rate and the credit constraint becomes non-binding.

The following lemma establishes this relationship formally.

Lemma 1. *An increase in the exogenous borrowing limit, α , reduces the discount factor of credit constrained households and has no impact on unconstrained households.*

Proof. Taking the derivative of the discount factor evaluated at $c_t = y_t + a_t - i_t + \alpha$ and $c_{t+1} = y_{t+1} + i_{t+1} - \alpha\rho$ with respect to α and applying the envelope theorem yields

$$\frac{d\phi}{d\alpha} = \frac{u_{c_t c_t} \beta E[u_{c_{t+1}}] + \rho u_{c_t} \beta E[u_{c_{t+1} c_{t+1}}]}{E[\beta u_{c_{t+1}}]^2} < 0.$$

□

The credit constraint never restricts the investment in harvesting capital directly as that would imply zero consumption. Thus, we conclude that both a decline of the interest rate and an increase of the borrowing limit affect resource use only through changes in the discount rate. Based on Lemma 1 we define the following:

Definition 1. *Credit market development is defined henceforth as a reduction of consumption discounting ϕ that is either caused by a decline in the market interest rate or an increase of the borrowing limit.*

A key finding of our paper is that the consequences of credit market development on resource extraction hinge crucially on property right security. The following proposition characterizes the impact of credit market development on resource exploitation, and makes explicit the dependence on property rights.

Proposition 1. *There exist two property rights security levels $\underline{\theta}$ and $\bar{\theta}$, where $0 < \underline{\theta} \leq \bar{\theta} \leq 1$, such that harvesting is increasing in credit market development when property rights are sufficiently weak ($\frac{dk^*}{d\phi} < 0$ for $\theta \leq \underline{\theta}$) and harvesting is decreasing in credit market development when property rights are sufficiently strong ($\frac{dk^*}{d\phi} \geq 0$ for $\theta > \bar{\theta}$).*

Proof. See Appendix A. □

Proposition 1 states that credit market developments always increases harvesting effort under insecure property rights. It also states that credit market development can lead to reduced resource extraction if $\bar{\theta} < 1$. This is the case if the impact of credit market development on the valuation of future resource stocks outweighs the impact on the harvesting costs. In addition, the two property rights security levels coincide (so $\underline{\theta} = \bar{\theta}$) if the policy function is monotonous.

The intuition for this proposition is that reduced discounting increases the marginal value of future income compared to current income. A lower discount rate induces more investment in harvesting if it increases future income relative to current income. This situation is more likely if households consider the future value of harvesting capital but neglect their impact on future resource stocks i.e. under insecure property rights. The proposition states further that this result is not only true for the extreme cases of private property and open access but also in a region close to the extremes.

This simple framework has given rise to two theoretical predictions that we now test empirically. The first is that credit market development increases harvesting effort under insecure property rights. The second is that this result can actually be reversed under sufficiently secure property rights.

3 Cross-country evidence from the global fishery

Global fisheries present an ideal test case for our theoretical setting: the resource is renewable, property rights vary substantially around the world and through time, and credit markets experience large exogenous changes in space and time. In the following we test the predictions from the theoretical framework using data from 5,573 fish stocks over 56 years, covering most of the world's commercial fisheries. We combine the fishery dataset with data on financial development and property rights security over these fish stocks.

An ideal experiment for testing the impact of credit market development on resource extraction under varying levels of property rights security would randomly assign different levels of credit market development and property right security to otherwise identical fisheries. We would then observe harvesting behavior and test whether credit market improvements increased, or decreased, resource extraction, 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). The establishment of a country's EEZ arose out of an international agreement and altered property rights in that country for all marine resources, not just specific fisheries. Thus, we argue that the timing of the rollout of EEZs can be considered exogenous to the status of individual fisheries. However, the ability to implement and to enforce these rights differ between countries and fish

stocks; we exploit this feature in a differences-in-differences framework.

Changes to credit markets around the world are also not randomly assigned to individual fisheries. Rather, credit markets vary at the country level in response to policy (such as rural credit subsidies or banking regulations), technological progress (such as microfinance and mobile money), and general economic development and capital accumulation. Indeed, changes to credit markets may either be driven by economic development or may drive economic development. Although a causal impact of fisheries on credit market development seems unlikely (the fishery sector is small in most countries compared to other economic sectors), credit market development may affect the demand for resources and the economic opportunities of resource harvesters. Even in the ideal experiment described above it would be difficult to disentangle the effect of credit market development on the discount rate and on the economic opportunities of the resource manager. However, controlling for economic development, general time trends and global shocks allows us to isolate the impact of credit market development on resource extraction. Sector specific credit allows us further to control for general credit market development while estimating the impact of sector specific credit on resource extraction. We describe the estimation strategy in detail after presenting our data sources.

3.1 The status of global fisheries

The global fishery generates 100 billion USD revenues annually (Arnason et al. 2017) and employs about 57 Million people directly (FAO 2016). In addition to its importance in terms of resource rents, it is the major source of proteins for many of the global poor (FAO 2016).

Despite their importance, many global fisheries are depleted below the level that maximize long-run harvests (Figure 1). It is widely agreed that a main driver of overfishing is over-investment in resource harvesting capital (Clark 2006). Resource economists often blame the lack of secure property rights over the resource as the major cause for this over-investment in harvesting capacity, but the theoretical model above suggests that changes in credit markets may actually spur over-investment in harvesting capital, particularly when property rights are weak.

High levels of overfishing cause large economic losses when resource stocks are driven to low levels that cannot produce sufficient fishery yields. Current estimates of the global inefficiency from mis-managed fisheries ranges from 53 Billion USD (Costello et al. 2016) to 86 Billion USD (Arnason et al. 2017); most of the losses from overfishing occur in the developing world. Reducing the current exploitation rates may therefore increase resource rents and additionally benefit the

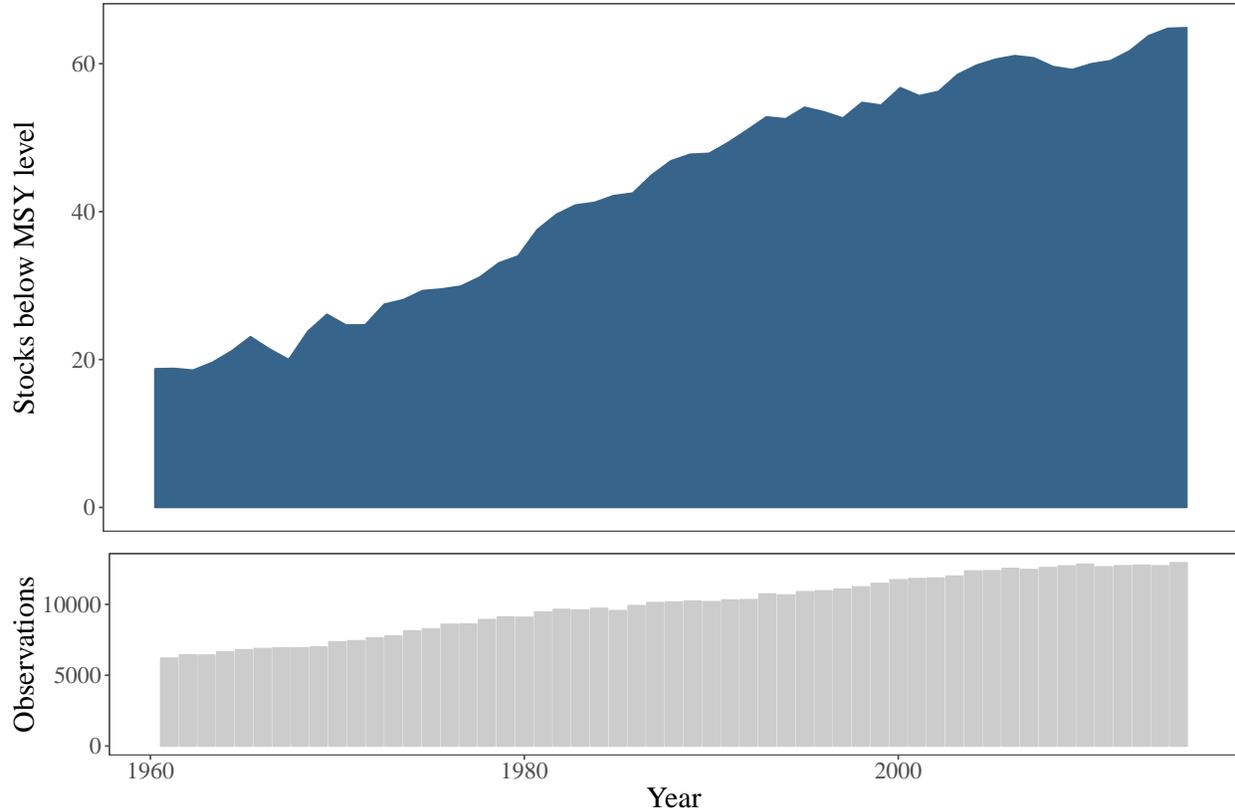


Figure 1: The figure shows the share of global fish stocks that are depleted below the level that would maximize long-run harvest (MSY level) in blue and the number of observations in our panel in gray. The share of stocks below the MSY level in our figure differs from the share of overfished stocks reported in FAO (2018) because the Food and Agriculture Organization of the United Nations (FAO) classify fish stocks as overfished when they drop below 40 % of the unfished stock level while our definition uses the MSY level as reference point. It is therefore more in line with the estimates of Costello et al. (2012). Further, we use additional data sources which are described in the next sub-sections.

global poor.

