

CHRISTIAN-ALBRECHTS-UNIVERSITÄT ZU  
KIEL

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**Structural Change  
in Resource-Abundant Economies**

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# Chapter 1

## Introduction

The introduction to this dissertation on natural resources and economic development is structured in two parts. The first part motivates the general topic whereas the second part declares my contributions to the individual chapters and states their state of publishing.

### 1.1 Motivation

Poverty and environmental degradation are among the most pressing global problems. The reduction of poverty and environmental sustainability are formulated as Millennium Development Goals by the United Nations. Large achievements in the reduction of global poverty have been made since the formulation of these goals but progress in environmental sustainability still lacks behind ([United Nations, 2012](#)). In fact, environmental sustainability and economic development may be conflicting goals. On the one hand, economic growth may cause environmental degradation as it increases the demand for natural resources ([Arrow et al., 1995, 2004](#)) and reduces the costs of resource usage ([Taylor, 2011](#); [Squires and Vestergaard, 2013](#)). On the other hand, abundant natural resources may hinder economic development. Biodiversity hot spots and high natural resource abundances are highly correlated with poverty ([Barbier, 2010](#);



Barrett et al., 2011) and a lack of economic growth (Sachs and Warner, 2001). These relationships between natural resources and economic development are, however, controversial (see e.g. Foster and Rosenzweig (2003) and Baland et al. (2010) for opposite findings), may be nonlinear (Brock and Taylor, 2005, 2010) and contingent on the distribution of the resources and the institutions that govern resource use (Baland and Platteau, 1997; Galor, 2011b; van der Ploeg, 2011). The present dissertation addresses the question of how environmental quality, wealth distribution and economic development are related. It focuses on the impact of resource abundance and wealth distribution on the structural transformation during the growth process, the effect of financial development on resource use and how the lack of rules and regulations in developing countries affect environmental quality and production. It uses theoretical modeling, model calibration and econometric techniques with data from field studies in Azerbaijan, India and Iran to answer this question. The choice of the field sites was mainly due to personal and scientific interest, local contacts and financing opportunities. The the exact questions that each chapter addresses evolved from the local conditions of the field sites.

In Chapter 2 I use an overlapping generations model with a resource-dependent and a resource-independent sector to show how the poor can be trapped in the resource-dependent sector when fixed costs of investment exist and credit markets are absent. This model confirms a positive but nonlinear relationship between poverty and environmental degradation. Lump-sum wealth transfers that increase inequality of wealth endowments can be intertemporally Pareto-efficient and resolve the poverty trap if common pool externalities are present. The introduction of tradable property rights has similar effects on development. Chapter 3 uses data from a field survey in India to show that a positive resource shock increases education levels. It shows further that educated individuals are more likely to engage in resource-independent occupations such that the resource shock induces a structural change that reduces resource dependency. Chapter 4 deals with credit market distortions and labor allocation between

skill-intensive intensive production and capital- and resource-intensive production. It uses a two-sector two-period model with different interest rates for borrowing secured by a collateral, for unsecured borrowing and for saving to show that the impact of changes in interest rates on labor reallocation depends on the initial wealth level of the household and the common pool externality. The last chapter (Chapter 5) uses a dynamic forest model with livestock and timber production to determine the socially optimal mix of forest usage. The calibrated model shows that the current lack of use rights over forest resources in Azerbaijan and Iran leads to low timber and livestock production. However, this mixed production induces high levels of biodiversity that renders mixed production optimal if biodiversity is highly valued.

## 1.2 Contributions

The dissertation consists of four chapters based on articles prepared for international peer-reviewed journals. Most chapters use data from several field surveys in the Middle east and India. In the following I state my contributions to the field studies and the resulting articles that constitute my dissertation.

The field survey in India was done in close collaboration with Marie-Catherine Riekhof and supported by the World Bank, the Chilika Development Authority and Palishree, a local NGO (Noack and Riekhof, 2011). The survey in Azerbaijan was financially supported by the Michael Succow foundation and the DAAD and was joint work with Michael Rietschel and Tobias Scharnweber. The field study in Iran was supported by the University of Theran and was undertaken by myself.

The article that underlays Chapter 2 is written together with Marie-Catherine Riekhof and Martin Quaas. The original idea of this chapter evolved in discussions with Marie-Catherine Riekhof inspired by our observations in India. The development of the modeling framework, the calculations and the writing was mainly done by myself but with inputs from Marie-Catherine Riekhof

and Martin Quaas. Both contributed substantially to the section on property rights. The article was presented in 2012 at the annual conference of the European Association of Environmental and Resource Economists (EAERE), the Monte Verita Conference on Sustainable Resource Use and Economic Dynamics (SURED), the workshop of Research Committee for Environmental and Resource Economics (AURÖ) of the German Economic Association (Verein für Socialpolitik), the annual conference of the International Institute of Fisheries Economics and Trade (IIFET), the summer school 'Equity and Efficiency in Fisheries', on a meeting of the EIGEN project in Lüneburg and on seminars of the Group of Environmental, Resource and Ecological Economics and the Institute for Regional Research of the University of Kiel. It is not accepted for publication by the time of writing.

Chapter 3 was prepared by myself and is part of a single authored article. It was presented in 2012 at the summer school 'Equity and Efficiency in Fisheries' and on seminars of the group of Environmental, Resource and Ecological Economics and the Institute for Regional Research of the University of Kiel. It is accepted for presentation on the conference of the Research Committee on Development Economics (AEL) of the German Economic Association and the annual EAERE conference in 2013. The paper is not accepted for publication by the time of writing.

Chapter 4 evolved as an idea together with Marie-Catherine Riekhof based on our field studies in India. The development of the modeling framework, the calculations and the writing was mainly done by Marie-Catherine Riekhof with inputs from Johannes Bröcker and myself. I contributed to the ideas and the writing of the article. The article was presented at the IIFET conference in 2012, the winter seminar of the German Section of the Regional Science Association in 2013 and on seminars of the Group of Environmental, Resource and Ecological Economics and the Institute for Regional Research of the University of Kiel.

The last chapter, Chapter 5, is about forest degradation in the Middle East. This article is based on my Diploma thesis which was substantially extended by a

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rigorous analytical treatment of the subject and the inclusion of biodiversity in the analysis during my doctoral studies. The main calculations and the writing of the article was done by myself with contributions of Martin Quaas, Michael Manthey, Jack Ruitenbeek and Marvie Mohadjer. A later version of the chapter was published in 'Ecological Economics' (Noack et al., 2010) and the article was presented at the Brown Bag Seminar of the University of Kiel in 2010, the Ulvön Conference on Environmental Economics and the AURÖ workshop in 2009.

## Chapter 2

# Redistribution and Development in Resource Abundant Economies

with Marie-Catherine Riekhof and Martin Quaas

**Abstract:** This paper explores the effect of wealth redistribution and the introduction of use rights on economic development. The development level of an economy with a traditional sector that uses a renewable common pool resource for production and a modern resource independent sector depends on the initial distribution of wealth. Redistributing wealth among the poor or introducing use rights for the resource can improve the welfare of the poorest and facilitate the transition from a resource based and poor economy to a modern developed economy. We apply our model to a large Indian inland fishery to show that individuals in the traditional sector are trapped in poverty and how redistribution of wealth or the introduction of use rights for the resource increase the incomes of the worst-off and trigger a process of development.

## 2.1 Introduction

The process of economic development is closely connected to a decline of the labor share in the natural resource sector, for example in agriculture (Gollin, 2010) or fisheries (Hannesson, 2007). Most theories of structural change explain the shift of labor from the natural resource sector to the manufacturing sector as a consequence of growth and assume that labor is allocated efficiently across both sectors (Acemoglu and Guerrieri, 2008; Hansen and Prescott, 2002; Kongsamut et al., 2001; Laitner, 2000). This assumption implies that the marginal productivity of labor is equal across both sectors which is, however, in sharp contrast to empirical evidence. In fact, the returns to human capital are much higher in the manufacturing sector than in agriculture and this income differential declines with the per capita GDP of a country (Gollin, 2010; Vollrath, 2009). Furthermore, a large share of income differences between countries can be attributed to this misallocation of labor (Duarte and Restuccia, 2010; Vollrath, 2009).

The underlying reasons for the inefficient allocation of labor and the low productivity in some economies can be explained by credit market imperfections, fixed costs of investment, and the unequal distribution of wealth (Galor and Zeira, 1993; Banerjee and Newman, 1993; Aghion and Bolton, 1997; Matsuyama, 2006). However, these models assume that the poor are employed and earn equal wages, and that production is resource independent. Most poor people are, however, self employed (Banerjee and Duflo, 2007) and live in rural areas where they rely on natural resources such as arable soil, pastures, fish stocks or forests for their income (Dasgupta, 2010). Use rights over such resources are often ill-defined or improperly enforced with resource degradation as a consequence (Goldstein and Udry, 2008; Stavins, 2011). Typical results are declining incomes which perpetuate the poverty trap. Besley et al. (2012) show how the introduction of property rights can improve the access to credit markets and therefore foster development and Wang (2012) shows further that property rights can also increase labor mobility. However, they neglect the positive effect of property rights on natural resource conservation (Costello et al., 2010).

In this paper we build a model to show how redistribution of wealth among the poor in the traditional resource based sector or the introduction of resource regulation can trigger a process of development. We apply our model to Chilika Lagoon, a large Indian inland fishery which is a typical example of a poor rural economy based on a common pool resource. At Chilika Lagoon incomes stagnated and fell behind the income of other occupational groups in the region during the last fifty years whereas the number of fishermen increased fivefold (see Section 2.5). In contrast to the case of Chilika Lagoon, [Hannesson \(2007\)](#) showed that the average income of Norwegian fishermen remained on par with other occupational groups in Norway during the last fifty years despite overfishing. The strong decline of fishermen in Norway enabled the remaining fishermen to expand their production and their incomes. In this paper we propose a theory that explains the differences between the Norwegian and the Indian example. We ask the question of how the wealth distribution of an economy is related to its labor share in the natural resource sector and its development level and how the introduction of resource regulation affects the country's development level.

In the following section we introduce an overlapping generation's model where agents can work in a traditional sector and harvest a natural resource under conditions of open access or work in a modern sector which is resource independent. In Section 2.3, we show that different steady states evolve, depending on the initial wealth distribution. The steady-state share of the workforce in the traditional sector is negatively related to the development level of the economy. The income difference between the poorer individuals in the traditional sector and the richer individuals in the modern sector declines with development. Section 2.4 demonstrates that a redistribution from the rich to the poor or a redistribution which initially increases wealth inequality among the poor in the traditional sector can be Kaldor-Hicks efficient. Additionally, both redistribution can also satisfy an intertemporal version of Rawl's maximin criterion. Section 2.4 also shows that a resource regulation which limits harvest has similar effects. Further, tradability of the harvesting permits can trigger a process of development that leads to a rich, developed economy with positive resource

rents. In Section 2.5, we apply our model to the fishery of Chilika Lagoon and explain the lack of response of the fishermen to their declining relative incomes with their inability to invest in outside options. We show that some redistributions are both efficient and just, while others lead to a process of development at the cost of the currently poor. The introduction of harvesting regulation is efficient and just but only triggers a process of development when harvesting permits are tradable. Section 2.6 concludes.

## 2.2 The Model

Consider a small open economy with two sectors of production, the traditional, 'resource'-based sector and the 'modern' sector, producing two goods that are traded on world markets at given prices. There are four factors of production: the resource stock, two types of sector-specific capital, and labor, which can be used in both sectors. The economy is inhabited by a continuum of individuals with a constant population size.

Each individual inelastically supplies one indivisible unit of labor. Individuals are identical, except for their initial monetary endowments,  $b_t$ , that their parents bequeath to them. The distribution of bequests among the individuals who are born in period  $t$  is described by the density function  $g_t(b)$ .

Each individual lives for two periods and has one child born in the second period of her life. An individual who is born at time  $t$  inherits wealth  $b_t$  and makes her investment decision in the first period  $t$  of her life. By deciding on whether to invest into capital specific to the traditional or the modern sector, the individual also chooses the sector she will work in. Both types of capital depreciate completely after one period of use. The individual works, uses the capital, earns income  $y_{t+1}$ , consumes a quantity  $c_{t+1}$  and bequeathes an amount  $b_{t+1}$  in the second period of her life,  $t + 1$ . The individual values consumption,  $c_{t+1}$ , and the bequest to her offspring,  $b_{t+1}$ , according to the utility function



(Banerjee and Newman, 1993; Galor and Zeira, 1993):

$$u_{t+1} = (1 - \delta) \log c_{t+1} + \delta \log b_{t+1}. \quad (2.1)$$

There are many different ways to introduce altruism. It could depend on the consumption level of the child or on her utility. For a detailed discussion of this utility function and its implication see Galor and Zeira (1993); Matsuyama (2011). Observations show that individuals transfer much less to their children than they consume (for example in the case of the Indian inland fishery considered in Section 2.5). We therefore assume that the amount parents bequeath leaves their child capital constraint.<sup>1</sup> This case prevails for

$$\delta \in (0, 1/2). \quad (2.2)$$

Utility maximization is subject to the budget constraint,  $y_{t+1} \geq c_{t+1} + b_{t+1}$ . The first-order conditions from utility maximization yield  $c_{t+1} = (1 - \delta)y_{t+1}$  and  $b_{t+1} = \delta y_{t+1}$ .

Following Galor and Zeira (1993) and Banerjee and Newman (1993) individuals working in the modern sector earn  $\alpha > 0$ , provided they have invested a fixed amount  $\beta > 0$  (with  $\beta < \alpha$ ) into specific capital. This sector-specific investment can be interpreted as a fixed capital cost of setting up a firm, of education or of migration from rural to urban areas.

Only individuals with an initial wealth level  $b_t \geq \beta$  can afford the fixed investment required to work in the modern sector<sup>2</sup>, because of missing credit

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<sup>1</sup>There are two steady state bequest levels for resource harvesters, depending on whether or not resource harvesters are capital constraint. Whether or not this is the case depends on the parameter  $\delta$ . If the altruistic part in the utility function dominates,  $\delta > 1/2$ , the non-binding case prevails and if the egoistic part dominates,  $\delta < 1/2$ , the constraint on investment in the harvesting capital becomes binding.

<sup>2</sup>We refrain from introducing a low skilled resource independent sector, since it does not change the main results.

markets.<sup>3</sup> In the following, we will refer to the individuals with initial wealth  $b_t < \beta$  as ‘poor’ and to the individuals with initial wealth  $b_t > \beta$  as ‘rich’. The income  $y_{t+1}^m$  of an individual who is born in period  $t$  and works in the modern sector is given by:

$$y_{t+1}^m = \alpha - \beta + b_t. \quad (2.3)$$

The superscript  $m$  denotes the modern sector. Income  $\alpha$  is independent of the number of workers, because it is not bounded by the renewable resource. One could interpret each individual in the modern sector as an entrepreneur that produces a new good. Each brings capital (fixed investment) as well as labor (see [Matsuyama \(2011\)](#)).

All individuals have open access to a renewable common pool resource, i.e. individuals working in the traditional sector neglect the impact of their harvest on the resource stock. Open access prevails for all agents in the economy, but the number of agents is fixed. If an individual decides to work in the traditional sector, she has to invest some amount  $k_t > 0$  into specific capital (for example, boats and fishing gear).

The Schaefer harvesting function describes the harvest of an individual engaged in the traditional sector. It has constant marginal productivity of effort,  $e_t$ , and constant marginal productivity of the resource stock,  $X_{t+1}$ . Effort is an intermediate input in harvesting produced by capital and labor ([Hannesson, 1983](#)). For mathematical convenience we assume that it is a Cobb-Douglas composite with output elasticities of capital and labor each equal to 1/2. Using that each individual supplies one indivisible unit of labor gives  $e_t = \sqrt{k_t}$ . With the factor productivity  $\gamma$ , the net income  $y_{t+1}^r$  of an individual who is born in period  $t$  and works in the traditional sector is given by

$$y_{t+1}^r = \gamma \sqrt{k_t} X_{t+1} - k_t + b_t. \quad (2.4)$$

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<sup>3</sup>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.

The superscript  $r$  denotes the resource sector. There is a direct feedback from aggregate harvest,  $H_{t+1}$ , to the size of the resource stock. Aggregate harvest  $H_{t+1}$  is the integral over all individual harvests, where each individual may be constrained in her harvesting decision by the distribution of inherited wealth,  $g_t(b)$ . Using the logistic growth function to describe the continuous net growth of the resource stock within a period, and assuming that for a given harvest level the stock immediately reaches its equilibrium level, the resource stock  $X_{t+1}$  is implicitly given by

$$\rho X_{t+1} \left( 1 - \frac{X_{t+1}}{\kappa} \right) - H(X_{t+1})_{t+1} = 0, \quad (2.5)$$

where  $\rho$  is the intrinsic growth rate of the resource, and  $\kappa$  is the carrying capacity of the ecosystem. The individual anticipates the resource stock as well as how many individuals will be in the resource sector and how they will invest. Thus, taking that into account she will decide on her own investment.

## 2.3 The Market Outcome

In this section we present the decentralized market solution with missing credit markets and no access regulation to the resource. We derive the steady state as well as the transitional dynamics. In the next section, we consider the efficient allocation and how it can be reached.

Individuals working in the traditional sector decide on capital input. They choose the investment level  $(\gamma X_{t+1}/2)^2$  that maximizes their income (2.4) for a given  $X_{t+1}$ , provided this capital investment is lower than their initial wealth  $b_t$ . Thus, they choose

$$k_t = k(b_t, X_{t+1}) = \min \left\{ b_t, (\gamma X_{t+1}/2)^2 \right\}. \quad (2.6)$$

We take the variable symbol without time index to denote the variable as function of other variables.

Individuals invest in harvesting capital up to the quantity where the marginal return to capital in resource harvesting equals the marginal return of unproductive capital. The constraint on investment in harvesting capital is binding if the marginal return to capital in resource harvesting exceeds the marginal return of unproductive capital at the point  $b_t$ . The individually optimal amount of capital investment in resource harvesting is at its maximum when the resource stock is at its carrying capacity. This situation yields the highest possible income in the resource sector.

For a given environment which is described by (2.3), (2.4), (2.5) and the distribution of wealth, the occupational choice of the individual follows from income maximization as

$$\begin{aligned} y_{t+1} &= y(b_t, X_{t+1}) \\ &= \max\{\mathbf{1}_\beta(b_t)(\alpha - \beta + b_t), \gamma\sqrt{k(b_t, X_{t+1})}X_{t+1} - k(b_t, X_{t+1}) + b_t\}. \end{aligned} \quad (2.7)$$

Each individual chooses the occupation that maximizes income subject to her initial wealth and given the resource stock including the responses of the other individuals. 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 has the option to work in the modern sector.

Individual wealth dynamics for the modern sector are given by

$$b_{t+1}^m = \delta(\alpha - \beta + b_t), \quad (2.8)$$

whereas individuals in the traditional sector bequeath

$$b_{t+1}^r = \delta(\gamma\sqrt{k_t}X_{t+1} - k_t + b_t) \quad (2.9)$$

to their offsprings. Note that the resource stock  $X_{t+1}$  is a function of the whole wealth distribution  $g_t(b)$  (cf. equations 2.6 and 2.5).

The amount of wealth that is transferred from generation to generation may decline or increase over time until a steady state is reached. In steady state, bequests, incomes, and the size of the resource stock are constant over time. The steady state bequest in the modern sector is given by

$$b_*^m = \frac{\delta}{1-\delta}(\alpha - \beta). \quad (2.10)$$

To ensure that a modern sector can persist we assume that

$$\delta\alpha > \beta, \quad (2.11)$$

i.e. the bequest of an individual working in the modern sector is large enough that her child can afford the fixed investment  $\beta$ .

The distribution of wealth degenerates in steady state, such that all individuals engaged in the same (traditional or modern) sector bequeath the same amount to their offspring. For the traditional sector we thus can solve (2.5) and (2.9) for their steady states values. The steady state bequest is given by (see Appendix A.1)

$$b_*^r = \left( \frac{\delta\rho\gamma\kappa}{\delta n_*\gamma^2\kappa + \rho} \right)^2, \quad (2.12)$$

where  $n_* \in [0, 1]$  is the mass of workers engaged in resource harvesting in steady state, which depends on the initial wealth distribution and will be studied in the subsequent analysis. The steady state bequest in the traditional sector increases in  $\gamma$  only if  $\gamma < \sqrt{\rho/(n_*\delta\kappa)}$  and decreases in  $\gamma$  for larger values of  $\gamma$  (see Lemma A.1 in Appendix A.2). This is because the harvesting efficiency parameter has two opposing effects on steady state bequest. It increases the efficiency of harvesting capital and labor and thus increases revenues, but the increase in aggregate harvesting efficiency reduces the stock size and thus impacts harvest negatively. The two opposing effects illustrate that a more efficient harvesting technology may be detrimental to incomes in the traditional sector when there is a common pool externality.

