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Use Rights for Common Pool Resources and Economic Development

Frederik Noack*[1,2], Marie–Catherine Riekhof[1,3], and Martin Quaas[1]

[1]Department of Economics, University of Kiel
[2]Bren School of Environmental Science & Management, University of California Santa Barbara
[3]CER-ETH—Center of Economic Research at ETH Zurich

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Abstract: This paper explores the long–run development of an economy with a traditional sector based on common–pool resource-use, a modern, resource–independent sector with fixed entry costs, and an imperfect capital market. We show theoretically that introducing resource-use regulations increases incomes in the traditional sector and that this can trigger a development process with labor reallocation to the modern sector. Allowing trade of resource-use rights, or distributing resource-use rights unequally, broadens the scope for development.

Key Words: natural resources and development, use rights and development, wealth distribution and occupational choice

JEL classification:Q28, Q20, O13, O15, O44

*Corresponding author, fnoack@ucsb.edu.

1 Introduction

Most of the global poor live in rural areas (IFAD 2011) and rely on natural resources such as arable soil, pastures, fish stocks, or forests for their livelihood (Millennium Ecosystem Assessment 2005; Angelsen et al. 2014). Use rights over such resources are often ill–defined or improperly enforced, with prevalent common pool externalities and resource degradation as a consequence (Dasgupta 2010; Stavins 2011; Costello et al. 2012). Inter-sector labor mobility is often low in developing countries, due to relatively high reallocation costs and the absence of credit markets (Bryan et al. 2014) or due to insecure property rights (Mullan et al. 2011), so that large rural–urban income gaps persist (Gollin et al. 2014).

In this article we ask how the introduction of credit markets and resource regulation affects rural income and labor reallocation to resource-independent production. We ask further how the initial distribution of use rights and their tradeability affect this development process.

It is well-known that regulating the access to common pool resources can increase efficiency and thus wealth (Gordon 1954). Resource economists have emphasized the economic benefits of rights-based management of common-pool resources (e.g., fisheries) in terms of increased static and dynamic efficiency of resource-use (Wilen 2000; Grafton et al. 2006; Costello et al. 2008; Heal and Schlenker 2008). This literature typically focuses on the inefficiencies stemming from inadequate regulation of resource-use, assuming that the economy is otherwise undistorted (Clark 1990). These assumptions are at odds with the reality in developing countries, where financial markets are malfunctioning, labor mobility is low and fixed costs are prevalent (Banerjee and Duflo 2005).

Most theories of structural change that explain the reallocation of labor across sectors also assume that labor is allocated efficiently across sectors and explain the shift of labor from the natural resource sector to the manufacturing sector by differences in capital intensity or by income elasticities of demand (Acemoglu and Guerrieri 2008; Hansen and Prescott 2002; Kongsamut et al. 2001; Laitner 2000). In an efficient labor allocation, the marginal productivity of labor is equal across all sectors. This is in sharp contrast to empirical evidence in low-income countries. In these countries, the returns to human capital are much higher in the manufacturing sector than in agriculture (Vollrath 2009; Gollin et al. 2014), and a large share of the income differences between countries can be attributed to this misallocation of labor (Vollrath 2009; Duarte and Restuccia 2010). An inefficient labor allocation and the resulting low productivity in parts of the economy have been explained by credit market imperfections in combination with fixed investment costs and unequal wealth distribution (Galor and Zeira 1993; Banerjee and Newman 1993; Aghion and Bolton 1997; Matsuyama 2006). None of these models has considered the resource-dependency of the rural poor and the absence of property rights over rural resources. The presence of common-pool resource externalities has effects on income distribution that are similar to the ones of pecuniary externalities in the labor market (e.g. the change in equilibrium wages). However, in contrast to the labor market effects, the definition and distribution of resource rights may create wealth and thus open new possibilities for development policies. This article studies under which circumstances these wider economic benefits of resource regulation could be achieved.

Some recent articles have focused on the impact of securing land rights on labor mobility in developing countries (Mullan et al. 2011; Wang 2012;

Chernina et al. 2014; Valsecchi 2014). These empirical studies generally find a positive relation between tradeability of property rights and labor reallocation. The studies explain their findings with the reduced risk of expropriation, which reduces the opportunity costs of migration.

In this paper we extend the argument by showing that tradable use rights over resources not only reduce the opportunity costs of labor reallocation but they can be used to finance the cost of labor reallocation. Further, in the presence of common-pool externalities, the redistribution of wealth can lead to a Pareto-improvement (Baland and Platteau 1997; Dayton-Johnson and Bardhan 2002). We will revisit this possibility as well.

Our theory combines the model of structural change by Galor and Zeira (1993) with a resource-economic model of common-pool resource-use. This perspective offers room for new types of policies that may help overcoming rural poverty traps by internalizing common pool externalities. We study different forms of rights-based management, including both non-tradable and tradable use rights. For tradable use rights, we further study the effect of different initial allocations. While the initial allocation does not affect the efficiency of resource-use, it affects the development process. We find that particular types of unequal initial allocation of tradable resource-use rights can be Pareto-superior compared to an equal initial allocation, and increase the scope for economic development.

The paper is structured as follows. In the next section we develop an overlapping-generations model where agents can work in a traditional sector and harvest a natural resource under conditions of open access, or work in a modern, resource-independent sector, if they are able to pay a fixed investment. In Section 3, we show that different steady states may emerge, depending on the initial wealth distribution and the share of the workforce in the traditional sector. Section 4 characterizes the first-best solution as benchmark. The two following sections look at second-best options. While Section 5 shows the impact of introducing a perfect credit market on the development outcomes given absent resource-use regulation, Section 6 demonstrates how the introduction of different types of resource-use regulation can trigger a development process in the absence of credit markets. In Section 7, we calibrate the model to a large Indian inland fishery to illustrate results and to numerically explore how outcomes change if we relax some of the assumptions that we needed for analytical results. Section 8 concludes.

2 Model

Consider a small open economy with two economic sectors, both producing goods that are traded on world markets at given prices. The 'traditional', resource-based sector uses labor, sector-specific capital and a renewable common pool resource for production. The 'modern' sector employs sector-specific capital and labor.

The economy is inhabited by a continuum of individuals with a constant population size normalized to one. Each individual lives for two periods and has one child born in the second period of her life. Individuals are identical, except for their initial wealth level, b_t, which they inherit from their parent. They may also differ with respect to the sector they work in.

In the first period of her life, t, the individual is born, inherits initial wealth b_t and makes her investment decision. By deciding whether to invest into capital specific to the traditional or the modern sector, the individual also chooses the sector she will work in.[1]

In the second period of her life, $t+1$, the individual inelastically supplies one indivisible unit of labor and uses the invested capital, which depreciates completely thereafter. The individual earns income y_{t+1}, consumes a quantity c_{t+1} and bequeaths an amount b_{t+1}.

Following Banerjee and Newman (1993) and Galor and Zeira (1993), each individual values consumption, c_{t+1}, and the bequest to her offspring, b_{t+1}, according to the utility function:[2]

$$u_{t+1} = (1-\delta)\log c_{t+1} + \delta \log b_{t+1}. \tag{1}$$

Following Galor and Zeira (1993), individuals working in the modern sector earn $\alpha > 0$, provided they have invested a fixed amount $\beta > 0$ (with $\beta < \alpha$) into sector-specific capital. One can interpret this sector-specific investment in different ways. It could, for example, be a fixed capital cost of setting up a firm, it could capture the cost of education, or it could represent the cost of rural–urban migration. Revenue α is independent of the

[1] As all decisions are made in the first period of life, the overlapping-generations model presented here could be transformed into an equivalent non-overlapping-generations model.

[2] Alternatively, the parent's altruism towards her child could be modeled by assuming that she draws utility from the consumption, or from the utility level, of her child. Compared to (1), an individual would then indirectly take all future generations into account when deciding on her own consumption and bequest. She may then sacrifice additional consumption if the higher bequest allows her descendants' escape from poverty. However, even in this set-up, there is a level of initial wealth at which the current generation is so poor that it is indifferent between making that extra sacrifice to future generations or using that unit of wealth for its own consumption. The households' behavior changes at this point. Thus adapting a more complicated setting with a utility function that takes future consumption or utility into consideration would not change the households' behavior qualitatively but would complicate the analysis considerably (Matsuyama 2011).

number of workers in the modern sector.[3] The income y^m_{t+1} in the modern sector of an individual born in period t is thus

$$y^m_{t+1} = \alpha - \beta + b_t, \tag{2}$$

with superscript m denoting the modern sector.

If an individual decides to work in the traditional sector, she has to invest some amount $k_t > 0$ into sector-specific capital (for example, boats and fishing gear in the case of a fishery). In contrast to β, k_t can be chosen continuously.[4] In the baseline scenario, access to the renewable common pool resource—the other input besides capital and labor—is free for all individuals. As the economy consists of a constant, but continuous mass of individuals, each individual working in the traditional sector neglects the impact of her harvest on the resource stock. Still, as the resource is rival in use, its productivity depends on the aggregate harvesting effort, which is assumed to be proportional to aggregate capital $K_t = \int_0^1 k_t(j)\, dj$, where $k_t(j) \geq 0$ is the capital used in resource harvesting by individual j.