3.2 Fisheries and credit markets

Before we test the impact of credit market on global fisheries formally we show suggestive evidence from the impact of Thailand’s Million Baht Village Fund Program on fishing. The Thai Million Baht Village Fund is one of the world’s largest governmental microfinance programs which was studied extensively by Kaboski and Townsend (2011, 2012). In this program, the central government allocated one million bath (about \$ 24,000) to each village in Thailand to initiate independent microfinance institutions. The program was rolled out in late 2001 and in 2002 most villages had

received the funding Kaboski and Townsend (2012). Figure 2 shows an event study graph of fish catches. The coefficients and confidence intervals are estimates for year dummies indicating the number of years before and after the implementation of the program in the year 2001. Fish catches in other countries of South East Asia are used as the reference group. Although standard errors are large due to the small sample (only 40 fish stocks within Thailand) and despite existing pretrends, the figure suggests that catches increased by about 20 % following the introduction of the village fund. Figure 2 suggests that credit market development increases resource harvesting which is in

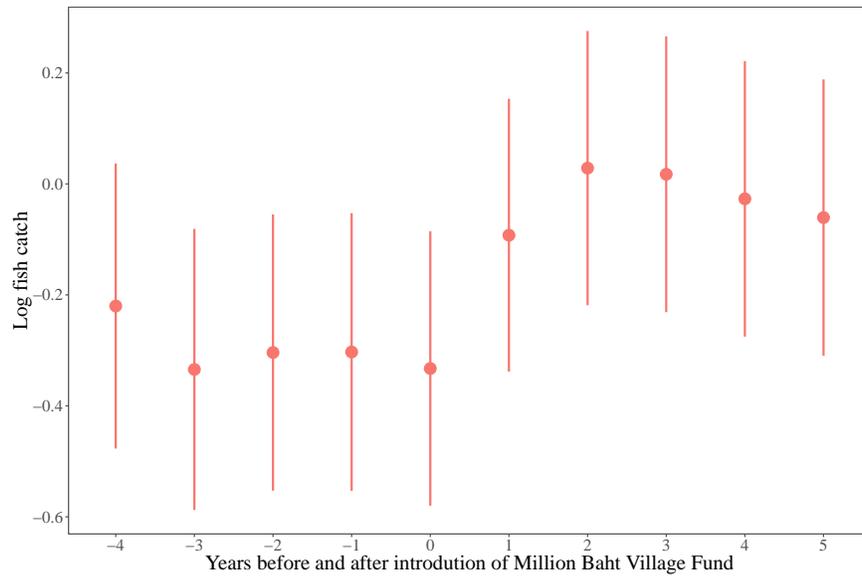


Figure 2: The figure shows the coefficients and 90 % confidence intervals of the year dummies d_t in the following regression: $\log(catch) = \sum_{t=-5}^5 \psi_t d_{jt} + \log(gdp_{ijt}) + stock_i + country_j + year_t$. The catch data are from the FAO for all countries in South East Asia (SEA) but the year dummies were set to -99 in all countries but Thailand. Fish catches of other SEA countries are included as a references catch levels i.e. to estimate the year dummy. Years are measured in years before and after the intervention in 2001.

line with our predictions for weak property rights over resources. In the following we describe the data to test the impact of credit market development under varying levels of property rights security.

3.3 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 gross domestic product (GDP) in constant 2010 USD, total factor productivity and unemployment rates are taken from the World

Bank World Development Indicators, the Penn World Tables version 9.0 and the International Labour Organization respectively.

Resource extraction in the fishery

We measure resource extraction using a panel of fish stocks and fish catches that covers 5,573 fish stocks from 142 countries over the period from 1950 to 2015. The sample includes the vast majority of all commercially exploited fish stocks globally but small-scale fisheries in developing countries may be less well represented.

We adopt the convention of measuring the resource extraction rate relative to the extraction rate that would achieve maximum sustainable yield (MSY).⁸ For example, an extraction rate of 1.5 indicates that the current extraction rate is 50% higher than the extraction rate that would achieve MSY. In that case, the fishery stock would be expected to 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 1.5 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 1.0 indicates an extraction rate that would lead to a long-term decline (and if large enough, a collapse of the resource stock). However, a temporary extraction rate above 1.0 could be economically optimal for an underexploited fish stocks, suggesting the importance of the 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 our empirical specification. The data on catches and stock sizes are an updated version of the database from Costello et al. (2016) who 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 (all stocks from the RAM database) or simulations based on the species biology and the catch history (all stocks from the FAO database). The data and methods to estimate the stock sizes for the FAO stocks are described in Costello et al. (2016). In one robustness test, we restrict our sample to only the stocks in the RAM database, which are considered more reliable than the simulated stocks. However, as stocks in the RAM database (i.e. those with formal stock assessments) tend to be concentrated in countries with both strong property rights and high levels of credit market development, we use the complete data set for our main specification in order to

⁸Fishing mortality, F is the ratio of harvest 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} .

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" in Belize). 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 3 provides the summary statistics for the exploitation rate by country over the entire time period. The figure highlights ten of the largest fishing nations from different continents and with different levels of economic development; we will highlight these countries as reference in the following figures. In the next subsection we show how the introduction of property rights over these resources affected the harvesting rates.

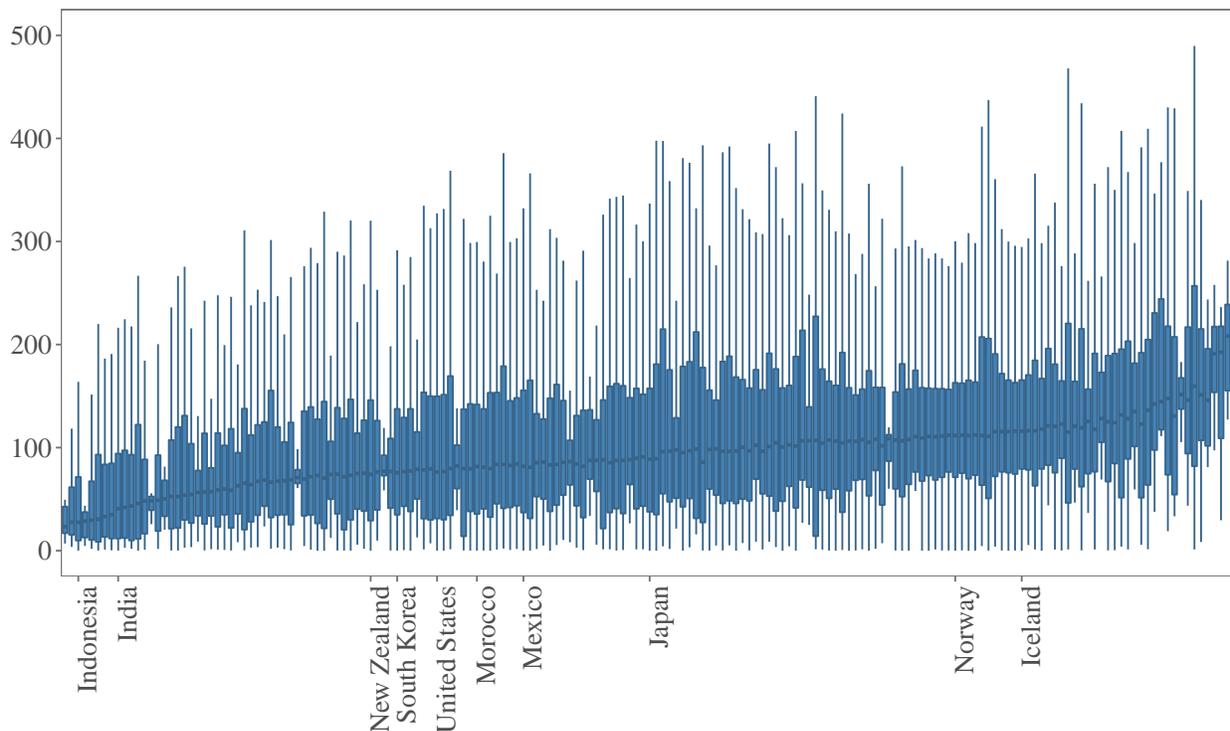


Figure 3: The boxplots show the median and the 25th and 75th percentiles of the exploitation rates by country. Harvesting rates within a country varies over time and across fish stocks.

Property rights security over fish stocks

Until the mid-1900's the world's ocean fisheries were essentially open access with limited possibilities for regulation. 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 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 ranges of fish stocks extended beyond the 12 nm zone such that domestic efforts to manage fisheries could be counteracted by increased harvesting effort by other fishing fleets outside the 12 nm zone. This situation changed dramatically with the adoption of UNCLOS because it granted exclusive an economic zone (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.⁹ The agreement assigned the exclusive property right to marine resources within a country’s EEZ. UNCLOS was widely regarded as a blanket assignment of property rights; while the 200 nm limit includes nearly all productive coastal waters, and thus covers about 90 % of global fish stocks (Ebbin et al. 2005), fisheries were not the main target of UNCLOS. Although all countries generally agree to the EEZs in general, the implementation and the enforcement of the law differed largely between countries. While some countries implemented and enforced their EEZs immediately (or even unilaterally before 1982), others are still struggling to enforce the rights over their fisheries resources (see e.g. Cabral et al. (2018)). Thus, the date of implementation of EEZs varies across countries. For these reasons, we regard the delineation of the 200 nm EEZs as exogenous to the health of fish stocks in a country. 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 these dates as marking the date of transition from open access to exclusive use rights over most fish stocks that reside in the EEZ of a country.