The steady state resource stock is given by (see Appendix A.1)

$$X_* = \frac{\rho\kappa}{\rho + \delta n_* \gamma^2 \kappa}. \quad (2.13)$$

While the steady state bequest increases with  $\delta$ , steady state income, which is given by  $b_*^r/\delta$ , increases in  $\delta$  only for  $\delta < \rho/(n_*\gamma^2\kappa)$ , but decreases with  $\delta$  for  $\delta > \rho/(n_*\gamma^2\kappa)$ . The reason is that the increase of bequest with  $\delta$  increases harvesting capital, thus aggravating resource overuse, which reduces income in the traditional sector. Higher altruism may therefore affect the economy adversely for a similar reason as technological efficiency. Income increases in the resource productivity, i.e. in  $\kappa$  and  $\rho$ . One could expect that a more productive resource attracts more harvesters, who then deplete the resource. This is not the case, because individuals working in the modern sector would anticipate depletion and would not enter.

To determine the mass of individuals who engage in resource harvesting in steady state ( $n_*$ ) we look at occupational choice next. The poor have no choice but to work in the traditional sector. A rich individual chooses to work in the modern (traditional) sector over working in the traditional (modern) sector in steady state if  $b_*^r < b_*^m$  ( $b_*^r > b_*^m$ ) and is indifferent between working in the traditional and the modern sector if  $b_*^r = b_*^m$ , which implies that the mass of individuals engaged in the traditional sector is

$$\underline{n} = \frac{\rho}{\gamma} \left( \frac{1}{\sqrt{b_*^m}} - \frac{1}{\delta\gamma\kappa} \right). \quad (2.14)$$

This mass of individuals in the resource sector decreases in the incomes of the industrial sector. This relation implies that when incomes rise in the modern sector, individuals leave the traditional sector and the income in the resource sector rises as a response, as it is the case in the Norwegian fishery (Hannesson, 2007).

Following Galor and Zeira (1993) we call an economy *developed* if the lowest

bequest steady state is larger than  $\beta$ , i.e. if all individuals can afford the investment which is necessary to work in the modern sector. We call an economy *underdeveloped* if the lowest bequest steady state is lower than  $\beta$ . This classification of 'development' differs from the common definition which refers to mean income. Our measure is relative and is therefore more related to the maximin criterion of Rawls.

Given  $b_*^m > \beta$  from assumption (2.11) the economy is developed in steady state if  $b_*^r \geq \beta$ , i.e. if  $n_* \leq \bar{n}$  with

$$\bar{n} \equiv \frac{\rho}{\gamma} \left( \frac{1}{\sqrt{\beta}} - \frac{1}{\delta \gamma \kappa} \right). \quad (2.15)$$

Assumption (2.11) also implies  $\bar{n} > \underline{n}$ , which reflects that steady-state incomes in both sectors can only be equal in a developed economy. The mass  $\bar{n}$  defines the maximum number of individuals that can escape poverty through resource harvesting. It increases in  $\rho$ ,  $\kappa$  and  $\delta$  and decreases in  $\beta$ . A more productive resource can lift a larger share of the population out of poverty. The influence of altruism,  $\delta$ , on development is also positive. However, higher technological efficiency has an ambiguous impact on development, as  $\bar{n}$  increases in  $\gamma$  only if  $\sqrt{\beta} > \rho \delta \gamma \kappa$ .

We further speak of a *modern economy* if there is no resource harvesting activity. A *traditional economy* in contrast is an economy where only resource harvesting takes place, and a *mixed economy* is an economy where both activities are undertaken.

As all individuals are rich in a developed economy, all can freely choose occupations. Thus, all three cases are possible. The following proposition gives conditions for a developed economy to be either modern, traditional or mixed:

**Proposition 2.1.** *A developed economy in steady state is modern if  $\underline{n} < 0$ , traditional if  $\underline{n} > 1$ , and mixed if  $0 \leq \underline{n} \leq 1$ .*

The proof is given in Appendix A.2.

The poor in an undeveloped economy have no choice but to work in the traditional sector. Hence, an undeveloped economy cannot be modern.

**Proposition 2.2.** *An undeveloped economy in steady state is traditional if  $n_* = 1$ , and mixed if  $\bar{n} \leq n_* < 1$ .*

In an undeveloped and mixed economy, the income levels in both sectors differ. If  $\bar{n} < 1$ , there are multiple steady states, and the economy can either be developed or undeveloped in steady state, depending on the initial number of poor. The main difference between an undeveloped and mixed and a developed and mixed economy is that in the former more individuals work in the traditional sector, driving the resource down which impoverishes the resource harvesters. This relation is in line with the empirical findings that less developed economies have a larger share of their workforce in the resource sector.

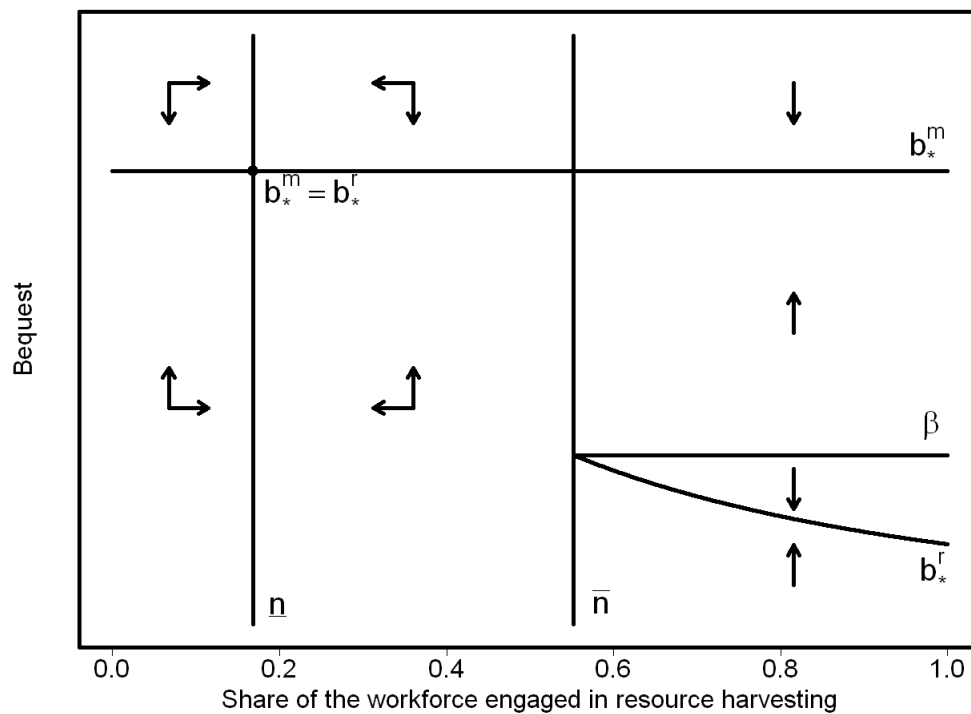
Next we want to analyze transitional dynamics to show how the different steady states evolve. Following Galor and Moav (2004) the economy contains two groups of individuals, the poor and the rich. The focus on only two groups is to clarify the argument on the circumstances in which a bigger share of the initially poor becomes rich. The fraction  $n^p \in [0, 1]$  of the individuals are poor and possess  $b_0 = b^p < \beta$  and the remaining fraction  $n^w = 1 - n^p$  are rich with  $b_0 = b^w \geq \beta$ . Further, we assume that the wealth motions are monotone (see Appendix A.3). All descendants of the rich stay rich because of (2.11). The descendants of the poor may accumulate wealth over time but they can only become rich if the bequest of one generation equals or surpasses  $\beta$  at one point in time. The poor can therefore only become rich if  $b_*^r \geq \beta$  for  $n = n^p$ , i.e. if  $n^p < \bar{n}$ .

Thus, an economy that starts with a large share of its population in poverty retains a large share of its population in poverty. This is stated formally in the following proposition.

**Proposition 2.3.** *A developed economy (an underdeveloped economy) evolves from an initial distribution of capital if  $n^p \leq \bar{n}$  ( $n^p > \bar{n}$ ).*



FIGURE 2.1: Phase Diagram.



The proof is given in Appendix A.4.

The steady states, the dynamics of bequest, and the share of individuals in the resource sector are depicted in Figure 2.1 for an intermediate productive resource where  $0 < \underline{n} < \bar{n} < 1$ . An economy that starts with a low share of poor individuals in the traditional sector ( $n < \bar{n}$ ) becomes a developed and mixed economy. 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 harvesting the resource ( $n > \bar{n}$ ) becomes a undeveloped and mixed economy. The wealth of the poor approaches  $b_*^r < \beta$  and the wealth of the rich approaches  $b_*^m > \beta$ . The share of individuals in the resource sector remains constant over time. The income of the poor in an undeveloped and mixed economy declines in the number of initially poor individuals,  $n^p = n$ .

## 2.4 Efficiency, Equity, and Resource Regulation

We now turn to the analysis of how inequality and economic development are interrelated by studying, first, the benchmark of the first best outcome, second, how redistributions of wealth may affect the development level of the economy, and, third, how regulation of access to the resource may affect the development of the economy. Throughout this section, we assume that the economy is in a steady state initially, such that the distribution of wealth is degenerated: all individuals in either sector have the same level of wealth. Additionally, we assume that the wealth dynamics are monotone (see Appendix A.3) such that no overshooting occurs.

### 2.4.1 First Best

We first consider the benchmark case of the long-term Kaldor-Hicks efficient allocation of capital and labor. Obviously, the economy considered here will fail to reach the first-best allocation because of missing credit markets and unregulated access to the resource. The steady-state allocation that is Kaldor-Hicks efficient is the one that maximizes aggregate income of all individuals in the second period of their life. It is characterized by the following conditions (see Appendix A.7):

$$k = \alpha - \beta \quad (2.16)$$

$$n = \frac{\rho}{\gamma} \left( \frac{1}{2\sqrt{\alpha - \beta}} - \frac{1}{\gamma\kappa} \right) \quad (2.17)$$

$$y^r = \frac{\gamma\kappa}{2} \sqrt{\alpha - \beta}. \quad (2.18)$$

Resource harvesting takes place in the first-best allocation, i.e.  $n > 0$ , if  $\sqrt{\alpha - \beta} < \gamma\kappa/2$  (cf. 2.17). If this condition is fulfilled, the resource is harvested at the maximum sustainable yield stock level  $X = \kappa/2$  and incomes are higher in the

traditional than in the modern sector, i.e.

$$y^r = \frac{\gamma \kappa}{2} \sqrt{\alpha - \beta} > \alpha - \beta = y^m. \quad (2.19)$$

The reason for this is that resource rents are generated in the traditional sector.

The first-best allocation could be implemented if there was a well-functioning credit market and if individuals in the traditional sector would hold individual harvesting rights with an appropriate restriction of the aggregate harvesting quantity. In the following we analyze how two types of second-best policies may foster development if such a first-best policy is not feasible.

### 2.4.2 Redistribution

We consider redistributions among individuals in the first period of their life, after they received their respective bequests, but before they decide on their investment. A redistribution decreases the wealth of  $\nu > 0$  individuals (the ‘disadvantaged’) by an amount  $\tau > 0$  and increases the wealth of  $\mu$  individuals (the ‘advantaged’) by an amount  $(\nu \tau)/\mu$ . A redistribution is feasible as long as  $b_t - \tau \geq 0$  for the wealth level  $b_t$  of the disadvantaged. A redistribution increases long-term Kaldor-Hicks efficiency if the aggregate income of the steady state that will be reached after the redistribution exceeds the aggregate income of the steady state that prevails without the redistribution. Taking wealth from some individuals and giving it to others is an issue of distributive justice. The application of an inter-generational version of the maximin criterion incorporates these concerns in our analysis. It asks if a redistribution benefits the worst-off individuals. A redistribution can further shift the economy from an underdeveloped state to a developed state if only  $\bar{n}$  individuals remain after the redistribution in the resource sector (see condition (2.15)).

When the redistribution is among the poor, the disadvantaged are the worst-off individuals in society. However, even they may benefit from a redistribution.

To show this, we consider redistributions where all poor individuals are affected by the redistribution, i.e.  $\mu = n_* - v$ , as then the amount taken from the disadvantaged is minimized for given values of  $\mu$  and  $\tau$ .

**Proposition 2.4.** *A one shot redistribution among the poor increases long-term Kaldor-Hicks efficiency if*

$$b_*^r + \frac{v}{n_* - v} \tau \geq \beta, \quad (2.20)$$

*and it benefits the worst-off individuals if additionally*

$$\sqrt{b_*^r} \left( 1 - n_* \frac{\gamma}{\rho} \sqrt{b_*^r} \right) \leq \sqrt{b_*^r - \tau} \left( 1 - v \frac{\gamma}{\rho} \sqrt{b_*^r - \tau} \right). \quad (2.21)$$

*The economy becomes developed if (2.20) holds and  $v \leq \bar{n}$ .*

The proof is given in Appendix A.5.

Under condition (2.20), the advantaged of the redistribution leave the traditional sector, thus alleviating the problem of resource-overuse. If condition (2.21) holds, the resulting increase in the incomes of the remaining resource harvesters due to the increasing resource stock is larger than the disadvantage from the redistribution. The result is in line with Baland and Platteau (1997) who show that more inequality can be a Pareto improvement in the management of the commons. Note also that the one shot redistribution defined by condition (2.21) is intertemporally Pareto efficient. Not only the disadvantaged individuals themselves, but also their descendants are better off after redistribution.<sup>4</sup>

Redistributions among the rich cannot increase long-term efficiency. It may even decrease long-term efficiency if  $v > \bar{n}$  and  $\max\{b_*^r, b_*^m\} - \tau < \beta$  such that the disadvantaged fall into poverty. In the same line, a redistribution from the poor to the rich cannot increase long-term efficiency either. By contrast, a redistribution from the rich to the poor may increase long-term efficiency. It

<sup>4</sup>Condition (2.20) is sufficient, but not necessary for a one-shot redistribution to increase long-term efficiency. A redistribution that increases inequality among the poor can increase long-term efficiency even if it does not satisfy (2.20) when the assumption of monotone bequest dynamics in the resource sector is relaxed.

may come in the form of a progressive income tax, if  $\mu = n_*$ , or as some more unequal form of redistribution if  $\mu < n_*$ .

**Proposition 2.5.** *A one shot redistribution from the rich to the poor increases long-term Kaldor-Hicks efficiency and benefits the worst-off if*

$$b_*^r + \frac{v}{\mu}\tau \geq \beta \quad \text{and} \quad b_*^m - \tau \geq \beta. \quad (2.22)$$

*The economy becomes developed if additionally  $v \leq \bar{n}$ .*

The proof is given in Appendix [A.6](#).

Redistributions will be difficult to implement even if they are Pareto efficient unless they are voluntary. In the following section we propose use rights as a market based redistributive policy.

### 2.4.3 Resource Regulation

While the focus in the previous section on redistribution was solely on increasing aggregate income through enabling some individuals to leave the resource sector, this section on resource regulation considers an additional channel to increase aggregate income, namely the reduction of resource overuse. We start with considering the pure effect of resource regulation. The regulation limits aggregate harvest to the level that 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 [A.8](#))

$$\bar{k} = \left( \frac{\gamma \rho \kappa}{2(n_* \gamma^2 \kappa + \rho)} \right)^2. \quad (2.23)$$

This way of regulation improves efficiency of resource use only if it is binding. This might not be the case if the resource harvesters are too poor to buy more than  $\bar{k}$  harvesting capital.

**Proposition 2.6.** *Regulating access to the renewable resource in the traditional sector increases long-run efficiency if*

$$\delta > \frac{\rho}{n_* \gamma^2 \kappa + 2\rho} \quad (2.24)$$

*and benefits the worst-off individuals if additionally  $b_*^r < b_*^m$ . Regulation suffices to develop the economy if*

$$\frac{\delta}{1 - \delta} \frac{\gamma^2 \rho \kappa^2}{4 (n_* \gamma^2 \kappa + \rho)} \geq \beta. \quad (2.25)$$

The proof is given in Appendix A.9.

If the altruistic part of utility is small enough (i.e. if (2.24) does not hold), individuals are so wealth-constrained that limiting individual resource use would not improve efficiency. This is the case if parents working in the traditional sector have a very low income or if the altruistic part of their utility function is low, as they then endow their children only with a very small amount of capital.

Condition (2.24) states that the poor are already wealthy enough to overuse the resource. Under this condition, limiting individual harvesting capital increases efficiency. Note that this increase in efficiency comes about without movement of labor from the traditional to the modern sector. The regulation benefits the worst-off individuals if condition (2.24) holds and the resource users are poorer than the individuals working in the modern sector. We show in Appendix A.9 that for a underdeveloped economy (2.25) implies (2.24), but not vice versa. Thus, being able to improve efficiency by regulating access to the resource does not always foster development.

Implementing the harvesting limit by means of individual tradable use rights broadens the scope for development, however, as some individuals may be able to afford the fixed investment required to work in the modern sector through selling their rights. As they leave the traditional sector, the problem of resource overuse further alleviates and aggregate income increases. This process may finally render the economy in a developed state. We explore this possibility in the following.

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 use it. We introduce the use rights in forms of harvesting capital allowances.<sup>5</sup> The initial harvesting capital allowances are grandfathered. The quantity of capital for each of the  $n_*$  fishermen is set to  $\bar{k}$ , as given by (2.23). The children of the resource harvesters then inherit the use rights from their parents.<sup>6</sup> For the next generation, the total harvesting capital allowance can either stay on the initial level or can be adapted to again maximize income of the current resource harvesters. The general results do not depend on either of the specifications.

In an underdeveloped economy, a use right market only improves efficiency further as compared to pure regulation if the 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 the initial situation by selling use rights. We only consider the situation where regulating alone is not sufficient to make everybody rich and additional income from selling the use right is needed to afford  $\beta$ . Individuals who are willing to buy an additional marginal harvesting capital allowance would bid up to the marginal productivity of harvesting capital. Thus, the market price  $p$  of the allowance would be equal to (see Appendix A.8)

$$p = \frac{n_* \gamma^2 \kappa + 2\rho}{2\rho}. \quad (2.26)$$

Note that the market price for the use rights increases in the number of resource harvesters. Still, since credit markets are absent, the bequest limits the amount

<sup>5</sup>Under the given assumptions this approach is equivalent to other forms of transferable use rights, in particular transferable harvesting rights, but the mathematics are more transparent.

<sup>6</sup>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.

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 that can leave the traditional sector each generation. However, as the following proposition states, once trade in use rights started, it is only a matter of time until the economy develops.

**Proposition 2.7.** *Assume (2.24). Resource regulation by means of transferable use rights moves the economy from undeveloped to developed if*

$$\frac{n_* \gamma^2 \kappa + 2\rho}{2\rho} \left( \frac{\gamma \rho \kappa}{2(n_* \gamma^2 \kappa + \rho)} \right)^2 + b_*^r \geq \beta. \quad (2.27)$$

The proof is given in Appendix A.10.

Under condition (2.27) some individuals will be able to leave the traditional sector. The remaining individuals will be better off, because first, reduced overall effort due to less labor increases the resource stock, and second, harvesting capital per individual increases. They thus bequeath a larger amount. Also, the market value of the resource use rights per individual increases over time. Thus, condition (2.27) will always be fulfilled for the next generation of resource users as well, and further individuals will leave the traditional sector. This process of development will end only if the economy is developed, i.e. when resource harvesters have no incentive to leave the traditional sector. This is the case for

$$y_*^r = y_*^m + p_* \bar{k}_* \quad (2.28)$$

with the steady state use right price  $p_*$  and the steady state capital allowance per capita  $\bar{k}_*$ . The duration until the economy reaches the steady state depends on the initial share of resource harvesters and their wealth, since credit markets are absent.



## 2.5 Case Study of an Indian Inland Fishery

The purpose of this section is twofold. First, we apply the model to the large inland fishery of Chilika Lagoon in Orissa, India, to demonstrate that it can explain why individuals stay in the traditional sector even though their incomes are low and declining relative to the average income in Orissa. Second, we show how the model can be used to evaluate redistributive policies and the introduction of use rights. All data stem from a field survey of 500 households that was carried out by the authors in 2011 (Noack and Riekhof, 2011).

The fishery at Chilika Lagoon comprised 32,500 active fishermen who harvested an annual amount of 19,200 metric tons (MT) of fish and shellfish in 2010/11. Per capita catches and real fishery incomes at Chilika Lagoon have fluctuated largely in the last 60 years without a clear trend (Figure 2.2).<sup>7</sup> Despite a declining relative income in the fishery, the number of fishermen has risen continuously during this period (Figure 2.3). The share of Orissa's workforce in the fishery also increased since 1950: the number of fishermen at Chilika Lagoon increased fivefold whereas the total population of Orissa increased only threefold. This increase of fishermen may have reduced the fish stock and caused the fishermen's incomes to stagnate. At present an average fisherman earns about 70 Rs per operation day.<sup>8</sup> In comparison, a teacher in a governmental school in rural areas of Orissa earns ten times more per day (World Bank, 2009).

Before applying the model to the case Chilika Lagoon fishery in Orissa we discuss the assumption of missing credit markets and the income alternatives in the modern sector that require some fixed investment.