To derive transparent, closed-form solutions, we assume that aggregate revenues in the traditional sector are $\gamma\, K_t\, (1 - \kappa\, K_t)$, which captures in a

[3] This is in contrast to the traditional sector. There are two different justifications for the assumption of a constant α. One is that production in the modern sector uses capital and labor with constant returns to scale. By choosing to work in the modern sector, households supply labor and capital in a constant ratio ($1/\beta$) and get the constant marginal returns to their capital and labor investment, α. The second justification is that the resource-based production—in contrast to the modern sector—is small relative to the economy, which is the case in the example of Section 7.

[4] In an alternative version of the model, we included an additional low-skilled production that did not require capital investment and that was independent of the resource. This assumption introduced a lower bound on income in the traditional sector but did not change the qualitative results of the study. It also increased the complexity of the results.

simple way that the marginal product of harvesting capital is positive at sufficiently low levels of harvesting effort and decreasing. The parameters γ and κ describe the productivity of the resource.[5] An individual investing the amount k_t of capital receives a fraction k_t/K_t of these aggregate revenues. Thus, an individual engaged in the traditional, resource-based sector earns income

$$y^r_{t+1} = \gamma k_t \ (1 - \kappa K_t) - k_t + b_t, \tag{3}$$

with superscript r denoting the resource-based sector.

We assume that there are no credit markets. Thus, only individuals with an initial wealth level $b_t \geq \beta$ can afford the fixed investment required to work in the modern sector.[6] In the following, we will refer to individuals with initial wealth $b_t < \beta$ as 'poor' and to individuals with initial

[5]Their meaning, as well as the entire production function, can be derived from a standard Gordon-Schaefer harvesting function (Gordon 1954; Schaefer 1957) and a resource with logistic growth in steady state (Clark 1990). Aggregate harvest according to a Gordon-Schaefer harvesting function is $H = q\,K\,X$, with the catchability coefficient q, aggregate capital K and the resource stock X. The resource stock X grows logistically according to $\rho\,X\,(1 - X/X_M)$ with the intrinsic growth rate ρ and the carrying capacity X_M. The stock in equilibrium is $X = X_M\,(1 - (q/\rho)\,K)$, aggregate harvest in equilibrium is

$$H = q\,K\,X_M\,(1 - (q/\rho)\,K).$$

Now define $\gamma \equiv q\,X_M$ and $\kappa \equiv q/\rho$ to obtain (3). The assumption that the resource is in equilibrium captures the property that resource dynamics are 'fast' relative to the 'slow' generational time scale considered here (Crépin 2007).

[6]The simplifying assumption of absent credit markets is stricter than in other studies (Galor and Zeira 1993; Banerjee and Newman 1993; Aghion and Bolton 1997; Matsuyama 2006). However, it does not change the qualitative results if credit markets are introduced as long as they are imperfect. Imperfect credit markets are common in developing economies.

wealth $b_t \geq \beta$ as 'rich'.

3 Market Outcome

This section describes the long-run market outcome when each individual chooses the occupation that maximizes income subject to her initial wealth and given the occupational choices of the other individuals.

Individual income is

$$y_{t+1} = y(b_t, K_{t+1}) = \max\{\mathbf{1}_\beta(b_t)(\alpha - \beta + b_t), \gamma b_t \ (1 - \kappa K_{t+1})\}. \quad (4)$$

The indicator function $\mathbf{1}_\beta(b_t)$ has the value one if $b_t \geq \beta$ and zero otherwise. It indicates whether an individual is rich and has the option to work in the modern sector. Provided marginal returns are larger than marginal costs, i.e. $\gamma(1 - \kappa K_t) > 1$, individuals in the traditional sector choose

$$k_t = b_t, \quad (5)$$

because production is linear in individual capital and individuals take aggregate harvesting effort K_t as given when deciding on their own capital use k_t. If marginal returns were smaller than marginal costs, there would be no one in the traditional sector.

The bequests drive wealth dynamics. Given the assumptions on preferences described by the utility function (1), a constant fraction δ of the income is transferred to the offspring. This implies $b_{t+1} = \delta y_{t+1}$. The amount of wealth that is transferred from generation to generation may decline or increase over time until a steady state is reached.

In the modern sector, individual wealth dynamics are

$$b^m_{t+1} = \delta(\alpha - \beta + b^m_t), \quad (6)$$

with the steady state bequest

$$b_*^m = \frac{\delta}{1-\delta}(\alpha - \beta). \tag{7}$$

To ensure that the modern sector persists over time, we assume that

$$\delta\alpha > \beta, \tag{8}$$

i.e. the bequest of an individual working in the modern sector is large enough for her child to be able to afford the fixed investment β.

In the traditional sector, individuals bequeath

$$b_{t+1}^r = \delta\,\gamma\,b_t\,\left(1 - \kappa\,K_t\right) \tag{9}$$

to their offspring. For simplicity, we assume that all individuals in the traditional sector bequeath the same amount in steady state, a result that follows endogenously if one includes slightly more complicated resources dynamics (Noack 2013). For the traditional sector, the steady state bequest is then given by (see appendix A)

$$b_*^r = \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*}, \tag{10}$$

where $n_* \in [0, 1]$ is the mass of workers engaged in resource harvesting in steady state, such that the aggregate harvesting effort is $K_* = n_*\,b_*^r$. The traditional sector only persists if $b_*^r > 0$, i.e. if

$$\delta\,\gamma > 1, \tag{11}$$

an assumption we impose in the following.

The steady state bequest in the traditional sector—and thus weather the individual is rich or poor—depends on the mass of resource harvesters in steady state. Following Galor and Zeira (1993), we call an economy *developed* if the lowest steady state bequest is larger than or equal to β, i.e.

if all individuals are rich and can afford the investment that is necessary to work in the modern sector. Unlike the common definition of 'development' which refers to mean income, our measure only considers the worst-off.[7]

As all resource harvesters are identical and given $b_*^m > \beta$ from assumption (8), the economy is developed in steady state if $b_*^r \geq \beta$, which is the case if and only if $n_* \leq \overline{n}$ with

$$\overline{n} \equiv \frac{\delta \gamma - 1}{\delta \gamma \kappa \beta}. \tag{12}$$

The mass $\overline{n}$ defines the maximum amount of individuals that can harvest the resource without being considered poor. Furthermore, once resource harvesters can afford to enter the modern sector, they will do so if they earn more in the modern sector than in the traditional sector and hence if $b_*^m > b_*^r$. They leave the traditional sector until $b_*^r = b_*^m$, which is the case if and only if $n_* = \underline{n}$ with

$$\underline{n} \equiv \frac{\delta \gamma - 1}{\delta \gamma \kappa} \frac{1 - \delta}{\delta (\alpha - \beta)}. \tag{13}$$

From assumption (8) follows $\overline{n} > \underline{n}$, as the steady state bequest in the modern sector exceeds β. This implies that in both sectors, steady-state incomes can only be equal in a developed economy. This result is supported by empirical evidence that the income gap between the traditional and the modern sector declines with GDP per capita (Vollrath 2009). Furthermore, the threshold value $\underline{n}$ for the mass of individuals in the traditional sector decreases in the incomes of the modern sector. To see this, differentiate (13) with respect to $(\alpha - \beta)$. This relation implies that when incomes rise in the modern sector, individuals leave the traditional sector.

[7]The concept is therefore related to the maximin criterion of Rawls (1971).

As $b_*^r = b_*^m > \beta$ from assumption (8), resource harvesters can afford to do so. As a response, incomes rise as well in the traditional sector, because the resource is distributed among fewer people. In the end, incomes in both sectors rise equally. This is what happened in the Norwegian fishery, for example, where incomes increased in the fishery and kept pace with incomes in the modern sector as the number of fishermen declined (Hannesson 2007). A very different outcome is observed in the example of the Indian fishery we will study in Section 7, where fishermen's incomes and the number of fishermen stagnated during the last decades, while income in other economic sectors rose constantly. The Norwegian example is in line with our results for a developed economy, while the Indian example matches our predictions for a non-developed economy.

To consider transitional dynamics, we follow Galor and Moav (2004) and consider a simplified setting with only two groups of individuals: A fraction $n^p \in [0, 1]$ of the individuals is initially poor and possesses $b_0 = b^p < \beta$, while the remaining fraction $1 - n^p$ is rich. We illustrate the effect of non-degenerated wealth distribution among the poor on the results in Section 7. However, as the harvesting technology is linear in individual wealth, the distribution of wealth among the individuals in the resource-dependent sector has no effect on the marginal productivity in resource harvesting, which is the relevant driving force for our results.