However, the strength of those rights depends largely on the capability of a country to enforce them. To quantify strength of those rights over the fisheries resources within the EEZs we use the Rule of Law Index from the Worldwide Governance Indicators of the World Bank (Kaufmann et al. 2011), which quantifies the quality of contract enforcement and the strength of property rights within countries. The index was calculated every two years between 1996 and 2002 and every year from then on. We interpolate the index on country level using Stineman interpolation (Moritz and Bartz-Beielstein 2017). We then normalize the index between 0 and 1 such that it matches the parameter θ in the theoretical model described above. In a robustness check we use the Legal System and Property Rights Index of the Fraser Institute (Fraser Institute 2016). Because

⁹The 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 as large than the total land area of the US; the EEZ of New Zealand is 15 times as large as its land area.

this index was only calculated every five years (from 1970-2000), we interpolate as described above. The index of the Fraser Institute puts more weights on the intertemporal changes of property rights security within each country such that differences of the index within countries over time are often larger than the differences between countries. In contrast, the World Bank index emphasizes the differences in the rule of law between countries. We show time series of our property rights index for the set of countries highlighted in Figure 3 in Appendix B.

Figure 4 depicts the mean harvest rate (in blue) and the property rights security (shaded areas) of ten of the world’s largest fishing nations. The figure shows that while resource extraction rates declined after the introduction of the EEZs in countries with strong property rights security such as Iceland or Norway, the introduction of the EEZs had little impact on resource extraction of countries with weak property rights such as India or Indonesia. Other countries such as the United States seem to respond slowly to the increased levels of property rights security.

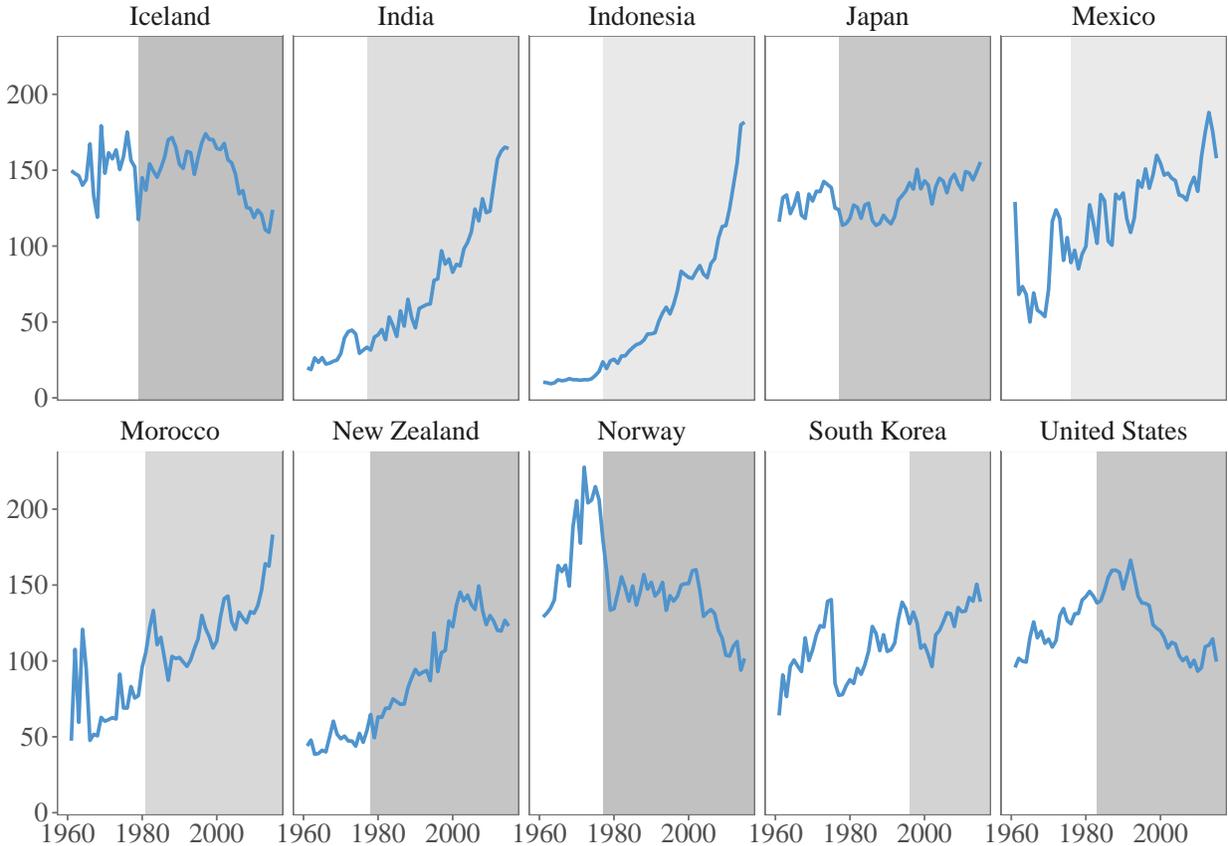


Figure 4: Mean extraction rate (in blue), the introduction of national EEZs (the start of the shaded area) and the Rule of Law index (shading).

Some highly migratory fish species (such as tuna) or fish stocks with large distributional ranges

(such as sharks) are caught by several nations. Fisheries managers have struggled with these stocks because it is impossible for any single country to establish secure property rights over the entire stock. Thus, even holding constant the rule of law and other property right fundamentals, a country’s security over a fish stock will depend on the spatial extent of the stock and the mobility of individuals of this species within its spatial range. To quantify this biological dimension of property rights security, we use the share of the total distribution 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.¹⁰ Although this variable captures the share of the stock within each EEZ, it does not quantify the mobility of each species within its range. While some species move constantly within their distributional range making it impossible to manage subpopulations independently, other species such as shellfish may be largely immobile. We therefore introduce a mobility parameter $M \in [0, 1]$ that we use to account for the mobility of a species within its total distribution range. Adding the dimensions of property rights together, we define our property rights security by

$$PR := EEZ \times ROL \times RA^M,$$

where ‘EEZ’ is a dummy variable that indicates whether a country has established an EEZ, ‘ROL’ is a normalized rule of law index and ‘RA’ is the share of the species total distribution that falls into the EEZ of a country. Table 1 illustrates the components of our property rights measure for yellowfin tuna (*Thunnus albacares*) and Caribbean spiny lobster (*Panulirus argus*) in the United States and Mexico and for the year 2010. Both species have considerable economic importance but while the yellowfin tuna is a pelagic species with a large range and high mobility within its range, the spiny lobster is a shellfish with a relatively small range and limited mobility. The first column of Table 1 indicates that both countries implemented their EEZ in 2010 but also that their ability to enforce the rights within their EEZs differed. This difference is, however, much larger according to World Bank rule of law index (ROL) compared to the index of the Fraser Institute (ROL(FI)). The ability to establish secure property rights over the fish stocks is further diminished 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 (RA) is in fact very small in both cases. In consequence, multiplying the range parameter with the other dimensions of property rights security ($EEZ \times ROL \times RA$) suggests

¹⁰The data are from Molinos et al. (2016) where the methodology is described.

that both countries are virtually unable to establish secure property rights over yellowfin tuna. This conclusion is, however, at odds with the claim of the National Oceanic and Atmospheric Administration (NOAA) which states that yellowfin tuna are sustainably managed in the US's EEZ, a statement that is mostly supported by the assessment of Seafood Watch, a sustainable seafood advisory lists developed by the Monterey Bay Aquarium. It also contradicts the finding of a tracking study which finds that yellowfin tuna and other tuna and shark species which were tagged in the California current (shared between the US and Mexico) stayed more than 80 % of their time in the California current (Block et al. 2011). We therefore introduce a mobility parameter $M \in [0, 1]$ which we set equal to $M = 0.2$ for pelagic species such as yellowfin tuna, $M = 0$ for shellfish species such as lobsters and $M = 0.1$ for all other species including different ground fish species. These mobility parameters imply that yellowfin tuna stay about 39 % ($RA^M=0.39$) and 42 % ($RA^M=0.42$) of their time in the EEZ of the US and Mexico respectively, in line with the findings of Block et al. (2011). The parametrization further implies that spiny lobsters do not move at all between EEZs. This is certainly a very strong assumption and as a robustness check we therefore center the un-transformed range parameter around unity ($RA1 = RA - \overline{RA} + 1$) such that the multiplication of the range parameter with the other components of property rights security does not change the mean of the measure.

The resulting property rights securities are shown in the last three columns of Table 1 and we report the impact of different property rights specifications on the results in the next section.