At Chilika Lagoon, credit markets exist to some degree, and 86 % of the fishermen are actually indebted. However, average loan sizes are small (about 30,000

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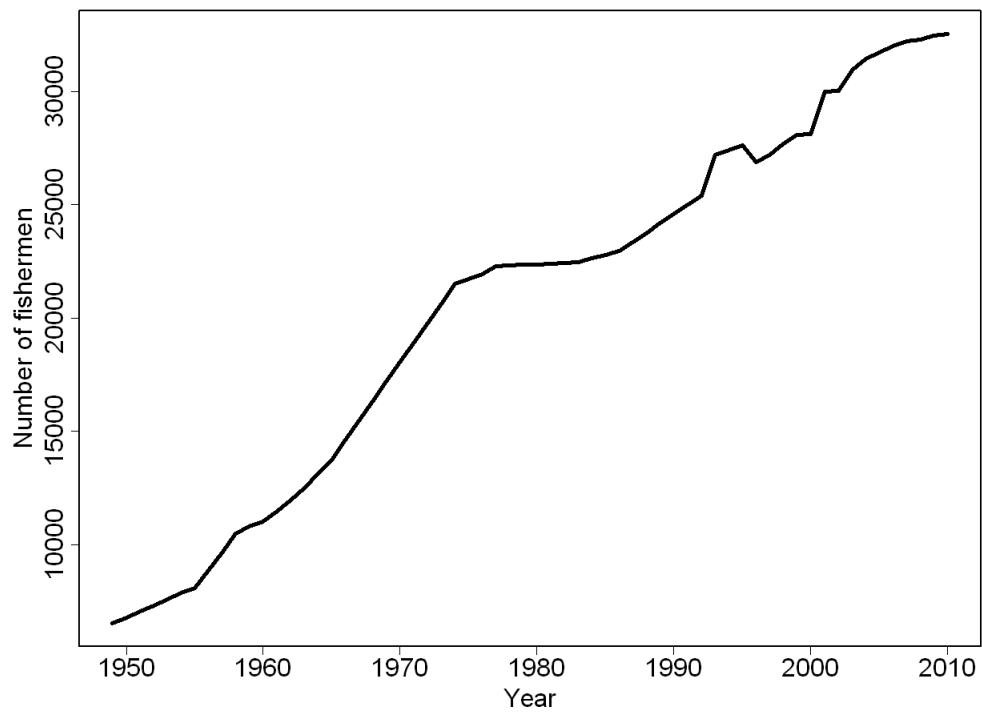
<sup>7</sup>The increase of catches in 2000 is due to a hydrological manipulation of the lagoon (Mohapatra et al., 2007).

<sup>8</sup>The exchange rate in 2011 was 1 USD  $\approx$  45 Rs.

FIGURE 2.2: Fish and Shellfish Landings.



FIGURE 2.3: Number of Fishermen.



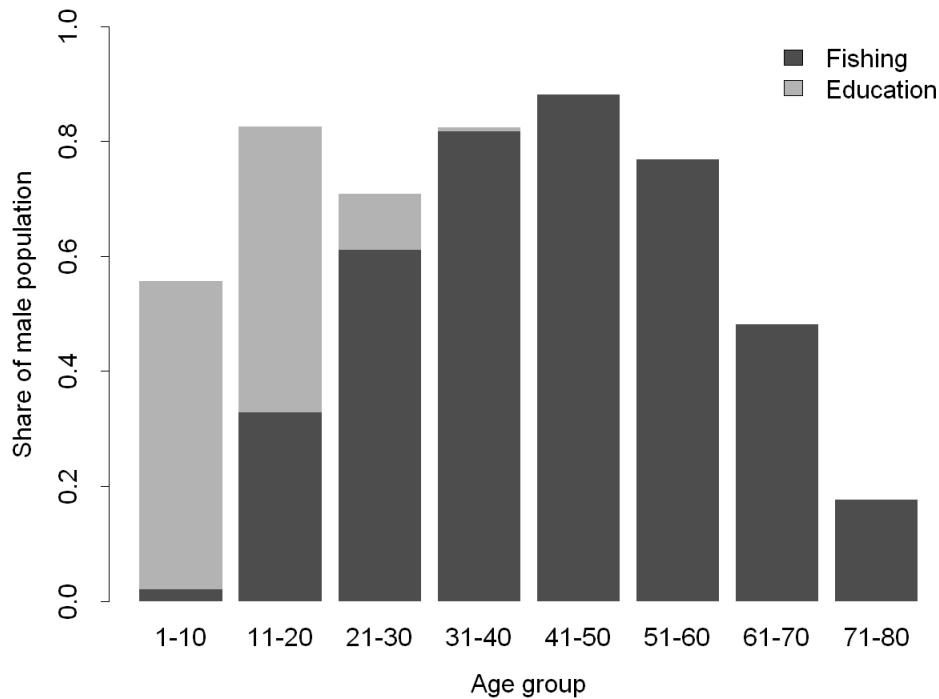
Rs) and average interest rates are high (56 % per year). Most importantly for our question, loan purposes are restricted. Most credit arrangements rely on fishing devices as collateral and are therefore only available for fishing purposes. Credit possibilities for education or other income alternatives are virtually absent. Only 0.5 % of the loans are used for education, and only 0.1 % are used for other income generating purposes. Even improving existing credit market conditions does not necessarily increase investment in income alternatives outside the resource sector (Chapter 4). Thus, it seems reasonable to assume missing credit markets for education or other forms of investment into income alternatives.

A second major assumption concerns the income alternative of fishermen in the modern sector. Very few individuals left the fishery to work for higher wages although such cases exist (e.g. five individuals out of the 500 surveyed fishing households work as teachers).<sup>9</sup> For our application of the model, we assume that the income alternative of fishermen is to work as teacher and that the fixed investment takes the form of education. We use teaching as income alternative since fishermen belong to the scheduled casts for which the government sets a proportion of all possible government positions aside. Finding a job as teacher may therefore be relatively easy for fishermen, while other jobs in the modern sector may be difficult to attain for fishermen because of the cast system. Further, the salaries for teachers are low compared to salaries for equally qualified workers in the governmental and non governmental sector (World Bank, 2009), and investment requirements to enter the education sector are relatively low as well. Using a job as a teacher to parameterize income in the modern sector and fixed investment requirements to enter the modern sector is thus a conservative assumption.

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<sup>9</sup>Some fishermen work as unskilled construction workers in nearby cities. Although daily wages for unskilled workers are higher than average daily fishing incomes, irregular employment and higher living costs may render construction work less attractive, and only the poorest fishermen work on construction sites. As mentioned in Section 2.2 an income alternative in the unskilled sector does not change the model results qualitatively. We neglect this alternative occupation in the following.

FIGURE 2.4: Main Activity.



### 2.5.1 Model Calibration

As the period (generation) length we use 40 years, which reflects the average number of years a fisherman spends harvesting in Chilika Lagoon i.e. from his early twenties until his early sixties. Figure 2.4 displays the share of the male population with either fishing or education as their main activity ( $n=3,492$ ).

Fish from the Chilika Lagoon is sold on national and global markets at a given price of 47.8 Rs per kg. In what follows, we express the units of fish directly in units of monetary value. Table 2.1 gives an overview over all calibrated parameters and initial variable values.

There is no information of resource productivity in Chilika Lagoon readily available. We therefore estimate the carrying capacity of the fish stock and its reproduction rate using the method developed by Martell and Froese (2012) with data on aggregate harvest from 2001 to 2010. Data on official landings is provided by the Chilika Development Authority. According to our survey, actual

harvest exceeds official landings by a factor of 1.6 due to landings at unofficial landing centers and fish for home consumption. We adjusted the official figures accordingly.

The obtained estimates are  $\rho = 1.8$  (sd = 0.9) and  $\hat{\kappa} = 57,000$  MT (sd = 23,000), corresponding to  $\kappa = 2724.6$  million Rs. The current (in 2010) fish stock can be calculated from these parameters and the current harvest  $H_{2010} = 19,200$  MT per year converted into monetary units as  $X_{2010} = \frac{\kappa}{2} - \sqrt{\left(\frac{\kappa}{2}\right)^2 - \frac{\kappa H_{2010}}{\rho}} = 679.2$  Mio Rs. This reflects that most commercially important fish stocks at Chilika Lagoon are currently slightly overfished (Bhatta et al., 2009), i.e.  $X_{2010}$  is smaller than the maximum sustainable yield stock  $\kappa/2$ .

Next we look at incomes and capital input in the fishery. An average fishing unit comprises a crew of 3.5 fishermen (sd = 2.5), and operates on 225 days per year (sd = 65). As capital inputs, all fishing units use nets, 95 % use boats, and 53 % use an engine. The value of average fishing capital is 88,480 Rs per fishing unit equaling 25,280 Rs per fisherman (see Appendix A.11). Total capital costs are 207 Rs per fishing unit and operation day (see Appendix A.11), about half of the revenues. With this capital input an average fishing unit catches 9.2 kg (sd = 8.7) of fish per operation day, yielding a revenue of 440 Rs (sd = 430) per operation day.

The fishermen in one fishing unit share the revenues such that the nets, the boat, the engine, and each fishermen receive an equal share. Each fisherman thus gets  $440/(3 + 3.5) \approx 70$  Rs per day, or  $40 \times 225 \times 70 = 630,000$  Rs over the whole working life as a fisherman. The three shares of the revenues that pay for the capital equal 203 Rs/day, roughly equal to the daily operation costs of capital and also roughly equal to half the overall cost.<sup>10</sup> With these estimates, we obtain  $\gamma = 630/(\sqrt{25.28} \times 680.29) = 0.184$ .

As discussed above, we assume that the income alternative of fishermen is to work as teacher. The salaries of teachers in 2011 were between 11,000 and

<sup>10</sup>Thus, our above assumption of an output elasticity equal to 1/2 is reasonable for the Chilika Lagoon fishery.

18,000 Rs per month in Orissa. We use the average of 14,500 Rs per month for calibration, which is also in line with the independent data for governmental secondary school teachers in rural areas of Orissa in 2005 (World Bank, 2009). Summing this over a period of 40 years gives  $\alpha = 6,960,000$  Rs.

Becoming a secondary teacher in India requires senior secondary education (two years), a bachelor's degree (tree years) and a teachers training course (one year) (UNESCO, 2006). The first ten years of primary education are obligatory and free in Orissa, but higher secondary and higher education is facultative and costly. In our survey the annual household spending per person attending senior secondary school or high school was 7,400 Rs (sd = 9,140), which is somewhat below average expenditures on senior secondary education in rural Orissa (World Bank, 2009). Households with children attending college spend annually on average 13,100 Rs (sd = 12,500) per student for education. Additionally, education has the opportunity costs of not working as a fishermen. Adding the opportunity costs to the education expenditure and summing over six years yields  $2 \times 7,400 + 3 \times 13,100 + 6 \times 225 \times 70 = 161,700$  Rs. This is a conservative estimation, as additional costs of living apart from the parents or alternatively the transportation costs are neglected. Agarwal (2006) for example reports 300,000 Rs as the size of an average student loan.

To calibrate the utility parameter  $\delta$ , we use two independent approaches. Since the steady state bequest in the fishery sector equals the amount of capital the child has available to set up a fishing unit, we may use the per capita setup costs of a fishing unit to estimate  $\delta$ , which is 4 % of the period income of a fisherman. As a second approach to estimate  $\delta$  we take the household expenditure on education, which may be taken as a proxy for the intergenerational wealth transfer. The average household expenditure share on education in our survey is 6.9 % (sd = 8.7) which is in line with the findings of Pattnaik and Kobayashi (2009) and Samal and Meher (2003). In what follows we assume that  $\delta$  is in between both estimates and use the figure  $\delta = 0.06$ .

TABLE 2.1: Parameter Values and Initial Values.

| symbol | $\rho$ | $\kappa$ | $\alpha$ | $\beta$ | $\gamma$ | $\delta$ | $X_{2010}$ | $n_*$  |
|--------|--------|----------|----------|---------|----------|----------|------------|--------|
| value  | 1.8    | 2,725    | 6.960    | 0.1617  | 0.184    | 0.06     | 680.3      | 32,500 |

The values for  $\kappa$ ,  $\alpha$ ,  $\beta$ ,  $X_{2010}$  are given in  $10^6$  Rs,  $n_*$  is the number of active fishermen and  $\rho$ ,  $\gamma$  and  $\delta$  are unitless.

## 2.5.2 Results and Robustness

With the values for the parameters and variables summarized in Table 2.1 the steady state bequest is  $b_*^r = 76,600$  Rs for fishermen and  $b_*^m = 434,000$  Rs for teachers.

As  $b_*^r < \beta$ , fishermen cannot afford the investment to become teachers, which explains why the fishermen stayed in the fishery at Chilika Lagoon even though the incomes are low and declining. The subjective perception of the fishermen in Chilika is in line with this result: 65 % of the surveyed households stated that the reason for not attaining higher education was that they could not afford it. We also found that the chance of children going to school or college increased significantly with the income of the household head.

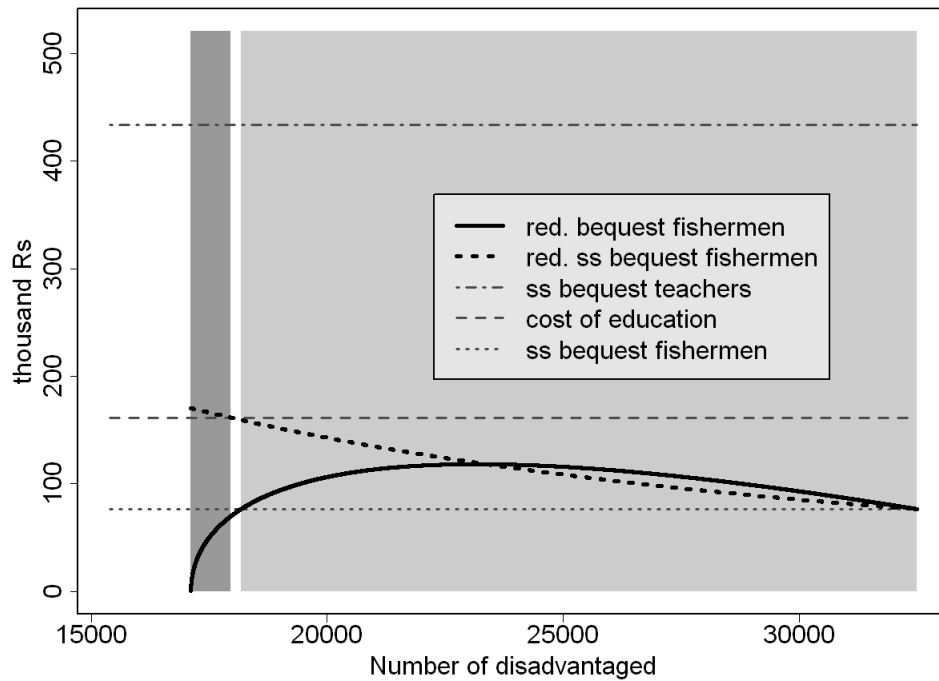
As a robustness check of this explanation, we consider which changes in parameter values would be necessary to change the result  $b_*^r < \beta$ . Keeping all other parameters as calibrated, educational costs,  $\beta$ , would need to decrease by 53 % or the intrinsic growth rate,  $\rho$ , would need to increase by 81 % to change this result. The fishermen remain trapped, i.e.  $b_*^r < \beta$ , for all possible values of the carrying capacity,  $\kappa$ , and for all  $\delta \in (0, 1/2)$ . These results indicate that the general conclusion that the fishermen in Chilika are trapped in poverty under current conditions is fairly robust.

### 2.5.3 Policies for Development

We will now apply the model to find and evaluate redistribution and regulation schemes that improve the situation of the fishermen. In Proposition 2.4 we showed that a redistribution among the fishermen may increase long-term efficiency. A redistribution that makes some individuals worse off may be politically infeasible. We therefore consider a one shot redistribution among the poor as defined in Proposition 2.4, which makes the worst-off individuals better off and leads to a Pareto improvement. An advantaged fisherman needs at least  $\beta - b_*^r$  Rs as a transfer payment to invest in education and leave the fishery. The most effective redistribution would give the advantaged the exact amount that is required to invest in education, and would include all fishermen in the redistribution scheme such that the costs of education for the advantaged is shared among the largest possible number of individuals. The amount taken from the disadvantaged is a function of their number,  $\tau = \frac{(\beta - b_*^r)(n_* - \nu)}{\nu}$ . The only remaining question is now to choose the number of disadvantaged,  $\nu$ . Figure 2.5 summarizes the results of redistribution depending on the number of disadvantaged. The horizontal lines depict the steady state bequest of fishermen and teachers before the redistribution as well as the cost of education. The figure further shows the average steady state bequest after redistribution and the amount that the first generation which is affected by redistribution bequeaths to their children. If the number of disadvantaged is too low, even taking away all their wealth will not be enough to lift the rest of the fishermen out of poverty. At least 17,113 disadvantaged fishermen are needed to pay the educational costs of the advantaged. If the number of disadvantaged increases, two interesting results arise. The lightly shaded area shows the redistributions for which also the worst-off individuals – the disadvantaged – benefit from the redistribution. Comparing the bequests of the disadvantaged before and after redistribution one sees that it increased after redistribution. This is due to the increased resource stock as a result of reduced aggregate and per capita fishing capital and reduced fishery labor. Second, there are redistributions marked



FIGURE 2.5: Redistributions.

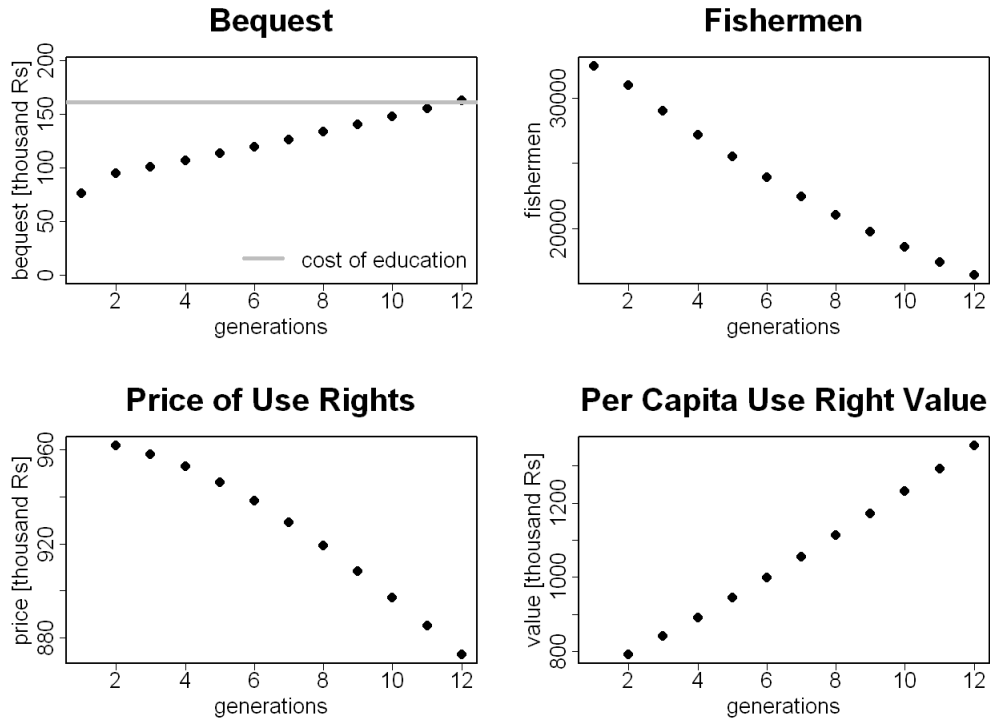


by the darkly shaded area in Figure 2.5 which do not improve the well-being of the worst-off, but for which the descendants of the disadvantaged become eventually rich and the economy develops. This may be considered a tradeoff between inter-generational justice and long-run efficiency.

In Section 2.4.3 we showed how the introduction of use rights may foster development. Such individual use rights might come in the form of individual transferable quotas (ITQs) or territorial use rights, which existed at Chilika Lagoon, but are no longer in place.<sup>11</sup> In the following we apply our results on resource regulation from Section 2.4.3 to the fishery at Chilika Lagoon. The optimal capital constraint for the initial number of fishermen is  $\bar{k} = 37,444$  Rs which results in steady state bequest of  $b_*^r = 93,920$  Rs (see Table 2.2). The regulation would increase incomes of the fishermen but not to a sufficient extent that the economy would become developed. However, when use rights are tradable, their market value enables some individuals immediately to leave

<sup>11</sup>The fact that 75 % of the species are migratory (Mohapatra et al., 2007) may reduce the effectiveness of territorial use rights.

FIGURE 2.6: Introduction of Use Rights.



the fishery which triggers the development process (Proposition 2.7). The limit to fishery capital,  $\bar{k}$ , can be either set only once such that the individual capital allowance in the next generation is  $\bar{k}_{t+1} = \bar{k}_t \left( \frac{n_t}{n_t - \epsilon_{t+1}} \right)$  with the number of fishermen  $n_t$  at time  $t$  and the number  $\epsilon_{t+1}$  of fishermen who leave the fishery at  $t + 1$ , or the capital allowance can be adjusted in each generation. Adjustment occurs to again maximize the average income in the resource sector. We report both results in Table 2.2.

Figure 2.6 summarizes the transitional dynamics that follow the introduction of individually transferable use rights where the allowed capital is set in the beginning and held constant henceforward (the dynamics are similar for a periodically adapted capital allowance). The number of individuals that leave the fishery each period is determined by the budget constraints of the remaining fishermen  $\bar{k}_t \left( 1 + \frac{\epsilon_{t+1}}{n_{t+1}} (1 + p_{t+1}) \right) \leq b_t^r$ .