The steady state in the modern sector is stable and wealth dynamics are monotone, as the slope of (6) in b_t^m is $0 < \delta < 1$. A steady state in the traditional sector is locally stable if $|db_{t+1}^r / db_t^r| < 1$, and b^p is sufficiently close to the steady-state level (Galor 2007). We have $|db_{t+1}^r / db_t^r| < 1$ if in

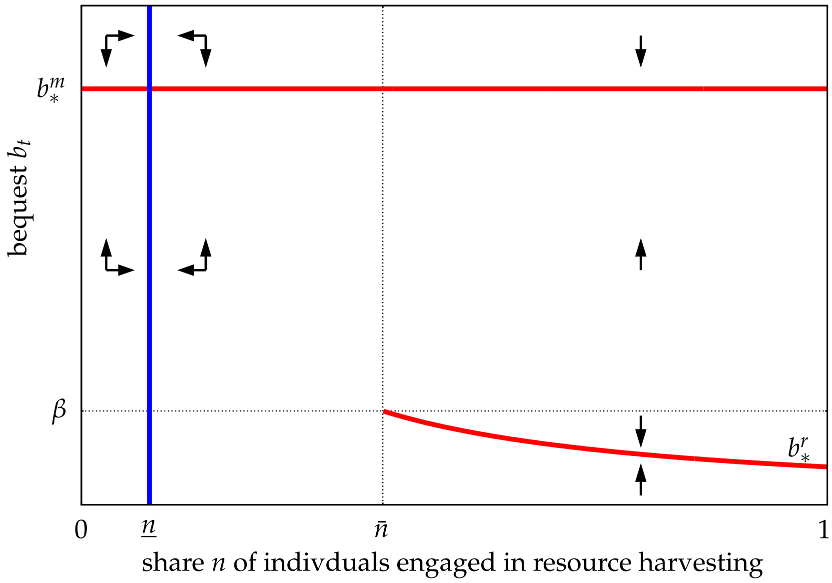

Figure 1: Phase diagram

addition to (11)[8],

$$\delta\gamma < 3, \tag{14}$$

which we assume in the following. This assumption plays an important role for our results as demonstrated in Section 7.

All descendants of the rich stay rich because of (8). The descendants of the poor may accumulate wealth over time, but they can only become rich if $n^P < \bar{n}$ under locally stable wealth dynamics. Figure 1 depicts the relation of wealth in the form of the bequest and the number of the initially poor for locally stable wealth dynamics.

An economy that starts with a low share of poor individuals in the tra-

[8]To verify this, consider

$$\frac{db^r_{t+1}}{db^r_t} = \frac{d}{db^r_t}\left[\delta\,\gamma\,b^r_t\,\left(1-\kappa\,n_*\,b^r_t\right)\right] = \delta\,\gamma\,\left(1-2\,\kappa\,n^*\,b^r_*\right) = \delta\,\gamma\,\left(1-2\,\frac{\delta\,\gamma-1}{\delta\,\gamma}\right) = -\delta\,\gamma+2,$$

which is larger than -1 if (14) holds; in addition to (11), which ensures $db^r_{t+1}/db^r_t < 1$.

ditional sector ($n^p < \overline{n}$) develops over time. The wealth of all individuals approaches $b_*^m = b_*^r$ and the share of the individuals in the traditional sector approaches $\underline{n}$. An economy that starts with many poor individuals ($n^p > \overline{n}$) remains poor and resource-dependent. The wealth of the poor approaches $b_*^r < \beta$, and the wealth of the rich approaches $b_*^m > \beta$. In this case, the share of individuals in the traditional sector remains constant over time. The income of the poor declines with the number of the initially poor, $n^p = n$.

4 First-best

In this section we briefly characterize the first-best setting with complete credit markets and full individual use rights over the natural resource. Throughout this section, we assume that the economy is initially in a steady state where all individuals in either sector have the same wealth level.

The first-best benchmark case includes the efficient allocation of capital and labor. The steady-state efficient capital and labor allocation maximizes aggregate income of all individuals in the second period of their lives. It is characterized by the following conditions (see appendix B):

$$K = \frac{\gamma - 1}{2\,\gamma\,\kappa}, \tag{15}$$

$$n = 0. \tag{16}$$

In the first-best allocation, the mass of individuals engaged in resource harvesting is zero, as labor is replaced by capital in this sector. This corresponds to a situation in which the resource is privately owned by a very small group of resource owners. This reflects the situation in a developed economy where very few individuals engage in capital-intense resource harvesting. The first-best allocation could be implemented if there was a well-functioning credit market and regulated resource-use.

5 Introducing a Credit Market

In what follows, we consider a situation in which such a first-best policy is not feasible. One possibility for a second-best setting would be the one where a well-functioning credit market exists, but access to the renewable resource is unregulated. As this is a situation commonly analyzed in resource economics (a brief literature review has been given in the introduction), we keep the analysis of this case rather short.

We continue to assume that all payments are made in the second period of an individual's life. In particular, k_t and β are thus expressed in values at $t+1$, just as incomes y_{t+1}. Individuals in resource harvesting earn an income $\hat{y}^r_{t+1} = (b_t - k_t) + \gamma\, k_t\, (1 - \kappa\, K_t)$. They would borrow and invest in harvesting capital k_t until marginal benefits, $\gamma\, (1 - \kappa\, K_t)$, equal marginal cost which are equal to one. Given the assumption of identical individuals, total capital used in resource harvesting is individual capital k_t times the number of individuals harvesting n_t, $K_t = n_t\, k_t$. In equilibrium, net income in resource harvesting is zero and each individual earns an income

$$\hat{y}^r_{t+1} = b_t. \tag{17}$$

If individuals invested less, profits could be made and other individuals would invest more. An individual in the modern sector born in t can consume or bequest an income

$$\hat{y}^m_{t+1} = b_t - \beta + \alpha \tag{18}$$

in $t+1$. In steady state, the mass of individuals working in the modern sector will tend to one, because $\hat{y}^m_{t+1} > \hat{y}^r_{t+1}$ which follows from $\alpha > \beta$. However, in difference to the first-best outcome characterized by equations (15) and (16), no resource rents are generated and aggregate capital is given by

$$K = \frac{\gamma - 1}{\kappa\gamma} \tag{19}$$

which is obviously larger than the optimal capital in resource harvesting given by (15), due to the fact that without resource-use regulation aggregate capital is allocated to resource harvesting such that its average product equals the marginal opportunity cost, while in first-best, the marginal product of capital equals the marginal opportunity cost. This implies that unregulated resource stocks are smaller than regulated resource stocks.

6 Resource Regulation

We now turn to the analysis of resource-use rights and economic development. We focus on situations without a credit market and analyze in this second-best setting how policies that affect only resource-use may foster development. We analyze in detail how regulation of access to the resource in form of use rights and their distribution affect the development of the economy. resource-use rights may have 'wider economic benefits' in that they do not only internalize common pool resource externalities, but additionally trigger development. As in the previous sections, we assume that the economy is initially in a steady state where all individuals in either sector have the same wealth level.

The dominant practical approach for initially allocating use rights is grandfathering the permits. Grandfathering means that use rights are freely distributed according to historical resource-use. As we start from steady state where all individuals in the resource sector have the same wealth level and harvest the same amount, all resource-users would—based on grandfathering—receive the same quantity of permits. We first consider this approach, but do not allow for trade. We then study a regulation that allows for trade. After that, we study an alternative approach of allocating initial rights, namely by means of a lottery. In each case, the children of the resource harvesters inherit the use rights from their parents.[9]

To analyze the effect of introducing non-tradable use rights that are grandfathered, we consider the equivalent situation of a regulation that limits access to the resource. We consider a situation in which holding a permit allows an individual to use a certain amount of harvesting capital ('capital allowances', or 'use rights', for a certain amount of harvesting capital), while the individual is not allowed to use more harvesting capital than the number of permits specify.[10]

The limit on aggregate harvest is such that it maximizes the aggregate steady state income of resource-users, given the number n_* of individuals in the traditional sector. Under the assumptions made here, this is equivalent to limiting individual harvesting capital to the level (see appendix C)

$$\bar{k} = \frac{\gamma - 1}{2\gamma n_* \kappa}. \tag{20}$$

[9]Since the parents only care for the bequest to their children but not for their utility, they do not take into account that resource incomes may eventually exceed incomes in the modern sector due to the resource rent.

[10]Under the given assumptions, this approach is equivalent to other forms of tradable use rights, in particular tradable harvesting rights, but the mathematics are more transparent.

This way of regulation increases the income of poor resource-users only if the resource harvesters are rich enough to buy more harvesting capital than $\bar{k}$, i.e. if $b^r_* > \bar{k}$ in steady state. Using (20) and (10), this would be the case if and only if

$$\delta > \frac{2}{1+\gamma}. \tag{21}$$

If the altruistic part of the utility function is very low—i.e. if condition (21) does not hold—, individuals are so wealth-constrained that limiting individual resource-use would not increase incomes. In the following, we assume that resource-users are wealthy enough to overuse the resource, i.e. that (21) holds. Under this condition, use rights in the form of harvesting capital allowances that limit individual harvesting capital for each of the n_* fishermen to $\bar{k}$—as given by (20)—increases efficiency. Note that this increase in efficiency comes about without any shift of labor from the traditional to the modern sector.