Our property rights security measure mainly reflects the government's ability to establish property rights security over resources, but may not capture the resource harvester's property rights security over the resource stocks. However, anecdotal and recent empirical (Costello and Grainger 2018) evidence shows that the harvesters successfully lobby for policies that are in line with their individual preferences. Changes in the harvesters' discount rates may therefore directly translate into adjustments of the harvesting policy. Further, an optimal harvesting policy must take harvesting costs into account. In that sense, our approach can be interpreted as the question if the regulator's policy takes the opportunity costs of harvesting into account.

Credit market development

Fundamentally this study is about credit markets and how they affect resource extraction under secure vs. insecure property rights. To measure credit market development we use the country average interest rates charged by banks for loans to the private sector and the volume of lending

	EEZ	ROL	ROL(FI)	RA	RA ^M	RA1	EEZ×ROL ×RA	EEZ×ROL ×RA ^M	EEZ×ROL ×RA1
Mexico									
Yellowfin tuna	1.00	0.39	0.67	0.01	0.42	0.87	0.00	0.16	0.34
Spiny lobster	1.00	0.39	0.67	0.10	1.00	0.95	0.04	0.39	0.37
United States									
Yellowfin tuna	1.00	0.83	0.78	0.01	0.39	0.86	0.01	0.32	0.71
Spiny lobster	1.00	0.83	0.78	0.16	1.00	1.01	0.13	0.83	0.83

Table 1: Property rights for yellowfin tuna and Caribbean spiny lobster in the US and Mexico

Notes: ‘EEZ’ indicates whether a country has established an EEZ, ‘ROL’ is the normalized World Bank rule of law index, ‘ROL(FI)’ is the normalized rule of law index of the Fraser Institute, ‘RA’ is the share of the range within an EEZ relative to the total distribution of a species, ‘RA^M’ is the range to the power of a mobility parameter, ‘RA1’ is the range centered around 1. The evaluation of the property rights index is for the year 2010.

to the private sector relative to GDP. The lending interest rate measures the cost of capital and we directly related it to the interest rate in Section 2. The volume of private credit is a common measure to describe credit market development in the financial literature (Levine et al. 2000; Beck and Levine 2004; Aghion et al. 2010, 2014; Mian et al. 2017) and is related to the credit constraints in Section 2.

The data on the volume private credit are from Levine et al. (2000) and Beck et al. (2010) and are updated by the World Bank. The data on lending interest rates stem from the International Financial Statistics from the International Monetary Fund (IMF). The methods used by the IMF to assess the lending interest rates differs between countries as the interest rate depends on the size and conditions of the loan. The country level differences of the assessment methods are, however, absorbed by the country level fixed effects in our empirical specification.

The volume of credit and the interest rates for the private sector may describe the credit conditions of fishermen only imprecisely. The FAO recently published 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 about 100 countries. Although the spatial and temporal extend of this data set is limited, 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 as little differences in the assessment dates of interest rates and inflation can lead to large discrepancies. We therefore exclude all periods of hyperinflation with inflation rates exceeding 30 % per year.

Figure 5 summarizes the data on credit market development. Panel A) displays the volume of lending to the private sector relative to GDP and panel B) summarizes the distribution of the lending interest rates by country.

The financial time series we use are generally available between 1960 and 2015 but their coverage differs. After merging the data sets and excluding periods of hyperinflation we exclude all observations where either lending interest rates or credit to the private sector are missing. This leaves us with 90,966 stock-year country level observations.

3.4 Empirical estimation

In this section we describe the empirical strategy for estimating the effect of credit market development on resource extraction under different levels of property rights security. We examine how the resource extraction rate responds to credit market development across different levels of property rights security. We have argued in the previous section that our main variation in the level of property rights security over time and between fish stocks and countries is exogenous. Our main concern is therefore that credit market development not only affects the fisheries sector but also other economic sectors and in turn the demand for fish and the technology available for fishing (Squires and Vestergaard 2013). Also, credit market development may depend on economic development itself with similar effects on technology and demand. We describe how we address these challenges after introducing our main regression specification:

$$\text{extraction}_{ijt} = \gamma_1 \text{rights}_{ijt} + \gamma_2 \text{credit}_{jt} + \gamma_3 \text{rights}_{ijt} \times \text{credit}_{jt} + X_{jt} + \mu_{ij} + \nu_t + \varepsilon_{ijt}. \quad (8)$$

Here ‘ extraction_{ijt} ’ denotes the harvest rate of stock i in country j at time t relative to the MSY harvest rate (as explained above) measured in percent. The variable ‘ rights_{ijt} ’ indicates the level of property right security over fish stock i . The variable ‘ credit_{jt} ’ the total volume of credit to the private sector in the first specification and is the credit market development measured by the lending interest rate in the second specification. The parameter μ_{ij} are country and fish stock specific fixed effects, ν_t are year fixed effects and ε_{ijt} is an error term clustered at the country

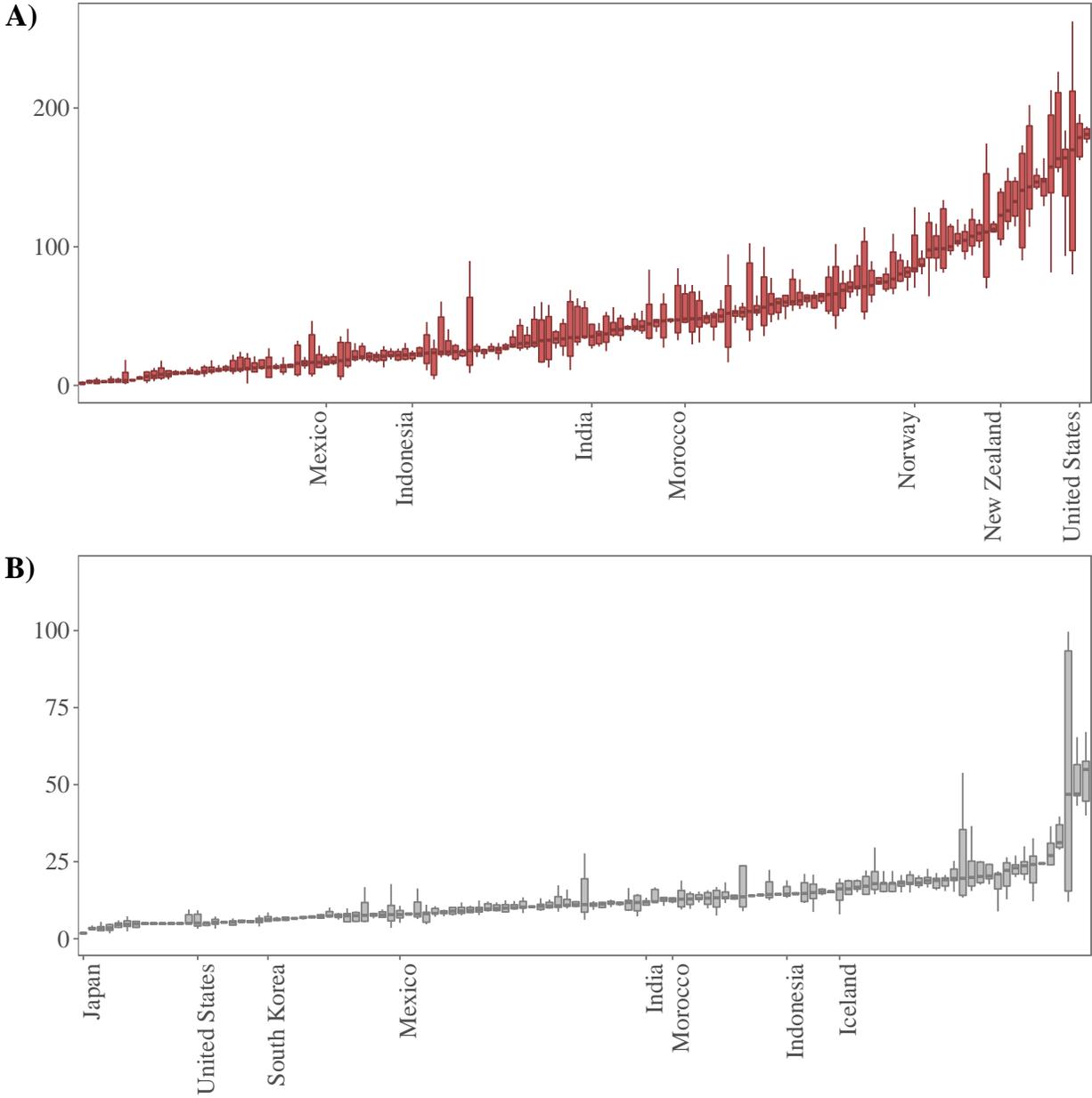


Figure 5: Panel A) shows the distribution of private credit relative to the GDP level while panel B) shows the distribution of the lending interest rates within countries. Variation of these two credit market variables within and across countries stem from credit market development and from inflation. Periods of hyperinflation (annual inflation rates exceeding 30 %) are omitted from the data. Iceland, Japan and South Korea are not highlighted in panel A) as they overlap with the United States (Iceland and Japan) and with New Zealand (South Korea). The data on lending interest rates for Norway and New Zealand are missing.

level. The vector X_{jt} contains GDP, GDP^2 , the normalized fish stock in year $t - 1$ as well as the inflation rate when credit market development is measured by changes in interest rates. We

transform all variables 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 harvest rates.¹¹ The transformation reduces the skewness of the distributions but also implicitly assumes an isoelastic relationship between credit market development and the harvest rate. This isoelastic relationship may evolve from isoelastic production functions such as Cobb-Douglas or CES but since we have not specified functional forms in our theoretical section we cannot tie this assumption directly to our theory.