In Figure 2.6, the regulation is introduced between the first and second generation such that the first generation depict the steady state that evolves from

TABLE 2.2: Performance of Policy Measures.

|                               | bequest   | income | # of fishermen |
|-------------------------------|-----------|--------|----------------|
| first best                    | 1,597,464 | 55,468 | 1,626          |
| status quo (ss)               | 76,561    | 2,658  | 32,500         |
| maximin red. (1)              | 118,363   | 4,110  | 23,173         |
| maximin red. (ss)             | 119,615   | 4,153  | 23,173         |
| development red. (1)          | 69,735    | 2,421  | 17,952         |
| development red. (ss)         | 433,934   | 15,067 | 5,448          |
| regulation (1)                | 92,878    | 3,225  | 32,500         |
| regulation (ss)               | 93,920    | 3,261  | 32,500         |
| tradable use rights 1 & 2 (1) | 94,846    | 3,293  | 30,968         |
| tradable use rights 1 (ss)    | 885,176   | 30,735 | 1,037          |
| tradable use rights 2 (ss)    | 1,120,337 | 38,901 | 1,947          |

Bequests (in Rs), incomes (in Rs/month), and the number of fishermen under different policy scenarios. The calculations take the steady state that evolves without any policy as reference point (status quo). (1) denotes the first generation which is affected by the respective policy and (ss) denotes the steady state which is reached after the policy is carried out. The 'maximin redistribution' is the redistribution that maximizes the income of the disadvantaged. The 'development redistribution' is the redistribution such that  $v = \bar{n}$ . 'Regulation' stands for the policy that permits only  $\bar{k}$  capital per individual but does not allow the trading of use rights. Tradable use rights 1 are use rights with a constant constraint on capital,  $\bar{k}$ , which is set for  $n_* = 32,500$ . Tradable use rights 2 are use rights with a variable constraint on capital,  $\bar{k}$ , which is set according to the remaining fishermen i.e.  $n_* = 1,947$  in steady state.

the status quo. The first panel shows the bequest of the fishermen. It increases through the introduction of use rights and keeps on increasing while the economy develops. When bequests rise above the educational costs the dynamics change and the economy becomes developed and mixed. The second panel shows the declining number of fishermen. When the economy becomes developed their number adjust more quickly to reach the steady state as given in Table 2.2. The third and fourth panels show the price per unit use right and the value of use rights per fishermen. Since the per capita capital allowance increases with the declining number of fishermen the value of the use rights per fishermen increases although its price declines.

Table 2.2 compares the outcomes of the different policies. Any policy that increases the bequest of the first generation affected by the policy as well as the bequest in the steady state is an intertemporal Pareto improvement, since the

bequest motions are monotone. All presented policy measures except for ‘development redistribution’ are such Pareto improvements. The policy that maximizes the average income of the present generation is the ‘maximin redistribution’ that maximizes the incomes of the worst-off (see Proposition 2.4). The policy that leads to the highest long-run Kaldor-Hicks efficiency is the introduction of tradable use rights (see Proposition 2.7) with variable capital allowances that adjust to the number of remaining fishermen, i.e. ‘tradable use rights 2’. The steady state that evolves from the ‘development redistribution’ and shifts the underdeveloped economy to a developed economy ( $v = \bar{n}$ ) results in the unregulated steady state of a mixed developed economy with  $n_* = \underline{n}$ . Average incomes in the whole economy and in the resource sector are lower than for the case of tradable use rights. However, even tradeable use rights set to maximize the current generations’ fishing income fail to reach the first best solution.

## 2.6 Conclusion

We have shown that an economy with absent credit markets and unregulated access to a common pool resource exhibits multiple steady states that differ in their development level. The more individuals engage in resource harvesting the smaller is the resource stock and the smaller are the steady state incomes in the traditional sector. High resource productivity and low costs to enter the modern sector enable more individuals to escape poverty, thus increasing the economy’s development level. Further, we have shown that redistributions among the poor or from the rich to the poor can increase long-run Kaldor-Hicks efficiency, increase the income of the worst-off individuals, and trigger a process of development. The same applies for the introduction of resource use regulation in general and tradable use rights in specific. Resource use regulation also creates a positive resource rent and thus increases the average income above the income level in unregulated economies, independent of their development level. Even though there is a multitude of regulation policies for common pool

resource available (Costello et al., 2010; Grafton et al., 2006), the challenge remains to find and implement the best policy for each specific situation.

## 2.7 Acknowledgements

We wish to thank Wenting Chen, Andrea Frommel, Toman Omar Mahmoud, Thomas McDermott, Linda Nostbakken, Jack Ruitenbeek, Max Thilo Stoeven, Jaume Ventura and the participants of the SURED, EAERE, IIFET and AUROE conferences for their comments on the paper. Further, we would like to thank Jyotirmayee Acharya, D.P. Dash, Manoranjan Dash, S.K. Mohanty, Ajit Kumar Pattnaik, Tapas Paul, Jack Ruitenbeek and our interviewers for their kind support during the field work. Finally, we acknowledge the financial support from the cluster of excellence 'Future Ocean', the BMBF funded EIGEN project and the World Bank.

## Chapter 3

# How Fish Stocks Affect Education in Indian Villages

**Abstract:** The study explores the links between resource productivity and education using time series and cross section data of a large Indian inland fishery. It exploits a spatially heterogenous increase of fish landings caused by a large-scale hydrological manipulation. The results show that educational attainments increase with fish landings. They further show that the probability of fishermen leaving the fishery increases with their education level, suggesting that the resource productivity increase reduce resource dependency.

### 3.1 Introduction

Education plays a major role in the occupational choices of the rural poor and off-farm returns to education often exceed those on-farm by far. (Taylor and Yunez-Naude, 2000; de Janvry and Sadoulet, 2001; Jolliffe, 2004). However, rural households are often constrained in their liquidity to invest in education and thus fail to shift their labor to resource-independent production. (Jensen, 2010; Uchida et al., 2009).<sup>1</sup> Positive resource shocks may lessen these financial

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<sup>1</sup>Recent developments in the theoretical work on structural change, credit market imperfections and investment in education are summarized in Matsuyama (2011).

constraints of the households but they may also provide incentives to remain in the resource-dependent sector and therefore impede long-run economic development ([van der Ploeg, 2011](#)). The current article asks the question whether a positive and persistent resource productivity shock increases investment in education and induces a labor reallocation from resource-dependent to resource-independent production.

Agricultural shocks may affect schooling in developing countries. [Jensen \(2000\)](#) showed for the Côte d'Ivoire that negative agricultural shocks decrease investment in education and [Beegle et al. \(2006\)](#) showed for Tanzania that adverse agricultural productivity shocks increase child labor and decrease school attendance. [Maccini and Yang \(2009\)](#) used rainfall variations to show that positive income shocks during the birth year had lasting impacts on individual educational attainments and incomes in Indonesia but they found no impact of rainfall variations in post-birth years on adult outcomes. However, these studies only regard temporary shocks caused by annual rainfall variation and the response of schooling to these shocks.<sup>2</sup> In contrast to these articles, the present study explores the impact of a persistent resource productivity increase on educational outcomes. It is therefore more related to [Foster and Rosenzweig \(1996\)](#) who found a positive relationship between long-run agricultural productivity increase caused by the green revolution and investment in education in rural India. However, they found substantial returns to education in agriculture ([Foster and Rosenzweig, 1996](#)) and little impact of education on labor reallocation from agriculture to the manufacturing sector ([Foster and Rosenzweig, 2008](#)). These findings are in contrast to [Jolliffe \(2004\)](#) who provided evidence for much higher returns to education in off-farm work than in on-farm work and also for a positive relationship between education and off-farm activities in Ghana. These studies concern only privately owned resources such as arable land where resource externalities play a minor role. Common pool resources are, however, widespread in the developing world ([Dasgupta, 2010](#); [Millennium Ecosystem](#)

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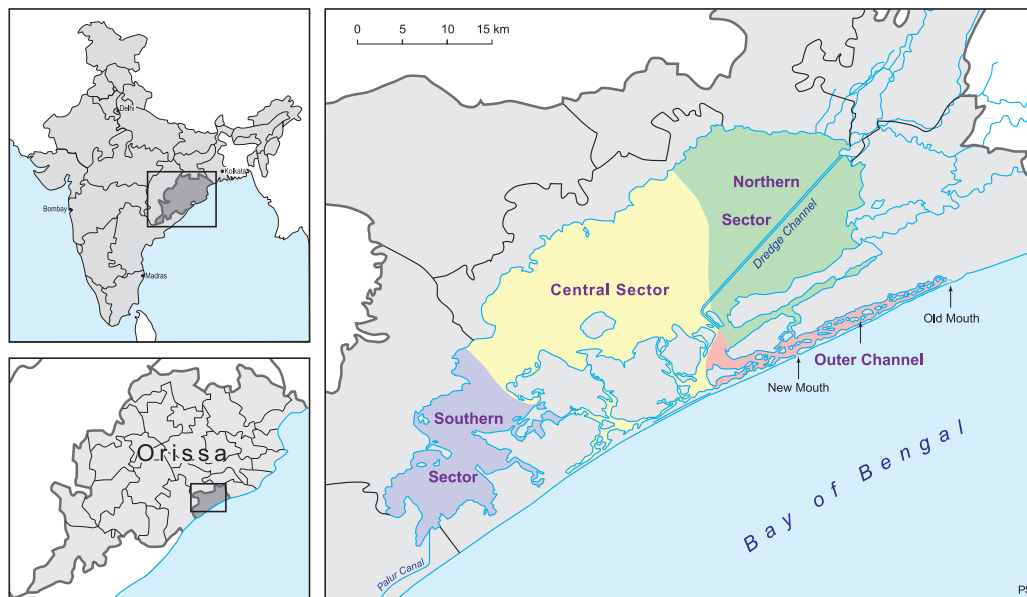
<sup>2</sup>There are similar findings for agricultural price fluctuations and education ([Grimm, 2011](#); [Kruger, 2007](#)).

[Assessment, 2005](#)) and my coauthors and I showed theoretically for a common pool resource under restricted open access (no harvesting restrictions but limited entry) that labor reallocation from the resource-dependent to the resource-independent sector exhibit a positive feedback (Chapter 2). We assumed that working in the resource-independent sector requires a fixed investment in education, that credit markets are absent (or distorted) and that harvesting reduces the resource stock which raises the unit harvesting costs (the common pool externality). [Olale and Henson \(2012\)](#) reveal this positive relationship between education and the exit from the fishery empirically in Kenya. The current study examines the relationship between the productivity of a common pool resource, education and the reallocation of labor from the resource-dependent to the resource-independent sector. It uses time series and cross-sectional data from Chilika Lagoon, a large Indian inland fishery under restricted open access ([Sekhar, 2004](#)). The fishery currently comprises 32,500 active fishermen that annually landed between 10,000 and 20,000 tonnes of fish and shellfish in the period from 2000 to 2010. Real incomes of the fishermen at Chilika Lagoon have constantly declined during the eighties and reached very low levels during the nineties. They increased suddenly in 2001 after a large-scale hydrological manipulation of the lagoon ([Mohanty et al., 2009](#); [Mohapatra et al., 2007](#)) and remained at high levels thereafter. In the present study, I use this sudden and spatially heterogeneous productivity shock in a differences-in-differences framework to show that investment in education increased with the resource productivity. Further, I show that the probability of traditional fishermen working in resource-independent occupations increases with their education levels. This reallocation of labor from resource-dependent to resource-independent production can be explained by the high returns to education in the resource-independent sector, which I found in the fishing communities around Chilika Lagoon.

The article is structured as follows. Section 3.2 provides a detailed background of the Chilika fishery, Section 3.3 describes the data sources and Section 3.4 contains the summary statistics. The relationship between the resource shock and



FIGURE 3.1: Map of Chilika Lagoon.



Prepared by Petra Sinuraya, modified from CDA.

education is described in Section 3.5 and Section 3.6 gives suggestive evidence on the relationship of education and occupational choices. Section 4.5 concludes.

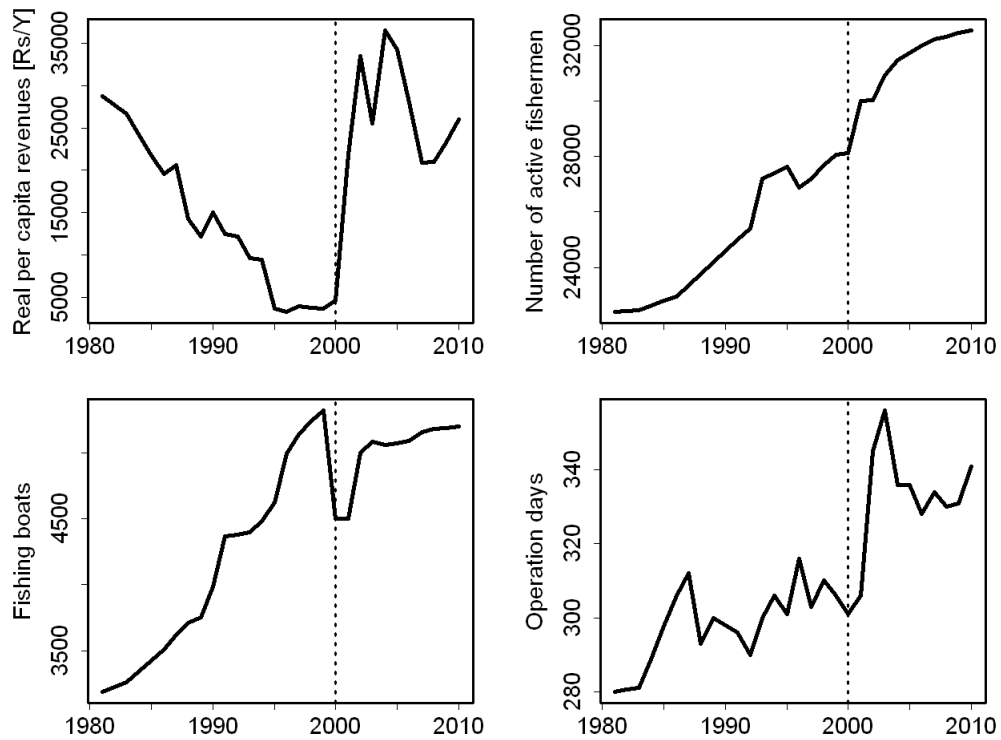
### 3.2 Chilika Lagoon and the Resource Shock

The study uses data from fishing communities of Chilika Lagoon in Orissa, India. The Chilika fishery currently has 32,500 active fishermen that harvested between 10,000 to 20,000 tonnes of fish and shellfish annually in the period from 2000 to 2010. Chilika Lagoon is a brackish estuary with large temporal salinity fluctuations governed by freshwater inflow through the rivers and saltwater intrusion from the sea. The productivity of the ecosystem depends largely on the hydrology such that the fish landings vary with the salinity levels (Mohanty et al., 2009; Mohapatra et al., 2007). The ecological conditions differ across regions of the lagoon which is divided into four ecological sectors (Figure 3.1). Monitoring by the Chilika Development Authority (CDA) is based on these ecological sectors but the sectors do not coincide with other administrative units. The northern sector (NS) is located in the Puri and Khurda district and is the

least saline since the Mahanadi distributaries discharges freshwater into the lagoon from the North. The central sector (CS) stretches from the Khurda to Puri district and the southern sector (SS) is situated in the Khordha, Puri and Ganjam district. Both sectors have intermediate salinity. The outer channel (OC) in the Puri district connects the lagoon with the sea and is the most saline sector. A smaller channel connects the SS to the sea, as well. The length of the outer channel increased in the decades before 2000 when the strong current in the Bay of Bengal shifted the sea mouth of the channel to the North-East. The amount of saltwater which entered the lagoon during high tide declined in this period and consequently the salinity levels of the lagoon decreased. Further, 75 % of the harvested fish species are migratory and had to pass through the long channel, which was blocked by nets and sediments (Ghosh et al., 2006; Mohapatra et al., 2007). The per capita fish catches declined continuously before the year 2000 and simultaneously the fishing revenues. Figure 3.2 shows the dynamics of real per capita income, the number of active fishermen, the number of fishing boats and number of fishermen operating days at Chilika Lagoon. The dotted line demarcates the year of the excavation of the new sea mouth. Fishermen regarded the declining salinity levels as an unsolved problem in 1999 (Samal and Meher, 2003). Therefore, I assume in the following that the increase in landings was unforeseen by the fishermen. In September 2000, a new sea mouth was excavated by the CDA that reduced the length of the connecting channel by 18 km. This hydrological intervention increased the salinity level of the lagoon and opened a new migration route for fish. Salinity levels increased immediately followed by a steep increase in aggregate landings and revenues within the next years (Figure 3.2).

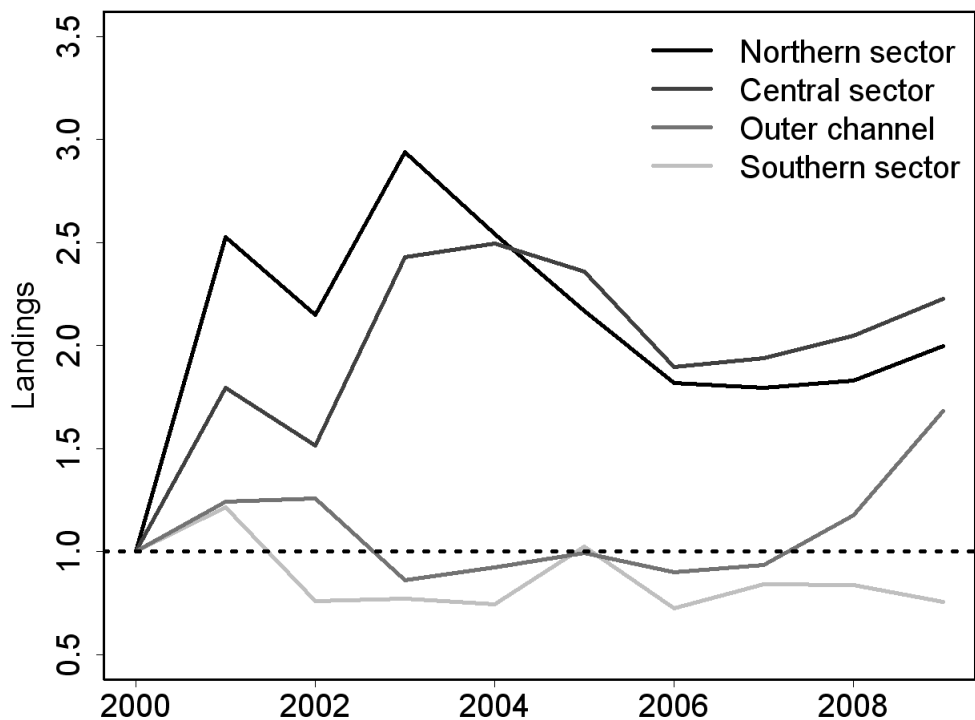
However, the increase of landings differed largely between the sectors (Figure 3.3). Fishermen benefitted least in the SS and OC from the hydrological intervention where the ecological changes were less pronounced. Moreover, fishermen in the SS and OC that used to harvest large quantities of migrating fishes in the channels were cut off from this opportunity by the hydrological intervention. Aggregate revenues for Chilika Lagoon increased even stronger than

FIGURE 3.2: Effort and Revenue Dynamics at Chilika Lagoon.



The data stem from the CDA.

FIGURE 3.3: Sector-Wise Harvest Dynamics at Chilika Lagoon.



The landings are normalized to the year 2000. The data are from 12 landing centers for which data are available for the whole period. The data stem from the CDA.

landings since valuable species such as large prawns (*Penaeus monodon*, *Penaeus indicus*, *Macrobrachium* spp.) increased disproportionately after the hydrological intervention. Also, the average number of operating days increased after the hydrological intervention which may reflect an increase of individual effort.<sup>3</sup> The number of boats declined due to the Orissa cyclone (Cyclone 05B) in 1999 and never recovered completely afterwards. The strong increase in boat numbers in 2001 was due to a compensation scheme. Although most fishing units use boats, they are still relatively immobile since motorization is low and remained relative constant during the period from 1996 to 2007 ranging between 30 to 40 % of the total fleet (Mohapatra et al., 2007; Pattnaik and Kobayashi, 2009). Bhatta et al. (2009) equipped fishermen boats with GPS data loggers over the year 2008 and showed that fishermen fish mainly in proximity to their village. I will therefore assume henceforward that the harvest of fishermen depend on the local ecological conditions.

The surveyed fishermen belong almost exclusively to traditional fishing sub-castes such as Keuta, Kandara, Kartia, Khatia, Tiara and Nolia or traditional fishermen that immigrated from Bangladesh. The only income source of these traditional fishermen used to be fishing and each sub-caste used specific fishing methods. This system was in place until the sixties (Jhingran and Natajaran, 1969) but weakened in the following decades (Samal and Meher, 2003). I will assume in the following, that the default occupation of the respondents is fishing.

I conclude this section by giving a brief overview of the educational structure in Orissa. Students in Orissa attend primary school from the age of five to the age of 13 and secondary school from the age of 14 to 15. Primary and secondary schools are free of charge and compulsory but costs of schooling increase still with education level (World Bank, 2009) and many children exit the educational system early (Government of Orissa, 2012). Secondary school is followed by two years of senior secondary school and several years of tertiary education

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<sup>3</sup>The fluctuations of operation days are due to varying weather conditions that occasionally keep fishermen from work.