However, if the situation is favorable enough in the beginning, resource regulation in the form of non-tradable use rights may be sufficient to trigger labor reallocation and the development process leading to wider economic benefits of resource-use rights.

Proposition 1. *Grandfathering non-tradable use rights of the renewable resource in the traditional sector will enable resource-users to escape poverty if*

$$n_* \leq \frac{\delta}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa} = n^R. \tag{22}$$

The proof is given in appendix D.

A binding regulation implies that individuals do not fully use their bequest for investment in harvesting capital. This means that some individuals have scope for increasing their harvest (and income) by using more harvesting capital, which may be allowed provided some others reduce harvesting effort. A market for use rights may evolve where some individuals sell their use right, and others buy it. Allowing to trade the individual use rights may broaden the scope for development and for wider economic benefits of resource regulation. As before, use rights take the form of harvesting capital allowances.

Allowing to trade use rights can improve efficiency, as compared to non-tradable use rights, only if the resource-users are poor and if individuals who sell use rights become sufficiently wealthy to enter the modern sector. Otherwise, no market transactions will occur, as no individual can improve over her initial situation by selling use rights.

Consider the situation in which non-tradable use rights are not sufficient to make everybody rich and additional income from selling the use right will be needed to afford β. An individual who is willing to buy an additional marginal harvesting capital allowance would bid up to the value of the marginal product of harvesting capital, minus its costs.[11] Thus, the market price p of the allowance would be equal to (see appendix C)

$$p = \frac{\gamma - 1}{2}. \tag{23}$$

Since credit markets are absent, the bequest limits the amount of fishery capital and additional use rights an individual can finance. This imposes a limit to the overall demand for use rights, and thus to the number of individuals who can leave the traditional sector in each generation. However,

[11] Individuals would bid up to the marginal productivity of capital if they bought the harvesting capital with the allowance. Since the harvesting capital depreciates completely after one period and as we assume that the allowance sellers can use their initial wealth for investing in modern production, the allowance has to be bought in addition to the harvesting capital.

as the following proposition states, once trade in use rights has started, it is only a matter of time until the economy develops.

Proposition 2. *Assume* (21) *and poor resource harvesters. Resource regulation with tradable use rights ultimately moves the economy to a developed state if*

$$n_* \leq \frac{1}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa} = n^T. \tag{24}$$

Proof. See appendix E. □

The threshold level n^T specified in proposition 2 is larger than $\bar{n}$ (see appendix E). This means that tradable resource-use rights will facilitate development for an economy that would not develop otherwise, which is the case if initially, $n_* \in (\bar{n}, n^T)$. Furthermore, $n^T > n^R = \delta n^T$, which means that allowing trade in resource-use rights broadens the scope for development.

Proposition 2 does not make any statement about the timing of labor reallocation. Dynasties may need to accumulate wealth through efficiency gains achieved by regulation before they become rich enough to sell their capital allowance and leave the traditional sector.

Alternatively, individuals may be rich enough, and labor reallocation starts immediately. If the economy is initially in a steady state without regulation, implementing resource-use regulation with tradable use rights enables some individuals to immediately leave the traditional sector if

$$n_* \leq \bar{n} + (1-\delta)\,n^T. \tag{25}$$

See appendix F for a proof.

Under condition (25), some individuals of a generation will be able to immediately leave the traditional sector by selling their resource-use rights. The net revenues from resource-use of the remaining individuals of that generation will remain unaffected by labor reallocation, as the aggregate effort remains constant and the increased revenues from resource harvesting equal the additional capital costs. However, this generation's descendants will be better off, as they not only inherit the same wealth in terms of capital as their parents, but also the extra wealth in terms of inherited capital allowances. The market value of total resource-use rights per individual increases over time, as each individual resource-user further down in the dynasty is better endowed with use rights, while the price of the use rights remains constant, cf. equation (23). Thus, condition (25) will always be fulfilled for the next generation of resource-users as well, and further individuals will leave the traditional sector (as also stated in Proposition 2). This development process will end when resource harvesters have no more incentives to leave the traditional sector.[12] This is the case for

$$y_*^r = y_*^m + p_* \bar{k}_*, \tag{26}$$

with the steady state use right price $p_* = p$ and the steady state capital allowance per capita $\bar{k}_* \geq \bar{k}$. How long it takes for the economy to reach the steady state depends on the initial share of resource harvesters and their wealth.

Up to now, we have studied a case where all individuals initially receive equal resource-use rights. An unequal initial allocation of resource-use rights may facilitate development in the case of an even higher number of resource-users. Starting from a situation without regulation, such an unequal initial distribution of the resource-use rights may be perceived as 'fair' if all resource-users have an equal chance in a lottery that allocates

[12]resource-users leave the traditional sector as long as they earn more from selling their use rights and go into the modern sector to earn $\alpha - \beta$.

the resource-use rights.

The most promising candidate for an unequal distribution of resource-use rights is the one where a mass ν of resource-users is endowed with rights that are just valuable enough to allow them to afford the capital β for moving into the modern sector, and that this extra endowment is made possible by reducing the resource-use rights of all $n_* - \nu$ other resource-users. We will refer to the resource-users that have an above-average endowment with resource-use rights as the 'advantaged' and the others as the 'disadvantaged' users. The value of the use rights is indirectly defined as

$$b^r_* + p\,\bar{k}^+_* = \beta \tag{27a}$$

$$\Leftrightarrow \qquad \bar{k}^+_* = \frac{2}{\gamma - 1}\left(\beta - \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*}\right). \tag{27b}$$

Feasibility requires that the initial wealth of the disadvantaged resource-users has to be sufficient to buy extra harvesting capital and extra use rights to endow the advantaged with the extra wealth needed to leave the traditional sector, i.e. (using (27a) as well as (10) and (20))

$$n_*\,\bar{k} + \nu\,p\,\bar{k}^+_* \leq (n_* - \nu)\; b^r_* \tag{28a}$$

$$\Leftrightarrow \qquad \nu \leq n_*\,\frac{b^r_* - \bar{k}}{b^r_* + p\,\bar{k}^+_*} = n_*\,\frac{b^r_* - \bar{k}}{\beta} = \frac{\delta\,(\gamma+1) - 2}{2\,\beta\,\delta\,\gamma\,\kappa}. \tag{28b}$$

Thus, an unequal distribution of resource-use rights can endow some individuals with sufficient wealth to leave the traditional sector immediately, as $\delta\,(\gamma+1) - 2 > 0$ due to (21) if the mass of advantaged is small enough.

Proposition 3. *If the economy is initially in a steady state without regulation, implementing resource-use regulation with tradable use rights and an unequal initial distribution of use rights, such that ν individuals receive* (27b) *and the remaining $n_* - \nu$ only receive $(n_*\,\bar{k} - \nu\,\bar{k}^+_*)\,/\,(n_* - \nu)$, (a) makes all individuals* *better off compared to the previous steady state and (b) enables some individuals to immediately leave the traditional sector if*

$$n_* < \frac{\bar{n}}{1 - \delta\, p} \quad \vee \quad 1 < \delta\, p. \tag{29}$$

Proof. See appendix G. □

In appendix G, we further show that the threshold for n_* specified in (29) is strictly larger than the one specified in (25). Thus, an unequal initial distribution via a lottery also enables development in situations in which an equal initial distribution cannot trigger labor re-allocation.

7 Numerical Example

In this section we calibrate our model to the artisanal fishery of Chilika lagoon in Odisha, India. We use the calibrated model to illustrate the potential effects of the different resource-use regulations for the fishermen around Chilika lagoon. Furthermore, we discuss the impact of local stability and inequality on the transitional wealth dynamics. We start by providing some background information before we present the model calibration and discuss the transitional dynamics.

7.1 Background and Data

Chilika lagoon is located at the bay of Bengal and is the largest coastal wetland ecosystem on the Indian sub-continent (Mohapatra et al. 2007). The fishery at Chilika lagoon comprised 32,500 active fishermen in 2010, who harvested an annual amount between 10,000 and 20,000 metric tons of fish and shellfish in the period 2009–2010. Except for the restriction that only traditional fishermen are allowed to fish, there are no formal fishing regulations at Chilika lagoon.

We use data from a stratified random household survey carried out in 2011 in 17 fishing villages around Chilika lagoon (Noack 2013; Riekhof 2014). Our sample includes interviews with a total of 600 fishermen households. The data contain information on education, occupational choice and incomes of all household members as well as on fishing capital. We complement the survey data by official figures on fishing effort and aggregate catches provided by the Chilika Development Authority.

7.2 Calibration

In this section we sketch the calibration procedure and report the values we assign to the parameters of equations (2) and (3). Further details on the data and calibration procedure can be found in appendix H.

We use the present values of lifetime income of fishermen and non-fishermen from our survey to calibrate the incomes of in the resource-dependent and resource-independent sector. We assume a working period (i.e. generation length) of 30 years and use a subjective discount rate of 10% p.a., which is in line with discount rates observed in experiments (Andersen et al. 2008). For the modern sector, this gives $\alpha = 0.52$ million Rupees. For the $n_* = 32,500$ fishermen in the traditional sector, $y^r = 0.165$ million Rupees.