Differences in levels of credit market development across countries are absorbed by country level fixed effects. However, the levels of credit market development will 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 γ_2 measures the impact of credit market development under open access, the parameter combination $\gamma_2 + \gamma_3$ represents the impact of credit market development under secure property rights. The parameter γ_1 reflect the impact of property rights on harvesting rates under mean fish stock-country specific levels of credit market development.

The fish harvest rate does not only dependent on investment in harvesting capacity but also on the fish stock, the demand for fish, the available technology and the opportunity cost of labor. Some of these variables may also drive credit market development creating the possibility for omitted variable bias. We address these concerns by introducing controls or fixed effects. We directly control for fluctuations in the resource base by including the fish stock as a control. We further include GDP in linear and squared form to control for general economic development that could drive the demand for both fish and credit. Fish is one of the most highly traded goods (between 35 to 40 % of the globally produced fish entered international markets between 2005 to 2015 (FAO 2018)) such that the price of fish is largely determined at the international level. This is especially true for the commercially harvested stocks of our data base. Year fixed effects therefore capture a large share of the demand fluctuations while country and fish stock fixed effects capture time constant differences in exploitation rates across fish species, fish stocks and countries. We address the concerns of omitted variables further in a robustness test in which we use data

¹¹The interpretation is only correct for sufficiently large values of the transformed variables. Bellemare and Wichman (2018) 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 interest rates respectively.

on sector specific credit market development (agriculture, fisheries & forestry) while controlling for overall credit market development. Although these data describe the financial environment of fishermen better than overall credit market development and in addition address the concerns about the impact of general economic development on resource extraction, they also create endogeneity problems as sector specific credits may respond to developments in the fishery sector. We therefore use the specification with general credit market development as our main specification and report the results on sector specific credit in a robustness test. In further robustness tests we include the unemployment rates as a proxy for the opportunity costs of fishing and the country specific total factor productivity to control for technological progress.

Harvest rates may further follow general time trends independent of resource regulation, the harvesting capacity, general economic development and demand fluctuations as well as changes in the size of fish stocks. Introducing time trends or including lagged dependent variables as controls remove these trends and estimates the parameters based on short term fluctuations around long term trends. Because the impact of the resource harvesters' decision to invest in new harvesting capital or to respond to new property rights security levels on resource extraction may only materialize slowly (e.g. it may take some time to build new fishing vessels), relying on short term fluctuations may fail to capture the relationship between credit market development and resource extraction. Focusing on short term fluctuations may therefore underestimate the impact of credit market development on resource extraction. We therefore use the specification (8) - with stock-country and year fixed effects - as our main specification and compare the results to alternative specifications with a) country level time trends and b) lagged dependent variables.

3.5 Results

Main Results

This section presents the results on the impact of credit market development on resource extraction. First, we present the results using the volume of credit to the private sector as credit market development indicator. We then report the results using the private sector interest rate as explanatory variable. In both specification we use a definition of the property rights measure that is solely based on the the implementation of EEZs and the rule of law within a country. We investigate the impact of introducing the biological dimension of property rights security in the following tables.

Table 2 reports the results using private credit as indicator for credit market development. All regression specifications control for GDP, GDP², the resource stock in $t - 1$ and further include

stock-country level fixed effects as well as year fixed effects. All controls are IHS transformed and standard errors are clustered at the country level.

The first column (Baseline) reports the result of our baseline regression specified in equation (8) with year and country - fish stock level fixed effects but without the interaction term of credit market development and property rights security. This specification estimates the mean impact of credit market development on resource extraction across all levels of property rights security. The results suggest that, holding all else constant, increasing the volume of credit to the private sector by one percent reduces resource extraction by 0.1 %. It further suggests, again holding all else constant, that increasing property rights security reduces resource extraction. The effect of property rights security is substantial. Our estimates suggest that increasing property rights security from open access to secure property rights reduces resource extraction by almost 40 %. Column two (Main) presents the results of our main specification that includes an interaction term of credit market development with property rights security over the resource. Including this interaction term allows us to test whether the effect of credit markets on harvest is mediated by property rights. The results of our main specification show that a one percent increase of credit to the private sector *increases* the harvest rate by 0.3 % under open access. In contrast, the same increase of credit to the private sector *decreases* resource extraction under secure property rights by 0.5 %.¹² These findings are consistent with our theoretical prediction that credit market development leads to increased resource harvesting under open access while it incentivizes resource conservation under secure property rights. The results of our baseline specification show further that increased property rights security reduces the harvest rates, plausibly because the resource owner takes the future values of resources into account. Changing the property rights security from open access to secure property rights reduces resource extraction by 50 % in this specification. Including country level time trends (column 3) and a lagged dependent variable (column 4) reduces the estimates but leave the qualitative results unchanged. The reduced estimates in these two specification suggest that the impact of credit market development on resource extraction is not only driven by short term fluctuations of credit markets but also by their long-term developments. Column (5), (6) and (7) use the same estimation equation as the main specification but restricts the sample to OECD countries (OECD), fish stocks with formal stock assessment (RAM), and fish stocks with data throughout the

¹²The marginal effect of the credit market development on the harvesting rates under secure property rights is given by the sum of the coefficient for credit market variable and the interaction term of the credit market variable with property rights security.

complete time period (Balanced). These specification therefore restricts the analysis to the data from the most reliable sources and focuses on developed countries. The results are, however, very similar to the results of the main specification. This finding is especially interesting with respect to the specification reported in column six (OECD) as it suggests that the impact is not statistically different between the complete sample and the sample from OECD countries.

The last column (Agriculture Credit) uses data on the volume of credit to the agricultural sector (including fisheries) to measure credit market development while including total credit to the private sector as a separate control (estimates not shown). The results using sector specific credit on resource extraction (column 9) are, however, very similar to the estimates using the volume of total credit to the private sector as credit market indicator (column 2). These findings therefore suggest that the impact of credit market development on resource extraction is not driven by the impact of credit market development on the rest of the economy or by omitted variables such as economic development in general but by changes of the capital costs and discount rates in the resource sector.

Next, we focus on the results using the lending interest rates as the credit market development indicator. Table 3 presents results on the impact of interest rate changes on the harvest rate of global fisheries. Again, all regression specifications control for GDP, GDP² and the resource stock in $t - 1$ using IHS transformations. In addition, we include the inflation rate and exclude all observations in times of hyperinflation with annual inflation rates exceeding 30 %. Otherwise, all regression specifications are as described for Table 2. However, in contrast to the previous specification, credit market development implies a decreasing interest rate and consequently, negative coefficients suggest that credit market development leads to increasing resource extraction.

Again, the first column (Baseline) reports the result for our baseline regression but without the interaction term of credit market development and property rights security. The result suggest that improved credit markets and increased property rights security over resource stocks reduce harvest rates. Our main specification in column (2) shows further that while credit market development reduces resource extraction under secure property rights the impact is weakly positive although not statistically significant under open access. The estimates of the main specification suggests that a one percent reduction of the interest rate reduces resource extraction under secure property rights by 0.3 % while it has no statistically significant impact on resource extraction under open access. These estimates are qualitatively similar across the different specification reported in columns (3) to (8). While these results generally confirm the results reported in Table 2 they are generally

Table 2: Resource harvesting and the volume of credit

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Baseline	Main	Trend	AR	Controls	OECD	RAM	Balanced	Agriculture Credit
Credit	-0.09* (0.05)	0.29*** (0.08)	0.12** (0.05)	0.08*** (0.02)	0.36** (0.15)	0.21*** (0.08)	0.32*** (0.09)	0.31*** (0.09)	0.21** (0.11)
Property rights	-0.39*** (0.08)	-0.50*** (0.09)	-0.12* (0.06)	-0.16*** (0.03)	-0.38*** (0.09)	-0.50*** (0.13)	-0.27*** (0.06)	-0.54*** (0.10)	-0.52*** (0.16)
Credit \times Property rights		-0.78*** (0.17)	-0.33*** (0.08)	-0.24*** (0.06)	-0.55*** (0.18)	-0.46*** (0.14)	-0.61*** (0.17)	-0.80*** (0.18)	-0.46*** (0.20)
Stock \times Country FE	Yes								
Year FE	Yes								
Country trend			Yes						
Observations	259,477	259,477	259,476	259,477	153,496	110,099	190,533	171,688	67,589
R ²	0.17	0.17	0.34	0.60	0.09	0.28	0.17	0.26	0.49

Notes: The regression specifications are *Baseline*: as defined by equation 8 but without interaction term, *Main*: as defined by equation (8), *Trend*: as 'Main' but including additional linear country level time trends, *AR*: as 'Main' but including the lagged dependent variable as control, *Controls*: as 'Main' but including unemployment and total factor productivity as controls, *OECD*: as 'Main' but sample restricted to OECD countries, *RAM*: as 'Main' but sample restricted to fish stocks with formal stock assessment, *Balanced*: as 'Main' but restricting the sample to fish stocks with data for the complete time period, *Agriculture credit*: Using volume of credit to the agriculture sector and controlling for volume of total credit, both from the FAO data base. All specifications include additionally stock-country fixed effects, year dummies, log gdp, log gdp squared and the fish stock size relative to its maximum MSY level in $t-1$. All variables are transformed using inverse hyperbolic sine transformation. Independent variables are additionally demeaned at the stock-country-level. Robust standard errors are clustered 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.

weaker. One reason for the reduced precision of the estimates could be that interest rates can fluctuate for given level of credit market developments while resource extraction rates adjust slowly to new levels of credit market development.