(see e.g. [Bandyopadhyay \(2008\)](#)). Tertiary education comprises colleges and other institutions of higher education. I will use this educational structure to determine the impact of the increase in landings on education in Section 3.5 and to derive the potential experience used in Section 3.6.

### 3.3 Data

This study is based on a field survey of 599 traditional fishermen households ([Noack and Riekhof, 2011](#)) and on data recorded by the CDA (their methodology is described in [Chilika Development Authority \(2005\)](#); [Mohanty et al. \(2009\)](#); [Mohapatra et al. \(2007\)](#)). The survey took place from February to April 2011. 502 traditional fishermen households with 2,923 individuals were interviewed in a general survey according to stratified random sampling. In addition, 97 traditional fishermen households with non-fishing income sources comprising 701 individuals were interviewed. The fishermen population was stratified geographically into four ecological sectors (NS, CS, SS, OC) and the population of each sector was stratified again according to the size of the settlements based on the data of [Pattnaik and Kobayashi \(2009\)](#). Settlements with less than 100 households were classified as small and settlements above this number as large. The sample size was proportional to the number of households in each stratum.

Sampling was done in two stages. In the first stage fishermen settlements were randomly selected. The probability of a settlement to be selected was proportional to its size. Once the settlement was chosen, we started at a random point and surveyed every  $x^{th}$  household where 'x' is the number of households per settlement divided by the target number of interviews per settlement. Therefore, each household of the fishermen population had the same probability of being selected. The additional households with alternative income sources were chosen with the help of the community leaders.

The household head or representative was interviewed but further household members were encouraged to help answer the questions. The questions concern household members who currently live in the household and individuals that left the household within the last twenty years. However, there is no information about complete households that left the fishing communities. Discussions with the community leaders revealed that the migration of complete households is almost absent although commuting and seasonal migration of household members increased in recent times. I assume, therefore, in the following, that I have the relevant information on all individuals that lived in the area during the last 20 years.

### **3.4 Summary Statistics**

In this section I report the educational situation and the occupations of the surveyed households. Education levels are low and dropout rates are high in the fishing communities around Chilika Lagoon (Table 3.1). About one fifth of the population has no formal education, whereas 58 % of the population completed primary school and 23 % attended but never completed primary school. Women generally have lower education levels than men and this gap increases with the education level. Only 10 % of the men and 4 % of the women have completed tertiary education (Table 3.1). [Noack and Riekhof \(2011\)](#) also asked for the reason why individuals did not attain higher education levels and 65 % of the respondents stated that they could not afford it. Only 12 % of the respondents stated that the family was not interested and 10 % stated that the student was not interested in attaining higher levels of education. Although 86 % of the fishermen households have outstanding loans, less than 3 % of these credits are used for educational purpose ([Noack and Riekhof, 2011](#)). Credits are mainly provided by informal money lenders and fish traders (50 % of the credits) and are tied to fishing activities. Microfinance institutions have increased their market share in recent times and provide 25 % of the credits but the money is conditional to productive investments with short-term returns (also mainly

TABLE 3.1: Education.

|  | NS | CS | SS | OC | total |
|--|----|----|----|----|-------|
| <b>Primary education (age &gt; 13)</b>           |    |    |    |    |       |
| Completion [%]                                   | 56 | 59 | 60 | 53 | 58    |
| Dropout [%]                                      | 27 | 23 | 21 | 22 | 23    |
| Completion men [%]                               | 61 | 60 | 66 | 61 | 62    |
| Completion women [%]                             | 49 | 57 | 51 | 40 | 50    |
| <b>Secondary education (age &gt; 15)</b>         |    |    |    |    |       |
| Completion [%]                                   | 35 | 38 | 41 | 36 | 42    |
| Dropouts [%]                                     | 13 | 14 | 13 | 12 | 13    |
| Completion men [%]                               | 41 | 40 | 49 | 41 | 43    |
| Completion women [%]                             | 26 | 35 | 30 | 28 | 30    |
| <b>Senior secondary education (age &gt; 17 )</b> |    |    |    |    |       |
| Completion men [%]                               | 24 | 25 | 34 | 26 | 27    |
| Completion women [%]                             | 15 | 22 | 20 | 16 | 18    |
| <b>Tertiary education (age &gt; 24 )</b>         |    |    |    |    |       |
| Completion men [%]                               | 11 | 11 | 10 | 8  | 10    |
| Completion women [%]                             | 3  | 5  | 5  | 2  | 4     |

Notes: All calculations are based on the general survey with 2,923 individuals.

fishing activities). The possibility to finance education by borrowing is therefore limited and the households rely mainly on current incomes to cover the costs of education. I will describe the impact of incomes on educational achievements in Section 3.5 using a differences-in-differences approach. Most men earn positive incomes but only 5 % of the women participate in the labor force (Table 3.2). The vast majority of men work in the fishery while most women with positive incomes have non-fishing occupations. Average incomes in the non-fishing sectors are higher than incomes in the fishing sector. However, incomes include the cost of capital depreciation such that incomes from self-employment are probably biased upwards. Income levels across sectors with different shares of self-employment are therefore difficult to compare. I will review the impact of education on occupational choices and earnings in Section 3.6.

TABLE 3.2: Occupations and Income.

|                               | NS  | CS  | SS  | OC  | total |
|-------------------------------|-----|-----|-----|-----|-------|
| <b>Occupation men</b>         |     |     |     |     |       |
| Labor force participation [%] | 92  | 98  | 95  | 94  | 95    |
| Fishing [%]                   | 86  | 95  | 85  | 86  | 88    |
| Non-fishing [%]               | 6   | 3   | 10  | 8   | 7     |
| <b>Occupation women</b>       |     |     |     |     |       |
| Labor force participation [%] | 3   | 6   | 8   | 1   | 5     |
| Fishing [%]                   | 1   | 0   | 1   | 0   | 1     |
| Non-fishing [%]               | 2   | 6   | 7   | 1   | 4     |
| <b>Income men</b>             |     |     |     |     |       |
| Total [Rs/day]                | 97  | 123 | 98  | 102 | 104   |
| Fishing [Rs/day]              | 95  | 115 | 91  | 92  | 96    |
| Non-fishing [Rs/day]          | 125 | 263 | 157 | 211 | 167   |
| Working days [days/year]      | 202 | 245 | 290 | 241 | 244   |
| <b>Income women</b>           |     |     |     |     |       |
| Total [Rs/day]                | 118 | 84  | 88  | 70  | 92    |
| Fishing [Rs/day]              | 113 | -   | 50  | -   | 92    |
| Non-fishing [Rs/day]          | 139 | 87  | 93  | 70  | 93    |
| Working days [days/year]      | 173 | 231 | 246 | 360 | 237   |

All calculations are based on the general survey.

Only the most important income sources of individuals of age between 25 and 65 years are included.

Individuals with incomes between 0 and 20 Rs per day are excluded from the sample to include only full-time workers.

### 3.5 Resources and Education

In this section, I will explain the impact of the hydrological intervention and the subsequent resource productivity increase on educational achievements. Few individuals attained senior secondary and tertiary education and the impact of the resource productivity increase on senior secondary and tertiary education cannot be measured with precision. I will concentrate henceforward on primary and secondary education.



### 3.5.1 Identification Strategy

To identify the impact of the resource productivity increase on education I use a difference-in-difference approach to exploit the spatial heterogeneity of the increase in landings. The impact of the resource shock on the educational outcomes  $y_{ijk}$  of individual  $i$  in sector  $j$  and age group  $a$  was estimated by

$$y_{ija} = \alpha_1 \text{shock}_j \times \text{post}_a + \alpha_2 \text{post}_a + \alpha'_3 \text{Sector}_j + \alpha'_4 X_{ija} + \varepsilon_{ija}, \quad (3.1)$$

where *shock* measures the average sector-wise increase of fish harvest relative to the baseline year of 2000, *post* indicates whether an individual was educated in the period that followed the resource productivity increase, *Sector* is a vector of regional dummies and  $X_{ijt}$  is a vector of individual controls that include age, sex and sub-caste dummies. The parameter of interest,  $\alpha_1$ , measures the impact of resource productivity increase on education. The other variables control for general time trends in education, regional differences and individual characteristics. The SS is used as reference sector since it was least affected by the hydrological intervention and has intermediate socioeconomic characteristics (Figure 3.3 and Table 3.1 and 3.6).

To measure the exposure of individuals to the resource shock I use the average increase of sector-wise landings compared to the baseline year of 2000. The boundaries of the ecological sectors do not coincide with administrative boundaries such that the effect of increasing landings is not confounded with regional education policies. I use the average increase of landings instead of annual changes since educational achievements are more responsive to average income levels than to current income levels (Dahl and Lochner, 2012). The single reference year that is used to measure the increase in landings is because no earlier regional catch data are available. However, this may not change the results qualitatively since the landings were relatively constant in the pre-intervention period and did not increase until 2001 (see Figure 3.2). The productivity increase was caused by the hydrological intervention although the subsequent

adjustment of fishing effort may also affect the aggregate fish landings (see Figure 3.2). However, the trend is not reversed by this bias since the average per capita fishing income was highest in the OC and SS in 1999 (Samal and Meher, 1999) and became highest in the NS and CS after the hydrological intervention (see Table 3.6).

The educational achievements are measured in primary and secondary school enrollment and completion. Dropout rates are very high in the fishing communities around Chilika Lagoon (see Table 3.1) such that school completion is the outcome of successive decisions to stay in school or to discontinue education. In a first approach, I therefore test whether school completion of individuals that were of school age or younger at the time of the resource productivity increase was affected. In a second approach, I test whether the share of children that ever went to school changed through the resource productivity increase. In this approach I compare the probability of individuals being enrolled at least once between cohorts that entered school age after the resource shock to cohorts that entered school age before the resource shock.

To define the group of individuals that were affected in their educational choices by the resource shock and the group of individuals that were not affected in their educational choices by the resource shock I use two successive age interval of 10 years. Individuals in the first age interval made their educational choices before the resource productivity shock and individuals in the second interval made their educational choices after the resource productivity shock. Ten years is the maximum interval such that all individuals in one group were exposed to a similar resource productivity and could have been enrolled in or completed the respective education level by the time of the survey. These considerations lead to the groups defined in Table 3.3.

Similar to Cutler et al. (2010) and Grimm (2011), I use OLS for an easy interpretation of the interaction terms.<sup>4</sup> Further, I cluster the standard errors at the

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<sup>4</sup>See Ai and Norton (2003) and Puhani (2012) for the interpretation of interaction terms in nonlinear models and Angrist and Pischke (2008) for a discussion of using OLS with binary data.

TABLE 3.3: Affected and Unaffected Groups.

|                                | Primary School (PS) |            | Secondary School (SS) |            |
|--------------------------------|---------------------|------------|-----------------------|------------|
|                                | Enrollment          | Completion | Enrollment            | Completion |
| affected group [age in 2001]   | <6                  | 4-13       | 4-13                  | 6-15       |
| unaffected group [age in 2001] | 6-15                | 14-23      | 14-24                 | 16-25      |

household level to account for correlated educational decisions among siblings.

### 3.5.2 Results

In the following I present the OLS estimates of the impact of the resource productivity increase on education. The results for (3.1) are given in Table 3.4.

TABLE 3.4: Resource Productivity and Education.

|                         | Primary           |                     | Secondary           |                   | Senior Secondary  | College           |
|-------------------------|-------------------|---------------------|---------------------|-------------------|-------------------|-------------------|
|                         | Enrollment        | Completion          | Enrollment          | Completion        | Completion        | Completion        |
| $shock_j \times post_a$ | -0.030<br>(0.023) | 0.121<br>(0.045)*** | 0.131<br>(0.047)*** | 0.096<br>(0.052)* | -0.030<br>(0.049) | -0.016<br>(0.028) |
| Observations            | 1138              | 1021                | 976                 | 986               | 907               | 683               |

Notes: Standard errors are clustered at the household level.

All regressions include sector fixed effects and treatment fixed effects and control for age, age squared, gender and sub caste at the individual level.

\*\*\* Significant at the 1 % level,

\*\* Significant at the 5 % level,

\* Significant at the 10 % level.

A doubling of the fish landings increased the probability to complete primary school by 12 %, to enroll for secondary school by 13 % and to complete secondary school by 10 %. These results establish a strong and positive relationship between resource productivity and education. However, the resource shock had no significant impact on the probability to enroll in primary school which is not surprising as the enrollment was close to 100% by the time of the shock. Further it had no impact on the share of individuals with completed primary education to enroll in or complete secondary school. These results suggest that the resource shock affected primary school dropout rates but not the probability to continue education after primary school. However, the total number of individuals that attended secondary school increased significantly after the

resource increase. An explanation for why the resource productivity increase had the largest impact on primary school dropout rates is that older children became more productive in the fishery after the resource productivity shock such that the opportunity costs of schooling increased more than proportionally with the age of children. This may also explain why there are no significant results for senior secondary and tertiary education.

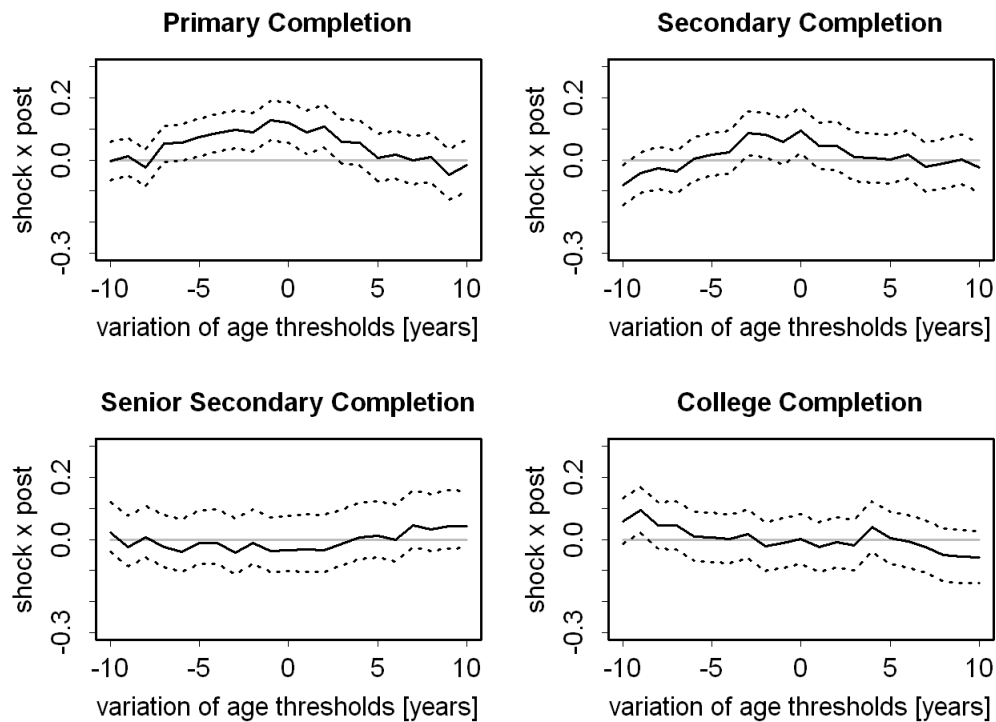
### 3.5.3 Robustness

In this section I show how a variation of the age thresholds that define the treatment and control groups affect the parameter estimates of (3.1). Age heaping as in Cutler et al. (2010) of ages that end with 0, 2, 5 and 8 occurs also in this survey and general time trends in education that correlate spatially with the resource productivity increase could possibly confound the results. In the following, I show how the estimated effect of resource productivity on education changes in response to varying age thresholds. The results are robust if the point estimates converge smoothly to zero as the age thresholds, that define the treatment and control groups diverge from the values which are given in Table 3.3.

Figure 3.4 depicts the point estimate and the confidence interval of the interaction term in dependence of the age thresholds. The solid lines show the parameter estimate of the interaction term ( $shock_j \times post_a$ ) with respect to a shift of the age thresholds that define the treatment and control groups. The dotted line is the confidence interval at the 95 % level. The fluctuations in the estimates as the age thresholds vary are probably due to age heaping but have no impact on the qualitative results. Figure 3.4 shows that the results are robust with respect to the age thresholds.

The increase in aggregate education could also be the consequence of the cyclone in 1999 and the resulting surplus labor. The damage of the cyclone was, however, spatially uncorrelated with the increase in fish landings such that the

FIGURE 3.4: Robustness.



effect of the cyclone is captured by the cohort dummy and not by the interaction term.

Another possible explanation for the resource shock is that the cyclone destroyed a large number of boats which led to a strong reduction of fishing effort. Reducing fishing effort may increase landings if the fish stock was heavily overfished previously (Clark, 2005). Since the cyclone was also exogenous, the cause of the productivity shock does not matter for the results.

### 3.6 Education and Occupational Choice

In this section, I test the impact of education on occupational choices and income in the fishery and the non-fishery sector to explain the impact of the resource productivity shock on labor reallocation. The surveyed households belong to traditional fishermen sub-castes such that a fishermen with a non-fishing (and also non-agricultural) occupation indicates a labor reallocation from

resource-dependent to the resource-independent production. I follow the approach of Taylor and Yunez-Naude (2000) and use a two stage Heckit procedure (Wooldridge, 2001) to determine the impact of education on activity choice and income. The probability of individual  $i$  in household  $j$  and sector  $k$  to engage in activity  $l$  is estimated by

$$P(y_{ijkl} > 0) = \Phi(\beta_1 Education_{ijk} + \beta_2' X_{ij} + \beta_3' Z_{jk} + \beta_4' Sector_k + \hat{\varepsilon}_{ijkl}), \quad (3.2)$$

where  $y_{ijkl}$  is the daily revenues from activity  $l$ ,  $\Phi$  is the probit function,  $Education_{ijk}$  is a vector of dummies that indicate the education levels that the individual completed (primary dropout, primary completion, secondary dropout, secondary completion, senior secondary completion, tertiary completion) and  $X_{ij}$  is a vector of individual controls including potential experience, potential experience squared, gender and dummies that indicate the individuals' kinship to the household head (household head, his wife, son 1, son 2, son 3, daughter, daughter-in-law, father, mother, brother, sister). The parameter of interest is  $\beta_1$  which indicates the effect of education on the probability to participate in activity  $l$ . The education levels are additive which implies that an individual has completed all education levels below the one which was indicated in the questionnaire. The potential experience is the number of years an individual could have worked, assuming that the individual reached the education level in the scheduled time (see Section 3.2) and started immediately working thereafter (Card, 1999). I use the kinship to the household head to correct for selection bias assuming that it affects the occupational choice more than the income. The vector  $Z_{jk}$ , indicates whether the household owns a fishing boat, a boat engine and the size of land that the household owns. Further, I control for sector fixed effects denoted by  $Sector_k$ . The errors are clustered again at the household level and the error term is denoted by  $\hat{\varepsilon}_{ijka}$ . I use (3.2) firstly to estimate the probability of individuals to earn an income that exceeds 20 Rupees (Rs)<sup>5</sup> per day, and secondly to estimate the probability of individuals to participate either in fishing or non-fishing activities conditional on labor force participation. The threshold of 20 Rs excludes

<sup>5</sup>All values are given in 2011 Rupees.

part-time workers but the exact level ( $\pm 20$  Rs) has no impact on the qualitative result. The results are shown in Table 3.5.

TABLE 3.5: Education and Activity Choice.

|                             | Labor Force Participation | Non-Fishing         |
|-----------------------------|---------------------------|---------------------|
| Primary dropout             | 0.062<br>(0.215)          | 0.342<br>(0.284)    |
| Primary completion          | 0.138<br>(0.339)          | -0.386<br>(0.625)   |
| Secondary dropout           | -0.079<br>(0.345)         | 0.612<br>(0.613)    |
| Secondary completion        | -0.087<br>(0.336)         | 1.005<br>(0.601)*   |
| Senior secondary completion | -0.072<br>(0.217)         | 0.602<br>(0.286)*** |
| Tertiary completion         | -0.060<br>(0.273)         | 1.017<br>(0.288)*** |
| n                           | 1053                      | 563                 |

Notes: Individuals between 25 and 65 years with either no income or income that equals or exceed 20 Rs per day are included in the regression.

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

All regressions include sector fixed effects, individual controls (potential experience, potential experience squared, gender) and household controls (fishing boat, boat engine, land size)(not displayed).

All regressions include dummies that indicate the kinship of the individual to the household head (himself, wife, son 1, son 2, son 3, daughter, daughter-in-law, father, mother, brother, sister)(not displayed).

\*\*\* Significant at the 1 % level,

\*\* Significant at the 5 % level,

\* Significant at the 10 % level.

From the 1053 individuals in the age range with complete data, 563 had a positive income. Education had no significant effect on labor force participation in general. Among the men, household heads and sons are more likely to participate in income generating activities and among the women, the wives of the household heads and their daughters are less likely to participate in income generating activities than average individuals (not displayed in Table 3.5). Individuals with higher education levels are more likely to engage in non-fishing activities than in fishing activities. The average of the sample marginal effects

on the probability to participate in non-fishing activities are -0.08 for completed primary education, 0.15 for completed secondary education, 0.12 for completed senior secondary education and 0.13 for completed tertiary education.<sup>6</sup> Adding these effects yields the marginal effect of an education level on the probability to work outside the fishery.