To calibrate the fixed costs of working in the modern sector, β, we use the costs of senior secondary education and add opportunity costs in the form of fishing income forgone. This gives $\beta = 0.033$ million Rupees. We use senior secondary education to calibrate the fixed costs since it is the first non-compulsory and very costly form of education in India and it has a large impact on the occupational choice and earnings of the fishermen at Chilika lagoon (Noack 2013). Dropouts from senior secondary education do not have significantly different earnings compared to individuals with only secondary education at Chilika lagoon, supporting the argument of fixed costs.

To calibrate the parameters of resource-dependent production in the traditional sector, we use the bio-economic microfoundation explained in footnote 4. We estimate the biological parameters describing the growth of the fish stock from time-series data on fish catches from 2001 to 2010 provided by the Chilika Development Authority. To convert biological productivity in fishing incomes, we additionally use data on fish prices on the relevant international markets, as well as data on individual and aggregate fishing capital from the survey. We obtain $\gamma = qX_m = 29$ and $K/n_* = q/\rho = 95,000$.

The last parameter to calibrate is the degree of altruism of parents toward their children, δ. We set $\delta = 0.10$, which ensures a locally stable steady state according to (14). The value is comparable to findings in the literature (Piketty (2011) and references herein).

Table 1 summarizes the parameters and their values.

Table 1: Values used in the case study

symbol	α	β	γ	κ	δ
value	0.52	0.033	29	0.000947	0.10

The values for α and β are given in million Rs; κ is in 1/million Rs; γ is in 1/generation lifetime = 1/30 years; and δ is dimensionless.

7.3 Numerical Illustration of the Theoretical Results

With the parameter values presented in Table 1, the steady state bequest is $b_*^r = 0.021$ million Rs in the traditional sector and $b_*^m = 0.054$ million Rs in the modern sector. The bequest in the modern sector exceeds educational costs β such that condition (8) is fulfilled and the modern sector can persist. The fishermen are trapped in poverty, as their steady state bequest is well below the educational costs, $b_*^r = 0.021 < 0.033 = \beta$.

Table 2 gives the threshold number of resource harvesters that allows development in the case of no regulation or a certain kind of regulation. In 2010, the actual number of fishermen in Chilika, $n_* = 32,500$ is above the threshold that would render the local economy developed in steady state without regulation, which is $\overline{n} = 21,000$.

Taking the number of resource harvesters as given, resource regulation in the form of non-tradable use rights would limit harvesting capital to $\bar{k} = 0.016 < 0.021 = b_*^r$ million Rs. This would raise the steady state bequest to $\bar{b_*^r} = 0.024$ million Rs, which is still well below the educational costs. As shown in Table 2, the corresponding threshold number of resource-users that allows development $n^R = 24,000$ is still below the number of actual fishermen in Chilika. Regulating the resource stock in this way is therefore not sufficient to develop the economy.

Allowing trade with use rights would broaden the scope for development considerably. The threshold population below which tradable use rights would lead to development of the local economy rises to $240,300$, which is more than seven times the current number of fishermen. With tradable use rights, many individuals could immediately afford the costs of education and leave the fishery, as indicated in the second to last row

	equation/ proposition	condition and value
economy developed in steady state	Eq. (12)	$n_* \leq \overline{n} = 21,000$
steady-state bequests equal in traditional and modern sectors	Eq. (13)	$n_* = \underline{n} = 12,800$
regulation with non-tradable, grandfathered use rights develops the economy	Prop. 1	$n_* \leq n^R = 24,000$
regulation with tradable grandfathered use rights develops the economy	Prop. 2	$n_* \leq n^T = 240,300$
regulation with tradable use rights-allocated by a lottery develops the economy	Prop. 3	$1 < \delta\, p = 1.4$

Table 2: Threshold values for number of resource-users. In 2010, the actual number of resource-users in Chilka was $n_* = 32,500$.

of Table 2. Given that tradable grandfathered use rights would already facilitate development, an initial allocation via a lottery, which would further broaden the scope for development, may not be required in the case of Chilika lagoon.

7.4 Numerical Illustration of the Transition Dynamics

The assumptions of equal wealth for all resource harvesters as well as a locally stable steady state in the resource sector allowed us to carve out the mechanisms that impede or foster development. In the following we numerically illustrate the transition dynamics in the unregulated market outcome, by considering three scenarios: First, we compute the transition dynamics for the parameterization reported in Table 1 with an equal wealth distribution. We assume that the current total fishing capital at Chilika lagoon, as calculated in appendix H, is equally distributed among the current number of fishermen. Second, we study the effect of an unequal wealth distribution, where one half of the current number of fishermen is 'rich' and owns capital just below β. The remaining capital is equally divided between the other, 'poor', fishermen. Third, we consider an unequal initial wealth distribution, and increase δ from $\delta = 0.10$ to $\delta = 0.15$. With this higher value of δ, the stability condition (14) is violated, and we study the effect of locally unstable dynamics for that case. If not otherwise specified, parameters are as in Table 1.

Figure 2 shows the simulation results for the three scenarios. The graphs in the left column show results for $\delta = 0.10$ with an equal initial wealth distribution (first scenario). The graphs in the center column show the results for $\delta = 0.10$, with the unequal initial distribution of wealth (second scenario), and the graphs in the right column show the transition dynamics for an unequal initial wealth distribution and the degree of altruism increased to $\delta = 0.15$ such that the steady state in the traditional sector is locally unstable (third scenario). The top row in Figure 2 shows the number of resource-users, the center row the resource stock, and the bottom row the bequest.

The first scenario with equal wealth distribution resembles the set-up of the theoretical model. The transitional dynamics are in line with our finding from the previous subsection that fishermen at Chililka lagoon are trapped in poverty, as they cannot afford the entry cost β for the modern sector. The first graph in the top row of Figure 2 shows that the number of resource-users over the successive generations remains constant at the initial value. For the given parametrization, an unequal wealth distribution does not change this result, as the second graph in the top row related to the second scenario shows. The resource stock, shown in the middle row, displays an identical development for the first and the second scenario, because the overall capital stock per period is identical for the two scenarios. The fish stock differs between generations because of the changing capital stock employed in the fishery. The difference in wealth distribution between the two scenarios can be seen in the bottom row, which shows bequests. In the case of unequal wealth distribution, two different bequest levels emerge. The reason for the relatively low impact of wealth distribution is the assumption that harvesting technology is linear in individual capital such that the capital distribution does not affect the resource dynamics. The insights are therefore dependent on the harvesting technology, and may change under concave harvesting technologies (Baland and Platteau 1997; Dayton-Johnson and Bardhan 2002; Noack 2013). A concave harvesting technology, however, tends to bring about a steady state with an equal wealth distribution (Noack 2013).

If we increase the degree of altruism to $\delta = 0.15$, such that locally unstable dynamics result, we find that all fishermen eventually leave the resource sector (see Figure 2, right column). The initial distribution matters for the duration of the development process. In the third generation, the rich group can leave. As this changes the capital amount in the resource sector, the overharvesting is reduced and one generation later, the poor also become rich enough to leave the traditional sector. Assumptions about the degree of altruism and local stability affect the results, and a high degree of altrusim, combined with unstable dynamics and an unequal initial wealth distribution, may lead to development, even without regulation.