Property Rights Security

Next, we investigate the impact of the our property rights specification on the result. For the previous results, we used a property rights variable based on the EEZ implementations and the ability of countries to enforce property rights right but not the biological differences across species. In the following we show how incorporating the biological dimension of property rights affects the estimates.

Table 4 presents the results for our main regression specification defined by equation 8 using the volume of credit as the credit market indicator. We restrict the sample to those observations for which all dimensions of property rights are available, including the species' spatial distribution. The results may therefore deviate from the results reported in Table 2.

Column (1) of Table 4 shows the results for a property rights security indicator that assigns full property rights security to all stocks after the introduction of a country's EEZs. This specification therefore neglects differences in the ability to enforce these rights between countries and over time. The coefficient for property rights security is not statistically significant in this specification and also the R^2 of the regression indicates the least explanatory power of this property rights specification, although differences across the regressions are generally small. Column (2) weights the EEZ indicator by the normalized rule of law index from the World Bank. This is the same regression as reported in column (2) of Table 2 using the slightly reduced sample. Column (3) reports the same property rights specification as in column (2) but using the normalized rule of law index from the Fraser Institute. The results are qualitatively similar to the results reported in column (2) but the R^2 suggests a slightly worse fit. The next three columns introduce the biological dimension of property rights security. Column (4) weights the property rights indicator with the share of the species' distribution within the EEZ. These weights reduces the property rights security for most species to almost zero because the range of the species' within the EEZs is small relative to their global distribution (see discussion in Section 3.3). The result for the non-interacted credit variable are, in consequence, similar to the results of the baseline specification without the interaction term reported in column (1) of Table 2. Column (4) weights the property rights variable with a range variable that takes both, the distribution and the mobility of fish species into account. The results are qualitatively similar to the results of our main specification

Table 3: Resource harvesting and the lending interest rate

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Baseline	Main	Trend	AR	Controls	OECD	RAM	Balanced	
Lending interest	0.18*** (0.05)	-0.05 (0.09)	0.05 (0.07)	-0.02 (0.03)	-0.03 (0.13)	-0.09 (0.10)	-0.12 (0.11)	-0.06 (0.11)
Property rights	-0.36*** (0.11)	-0.52*** (0.13)	-0.19** (0.08)	-0.19*** (0.05)	-0.18* (0.11)	-0.44*** (0.17)	-0.40*** (0.11)	-0.64*** (0.15)
Lending interest \times Property rights		0.37** (0.16)	0.04 (0.09)	0.14** (0.05)	0.05 (0.16)	0.28* (0.17)	0.30 (0.18)	0.57*** (0.22)
Stock \times Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country trend			Yes					
Observations	145,780	145,780	145,780	145,780	85,573	61,034	115,611	75,558
R ²	0.54	0.54	0.63	0.75	0.52	0.73	0.55	0.56

Notes: The regression specifications are *Baseline*: as defined by equation 8 but without interaction term, *Main*: as defined by equation (8), *Trend*: as 'Main' but including additional linear country level time trends, *AR*: as 'Main' but including the lagged dependent variable as control, *Controls*: as 'Main' but including unemployment and total factor productivity as controls, *OECD*: as 'Main' but sample restricted to OECD countries, *RAM*: as 'Main' but sample restricted to fish stocks with formal stock assessment, *Balanced*: as 'Main' but restricting the sample to fish stocks with data for the complete time period, *Agriculture credit*: Using volume of credit to the agriculture sector and controlling for volume of total credit, both from the FAO data base. All specifications include additionally stock-country fixed effects, year dummies, log gdp, log gdp squared and the fish stock size relative to its maximum MSY level in $t-1$. All variables are transformed using inverse hyperbolic sine transformation. Independent variables are additionally demeaned at the stock-country-level. Robust standard errors are clustered 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.

reported in column (2) of Table 2 and table 4. However, multiplying the rule of law index with the range parameter reduces the property rights index for most species. The estimated magnitude of the impact of property rights security on resource harvesting in non-interacted and interacted form increase in consequence to these changes. The specification reported in column (6) preserves the mean property rights security compared to the main specification as it centers the range parameter around one. The parameter estimates are very similar to the ones reported in column (2) but in contrast to the specification in column (2) it exploits additional property rights differences across species within a country.

Figure 6 depicts the distribution of the property rights measures used in columns (2), (4), (5) and (6) of Table 4. The property rights measures defined by $EEZ \times ROL$, $EEZ \times ROL \times RA$ and $EEZ \times ROL \times RA^M$ in panels A, B and C of Figure 6 share the appealing feature that they are restricted between 0 and 1. However, introducing the biological dimension in panel B) and C) reduces the mean property rights security compared to panel A). This effect is more pronounced in panel B) which does not take the mobility within the range distributions into account. The mean property rights security in panel D) is the same as in panel A) but it contains property rights values above one contradicting our theory in section 2. We therefore prefer the property rights specifications depicted in panel A) and C).

Table 5 presents the same estimates as in Table 4 but using the lending interest rate as credit market indicator. Again, the property right specification $EEZ \times ROL$, $EEZ \times ROL \times RA^M$, and $EEZ \times ROL \times RA1$ yield qualitatively very similar results to the main specification shown column (2) of Table 5 while the results for the property rights security specification reported in column (1) and (3) resemble more the results for the baseline specification without interaction term reported in Table 5.

Overall, the empirical results are strongly consistent with our theoretical predictions that credit market development leads to increased resource extraction under open access while it reduces resource extraction when property rights are secure. Next, we illustrate the magnitude of the effects.

3.6 Simulations

How economically and ecologically significant is the magnitude of our estimated effect of credit markets on natural resource harvesting? Here we illustrate the impact of credit market development and property rights security on resource extraction using parameter estimates from our

Table 4: Property rights measures, resource harvesting and the volume of credit

	(1)	(2)	(3)	(4)	(5)	(6)
	EEZ	EEZ×ROL	EEZ×ROL(FI)	EEZ×ROL ×RA	EEZ×ROL ×RA ^M	EEZ×ROL ×RA1
Credit	0.09 (0.11)	0.26*** (0.08)	0.19* (0.10)	-0.01 (0.05)	0.18*** (0.06)	0.25*** (0.07)
Property rights	-0.09 (0.07)	-0.54*** (0.10)	-0.28*** (0.10)	-1.26*** (0.15)	-0.82*** (0.10)	-0.58*** (0.08)
Credit × Property rights	-0.28*** (0.10)	-0.77*** (0.17)	-0.60*** (0.16)	-0.96*** (0.30)	-0.89*** (0.20)	-0.68*** (0.15)
Stock × Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	220,877	220,877	220,877	220,877	220,877	220,877
R ² (full model)	0.53	0.54	0.53	0.54	0.54	0.54
R ² (proj model)	0.01	0.02	0.01	0.02	0.03	0.02

Notes: All regression specifications are as defined by equation (8) but they differ with respect to the property rights variable. Property rights security equals zero before the introduction of EEZs in all specifications. After the introduction it equals (1) EEZ: unity, (2) EEZ×ROL: the normalized rule of law index of the World Bank, (3) EEZ×ROL(FI): the normalized rule of law index of the Fraser Institute, (4) EEZ×ROL×RA: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ, (5) EEZ×ROL×RA^M: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ to the power of a mobility parameter, EEZ×ROL×RA1: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ centered around unity. All specifications include additionally stock-country fixed effects, year dummies, log gdp, log gdp squared and the fish stock size relative to its maximum MSY level in $t - 1$. All variables are transformed using inverse hyperbolic sine transformation. Independent variables are additionally demeaned at the stock-country-level. Robust standard errors are clustered 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.

main specification from Table 2.¹³ The blue boxplots in Figure 7 depict the actual within country

¹³To compute resource extraction rates under different levels of credit market development and property rights security we use the following approach:

$$\begin{aligned} \text{extraction}_{ijs} = & \sinh[\text{lhs}(\text{extraction}_{ijt}) + \gamma_1(\text{rights}_{ijs} - \text{rights}_{ijt}) + \gamma_2(\text{credit}_{ijs} - \text{credit}_{ijt}) \\ & + \gamma_3(\text{rights}_{ijs}\text{credit}_{ijs} - \text{rights}_{ijt}\text{credit}_{ijt})] \end{aligned}$$