In a second step, I test whether the returns to education are higher in non-fishing occupations than in the fishery. Higher returns to education in the non-fishing sector can explain why the probability to work in non-fishing occupations increases with the education level. To test the impact of education on income I regress log daily incomes in fishing and non-fishing occupations on education and individual, household and regional controls using

$$\log(y_{ijkl}) = \gamma_1 Education_{ijk} + \gamma_2' \bar{X}_{ijk} + \gamma_3' Z_{jk} + \gamma_4' Sector_k + \gamma_5 imr_{ijkl} + \bar{\epsilon}_{ijkl}. \quad (3.3)$$

The vector  $\bar{X}_{ijk}$  contains potential experience, potential experience squared and gender. The term  $imr$  is the inverse Mills ratio from (3.2) and  $\bar{\epsilon}_{ijkl}$  is the error term. The other variables are as described for (3.2). The parameter of interest is  $\gamma_1$  and measures the impact of an additional education level on income. I run this regression for all occupations and fishermen and non-fishermen incomes separately. Incomes include the costs of capital depreciation and are therefore biased towards incomes from self-owned businesses with high investment costs such as fishing (see Section 3.4). However, the returns to education are probably unaffected from this bias. The results of (3.3) are summarized in Table 3.6.

There are positive returns to primary, senior secondary and college education as shown in the first column of Table 3.6. Primary school completion increases incomes by approximately 30% (0.101+0.179), secondary education yields no financial returns but senior secondary school completion and college completion increase incomes by 40% or 65% respectively. However, the effects are mainly

<sup>6</sup>The OLS estimates are -0.03, 0.09, 0.19, and 0.28 respectively.



TABLE 3.6: Education and Income.

|                                    | Total<br>income        | Fishing<br>income     | Non-fishing<br>income |
|------------------------------------|------------------------|-----------------------|-----------------------|
| Constant                           | 2.334<br>(0.508)***    | 3.909<br>(0.539)***   | 2.987<br>(0.477)***   |
| Primary school dropout             | 0.101<br>(0.061)*      | 0.017<br>(0.056)      | 0.346<br>(0.270)      |
| Primary school completion          | 0.179<br>(0.104)*      | 0.058<br>(0.075)      | 1.361<br>(0.433)***   |
| Secondary school dropout           | -0.181<br>(0.119)      | -0.087<br>(0.086)     | -0.871<br>(0.326)***  |
| Secondary school completion        | -0.066<br>(0.122)      | -0.069<br>(0.084)     | -0.688<br>(0.273)**   |
| Senior secondary school completion | 0.359<br>(0.127)***    | -0.088<br>(0.085)     | 0.779<br>(0.223)***   |
| Tertiary education                 | 0.260<br>(0.167)       | -0.035<br>(0.137)     | -0.192<br>(0.250)     |
| Potential experience               | 0.047<br>(0.012)***    | 0.018<br>(0.010)*     | 0.080<br>(0.025)**    |
| Potential experience squared       | -0.0008<br>(0.0002)*** | -0.0004<br>(0.0001)** | -0.0011<br>(0.0004)** |
| imr                                | 0.775<br>(0.218)***    | 0.178<br>(0.133)      | -0.230<br>0.142       |
| n                                  | 522                    | 406                   | 109                   |

Notes: Individuals between the age of 25 and 65 years with either no income or incomes that equals or exceed 20 Rs per day are included in the regression.

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

All regressions include sector fixed effects, individual controls (potential experience, potential experience squared, gender) and household controls (fishing boat, boat engine, land size)(not displayed).

\*\*\* Significant at the 1 % level,

\*\* Significant at the 5 % level,

\* Significant at the 10 % level.

driven by the higher base income in the fishery sector, the high returns to education in the non-fishery sector and the self selection of individuals with higher education into the non-fishery sector. Individuals with completed secondary education are more likely to work outside the fishery where their incomes are

70 % higher than the incomes of individuals without formal education.<sup>7</sup> These results show that increasing education levels can induce a labor reallocation to resource-independent production. This labor reallocation can be explained by differences in the returns to education between both sectors.<sup>8</sup>

### 3.7 Conclusions and Discussion

This study explores the link between education and natural resources, using data from an Indian inland fishery. Rising resource productivity increases investment in education and more educated individuals are more likely to work in the resource-independent sector where they earn higher incomes. These results suggest that low incomes in the resource-dependent sector cause low levels of investment in education, which impedes the transition from a resource-dependent to a resource-independent economy. There are several possible explanations for this poverty trap, such as fixed costs of education (Chapter 2), the failure of parents to internalize the full benefits of education, or high discount rates that reduce the present value of future returns to education (Baland and Robinson, 2000). Further research is needed, however, to explain the link between parental incomes and the educational achievements of their children in poor, rural economies.

### 3.8 Acknowledgements

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<sup>7</sup>Since the education levels are additive:  $1.361 - 0.688 = 0.673$ .

<sup>8</sup>These results are qualitatively similar if the distinction is made between generally resource-dependent occupations (including fishing, farming and harvesting of other plants and animals) and resource-independent occupations, since the respondents belong almost exclusively to traditional fishing sub-castes.

Acharya, D.P. Dash, Manoranjan Dash, S.K. Mohanty, Ajit Kumar Pattnaik, Tapas Paul, Jack Ruitenbeek and our interviewers for the support during the fieldwork. Last but not least I would like to thank Petra Sinuraya for producing the map of Figure 3.1.

## Chapter 4

# When will Higher Interest Payments Lead to More Education?

with Marie-Catherine Riekhof

**Abstract:** Based on observations from field studies in fishing communities in India, we include a fragmented credit market into a two-sector, two-period model with common pool externalities to establish conditions under which credit market distortions either increase or decrease education. We show that higher interest payments increase education if their negative effect on capital investment and therefore labor productivity in low-skilled production outweighs their positive effect on subjective discounting and therefore the present value of high-skilled production. Positive common pool externalities from reduced capital investment in low-skilled production can counterbalance the impact of capital changes on low-skilled labor productivity and therefore on education. The overall outcome depends on the affected interest factor, the household's initial wealth and the common pool externality.

## 4.1 Introduction

One of the most pressing global challenges is poverty reduction. In addressing this challenge, a focus on human capital formation is one of the most promising approaches (Lucas, 1988; Galor, 2011a; Hanushek and Woessmann, 2008; Becker et al., 2011). Although there are substantial returns to education, ranging from 7 to 20 % increase in income per year of schooling (Psacharopoulos and Patrinos, 2004; Duflo, 2001; Banerjee and Duflo, 2005), education levels are still low in most developing countries and cause 20 % of the cross-country differences in output per worker (Schoellman, 2012). Many children and adolescents contribute to the household's income instead of going to school, partly because credit markets for the poor are informal, fragmented and cannot facilitate optimal investment allocation (Banerjee and Duflo, 2005). Households may invest too little in education if the direct and opportunity costs of education are high and credit markets are absent (Baland and Robinson, 2000; Ranjan, 1999, 2001) but improved credit markets do not necessarily lead to more education. Empirical evidence is mixed. While Dehejia and Gatti (2005) and Beegle et al. (2006) suggest that improving credit markets increases investment in education and reduces child labor, Islam and Choe (2013) and Maldonado and González-Vega (2008) show that increasing access to credits increases child labor and reduces investment in education. Banerjee et al. (2010) find no effect of microcredit on education, while Holvoet (2004) finds positive effects of microfinance on education but only if the loans are received through a women's group.

Fragmented credit markets and poorly defined property rights often co-exist in developing economies (Banerjee and Duflo, 2005) and many of the globally poor depend on common pool resources such as rangelands, forests and fish stocks for their incomes (Millennium Ecosystem Assessment, 2005; Dasgupta, 2010). The occupational choices of the individuals are therefore often interdependent via common pool externalities. Growing resource-dependent production may induce resource degradation and impose a negative externality on the resource users. Labor reallocation from the resource-dependent to the

resource-independent sector may increase the resource abundance and thus the productivity of the resource-dependent sector.

We argue in this paper that the effect of credit market improvements on education depends a) on the affected interest factor, b) on the initial wealth of the household and c) on the presence of common pool externalities. Based on observations from our field study on fishing communities around Chilika lagoon, India, we include a fragmented credit market into a two sector, two period model with common pool externalities to establish conditions under which credit market improvements either increase or decrease education.

Informal credit markets around Chilika lagoon consist of three main segments. Money lenders offer loans not tied to a special purpose at high interest rates. Fish traders, and to a lesser extent microfinance organizations and cooperatives, offer lower priced loans for tangible business investments, where the productive investments serve as collateral. Since human capital cannot be seized in case of default, higher future income due to education does not count as collateral. The third segment comprises saving, but it is poorly developed. Credit markets around Chilika lagoon are not exceptional. Credit markets in developing countries are often distorted and interest rates differ depending on the purpose of the loan and the lender ([Bardhan and Udry, 1999](#), , Chapter 7). Credit markets are also often interlinked with other markets ([Hoff and Stiglitz, 1990](#); [Ghosh et al., 2000](#)) especially when debtor and creditor are interdependent in trade and production ([Basu, 1997](#)). Our model includes a low interest rate for saving, an intermediate interest rate for borrowing secured by a seizable collateral in form of a business investment and a high interest rate for unsecured borrowing to capture the fragmented credit markets.

Our model is close to the model of [Lochner and Monge-Naranjo \(2011\)](#) who include two different loan types in their model, but allow a higher future income due to education as collateral. [Jafarey and Lahiri \(2002\)](#) also study the impact of credit market distortions on child labor but their focus is on the effectiveness

of trade sanctions to reduce child labor. Further, our approach resembles [Dumas \(2013\)](#), who analyzes the effects of market imperfections on child labor but in contrast to our study focuses on labor market imperfection and adapts an empirical approach to determine the sign of the unclear effects. Also, [Bhalotra and Heady \(2003\)](#) find that land holdings increase child labor but as far as we know only [Bluffstone \(2008\)](#) discusses child labor and common pool resources. He finds that improved common property forest management increases child labor.

Our results show that the activity of the representative household on the credit market depends on its initial wealth. The household saves for very high levels of initial wealth and becomes inactive on the financial market if its initial wealth falls below a certain level. The household borrows money for the low interest factor to invest in low-skilled production if the initial wealth reduces further. The household borrows money for investment and consumption using secured and unsecured credits if it is endowed with comparably very low levels of initial wealth. The main results are that changes in the interest factors have different effects on the household's time allocation depending on its wealth level, the interest factor and the common pool externality. A very poor household increases education if the unsecured interest factor decreases but reduces education if the secured interest factor decreases. The latter result becomes ambiguous in the presence of common pool externalities. The effect of a decreasing secured interest factor on time allocation is ambiguous if the household uses only loans secured by a collateral. The same holds true for changes in the interest factor for saving for rich households that save. Results now depend on the partial output elasticities, the elasticity of substitution between capital and labor in the low-skilled sector, the intertemporal elasticity of substitution as well as the interest factor.

The remainder of the paper is organized as follows. Section [4.2](#) introduces the model framework and Section [4.3](#) presents the results without common pool resources. Section [4.4](#) introduces a common pool resource and presents the new results. Section [4.5](#) concludes.

## 4.2 The Model

We consider a two-period model of an economy with distorted credit markets and a high-skilled as well as a low-skilled sector. A representative household inelastically supplies one unit of labor each period. The household allocates labor between low-skilled production and education in the first period and between low- and high-skilled production in the second period. We assume that education is a prerequisite for working in the high-skilled sector. The share of labor allocated to education in the first period equals therefore the share of time allocated to high-skilled production in the second period and the time share allocated to low-skilled production is also the same in both periods. In the following, we describe production, markets and the household in more detail.

### 4.2.1 Production

Production in the low-skilled sector uses physical capital  $k$  and labor  $l$ . The low-skilled sector produces output  $h(l, k)$  using a strictly increasing and strictly concave technology that satisfies the Inada conditions. Production in the high-skilled sector uses educated labor  $b$  as input with the production technology  $w(b)$  and  $b = 1 - l$ . The production technology  $w$  is also strictly increasing and strictly concave and satisfies the Inada conditions.

### 4.2.2 Markets

Demand for output is perfectly elastic at constant prices. Labor markets are nonexistent for low-skilled labor, while credit markets are present but distorted. The household chooses the amount  $s \geq 0$  it saves at a fixed interest factor  $\phi$ , the amount it borrows  $v \geq 0$  constrained by the collateral  $k$  according to

$$v \leq k \tag{4.1}$$



at the fixed interest factor  $\tau$ , and the amount  $z \geq 0$  it borrows at the fixed interest factor  $\iota$ , with

$$1 < \phi < \tau < \iota < \infty. \quad (4.2)$$

The investment in physical capital constrains the loan size  $v$  at the intermediate interest factor  $\tau$ . The unsecured loan  $z$  reflects the possibility for a second, unconstrained, but higher-priced loan. In other words, credit supply is perfectly elastic at the interest factor  $\tau$  as long as the capital investment serves as collateral. For a loan that exceeds the capital investment, credit supply is perfectly elastic at the higher interest factor  $\iota$ . We use the simplification of unconstrained borrowing without collateral to focus on the secured loan, but to still capture the fragmented nature of the credit market. Furthermore, we abstract from asymmetric information which may cause moral hazard or adverse selection. We suppose that the threat of taking away the productive investment poses enough incentives to repay the loan.

### 4.2.3 The Representative Household

The household is endowed with exogenously given initial wealth  $\kappa \geq 0$  and one unit of labor per period. Following [Jafarey and Lahiri \(2002\)](#) and [Bhalotra and Heady \(2003\)](#) we model the household as a single decision maker and abstract from intra-household bargaining on time allocation. One interpretation is that the household head sees schooling as an investment and decides on how much to invest such that there is a trade-off between child labor and schooling. We abstract from other educational costs.

The household can invest in physical capital for the low-skilled activity at the beginning of the first period. Capital lasts without depreciation until the end of the second period and depreciates completely thereafter. This way, the investment represents a durable good that lenders allow as collateral.

The household has strictly convex, strictly monotone and homothetic preferences. Preferences can thus be represented by a strictly quasi-concave and linear

homogeneous utility function  $u(c_1, c_2)$  that is strictly increasing in consumption in period one,  $c_1$ , and period two,  $c_2$  and satisfies the Inada conditions. All incomes, capital, loans, savings and initial wealth are measured in units of the consumption good.

The household maximizes utility  $u(c_1, c_2)$  subject to

$$\begin{aligned} c_1 + k + s &\leq h(l, k) + \kappa + v + z \\ c_2 + \tau v + \iota z &\leq h(l, k) + w(1 - l) + \phi s, \\ v &\leq k \end{aligned} \tag{4.3}$$

with non-negative variables  $k, v, l, s, z, c_1$ , and  $c_2$ . The corresponding Lagrangian is

$$\begin{aligned} y(c_1, c_2, l, k, v, z, s, \lambda_1, \lambda_2, \lambda_3) &= u(c_1, c_2) \\ &+ \lambda_1 [h(l, k) + \kappa + v + z - c_1 - k - s] \\ &+ \lambda_2 [h(l, k) + w(1 - l) + \phi s - c_2 - \tau v - \iota z] \\ &+ \lambda_3 (k - v) \end{aligned} \tag{4.4}$$

with shadow prices for consumption  $\lambda_1$  and  $\lambda_2$  in the first and second period, respectively, and shadow price  $\lambda_3$  for the capital constraint of the secured loan. In the next section we derive the optimal solution.

#### 4.2.4 Optimality Conditions

In the following, we omit the arguments of the functions writing  $h$  instead of  $h(l, k)$  and so on. Further, we use subscripts to denote partial derivatives. For marginal utilities we write  $u_1$  for  $\partial u / \partial c_1$  and  $u_2$  for  $\partial u / \partial c_2$ . The Kuhn-Tucker

optimality conditions are

$$\begin{aligned}
u_1 - \lambda_1 &= 0 \\
u_2 - \lambda_2 &= 0 \\
\lambda_1 h_l + \lambda_2 (h_l + w_l) &= 0 \\
\lambda_1 (h_k - 1) + \lambda_2 h_k + \lambda_3 &= 0 \\
\lambda_1 - \lambda_2 \tau - \lambda_3 &\leq 0, & v \geq 0, & v(\lambda_1 - \lambda_2 \tau - \lambda_3) = 0 \\
\lambda_1 - \lambda_2 \iota &\leq 0, & z \geq 0, & z(\lambda_1 - \lambda_2 \iota) = 0 \\
-\lambda_1 + \lambda_2 \phi &\leq 0, & s \geq 0, & s(-\lambda_1 + \lambda_2 \phi) = 0 \\
h + v + z + \kappa - c^1 - s - k &\geq 0, & \lambda_1 \geq 0, & \lambda_1 (h + v + z + \kappa - c^1 - s - k) = 0 \\
h + w + s\phi - c^2 - v\tau - z\iota &\geq 0, & \lambda_2 \geq 0, & \lambda_2 (h + w + s\phi - c^2 - v\tau - z\iota) = 0 \\
k - v &\geq 0, & \lambda_3 \geq 0, & \lambda_3 (k - v) = 0,
\end{aligned} \tag{4.5}$$

where the equality of the first four conditions follows from the Inada conditions.

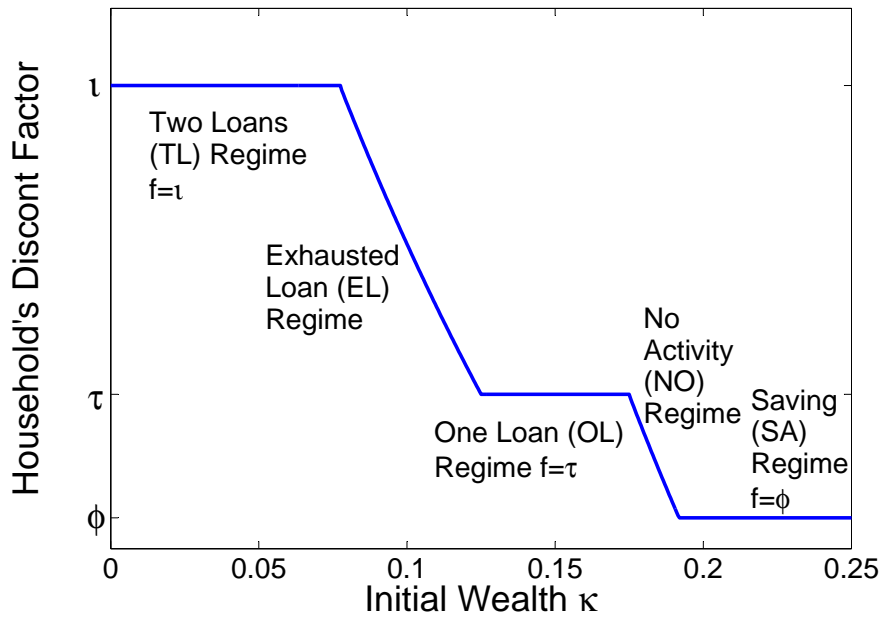
We define the household's consumption discount factor as

$$f := \frac{u_1}{u_2} = \frac{\lambda_1}{\lambda_2} \tag{4.6}$$

that displays the price, in terms of period two goods, for an extra unit of a period one good the household is willing to pay to shift a marginal income unit between periods. It equals the relevant market interest factor if the household is not credit constrained.

The household's discount factor depends on its initial wealth level. A poorer household has a higher discount factor and will borrow even at high interest costs. A richer household has a lower discount factor, may not borrow but may save. The model features five possible credit regimes that are related to the initial wealth level. The resulting discount factors are depicted in Figure 4.1. The different credit regimes follow from the Kuhn-Tucker conditions (see Appendix B.1) and will be described in the following.

FIGURE 4.1: Discounting, Credit Market Regimes and Initial Wealth.



The proof is given in Appendix B.2

The five credit regimes from low to high initial wealth:

1. Two loans regime (TL):  $z > 0, v = k, s = 0, f = \iota$ , and  $\frac{\lambda_3}{\lambda_2} = \iota - \tau$ : The household exhausts the secured loan and takes out an additional loan.
2. Exhausted loan regime (EL):  $z = 0, v = k, s = 0, \tau \leq f \leq \iota$ , and  $\frac{\lambda_3}{\lambda_2} = f - \tau$ : The household exhausts the secured loan but does not take an additional loan.
3. One loan regime (OL):  $z = 0, k > v > 0, s = 0, f = \tau$ , and  $\lambda_3 = 0$ : The household takes out a secured loan, but does not exhaust it.
4. No credit market activities regime (NO):  $z = 0, v = 0, s = 0, \phi \leq f \leq \tau$ , and  $\lambda_3 = 0$ : The household neither borrows nor lends.
5. Saving regime (SA):  $z = 0, v = 0, s > 0, f = \phi$ , and  $\lambda_3 = 0$ : The household saves.

Obviously, the household does not save and borrow at the same time. Starting in the TL-regime, a relatively richer household has a smaller unsecured loan compared to a poorer household in the TL-regime such that for both  $f = \iota$  (compare Figure 4.1). For some wealth level, the EL-regime is reached. Then, labor allocation and capital investment and therefore the secured loan as well differ depending on initial wealth. The richer the household, the smaller the household's discount factor until the OL-regime is reached. In the OL-regime, the size of the secured loan depends on initial wealth and keeps  $f = \tau$ . In the NO-regime,  $k$  and  $l$  vary again for different initial wealth levels. If the initial wealth of the household is large, saving becomes the optimal choice and the household is in the SA regime. The amount saved depends on initial wealth such that  $f = \phi$ .