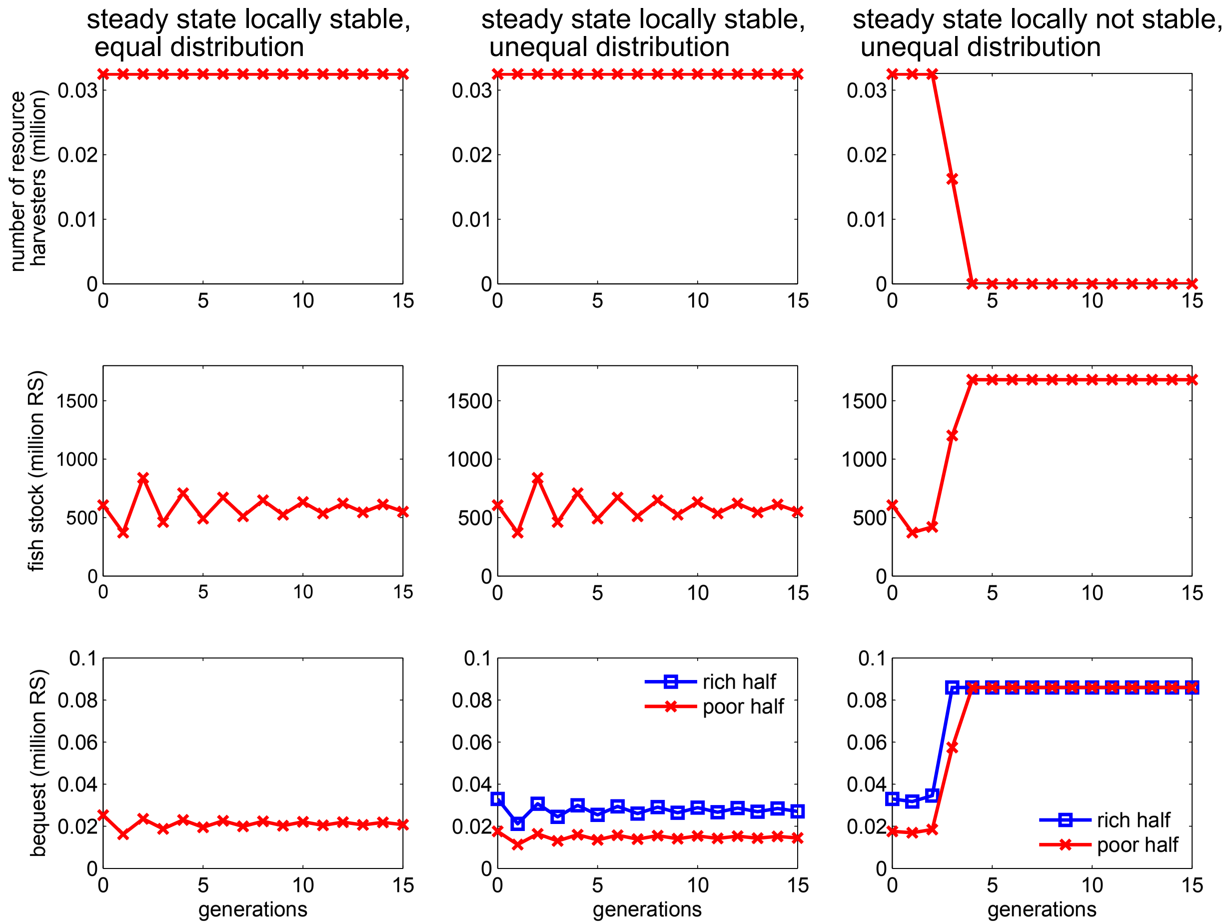

Figure 2: Simulation Resource Dynamics

Graphs in the left column show the dynamics of the number of resource harvesters (top row), fish stock in million rupees (middle row) and bequest (bottom row) over successive generations for an equal initial distribution of the total capital in the fishery sector, and for parameter values as reported in Table 1. Graphs in the center column show the same for an unequal initial wealth distribution, and graphs in the right column for an unequal initial wealth distribution and a higher level of altruism, $\delta = 0.15$, such that the steady state in the traditional sector is locally unstable.

8 Conclusion

In this paper, we have shown that the introduction of use rights for common pool resources in developing economies does not only increase efficiency and incomes of the resource harvesters, but may help trigger a development process. This is because the extra wealth created by rights-based regulation may facilitate labor reallocation from common-pool resource harvesting to a resource-independent sector of the economy, which benefits both the remaining resource-users and those who enter resource-independent production.

The type of regulation plays an important role. Allowing trade with use rights increases efficiency compared to regulation by means of non-tradable resource-use rights. On top of this, a tradable use right is an asset that can be sold to cover the fixed costs of education. The scope for triggering a development process is thus substantially broadened by the introduction of tradable use rights. Moreover, an unequal initial allocation of use rights through a lottery may help some individuals to leave resource harvesting in a very poor economy, which is beneficial for the remaining resource-users.

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Appendix

A Steady-State in the Traditional Sector

In steady-state, all n_* individuals engaged in resource harvesting have the same initial wealth b^r_*, and all invest this into resource harvesting. Using this, and $b^r_{t+1} = b^r_t = b^r_*$ in (9) leads to the steady-state condition

$$b^r_* = \delta\,\gamma\,b^r_*\,\left(1 - \kappa\,n_*\,b^r_*\right). \tag{30}$$

Canceling b^r_* and rearranging leads to (10).

B First-Best

The first-best allocation is found by maximizing the present value of income with respect to n and k:

$$\begin{aligned} & \max_{n,k} \{n\,\gamma\,k\;(1-\kappa\,n\,k) - n\,k + (1-n)\,(\alpha-\beta)\} \\ \Leftrightarrow \quad & \max_{n,K} \{\gamma\,K\;(1-\kappa\,K) - K + (1-n)\,(\alpha-\beta)\}\,. \end{aligned}$$

The first-order conditions written as complementarities are

$$\begin{gathered} \gamma(1-2\kappa K)-1 \leq 0, \quad K \geq 0, \quad K\,(\gamma(1-2\kappa K)-1) = 0 \\ -(\alpha-\beta) \leq 0, \quad n \geq 0, \quad n\,(-(\alpha-\beta)) = 0. \end{gathered}$$

For $n \neq 0$, the second complementary condition would not hold as $\alpha > \beta$. We thus obtain $n = 0$ and $K = (\gamma-1)/(2\,\gamma\,\kappa)$.

C Resource Regulation

Maximizing steady-state bequest of n_* resource harvesters with respect to $\bar{k}$ is equivalent to

$$\max_{\bar{k}} \left\{\gamma\,\bar{k}\;\left(1-\kappa\,n_*\,\bar{k}\right) - \bar{k}\right\}.$$

The first-order condition of this optimization problem yields

$$\begin{aligned} & \gamma\;\left(1-2\,\kappa\,n_*\,\bar{k}\right) = 1 \\ \Leftrightarrow \quad & \bar{k} = \frac{\gamma-1}{2\,\gamma\,\kappa\,n_*}. \end{aligned}$$

At this input level, the *indiviudal* marginal productivity of harvesting capital, i.e. given $K = n_*\,\bar{k}$, is

$$p = \gamma\;\left(1-\kappa\,n_*\,\bar{k}\right) - 1 = \gamma\,\kappa\,n_*\,\bar{k} = \frac{\gamma-1}{2},$$

with the market price p for allowances that will evolve if trade is allowed.

D Proof of Proposition 1

We have $\bar{k} < b^r_*$ if and only if

$$\begin{aligned} & & \frac{\gamma - 1}{2\,\gamma\,\kappa\,n_*} < \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*} \\ \Leftrightarrow & & \delta\,\gamma - \delta < 2\,\delta\,\gamma - 2 \\ \Leftrightarrow & & 2 < \delta\,(1+\gamma) \end{aligned}$$

which holds if and only if (21) holds.

If (21) holds, the steady-state bequest of resource-users is

$$\bar{b}^r = \frac{\delta}{1-\delta}\,\gamma\,\bar{k}\,\left(1 - \kappa\,n_*\,\bar{k}\right) = \frac{\delta}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*}. \tag{31}$$

We have $\bar{b}^r > \beta$ if

$$\frac{\delta}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*} > \beta \tag{32}$$

$$\Leftrightarrow \quad \frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa\,n_*} > \frac{1}{\delta} - 1 \tag{33}$$

$$\Leftrightarrow \quad \delta > \left(1 + \frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa\,n_*}\right)^{-1}. \tag{34}$$

E Proof of Proposition 2

As the price of the resource-use right is (23), the value of the right to use a capital input (20) is

$$p\,\bar{k} = \frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*}.$$

Under regulation, a resource-user obtains a steady-state bequest

$$b^r_* = \frac{\delta}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*}. \tag{35}$$

Thus, total wealth is greater than β, $b^r_* + p\,\bar{k} \geq \beta$, if

$$\frac{1}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*} \geq \beta. \tag{36}$$

Rearranging leads to (24). Under this condition, some resource-user will leave the traditional sector. This increases the incomes of the remaining resource-users, thus enabling further development in the next generation. This development process continues until the economy has reached a 'developed' state.

$$\begin{aligned}
& \bar{n} = \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,\beta} \leq \frac{1}{1-\delta}\,\frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa} \\
\Leftrightarrow \quad & 4\,(1-\delta)\,(\delta\,\gamma - 1) \leq \delta\,(\gamma-1)^2 \\
\Leftrightarrow \quad & 4\,\delta\,\gamma - 4\,\delta^2\,\gamma - 4 + 4\,\delta \leq \delta\,\gamma^2 - 2\,\delta\,\gamma + \delta \\
\Leftrightarrow \quad & 6\,\delta\,\gamma + 3\,\delta \leq \delta\,\gamma^2 + 4\,\delta^2\,\gamma + 4 \\
\Leftrightarrow \quad & \delta\,(6\,\gamma + 3 - \gamma^2 - 4\,\delta\,\gamma) \leq 4
\end{aligned}$$

The maximum of the left-hand-side with respect to γ is $4\,\delta\,(3\,(1-\delta)+\delta^2)$, which is monotonically increasing in δ and equal to 4 for $\delta = 1$.

F Proof of Equation (25)

Some individuals can immediately leave the traditional sector if the sum of their initial wealth b_*^r and the value of their resource-use right exceeds β, i.e. if

$$\frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*} + \frac{(\gamma-1)^2}{4\,\gamma\,\kappa\,n_*} = \frac{\delta\,(\gamma+1)^2 - 4}{4\,\delta\,\gamma\,\kappa\,n_*} \geq \beta.$$

Rearranging leads to (25).