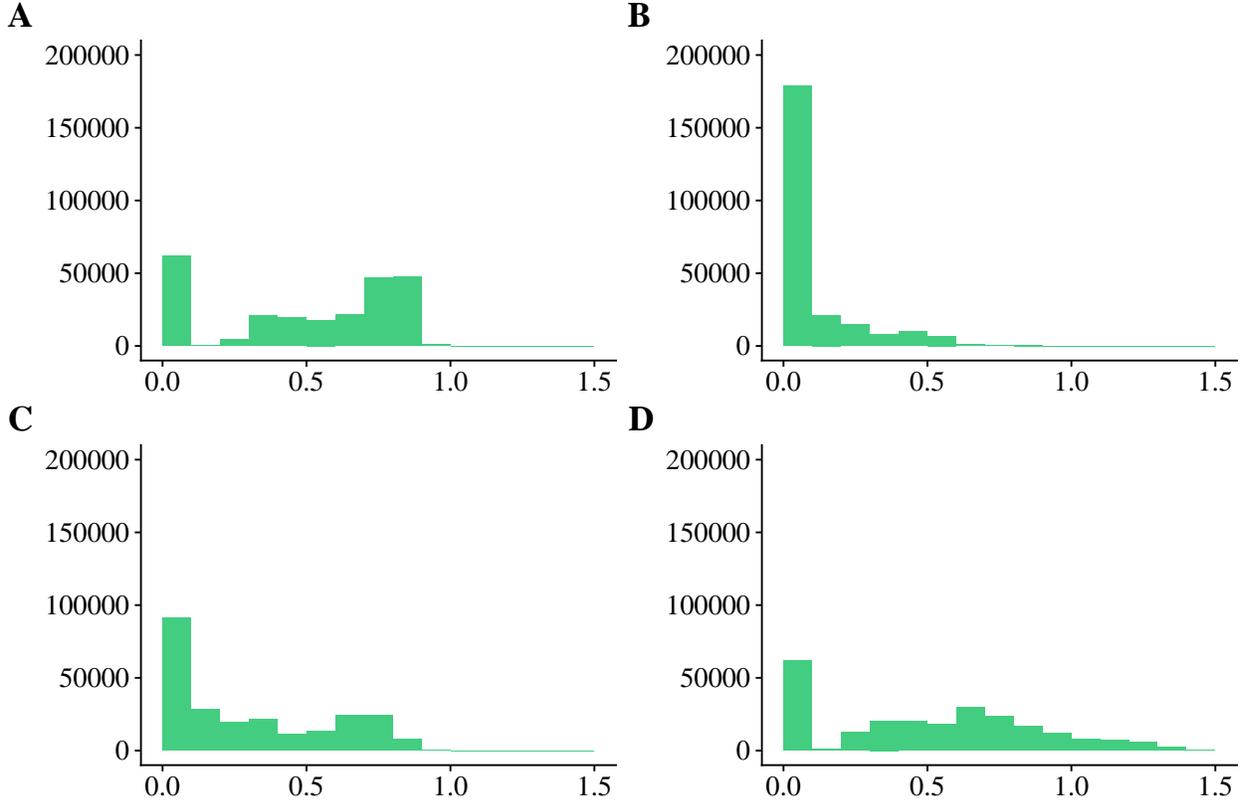


Figure 6: Distribution of property rights security across fish stocks and over time. The panels are A: $EEZ \times ROL$, B: $EEZ \times ROL \times RA$, C: $EEZ \times ROL \times RA^M$, D: $EEZ \times ROL \times RA1$.

distribution of resource extraction rates in the year 2012. The red boxplots simulate how those distributions would change under a hypothetical shock in credit market development and property rights security. We simulate the effects of three alternative hypothetical shocks. The red boxplots of panel A) depict the distribution of resource extraction rates after a global raise in the volume of credit to US levels (171 % 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 a simultaneous change of property rights 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 same countries as in Section 3.3 are highlighted.

The simulations depicted in panel A) show that credit market development has only a negligible

where the variable and parameter definitions are as in equation (8), the parameter values for γ_1 to γ_3 are from Table 2, s denotes the value of a variable after the shock, ihs is the inverse hyperbolic sine transformation and $sinh$ is the hyperbolic sine function.

Table 5: Property rights measures, resource harvesting and the lending interest rate

	(1)	(2)	(3)	(4)	(5)	(6)
	EEZ	EEZ×ROL	EEZ×ROL(FI)	EEZ×ROL ×RA	EEZ×ROL ×RA ^M	EEZ×ROL ×RA1
Lending interest	0.25** (0.11)	-0.02 (0.08)	0.17* (0.10)	0.10** (0.05)	-0.03 (0.09)	-0.11 (0.08)
Property rights	-0.11 (0.09)	-0.54*** (0.14)	-0.20* (0.11)	-1.37*** (0.20)	-0.83*** (0.19)	-0.65*** (0.14)
Lending interest × Property rights	-0.07 (0.12)	0.32** (0.15)	0.02 (0.16)	0.84*** (0.27)	0.61*** (0.20)	0.46*** (0.14)
Stock × Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	121,581	121,581	121,581	121,581	121,581	121,581
R ² (full model)	0.56	0.56	0.56	0.56	0.57	0.56
R ² (proj model)	0.01	0.01	0.01	0.02	0.02	0.02

Notes: All regression specifications are as defined by equation (8) but they differ with respect to the property rights variable. Property rights security equals zero before the introduction of EEZs in all specifications. After the introduction it equals (1) EEZ: unity, (2) EEZ×ROL: the normalized rule of law index of the World Bank, (3) EEZ×ROL(FI): the normalized rule of law index of the Fraser Institute, (4) EEZ×ROL×RA: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ, (5) EEZ×ROL×RA^M: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ to the power of a mobility parameter, EEZ×ROL×RA1: the normalized rule of law index of the World Bank multiplied by the share of the species' range within the EEZ centered around unity. All specifications include additionally the inflation rate, stock-country fixed effects, year dummies, log gdp, log gdp squared and the fish stock size relative to its maximum MSY level in $t - 1$. All variables are transformed using inverse hyperbolic sine transformation. Independent variables are additionally demeaned at the stock-country-level. Robust standard errors are clustered at the country level. Significance levels: *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

impact on overall resource extraction rates under current levels of property rights security. The main reason for the small impact of credit market development is that most countries have intermediate levels of property rights security such that the impact of credit market development on the value of future resource stocks and the impact on capital costs cancel out. In other words, the impact

of credit market development on the capacity of the harvesting fleet and on more strict resource regulation cancel each other out.

The simulations in Panel B) show that increasing property right security to its maximum level is likely to have a much more meaningful effect (than did credit market improvements) on resource extraction. However, improving credit markets and property rights security simultaneously as shown in panel C) has the largest impact on resource extraction because increasing property rights security amplifies the positive impact of credit market development on resource conservation.

To interpret these simulations results quantitatively, we can compare the share of stocks that are fished at unsustainable levels ($F/F_{MSY} > 1$) to the harvest rates that would result from improvements in property right security, credit market development, or both. The share of stocks that were fished at unsustainable levels in 2012 was 51 %. Our simulation reveals that a global credit market development that raises the volume of credit to US levels would reduce the share of unsustainably harvested fish stocks to 46 % while increase property rights security to maximum levels would reduce the share of unsustainably harvested fish stocks to 35 %. Improving property rights security and credit markets simultaneously would further reduces the share of overfished fish stocks to 22 %. While these results suggest important ecological benefits, it is difficult to quantify the welfare impacts. There are, however, two key welfare implications from our results which we will discuss below.

4 Discussion and Conclusions

Since at least the 19th century, economists have emphasized the importance of the discount rate in determining economically rational natural resource use and environmental conservation. Despite the prominent role of discounting for resource management and the rapid expansion of financial markets around the world, to our knowledge, this is the first study to empirically estimate the impact of credit market development on resource extraction.

At first glance there are two possible consequences of credit market developments. First, improving access to credit lowers the cost of capital. This effect may cause resource harvesters to invest in more harvesting capital (fishing boats, chainsaws, deeper wells, etc.), which would exacerbate the tragedy of the commons. But second, credit market improvements lower the discount rate, which raises the intertemporal opportunity cost of extraction, which could lead to enhanced resource conservation. We showed that the ultimate consequence of improved credit markets on