In other words, credit demand declines from  $v = k$  and  $z > 0$ , to  $v = k$  and  $z = 0$ , to  $k > v > 0$  and  $z = 0$  as the household's discount factor decreases from  $f = \iota$  to  $\iota \geq f \geq \tau$  to  $f = \tau$ . As the household's discount factor decreases further, the household does not use the credit market until  $f = \phi$ , when it starts to save. While all five credit regimes can theoretically occur, it depends on the parameter combinations if all regimes occur for positive and finite initial wealth levels.

Optimal capital investment and labor allocation depend on the subjective discount factor as depicted by the first order conditions

$$\begin{aligned}
 h_l(1 + f) - w_{1-l} &= 0, \\
 h_k(1 + f) - \tau &= 0 \quad \text{for the TL-, EL- and OL- regimes and} \\
 h_k(1 + f) - f &= 0 \quad \text{for the NO- and SA-regimes.}
 \end{aligned} \tag{4.7}$$

The condition for optimal labor allocation applies in all credit-regimes while the first first order condition for capital investment only applies in the TL-, EL-, and OL-regime and the second only applies only in the NO-, and SA-regime. The first order condition for labor equates the discounted marginal returns to labor in low-skilled production with returns to labor in high-skilled production. The

first order conditions for capital equate marginal discounted returns of capital in low-skilled production with the marginal costs of capital. Capital investment and labor allocation differ between the credit regimes.

### 4.3 Interest Factors and Labor Allocation

In this section we analyze the impact of credit market improvements in the form of lower interest factors on time allocation between low-skilled labor and education. Lower interest factors increase welfare of the indebted household by decreasing interest payments. However, resulting changes in education levels may affect future generations negatively as lower education leads to lower future incomes and the household head neither considers the full adult life of his children nor future generations.

We consider how changes in  $\iota$ ,  $\tau$  and  $\phi$  affect education in the five different credit regimes. Since education is defined as  $1 - l$ , changes in education and low-skilled work,  $l$ , have opposite signs. We introduce  $\alpha := h_l l / h$  as the output elasticity of labor in low-skilled production and  $1 - \alpha := h_k k / h$  as the output elasticities of capital in low-skilled production. Further, we define the elasticity of substitution between capital and labor in low-skilled production by

$$\sigma := \frac{d \ln(l/k)}{d \ln(h_k/h_l)}$$

and the intertemporal elasticity of substitution in consumption by

$$\eta := \frac{d \ln(c_2/c_1)}{d \ln(u_1/u_2)}.$$

To determine the direction of change in low-skilled work due to a change in interest factors we take the total differential of the first order conditions (4.7) and reduce it to

$$\text{sgn} \left( \frac{dl}{di} \right) = \text{sgn}(-y_{li}^* y_{kk}^* + y_{ki}^* y_{lk}^*), \quad (4.8)$$

TABLE 4.1: Low-Skilled Work and Interest Factor Changes.

| Credit Regime | $\text{sgn}(dl/di)$ | $\text{sgn}(dl/d\tau)$   | $\text{sgn}(dl/d\phi)$                                   |
|---------------|---------------------|--|--|
| TL            | $>0$                | $<0$   | $=0$   |
| EL            | $=0$                | $=\text{sgn}\left(\sigma\left(\frac{f+\frac{c_2}{c_1}}{1+f}\right) - 1 - \frac{\eta c_2}{fh}\right)$ | $=0$   |
| OL            | $=0$                | $=\text{sgn}\left(\tau - \frac{1-\alpha}{\alpha}\right)$   | $=0$   |
| NO            | $=0$                | $=0$   | $=0$   |
| SA            | $=0$                | $=0$   | $=\text{sgn}\left(\phi - \frac{1-\alpha}{\alpha}\right)$ |

The proofs are in the Appendix B.4.

where  $l^j$  denotes the time allocated to low-skilled work in credit regime  $j \in \{TL, EL, OL, NO, SA\}$ , the interest factors are given by  $i \in \{\phi, \tau, \iota\}$  and  $y^*$  denotes the maximized Lagrangian with first derivatives  $y_l^*$  and  $y_k^*$ . Appendix B.3 provides a detailed derivation of the expression. The results for  $dl^j/di$  are summarized in Table 4.1 and differ depending on the credit regime and the affected interest factor (see Appendix B.4 for a detailed derivation).

The following mechanisms determine the results. A change in an interest factor may affect the costs of capital as well as discounting. The former leads to a change in production patterns, while the latter may affect both production and consumption. We identify three effects that determine the direction of change in labor allocation and term them ‘productivity effect’ (a change in production patterns due to a change in capital costs), ‘intertemporal effect’ (a change in production patterns due to a change in discounting), and ‘credit constraint effect’ (a change in consumption pattern due to a change in discounting).

The **productivity effect** captures the impact of changes in capital investment on labor productivity in the low-skilled sector. Capital investment adjusts to changes in its market price  $\tau$  (in the TL-,EL-,OL-regimes) or opportunity costs  $\phi$  (in the SA-regime). If the interest factor for saving  $\phi$  increases, saving will become more attractive relative to investment in the low-skilled sector. If capital costs  $\tau$  or opportunity costs of capital  $\phi$  increase, capital investment and thus low-skilled labor productivity decrease. The productivity effect decreases low-skilled labor and increases education.

The **intertemporal effect** captures the effect of changes in subjective discounting on production patterns. If the subjective discount factor increases, the value of present day income increases such that more capital is invested to increase low-skilled income. The same is true for labor such that the intertemporal effect increases low-skilled labor and decreases education.

The **credit constraint effect** only occurs if credit constraints bind and intertemporal consumption allocation via credit markets is limited. The household uses labor reallocation to smooth consumption over time. Two counteracting sub-effects arise. Higher capital costs imply that a larger amount has to be repaid in the second period such that the household increases education while decreasing low-skilled work. However, higher capital costs imply a smaller loan amount, such that less has to be repaid in the second period and education decrease while low-skilled work increases.

We now consider the prevalence of the effects for the different combinations of interest factor changes and credit regimes. In the TL-regime, the household discounts with  $f = \iota$  and faces capital costs  $\tau$ . Using (4.8) to evaluate the impact of an increasing unsecured interest factor  $\iota$  on time allocation in the TL-regime yields

$$\text{sgn} \left( \frac{dl^{TL}}{d\iota} \right) = \text{sgn} \left( \underbrace{(h_k h_{lk} - h_l h_{kk})}_{\text{intertemporal effect}} (1 + \iota) \right).$$

Low-skilled work increases and education declines. This is a standard results. A change in the unsecured interest factor  $\iota$  does not affect capital costs  $\tau$  (no productivity effect), but it affects discounting. Consumption patterns are not affected, because the household is not credit constrained (no credit constraint effect), but production patterns are. Thus, the intertemporal effect determines the overall change. The time allocations in all other credit market regimes are unaffected by a change of  $\iota$  since capital costs and subjective discounting are independent of  $\iota$  in all but the TL-regime.



If the secured interest factor  $\tau$  in the TL-regime increases instead, the labor allocation changes according to

$$\text{sgn} \left( \frac{dl^{TL}}{d\tau} \right) = \text{sgn} \left( \underbrace{-h_{lk}(1+\iota)}_{\text{productivity effect}} \right)$$

and low-skilled work decreases while education increases. Discounting is not affected and neither an intertemporal nor a credit constraint effect occur. Since the capital costs  $\tau$  are affected, the productivity effect is present and determines the overall change.

All three effects occur if the secured interest factor  $\tau$  changes in the EL-regime. The household is credit constrained and the secured interest factor depicts the capital costs and is part of the subjective discount factor. Using (4.8) yields

$$\text{sgn} \left( \frac{dl^{EL}}{d\tau} \right) = \text{sgn} \left( \underbrace{f\tau}_{\text{c. constr. e.}} \underbrace{(h_k h_{lk} - h_l h_{kk})(1+f)}_{\text{intertemp. e.}} \underbrace{-h_{lk}(1+f)}_{\text{prod. e.}} \underbrace{-f_k h_l}_{\text{c. constr. e.}} \right), \quad (4.9)$$

which becomes

$$\text{sgn} \left( \sigma \left( \frac{f + \frac{c_2}{c_1}}{1+f} \right) - 1 - \frac{\eta c_2}{fh} \right) \quad (4.10)$$

after some calculus (see Appendix B.4 for details). Expression (4.10) is positive for a small elasticities of intertemporal substitution  $\eta$  or a large elasticities of substitution in low-skilled production  $\sigma$ . It is negative for a large  $\eta$  and a small  $\sigma$ . A small elasticity of substitution between capital and labor in low-skilled production implies a low substitutability between input factors. Thus, if capital is reduced due to an increase in  $\tau$ , it is costly to compensate capital with low-skilled work. The productivity effect dominates and a higher interest factor leads to less low-skilled work and more education.

In the OL-regime, the secured interest factor  $\tau$  represents the discount factor as well as capital costs and

$$\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) = \text{sgn} \left( \underbrace{(h_k h_{lk} - h_l h_{kk})(1 + \tau)}_{\text{intertemporal effect}} \underbrace{-h_{lk}(1 + \tau)}_{\text{productivity effect}} \right) \quad (4.11)$$

which becomes

$$\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) \text{sgn} \left( \tau - \frac{1 - \alpha}{\alpha} \right) \quad (4.12)$$

after rearrangement and substituting in the output elasticities of capital and labor (A detailed derivation is given in Appendix B.4). Since the household is not credit constrained, only the intertemporal and the productivity effect occur. Both effects draw in different directions such that the change of low-skilled work is ambiguous. Equation (4.12) implies that the effect of a higher interest factor on low-skilled labor is negative for  $\alpha < 1/(1 + \tau)$ , and positive for  $\alpha > 1/(1 + \tau)$ . The increase of the secured interest factor leads to more education and less low-skilled work if the productivity effect dominates the intertemporal effect, i.e. if the output elasticity of labor in the low-skilled sector is sufficiently small with  $\alpha < 1/(1 + \tau)$ .

An increasing secured interest factor in the NO- and the SA-regimes has no effect on time allocation as it neither affects the subjective discount factor nor the capital costs in these regimes. The same applies for changes of the saving interest factor and time allocation in the TL-, EL-, OL- and NO-regimes. The effect of an increasing interest factor for saving on time allocation in the SA-regime is equivalent to the effect of an increasing interest factor for borrowing secured by a collateral in the OL-regime. The household is not credit constrained and the interest factor on saving  $\phi$  represents the discount factor as well as the opportunity costs of capital.

## 4.4 Common Pool Externalities

In this section we consider additionally a common pool resource with poorly defined property rights. Low-skilled production depends on a regenerative resource, but high-skilled production is resource-independent. A fixed number of potential resource users has unrestricted access to the resource and the number of resource users is sufficiently large to avoid strategic behavior. Low-skilled production of the representative household is given by  $\bar{h}(l, k, x) = h(l, k)x$  with ‘effort’  $h(l, k)$  and the resource stock  $x$ . The multiplicative combination of effort and the resource stock is a common assumption in resource economics (Hannesson, 1983; Clark, 2005; Conrad, 2010) and simplifies the subsequent analysis. Aggregate harvest reduces the stock size of the resource such that  $x$  is a function of aggregate labor  $L$  and aggregate capital  $K$  with  $x_K < 0$  and  $x_L < 0$ . Due to the large number of resource users, each harvester neglects its individual effect on the resource stock and the first order conditions become

$$\begin{aligned} h_l(1 + f)x - w_{1-l} &= 0, \\ h_k(1 + f)x - \tau &= 0 \quad \text{for the TL-, EL- and OL- regimes and} \\ h_k(1 + f)x - f &= 0 \quad \text{for the NO- and SA-regimes.} \end{aligned} \tag{4.13}$$

Resource dynamics differ largely in their speed. Forest growth can be very slow whereas the dynamics of rangelands or some fish species are relatively fast compared to a human lifetime. Our work is motivated by the Indian inland fishery of Chilika lagoon where catches increased several fold within two years after an ecological regime shift. We therefore suppose a fast growing resource for our model and assume that the resource reaches its steady state immediately at the beginning of each period for a given level of aggregate harvesting effort. The resource stock will be the same in both periods because  $l$  and  $k$  do not differ between periods. To simplify the analysis further we assume identical harvesters of mass one such that  $L = l$  and  $K = k$ . We define the stock elasticity that measures the response of the steady state resource stock to harvesting effort

as

$$\varepsilon = -\frac{x_h h}{x}. \quad (4.14)$$

The stock elasticity is a measure for the common pool externality and increases with the impact of the harvest on the steady state stock size. The stock elasticity is high for resources with low reproduction rates and low density dependent mortality rates such as whales and it is high for resources with low depletion rates such as fertile soil or resources with high reproduction rates and high density dependent mortality rates such as some fish species. There is no common pool externality for  $\varepsilon = 0$  and the results are as in Table 4.1.

The direction of the overall effect of interest factor changes on time allocation is still determined by (4.8) but with the first order conditions (4.13) instead of (4.7). Although the individual harvester neglects his impact on the resource, his marginal productivity of capital and labor in (4.13) is still affected by changes in the resource abundance. He thus takes into account that the resource reacts to effort changes resulting from interest factors changes. Table 4.2 summarizes the change in low-skilled work in response to interest factor changes for the different credit regimes. Appendix B.5 derives the results.

TABLE 4.2: Low-Skilled Work and Interest Factor Changes with Common Pool Externalities.

| Regime | $\text{sgn}(dl/dt)$ | $\text{sgn}(dl/d\tau)$  | $\text{sgn}(dl/d\phi)$   |
|--------|---------------------|---|--|
| TL     | $> 0$               | $= \text{sgn}(-1 + \varepsilon\sigma)$  | $= 0$  |
| EL     | $= 0$               | $= \text{sgn}\left(\sigma\left(\frac{f+c_2}{1+f}\right) - 1 - \frac{\eta c_2}{fhx} + \varepsilon\sigma\left(\frac{\eta c_2}{fhx} + \frac{1-c_1}{1+f}\right)\right)$ | $= 0$  |
| OL     | $= 0$               | $= \text{sgn}\left(\tau - \frac{1-\alpha}{\alpha} + \varepsilon\frac{\sigma(1+\tau)(1-\alpha)}{\alpha}\right)$  | $= 0$  |
| NO     | $= 0$               | $= 0$   | $= 0$  |
| SA     | $= 0$               | $= 0$   | $= \text{sgn}\left(\phi - \frac{1-\alpha}{\alpha} + \varepsilon\frac{\sigma(1+\tau)(1-\alpha)}{\alpha}\right)$ |

The results of Table 4.2 differ from the results of Table 4.1, because of the **resource effect**. The resource effect reflects the impact of changes in the resource stock size on marginal labor productivity in low-skilled production and represents the negative externality of harvesting. If capital investment in the harvesting sector decreases as a response to rising capital costs, the resource stock recovers and marginal labor productivity in low-skilled production increases. The resource effect therefore draws in the opposite direction as the productivity effect and occurs only when the productivity effect also occurs. This implies that the resource effect only occurs in the TL-, EL- and OL-regime as a response to a change in the secured interest factor and in the SA-regime as a response to a change in the savings interest factor. All other cases are unaffected by the introduction of a common pool externality. If the secured interest factor changes in the TL-regime, the direction of change in low-skilled work is determined by

$$\text{sgn} \left( \frac{dl^{TL}}{d\tau} \right) = \text{sgn} \left( \underbrace{-h_{lk}x(1+\iota)}_{\text{productivity effect}^{<0}} \underbrace{-h_{lx}x_k(1+\iota)}_{\text{resource effect}^{>0}} \right) = \text{sgn} \left( \varepsilon - \frac{1}{\sigma} \right).$$

The sign of  $dl^{TL}/d\tau$  depends on the relative size of the two elasticities. A large stock elasticity implies that the resource recovers strongly after a reduction in total harvesting capital which increases the marginal productivity of labor and increases the time allocated to low-skilled labor. A large substitution elasticity in the low-skilled sector implies that capital can easily be substituted by labor which also increases the time which is allocated to low-skilled production.

The direction of change in labor allocated to low-skilled production in the EL-regime as a response to an increase of the secured interest factor is determined by

$$\text{sgn} \left( \frac{dl}{d\tau} \right) = \text{sgn} \left( f_\tau \underbrace{(1+f)(h_k x h_{lk} x - h_l x h_{kk} x)}_{\text{intertemp. e.}^{>0}} - f_k h_l x \underbrace{-(1+f)h_{lk} x}_{\text{prod. e.}^{<0}} \underbrace{-(1+f)h_{lx} x_k}_{\text{resource e.}^{>0}} \right).$$

Rearrangement and substituting in the elasticities yield

$$\text{sgn} \left( \sigma \left( \frac{f + \frac{c_2}{c_1}}{1 + f} \right) - 1 - \frac{\eta c_2}{f h x} + \varepsilon \sigma \left( \frac{\eta c_2}{f h x} + \frac{1 - \frac{c_2}{c_1}}{1 + f} \right) \right).$$

As without the resource externality, low-skilled labor decreases for a secured interest factor increase if the elasticity of substitution between labor and capital in the low-skilled sector is low. The resource externality has a positive impact on the time allocated towards low-skilled work in most cases as the secured interest factor increases. The effect of the resource externality on changes in low-skilled labor is only negative if consumption increases strongly over time.

The direction of change in low-skilled work in the OL-regime is determined by

$$\text{sgn} \left( \frac{dl}{d\tau} \right) = \text{sgn} \left( \underbrace{(1 + \tau)(h_k x h_{lk} x - h_l x h_{kk} x)}_{\text{intertemp. e.}} \underbrace{-(1 + \tau) h_{lk} x}_{\text{prod. e.}} \underbrace{-(1 + \tau) x_k h_l}_{\text{resource e.}} \right)$$

which is equivalent to

$$\text{sgn} \left( \frac{dl}{d\tau} \right) = \text{sgn} \left( \frac{1}{\sigma} \left( \frac{\tau}{(1 - \alpha)(1 + \tau)} - 1 \right) + \varepsilon \right).$$

The expression is positive for a large substitution elasticity in low-skilled production  $\sigma$  or a large stock elasticity  $\varepsilon$ .

It can only become negative for  $\tau < (1 - \alpha)/\alpha$  and a small  $\sigma$  or a small  $\varepsilon$ . As in the case without resource externality, the condition for results in the SA-regime are the same as in the OL-regime with  $\phi$  instead of  $\tau$ .

A strong resource externality leads to a strong recovery of the resource as capital is withdrawn from resource harvesting which has a positive effect on labor productivity in the low-skilled sector. Thus, a large common pool externality i.e. a large  $\varepsilon$ , leads to an increase of low-skilled labor with increasing interest factors. In other words, credit market reforms that lower interest factors are more likely to increase education in the presence of common pool externalities.

## 4.5 Conclusion

This article examines the impact of interest rate changes on low-skilled labor and education in developing economies with and without common pool resources. Our model is motivated by the fragmented credit markets in fishing villages around Chilika Lagoon, India, which are typical for informal credit markets in developing economies. While it seems natural to respond to the observed low education and high rural interest rates by improving credit markets we have shown that lower interest rates can actually decrease education. The mechanism leading to this result is the ‘productivity effect’: lower capital costs increase investment in the low-skilled sector, which increases marginal productivity of low-skilled labor. Counteracting mechanisms are that lower subjective discounting increases the present value of future benefits from education and that resource externalities lower or reverse the productivity effect. Which of these effects occur, depends on the household’s initial wealth, the affected interest factor and the presence of common pool externalities. Which of the occurring effects dominate, depends on the substitutability of labor and capital in low-skilled production, the interest rate, the intertemporal elasticity of substitution in consumption and on the size of the common pool externality. Credit market improvements are more likely to increase education if capital can easily replace labor in low-skilled production, if the output share of capital is high, the household has low preferences for consumption smoothing, the interest rates are high and there are strong common pool externalities.

Interest factor reductions that decrease capital costs and increase investment in low-skilled production improve the welfare of the current generation. The policy may however negatively affect future generations if parents do not consider the full life of their offspring and higher capital investment increases child-labor in low-skilled production. Credit market improvements are unequivocally beneficial if their negative effect on subjective discounting outweighs the positive effects on child-labor productivity such that education increases.



## **4.6 Acknowledgements**

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## Chapter 5

# Separate or Mixed Production of Timber, Livestock and Biodiversity in the Caspian Forest

with Michael Manthey, Jack Ruitenbeek and Marvie  
Mohadjer

The article is available at <http://www.sciencedirect.com/science/article/pii/S0921800910003216>

**Abstract:** The temperate deciduous forest on the northern slopes of the Alborz Mountains has a high biological diversity and many endemic species. Huge areas are still old-growth forest but logging and grazing have degraded large parts of the forest. These degraded areas have low timber and forage yields and a species composition that differs from its natural state. In this study we present an analytical and a numerical solution to the forest management problem by optimizing the benefits of livestock production, timber harvest and biodiversity conservation. We focus on the ecological interactions rather than on

administrative restrictions. Our findings are based both, on theoretical considerations and field investigations of ecological and economic parameters in Azerbaijan and Iran. The results of the numerical optimization suggest that it is optimal to separate timber and livestock production if biodiversity is not valued. Livestock rearing is preferable at high discount rates whereas timber production becomes more profitable at low discount rates. If the valuation of diversity exceeds a certain threshold a combination of timber production and livestock rearing is socially optimal since it yields a high biological diversity.