G Proof of Proposition 3

The capital used in resource harvesting by each of the disadvantaged resource users amounts to $n_*\,\bar{k}/(n_* - \nu)$, such that each disadvantaged resource-user has an income

$$b^r_- \equiv \frac{n_* \bar{k}}{n_* - \nu} \left(\frac{\delta\,(\gamma+1)}{2} - 1 \right) - \frac{\nu}{n_* - \nu}\, p\, \bar{k}^+_* + b^r_* \geq b^r_* \tag{37}$$

$$\Leftrightarrow \qquad \frac{\gamma-1}{2\,\gamma\,\kappa}\,\frac{\delta\,(\gamma+1)-2}{2} \geq \nu \left(\beta - \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*} \right). \tag{38}$$

This inequality holds for all feasible transfers if

$$\frac{\gamma-1}{2\,\gamma\,\kappa}\,\frac{\delta\,(\gamma+1)-2}{2} \geq \frac{\delta\,(\gamma+1)-2}{2\,\beta\,\delta\,\gamma\,\kappa} \left(\beta - \frac{\delta\,\gamma - 1}{\delta\,\gamma\,\kappa\,n_*} \right) \tag{39}$$

$$\Leftrightarrow \qquad \delta\,\frac{\gamma-1}{2} \geq 1 - \frac{\delta\,\gamma-1}{\delta\,\gamma\,\kappa\,n_*\,\beta} \tag{40}$$

$$\Leftrightarrow \qquad \delta\,p \geq 1 - \frac{\bar{n}}{n_*} \tag{41}$$

$$\Leftrightarrow \qquad \frac{\bar{n}}{n_*} \geq 1 - \delta\,p \tag{42}$$

$$\Leftrightarrow \qquad n_* \leq \frac{\bar{n}}{1-\delta\,p} \quad \vee \quad \delta\,p > 1 \tag{43}$$

$$\frac{\bar{n}}{1-\delta\,p} = \frac{\delta\,\gamma-1}{\delta\,\gamma\,\kappa\,\beta}\,\frac{1}{1-\delta\,\frac{\gamma-1}{2}} \geq \bar{n} + \frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa} \tag{44}$$

$$\Leftrightarrow \qquad \delta\,\frac{\gamma-1}{2}\,\frac{\delta\,\gamma-1}{\delta\,\gamma\,\kappa\,\beta} \geq \frac{(\gamma-1)^2}{4\,\beta\,\gamma\,\kappa} \left(1 - \delta\,\frac{\gamma-1}{2} \right) \tag{45}$$

$$\Leftrightarrow \qquad 4\,(\delta\,\gamma - 1) \geq (\gamma-1)\;(2 - \delta\,(\gamma-1)) \tag{46}$$

$$\Leftrightarrow \qquad \delta\,(4\,\gamma + (\gamma-1)^2) \geq 2\,(\gamma-1) + 4 = 2\,(1+\gamma) \tag{47}$$

$$\delta\,(4\,\gamma + (\gamma-1)^2) > \frac{2}{1+\gamma}\,(4\,\gamma + (\gamma-1)^2) = 2\,(1+\gamma). \tag{48}$$

H Model Calibration to Chilika Lagoon Fishery

We use data from a household survey carried out in 2011 in 17 fishing villages around Chilika lagoon (Noack 2013; Riekhof 2014). Chilika lagoon has four ecological zones that mainly differ with respect to their salinity levels. Village selection followed a stratification strategy based on village size and ecological zones. Our sample includes interviews with a total of 500 randomly-selected fishermen households and 100 additional households that had alternative income sources. All households live in fishermen villages and belong to traditional fishermen sub-castes. The data contains information on education, occupational choice and incomes of all household members as well as on fishing capital (Noack 2013; Riekhof 2014). We complement the survey data by official figures on fishing effort and aggregate catches provided by the Chilika Development Authority.

Table 3 provides the summary statistics for the survey. It displays labor force participation, occupations, income and personal characteristics for the entire sample and for individuals with either only compulsory education or less education (no formal education, primary education, secondary education), as well as for individuals with post-compulsory or higher education (senior secondary education, college). We say that an individual participates in the labor force if he or she earns at least 15 Rs (0.3 USD) per day on average.

Most individuals that earn an income work in the fishery. Only 20% of the individuals with compulsory or less education work in non-fishing occupations, while almost 50% of the individuals with at least post-compulsory education work in non-fishing occupations. A large fraction of former fishermen is employed in the public sector. This may be due to governmental quotas for scheduled castes[13] to which the fishermen belong. Table 3 suggests that post-compulsory education has a large effect on occupational

[13]Designation given by the Indian Government to historically disadvantaged groups in India.

Table 3: Summary Statistics

	Total	Compulsory education	Post-compulsory education
Labor force participation (lfp) [%]	51	49	60
Fishing [% from lfp]	75	79	54
Non-fishing [% from lfp]	25	21	46
Public sector [% from non-fishing]	9	2	24
Annual income [Rs]	41,000	32,000	85,000
Standard deviation annual income [Rs]	65,000	44,000	115,000
Age [years]	41	42	35
Men [%]	56	52	75
n	1,753	1,482	271

Only individuals between 24 and 65 years are included.

choices and income.

In terms of our model, the fishery constitutes the traditional sector, while the alternative is to work in a non-fishing sector that, on average, offers a substantially higher income, but may also require expensive investment in education (see Table 3). While in Odisha the first ten years of education (primary and secondary school) in Odisha are compulsory and free, post-secondary and college education is optional and costly. As graduation matters more than years of schooling around Chilika lagoon, and as there are no returns to education in fishing[14], the direct and opportunity costs of acquiring that higher education level correspond to a fixed investment in modern-sector-specific human capital. Below we quantify these fixed costs of education for fishermen around Chilika.

[14]See below and Fafchamps and Quisumbing (1999) for further evidence.

Credit markets exist to some degree at Chilika lagoon, and 86% of the fishermen are actually indebted. However, on average, loan sizes are small (about 30,000 Rs) and interest rates are high (56% per year). Most importantly for our issue, loan purposes are restricted. Most credit arrangements depend on fishing activities and are therefore only available for fishing purposes (Riekhof 2014). Credit possibilities for education or other income alternatives besides fishing are virtually absent. A negligible share of only 0.5% of the loans is used for education, and only 0.1% is used for other income-generating activities. Thus, essentially, a credit market for education or other forms of investment into income alternatives does not exist in Chilika, and households must finance education from their current wealth.

Next, we estimate the effect of education on incomes, using a two-stage Heckman model that controls for selection bias. This is important, as education may affect reservation wages and therefore the probability to accept a job offer for a given wage. These changes in the probability to work may have large effects on the estimated returns to education. In the first stage, we estimate the probability of individual i in household j to earn income y_{ijl} in activity l by

$$P(y_{ijl} > y_{min}) = \Phi(A_0 + A_1\, Education_{ij} + A_2\, X_{ij} + A_3\, Z_{ij} + \varepsilon_{ijl}), \quad (49)$$

where $P(y_{ijl} > y_{min})$ is the probability to earn an annual income, y_{ijk} that is higher than the threshold, y_{min}. The threshold excludes part-time workers and is exogenously set at 5000 Rs per year (ca. 100 US$ in 2011). Changing this value has no qualitative effect on the results. On the right-hand side of (49), there is the probit function Φ, the vector $Education_{ij}$ including dummies for the four different educational levels (primary, secondary, senior secondary, college), and the vectors X_{ij} and Z_{ij} containing individual and household control variables.

Education levels are achieved one after another, hence, the entries in $Education_{ij}$ equal one up to the highest achieved education level, and zero for yet higher levels. For example, if senior secondary school is the highest educational level achieved, the vector of educational dummies is [1,1,1,0]. Individual control variables in X_{ij} include potential experience, potential experience squared, gender and dummies that indicate whether the household possesses a boat and a boat engine. The potential experience is the number of years an individual could have worked, assuming that this individual reached the education level in the scheduled time and started working thereafter immediately (Card 1999). Household control variables in Z_{ij} include the size of the household, the number of children in the household and the amount of landholdings. The latter has no effect on earnings since income from farming plays no role in fishing communities, but is an asset indicator. As these household control variables affect occupational choices but have little effect on individual earnings, they are included only in the first stage.

In the second stage, we estimate the effect of education on the logarithm of income by

$$\log(y_{ijl}) = B_0 + B_1\ Education_{ij} + B_2\ X_{ij} + B_3\ imr + \epsilon_{ijl}, \tag{50}$$

where we include the Inverse Mills Ratio (*imr*) from the first stage to correct for the selection bias.

Estimation results are shown in Table 4. The first panel shows the effect of education on occupational choice (first stage) whereas the second panel depicts the returns to education (second stage). Columns (1) and (2) show results for income in general, specification (2) includes village dummies.