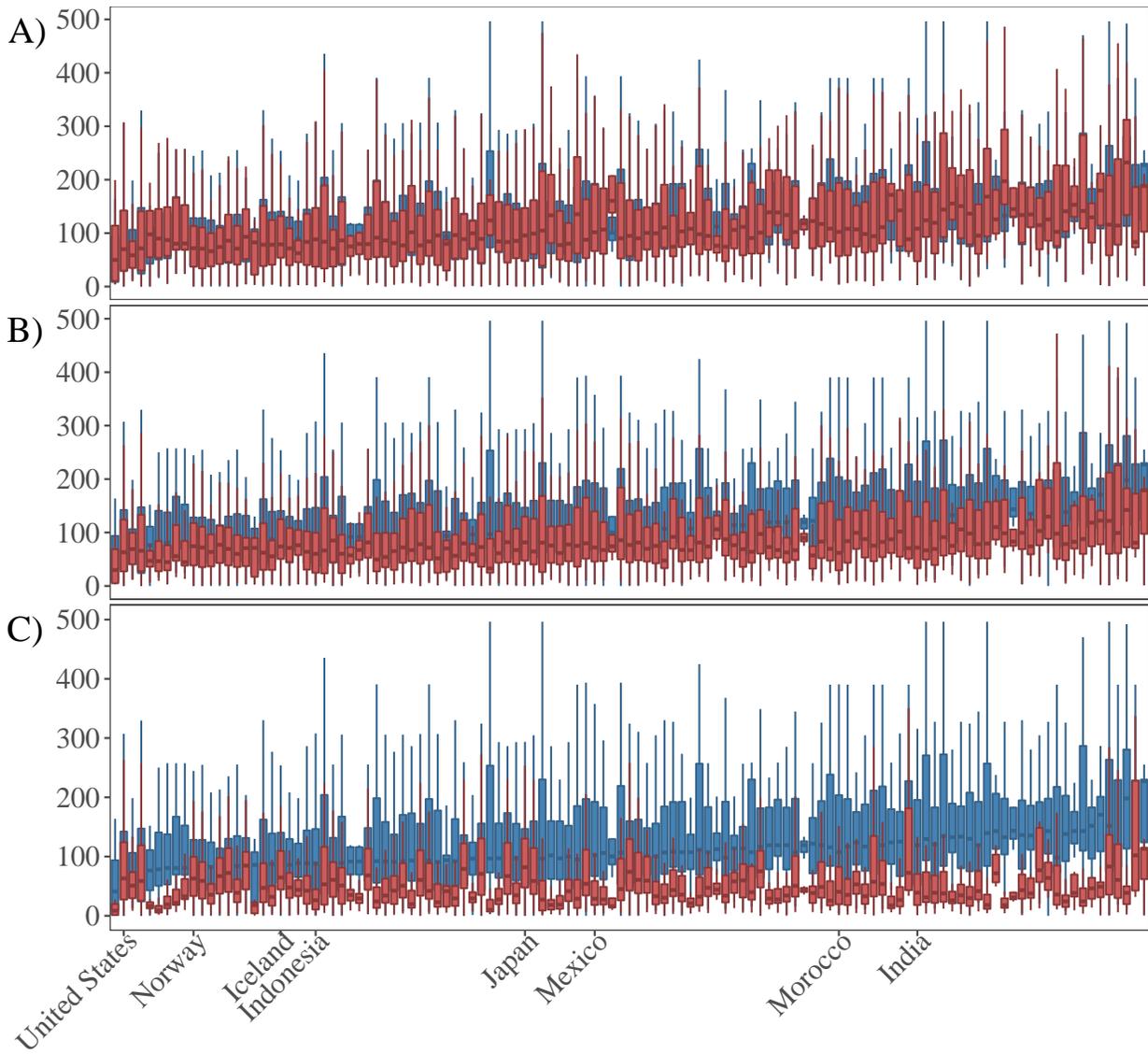


Figure 7: The figure shows the current within country distribution of resource extraction in 2012 in blue and in red A) the distribution of resource extraction rates after a global conversion of interest rates to US levels (3.25 %) B) a global increase of property rights security to unity and C) a simultaneous change of interest rates to 3.25 % and property rights security to unity.

resource extraction is likely to hinge critically on the degree of property right security. To test the theory empirically, we make use of a new data set on fish catches and fish stocks sizes combined with data on property rights 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 rights security affect re-

source extraction. In an open access setting, we find that a 1% increase of the private credit to the private sector *increases* extraction by 0.3%, but that the same increase in credit to the private sector in a secure property rights setting actually *decreases* extraction by 0.49 %. We find similar effects for the private sector interest rate as credit market indicator. The parameter estimates of our main specification indicate that a reduction of the private sector interest rate by 1% has a negative but not significant impact under open access but decreases resource extraction under secure property rights by 0.32 %. The results show further that increasing property rights security from open access to complete property rights security reduces resource extraction rates by about 50 %.

To comment on the practical significance of these findings, we simulated the consequences of hypothetical credit market and property rights improvements. These simulations suggest that holding property rights at their current levels, credit market improvements alone have only negligible effects on harvest. This is likely because the dual effects of credit market improvements on investment in harvesting capital and on resource regulation essentially cancel each other under current levels of property rights. However, the simulations show that in a world with secure property rights, credit market improvements can lead to large reductions in harvest, with economically and ecologically significant benefits.

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. Our results show that improving property rights security and promoting credit market development has the potential to reduce overfishing to less than one half of current levels (in 2012). To quantify the exact economic benefits of these reductions of overfishing is beyond the scope of this paper, but a rough estimate would be to reduce these losses by more than one half (more than 43 Billion USD).

There is, however, another important implication of our results. While the resource rents remain constant at zero for fish stocks under open access, the net 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 harvest rates. This finding suggests that the opportunity costs of open access or insecure property rights increases with financial development as the wedge between socially optimal and open access harvest rates increase. This finding suggests that resource regulation becomes more important with financial development and provides an explanation why resources in developed countries tend to be more highly regulated.

Our theory applies well beyond fisheries to all renewable resources such as timber, surface

and ground water, game, etc. For all such resources, credit market improvements will interact in important and economically significant ways with institutions that govern tenure and security of access to those resources to ultimately drive the extraction incentives. Our results suggest that as credit markets in these locales are improved, we can expect to see a divergence of outcomes: For resources with strong property rights, these credit market improvements are likely to drive resource recovery. But for resources with weak tenure or where expropriation is likely, these credit market improvements could further exacerbate the tragedy of the commons.

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A Proof of Proposition 1

Proof. The proof follows in two steps. The first step show the impact of ϕ on the extremes, $\theta = 0$ and $\theta = 1$. The second part establishes continuity of k^* .

1. Implicitly differentiating (7) with respect to ϕ for $\theta = 0$ and using the relationship $(ph_{k_{t+1}} - 1) = -(1 - \delta)/\phi$ yields

$$\frac{dk^*}{d\phi} = \frac{J_{k\rho}}{-J_{kk}} = \frac{(ph_{k_{t+1}}^t - 1)}{-J_{kk}} = \frac{1 - \delta}{\phi J_{kk}} < 0.$$

Note that the value function is concave (see Acemoglu (2009, p. 189) for a proof) such that $J_{kk} < 0$. Repeating the exercise with $\theta = 1$ yields

$$\frac{dk^*}{d\phi} = -\frac{J_{k\phi}}{J_{kk}} = \frac{(ph_{k_{t+1}}^t - 1)}{-J_{kk}} = \frac{1 - \delta - ph_{x_{t+1}}^{t+1} f_x^t h_{k_{t+1}}^t}{\phi J_{kk}} \begin{matrix} \leq \\ \geq \end{matrix} 0.$$

To see the ambiguity consider the cases of no capital depreciation, $\delta = 0$, and no stock dependence of the harvest $h_{x_{t+1}}^{t+1} = 0$. Next consider complete capital depreciation, $\delta = 1$, and stock dependent harvest, $h_{x_{t+1}}^{t+1} > 0$.

2. Continuity of the policy function, k^* , follows from the continuity of the objective function (see Acemoglu (2009, p. 190) for a proof).

Combing 1 & 2, there must be a $\underline{\theta} > 0$ such that $\frac{dk^*}{d\phi} < 0$ for $\theta \leq \underline{\theta}$ and a $\bar{\theta} \leq 1$ such that $\frac{dk^*}{d\phi} > 0$ for $\theta > \bar{\theta}$. For $\delta + ph_{x_{t+1}}^{t+1} f_x^t h_{k_{t+1}}^t \leq 1$ either $\bar{\theta} = 1$ or $\bar{\theta} = \underline{\theta} = 1$. In addition, if the policy function is monotoneous then $\bar{\theta} = \underline{\theta}$ for all $\bar{\theta}, \underline{\theta} \in (0, 1]$. \square

B Data

The following figures show the property rights security index for fish stocks using the Rule of Law Index of the World Bank and the Legal System and Property Rights Security index of the Fraser Institute for the same set of countries highlighted in Section 3.3.

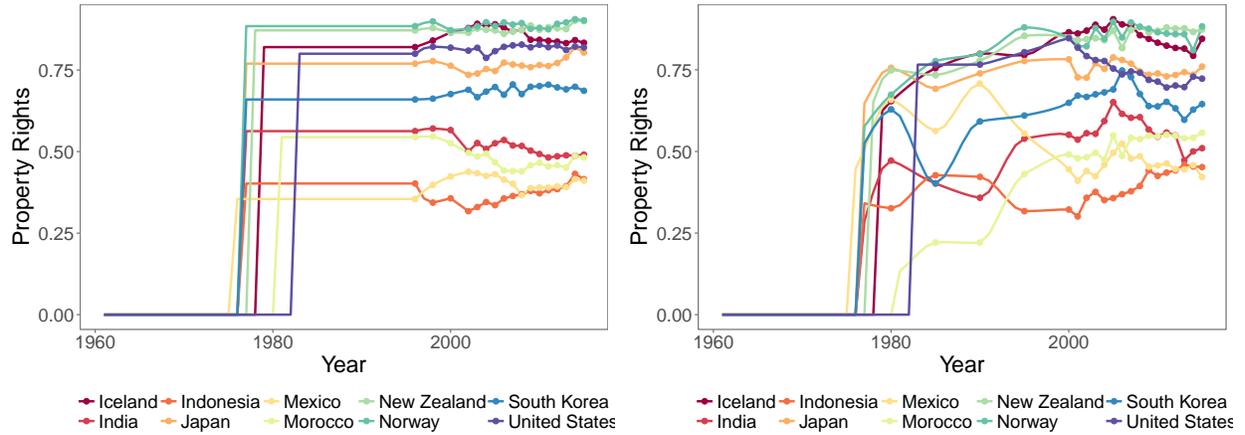


Figure 8: Property rights security index using the World Bank rule of law index with linear extrapolation.