Table 4: Activity choice, income and education.

labor force participation	total		fishing	non–fishing
	(1)	(2)	(3)	(4)
primary	-0.144	-0.142	0.265	-0.546***
	(0.144)	(0.160)	(0.166)	(0.192)
secondary	0.026	0.083	-0.281	0.359
	(0.183)	(0.197)	(0.200)	(0.234)
senior secondary	-0.089	-0.010	-0.416**	0.425**
	(0.184)	(0.203)	(0.193)	(0.203)
college	-0.080	-0.129	-0.636**	0.417*
	(0.222)	(0.243)	(0.257)	(0.221)
experience	0.070***	0.091***	0.061***	0.038**
	(0.017)	(0.019)	(0.021)	0.019
experience squared	-0.0011***	-0.0015***	-0.0009***	-0.0006**
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
controls	✓	✓	✓	✓
village dummies		✓		

income	total		fishing	non-fishing
	(1)	(2)	(3)	(4)
primary	0.008	-0.005	-0.096	0.846**
	(0.092)	(0.084)	(0.072)	(0.337)
secondary	0.092	0.138	0.091	0.005
	(0.111)	(0.098)	(0.089)	(0.350)
senior secondary	0.577***	0.308***	0.108	0.957***
	(0.115)	(0.103)	(0.105)	(0.281)
college	0.055	0.327**	-0.322**	-0.043
	(0.146)	(0.130)	(0.162)	(0.254)
experience	0.034***	0.031**	0.016	0.070***
	(0.015)	(0.015)	(0.012)	0.023
experience squared	-0.0006**	-0.0005**	-0.0004*	-0.0008**
	(0.0002)	(0.0002)	(0.0002)	(0.0003)
controls	✓	✓	✓	✓
village dummies		✓		
n	1053	1053	1053	1053

Notes: Individuals between 25 and 65 years are included in the regression.

Standard errors are given in parentheses.

***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

Column (3) display the results for participation in fishing and (4) in non–fishing activities.

Although education has no significant effect on labor force participation in general, senior secondary education and college education reduce participation in fishing by 7% and 11%, respectively, and increase participation in non-fishing activities by 7% in both cases. The values are the average of the sample marginal effects, including women. Note that the effect of education on activity choice is additive, such that the probability for an individual entering an activity is determined by the sum of parameter estimates for all education levels that he or she has completed.

Only education levels above compulsory education (secondary education) affect incomes in general. On average, individuals with senior secondary education earn 30.8% to 57.7% higher incomes than individuals with secondary education and individuals with college education still earn about 60% higher incomes than individuals with only secondary education. Considering returns to education for fishing and non-fishing activities separately shows that large parts of the returns to education stem from the impact of education on occupational choice. The main impact of college education on income stems from the higher probability of working outside the fishery, and there are even negative returns on college education on income in the fishery sector.

Including village dummies (2) reduces the estimates of the returns to senior secondary education, but leaves the estimates for returns on college education unchanged at about 60% (effects are again additive). This indicates that individuals with senior secondary education select in local occupations that are more strongly affected by unobserved factors at village level. Regression (3) and (4) also show that the effect of experience on earnings is larger in non-fishing occupations than in the fishery, which also has a large impact on lifetime earnings.

We calculate the present value of the lifetime income in both the modern and the traditional sector, based on our results from Table 4. These results give yearly incomes $\tilde{y}_l(e, l, \tau, X)$, differentiated according to education level e, the activity l, the potential experience in that year τ, as well as differentiated according to individual characteristics summarized in X.

The present values of the lifetime incomes ($\tau = 1, \ldots, 30$ years) are then

$$\tilde{Y}^l = \sum_{\tau=1}^{30} \tilde{y}_l(e, l, \tau, X) \times 1.1^{-(\tau-1)} \text{ with } l = r, m,$$

where we have used an intra-period discount rate of 10% per year.

We identify individuals having up to secondary education as workers in the traditional sector, as they are very likely to work in the fishery (mean probability 0.7 from regression 49), and as they have small education costs (see Table 5).

We identify individuals with senior secondary and college education with workers in the modern sector, as they are much less likely to work in the fishery (mean probabilities of 0.5 and 0.3 respectively) and have high education costs. The parameter estimates are given by regression specification (3) and (4) of Table 4.

We estimate the direct costs of education using the self–reported monthly expenditures on education in the following regression framework:

$$cost_j = b_0 + B_1 * Students_j + \varepsilon'_j. \tag{51}$$

The self-reported monthly expenditure on education of household j in Rupees is denoted by $cost_j$. Only households with children in school report education expenditures. $Students_j$ is a vector with the number of children

Table 5: Direct costs of education in Rs per month.

	(1)	(2)
constant	349***	130*
	(65)	(73)
primary	-35	-21
	(33)	(33)
secondary	79	95*
	(53)	54
senior secondary	239***	227***
	(51)	(52)
college	583***	540***
	(116)	(110)
village dummies		✓
n	439	439

Standard errors are clustered at the household level and are given in parentheses.

*** Significant at the 1% level,

** Significant at the 5% level,

* Significant at the 10% level.

in household j that currently attend primary school, secondary school, senior secondary school or college. The vector for a household with two children in secondary school woul be $[0, 2, 0, 0]$. The error term is denoted by ε'_j. The coefficients of interest, B_1, measure how much an additional student in a specific school level increases the educational spendings of a household. Regression results are reported in Table 5. We include village dummies in the second regression specification reported in column (2) to control for unobservables like local infrastructure.

Most households (i.e. 439) had children at school. The estimates for the constant, b_0, show that once one child of the household is in school, significant costs occur. The marginal costs for the education of a child in senior secondary school and college are 227 to 239 Rs and 540 to 583 Rs per month, respectively. The marginal costs of educating an extra child in primary or secondary school are not significantly different from zero. The results from the specification with and without village dummies are very similar.

The direct costs are calculated from the regression results of Table 5 multiplied by the average duration of senior secondary schooling (two years). Additional opportunity costs comprise the fishing income forgone during the time of education, i.e. during these two years. The present value (at a discount rate of 10% per year) of the direct costs of senior secondary education is 0.005 million Rs, and the present value of the opportunity costs for senior secondary education is 0.028 million Rs, such that $\beta_s = 0.033$ million rupees.

Finally, we estimate the intrinsic growth rate of the fish stock, ρ, and the stock's carrying capacity, X_M, using the method from Martell and Froese (2013) with data on aggregate harvest from 2001 to 2010 provided by the Chilika Development Authority to the authors. The method uses the observation that only a small range of productivity parameters can maintain a fish stock for the given harvest time series under the assumption of logistic resource growth. We only use data from the years after 2000, as a large increase of fish catches in 2000 is due to a large-scale hydrological intervention which may have affected the productivity parameters of the fishery. We obtain estimates $\widetilde{\rho}$ =1.9/year (sd=1) for the intrinsic growth rate and $\widetilde{X}_M = 35,000$ (sd=14,000) tons for the carrying capacity.

Fish from Chilika lagoon is sold on national and global markets at a given average price of 48 Rs per kg. In what follows, we express the units of fish directly in units of monetary value to measure everything in the same unit, which leads to $X_M = 1,680$ million Rs.

To obtain the productivity parameter q, we use

$$\tilde{Y}^r = \sum_{t=1}^{30} \tilde{y}_l(e,t,X) \times 1.1^{-(t-1)} = \sum_{t=1}^{30} \widetilde{q}\, k_t\, X_M\, (1 - (\widetilde{q}/\widetilde{\rho})\, K_t) \times 1.1^{-(t-1)}.$$

As we assume steady state values for capital and fish stock, we define $q := \sum_{t=1}^{30} \tilde{q} 1.1^{-(t-1)}$, as well as $\rho := \sum_{t=1}^{30} \widetilde{\rho} 1.1^{-(t-1)}$. $\rho = 18$ is now the discounted intrinsic growth rate of the resource stock over a period of 30 years. Then, we obtain

$$\tilde{Y}^r = q\, k\, X_M\, (1 - (q/\rho)\, K). \tag{52}$$

For $\tilde{Y}^r$, we use the calculated present-value life-time income in fisheries, $\tilde{Y}^r = 0.165$. The values for K_t and k_t are calculated as follows. Total fishing capital is the sum of the current values of boats, boat engines and other fishing equipment per fishing unit, which yields 88,500 Rs on average. Fishing capital of an average fishing unit comprises 63 kg (sd = 73) of nets, at a price of 680 Rs per kg (sd = 960). In addition, 95% of the fishing units use a boat worth 38,000 Rs (sd = 28,640), and 53% use an engine, which costs 18,000 Rs (sd = 8,230). The average costs for setting up a fishing unit are therefore $63 \times 680 + 0.95 \times 38,000 + 0.53 \times 18,000 = 88,480$ Rs.

The fishing capital is usually owned by the crew, which comprises 3.5 fishermen on average. Dividing fishing capital per fishing unit by the number of crew members yields a fishing capital per fishermen of $k = 0.0253$ million Rs. Multiplying with the number of active fishermen, $n_* = 32,500$, yields a total fishing capital $K = 822.25$ million Rs.

We solve equation (52) numerically to obtain $\widetilde{q}$. From the two solutions for q, we use the higher value for overfished resources, $q = 0.017$, as most fish stocks at Chilika are classified as slightly overfished (Pattnaik and Kobayashi 2009). Then, $\gamma = qX_m = 29$ and $\kappa = q/\rho = 9.5 \times 10^{-4}$.

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