### **Erratum**

The statement on page 73 of the published article: "The Hessian is either positive or negative semidefinite depending on the benefits of diversity,  $p_d$  (Appendix A). However Arrow's sufficiency criteria can still be met since the Lagrangian is concave in  $w$  for any  $h$  and  $s$ ." is wrong. The sufficiency criteria concern the *maximized Lagrangian* and nothing can be said about its curvature.

# Appendix A

## Appendix to Chapter 2

### A.1 Steady-State in the Traditional Sector

As all  $n_*$  individuals engaged in resource harvesting start off with the same steady state bequest level  $b_*^r$ , all of them invest

$$k_* = \min \left\{ (\gamma X_*/2)^2, b_*^r \right\}, \quad (\text{A.1})$$

where  $X_*$  is the steady-state resource stock. We consider the two cases (i)  $k_* = (\gamma X_*/2)^2$  and (ii)  $k_* = b_*^r$  in turn.

In case (i), the steady-state resource stock is obtained from (2.5) as

$$X_* = \frac{\rho \kappa}{\rho + \frac{1}{2} n_* \gamma^2 \kappa}. \quad (\text{A.2})$$

Using this in (2.9) leads to

$$b_*^r = \frac{\delta}{1 - \delta} (\gamma X_*/2)^2. \quad (\text{A.3})$$

By assumption (2.2),  $b_*^r < (\gamma X_*/2)^2$ , which contradicts the initial assumption that capital investment is not constraint. Given assumption (2.2) case (i) does not occur.

In case (ii) the steady-state resource stock is obtained from (2.5) as

$$X_* = \kappa \left( 1 - \frac{n_* \gamma \sqrt{b_*^r}}{\rho} \right). \quad (\text{A.4})$$

Using this in (2.9) leads to (2.12). Plugging (2.12) into (A.4) yields (2.13).

## A.2 Proof of Proposition 2.1

For clarity in the proofs we will use the following lemma:

**Lemma A.1.** *The steady state bequest from resource harvesting,  $b_*^r$ , increases in  $\delta$ ,  $\rho$  and  $\kappa$ . It increases in  $\gamma$  only if  $\rho > n\delta\gamma^2\kappa$  and decreases in  $\gamma$  if the opposite holds.*

The proof for this lemma follows from the partial derivatives of (2.12) with respect to the respective parameters.

Proof of Proposition 2.1 Linearity and a slope smaller than unity of (2.8) together with (2.11) imply that  $b_{t+1}^m > b_t^m \forall b_t^m \in [\beta, b_*^m)$ . Define  $h$  as the share of individuals for a given wealth level and a given resource stock that work in the traditional sector. From utility maximization it follows that  $h(b_*^r, X_*) = 0 \forall b_*^r \in [\beta, b_*^m)$  since  $b_*^r < b_*^m$  implies  $y_*^r < y_*^m$  where  $y_*^j = b_*^j / \delta$  and  $j \in \{m, r\}$ .  $\lim_{b_t \rightarrow 0} db_{t+1}^r / db_t^r = \infty$  and  $b_{t+1}^r = 0$  for  $b_t^r = 0$  imply that  $b_{t+1}^r > b_t^r \forall b_t^r \in (0, b_*^r)$ . It follows that  $h(b_*^m, X_*) = 1 \forall b_*^m \in [\beta, b_*^r)$ . If  $b_*^r = b_*^m$  then the steady state incomes are equal in both sectors and the individuals are indifferent between both occupations.  $\square$

We have shown in the proof for Lemma A.1 that  $b_{t+1}^r > b_t^r \forall b_t^r \in (0, b_*^r)$ . It follows that there is no bequest steady state below  $\beta$  if  $b_*^r \geq \beta$ .

Developed, modern economy: From Lemma A.1 we know that there are no resource harvesters in steady state if  $\beta \leq b_*^r < b_*^m$ . It follows that if  $\beta \leq b_*^r < b_*^m$  then all individuals work in the modern sector in steady state and earn  $b_*^m / \delta$ .

Developed, mixed economy: The income from resource harvesting for a degenerated distribution of capital where  $n_* \in [0, 1]$  individuals inherit  $b_t$  is given by

$$\tilde{y}_{t+1} = \gamma\sqrt{k_t}\kappa \left(1 - \frac{\gamma n_*}{\rho}\sqrt{k_t}\right) - k_t + b_t, \quad (\text{A.5})$$

where  $\partial\tilde{y}_{t+1}/\partial n_* < 0$ . For the developed, mixed economy to occur, the income in the modern sector, the resource productivity and the harvesting efficiency must be such that  $\gamma\sqrt{k_t}\kappa \left(1 - \frac{\gamma}{\rho}\sqrt{k_t}\right) - k_t + b_*^m < \alpha - \beta + b_*^m < \gamma\sqrt{b_*^m}\kappa$ . It follows that there must be a  $n_*$  such that  $\gamma\sqrt{b_*^m}\kappa \left(1 - \frac{\gamma n_*}{\rho}\sqrt{b_*^m}\right) = \alpha - \beta + b_*^m$ . The bequest is only in steady state if the income from resource harvesting equals the incomes in the modern sector. The share of individuals that equalize the income across both sectors is given by (2.14).

Developed, traditional economy: Follows directly from Lemma A.1.

### A.3 Stability and Monotonicity

The steady state bequest in the modern sector is locally stable. This follows from the slope of (2.8) with respect to  $b_t$  which is given by  $\delta$  for all levels of bequest. The steady state in the industrial sector is therefore attractive for all bequests in the interval  $[\beta, \infty)$  if  $b_*^r < \beta$ . The conditions for local stability of the bequest in the resource sector are characterized in the following. The bequest of all dynasties of resource harvesters approach (2.12) if the bequest of all resource harvesters is equal, sufficiently close to (2.12) and

$$4n_*\gamma^2\delta\kappa < 3\rho. \quad (\text{A.6})$$

The motions of the bequest towards the steady state bequest (2.12) are monotone if the bequest of all resource harvesters is equal, sufficiently close to (2.12) and

$$4n_*\gamma^2\delta\kappa < \rho. \quad (\text{A.7})$$

The resource stock for a degenerated distribution of harvesting capital is given by

$$\tilde{X}_{t+1} = \kappa \left( 1 - \frac{\gamma n_*}{\rho} \sqrt{b_t} \right). \quad (\text{A.8})$$

Setting  $X_{t+1} = \tilde{X}_{t+1}$  in (2.9) and differentiate it with respect to  $b_t$ , then setting  $b_t = b_*^r$  yields

$$\frac{\partial b_{t+1}^r}{\partial b_t^r} = \frac{1}{2} - \frac{2n_*\gamma^2\delta\kappa}{\rho}$$

which is always equal or smaller than  $1/2$ , larger than minus one if  $4n_*\gamma^2\delta\kappa < 3\rho$  and positive if  $4n_*\gamma^2\delta\kappa < \rho$ .

Differentiating (2.9) with respect to  $b_t$  and setting then  $X_{t+1} = \tilde{X}_{t+1}$  and  $b_t = b_*^r$  yields

$$\frac{\partial b_{t+1}^r}{\partial b_t^r} = \frac{\rho + n_*\delta 4\gamma^2\kappa}{2\rho} \left( 1 - \frac{n_*4\gamma^2\delta\kappa}{\rho + n_*\delta 4\gamma^2\kappa} \right) = \frac{1}{2}.$$

## A.4 Proof of Proposition 2.3

Monotonicity implies stability. Note that  $n^p \leq \bar{n}$  implies  $b_*^r \geq \beta$  for  $n_* = n^p$ . It follows that the economy becomes developed if  $n_* \leq \bar{n}$  since the only steady state is in the interval  $[\beta, \infty)$  and its basin of attraction is  $[0, \infty)$ . Now we need to establish that  $n_* \leq n^p$  for  $b^p = b_*^r$ . From Lemma A.1 follows that the rich never engage in resource harvesting if  $b_*^r < \beta$ . It follows that there can be no  $b_*^r < \beta$  if  $n^p \leq \bar{n}$ . The same argument applies to the second case of Proposition 2.3.

## A.5 Proof of Proposition 2.4

A redistribution that increases the initial wealth of the advantaged above  $\beta$  shift them to the basin of attraction of  $b_*^m$ . A reduction of individuals in the poor bequest steady state increases the steady state wealth of the poor since  $\partial b_*^r / \partial n_* < 0$ . A redistribution that satisfies (2.20) increases the share of the

rich and in the long run the wealth of the poor and thus increases long-term Kaldor-Hicks efficiency.

The worst-off are the disadvantaged in the first generation when (A.7) holds. Condition (2.20) states that the share of the individuals in the poor steady state reduces by  $\mu$  such that  $\nu = n_* - \mu < n_*$  and the resource stock increases. If the increasing resource stock overcompensate the disadvantaged we have

$$\gamma \sqrt{b_*^r - \tau} \kappa \left(1 - \frac{\gamma \nu}{\rho} \sqrt{b_*^r - \tau}\right) \geq \gamma \sqrt{b_*^r} \kappa \left(1 - \frac{\gamma m_*}{\rho} \sqrt{b_*^r}\right)$$

which reduces to (2.21). Note further that if  $k(b_*^r, X_*) \leq b_*^r$  binds then  $k(b_*^r - \tau, X_* + \epsilon) \leq b_*^r - \tau$  must bind for any  $\epsilon \geq 0$  as well.

## A.6 Proof of Proposition 2.5

There are only poor individuals in steady state if the economy is underdeveloped and  $b_*^r < b_*^m$  for  $n_* \rightarrow 1$ . If (2.22) holds then  $\min\{b_*^m - \tau, b_*^r + \nu\tau/(1 - \nu)\} \geq \beta$  and all individuals are rich. The rest follows from  $[\epsilon b_*^r + (1 - \epsilon)b_*^m] < b_*^m / \delta \forall b_*^r \in [0, \beta)$  with  $\epsilon \in (0, 1)$ .

## A.7 First Best

The first best allocation is found by maximizing income with respect to  $n$ ,  $k$ , and  $X$ :

$$\begin{aligned} & \max_{n, k, X} \left\{ n \left( \gamma \sqrt{k} X - k \right) + (1 - n) (\alpha - \beta) \right\} \text{ s.t. } n \gamma \sqrt{k} X = \rho X (1 - X/\kappa) \\ \Leftrightarrow & \max_{n, k} \left\{ n \left( \gamma \kappa \sqrt{k} - \left( n \frac{\gamma^2 \kappa}{\rho} + 1 \right) k \right) + (1 - n) (\alpha - \beta) \right\} \end{aligned}$$



The first-order conditions are

$$\begin{aligned} \frac{1}{2} \gamma \kappa \frac{1}{\sqrt{k}} - n \frac{\gamma^2 \kappa}{\rho} - 1 &= 0 \\ \gamma \kappa \sqrt{k} - 2n \frac{\gamma^2 \kappa}{\rho} k - k - (\alpha - \beta) &= 0 \end{aligned}$$

Rearranging leads to (2.16) and (2.17). Inserting (2.16) and (2.17) into  $\gamma \sqrt{k} X - k$  with the given constraint leads to (2.18).

## A.8 Resource Regulation

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

$$\max_{\bar{k}} \left\{ \gamma \sqrt{\bar{k}} \kappa \left( 1 - n_* \frac{\gamma}{\rho} \sqrt{\bar{k}} \right) - \bar{k} \right\}$$

The first-order condition of this optimization problem yields

$$\begin{aligned} \bar{k} &= \left( \frac{\gamma \rho \kappa}{2(n_* \gamma^2 \kappa + \rho)} \right)^2 \\ \bar{X}^* &= \frac{\kappa}{2} \left( 1 + \frac{\rho}{n_* \gamma^2 \kappa + \rho} \right) \\ \bar{b}_r^* &= \frac{\delta}{1 - \delta} \frac{\gamma^2 \rho \kappa^2}{4(n_* \gamma^2 \kappa + \rho)} \end{aligned}$$

At a resource stock of size  $\bar{X}$ , the individual marginal productivity of harvesting capital is

$$p = \frac{d}{d\bar{k}} \left[ \gamma \sqrt{\bar{k}} \bar{X}^* \right] = \frac{\gamma}{2\sqrt{\bar{k}}} \bar{X}^* = \frac{n_* \gamma^2 \kappa + 2\rho}{2\rho}$$

## A.9 Proof of Proposition 2.6

We have  $\bar{k} < b_*^r$  if and only if

$$\frac{\gamma \rho \kappa}{2 n_* \gamma^2 \kappa + 2 \rho} < \frac{\gamma \rho \kappa}{n_* \gamma^2 \kappa + \rho / \delta'}$$

which holds if and only if (2.24) holds. Under this condition, we also have  $\bar{b}^r > b_*^r$ , as

$$\begin{aligned} \frac{d}{d\bar{k}} \left[ \gamma \sqrt{\bar{k}} \kappa \left( 1 - n_* \frac{\gamma}{\rho} \sqrt{\bar{k}} \right) - \bar{k} \right] \Big|_{\bar{k}=b_*^r} &= \frac{1}{2} \gamma \frac{1}{\sqrt{b_*^r}} \kappa - n_* \frac{\gamma^2 \kappa}{\rho} - 1 \\ &= \frac{-n_* \gamma^2 \kappa + \rho / \delta - 2 \rho}{2 \rho} < 0. \end{aligned}$$

Using that  $b_*^r < \beta$ , with  $b_*^r$  given by (2.12), condition (2.25) implies

$$\begin{aligned} \frac{\delta}{1 - \delta} \frac{\gamma^2 \rho \kappa^2}{4 (n_* \gamma^2 \kappa + \rho)} &> \left( \frac{\delta \rho \gamma \kappa}{\delta n_* \gamma^2 \kappa + \rho} \right)^2 \\ \Leftrightarrow (\delta n_* \gamma^2 \kappa + \rho)^2 &> \delta \rho (1 - \delta) 4 (n_* \gamma^2 \kappa + \rho) \\ \Rightarrow \delta (n_* \gamma^2 \kappa + 2 \rho)^2 &> 2 \rho (n_* \gamma^2 \kappa + 2 \rho) \\ \Rightarrow \delta > \frac{2 \rho}{n_* \gamma^2 \kappa + 2 \rho} &> \frac{\rho}{n_* \gamma^2 \kappa + 2 \rho}. \end{aligned} \quad (\text{A.9})$$

## A.10 Proof of Proposition 2.7

The amount parents bequest is higher than what they inherited, because their income increased. It thus suffices to show that the market value of the capital allowance per capita increases in the number  $\epsilon$  of fishermen that leave the sector. We show this for the regulation scenario where the total capital allowance is optimally adjusted according to the number of fishermen in the resource sector in a given period. The capita market value of a harvesting allowance increases

with  $\epsilon$ :

$$\begin{aligned} \frac{d}{d\epsilon} \left[ \frac{(n_* - \epsilon)\gamma^2\kappa + 2\rho}{2\rho} \left( \frac{\gamma\rho\kappa}{2((n_* - \epsilon)\gamma^2\kappa + \rho)} \right)^2 \right] \\ = -\epsilon\gamma^2\kappa + \frac{(n_* - \epsilon)\gamma^2\kappa + 2\rho}{(n_* - \epsilon)\gamma^2\kappa + \rho} 2\epsilon\gamma^2\kappa > 0. \end{aligned}$$

## A.11 Capital costs of fishing in Chilika lagoon

As fishing capital, an average fishing unit owns 63 kg (sd = 73) of nets, at a price of 680 Rs per kg (sd = 960), 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 cost to setup a fishing unit is therefore  $63 \times 680 + 0.95 \times 38,000 + 0.53 \times 18,000 = 88,480$  Rs. Using the average live spans of 5.9 years (sd = 6.3) for nets, 10.6 years (sd = 5.6) for boats, and 8.2 years (sd = 3.9) for engines, and yearly repair costs of 130 Rs (sd = 260) per kg of net, 3,970 Rs (sd = 5,020) for a boat, and 5,480 Rs (sd = 3,640) for an engine, and fuel costs of 3.71 (sd = 3.0) per day at 45 Rs per liter for a motorized fishing unit, we obtain capital costs of  $(63 \times (680/5.9 + 130) + 0.95 \times (38,000/10.6 + 3,970) + 0.53 \times (18,000/8.2 + 5,480)) / 225 + 0.53 \times 3.7 \times 45 = 207$  Rs per fishing day.

# Appendix B

## Appendix to Chapter 4

### B.1 Derivation of the Five Credit Regimes

From the Kuhn-Tucker conditions (4.5) and definition (4.6) follows

$$\begin{aligned} (A) \quad & v = 0 \text{ or } f = \tau + \frac{\lambda_3}{\lambda_2} \\ (B) \quad & z = 0 \text{ or } f = \iota \\ (C) \quad & s = 0 \text{ or } f = \phi \\ (D) \quad & \lambda_3 = 0 \text{ or } v = k. \end{aligned} \tag{B.1}$$

Table B.1 list the 16 possible combinations between A,B,C and D and shows that only five combinations (TL, EL, OL, NO and SA) do not lead to contradictions.

TABLE B.1: Credit Market Regimes.

|                | 0               | 1                      |       |          |    |    |    |    |    |    |    |    |    |    |   |    |   |    |   |    |
|----------------|-----------------|------------------------|-------|----------|----|----|----|----|----|----|----|----|----|----|---|----|---|----|---|----|
| A              | $v = 0$         | $f = \tau + \lambda_3$ | 1     | 1        | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0 | 0  | 0 | 0  | 0 | 0  |
| B              | $w = 0$         | $f = \iota$            | 1     | 1        | 1  | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 0 | 0  | 0 | 0  | 0 | 0  |
| C              | $s = 0$         | $f = \phi$             | 1     | 1        | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | 0 | 1  | 1 | 0  | 0 | 0  |
| D              | $\lambda_3 = 0$ | $v = k$                | 1     | 0        | 1  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 1  | 0 | 1  | 0 | 1  | 0 | 1  |
| Credit regime  |                 |                        | -     | -        | TL | -  | -  | EL | OL | -  | -  | -  | -  | -  | - | -  | - | -  | - | -  |
| Contradictions |                 |                        | R1,R2 | R1,R2,R3 | -  | R3 | R2 | R2 | R2 | R1 | R1 | R3 | R4 | R4 | - | SA | - | R4 | - | R4 |

R1-4 (see below) indicate, why certain combinations do not work.

1. R1:  $f = \iota$  and  $f = \phi$  (B=1 and C=1) is not possible since  $\iota \neq \phi$ .
2. R2:  $f = \tau + \lambda_3$  and  $f = \phi$  (A=1 and C=1) is not possible since  $\tau > \phi$  and  $\lambda_3 \geq 0$ .
3. R3:  $\lambda_3 = 0$  and  $f = \iota$  (B=1 and D=0) is not possible since  $\lambda_3 > 0$  is needed to fulfill  $\iota = f \leq \tau + \lambda_3$  and  $\iota > \tau$ .
4. R4:  $v = 0$  and  $v = k$  is not optimal because it implies  $k = 0$  which is ruled out by the Inada conditions.

## B.2 Relation between Household's Discount Factor, Credit Market Regimes and Initial Wealth Level

We show that  $f(\kappa)$  is a non-increasing continuous function in  $\mathbb{R}_{+0}$ . Define  $Z(\kappa) = \sup_{c_1, c_2, q} \{u(c_1, c_2) | c_1 - g_1(q) \leq \kappa, c_2 - g_2(q) \leq 0, q \geq 0\}$  with the vector  $q$  of an arbitrary dimension. Furthermore,  $g_1 = h + v + z - k - s$  and  $g_2 = h + w + \phi s - \tau v - \iota z$ , both concave, such that  $Z$  is also concave. Take  $f(\kappa) := \frac{u_1}{u_2}$ , evaluated at  $(c_1^*, c_2^*)$  for which the supremum is attained.

Consider  $\tilde{Z}(\kappa) = u(c_1, c_2^*)$  with  $c_1 = \kappa + g_1(q^*)$ . Then,  $Z(\kappa) \geq \tilde{Z}(\kappa)$  with equality for  $\kappa = \kappa^*$ , and  $\tilde{Z}'(\kappa^*) = u_1(c_1^*, c_2^*)$ . Hence,  $Z'_+(\kappa^*) \geq u_1(c_1^*, c_2^*) \geq Z'_-(\kappa^*)$ . Furthermore, as  $Z$  is concave,  $Z'_-(\kappa^*) \geq Z'_+(\kappa^*)$ . Therefore,

$$Z'_+(\kappa^*) = Z'_-(\kappa^*) = u_1(c_1^*, c_2^*).$$

$\frac{u_1}{u_2}$  is increasing in  $u_1$  due to linear homogeneity of  $u$  such that it is non-increasing in  $\kappa$ . The rest follows from the credit regimes definition.

### B.3 Derivation of Equation (4.8)

To determine the sign of  $dl/di$  with  $i \in \{\iota, \tau, \phi\}$  we use the implicit function theorem and Cramer's Rule, i.e.  $dl/di = |H^{j,i}|/|H^j|$  for  $j \in \{TL, EL, OL, NO, SA\}$  and the Jacobian matrix given by

$$H^j = \begin{bmatrix} y_{l\iota}^* & y_{lk}^* \\ y_{kl}^* & y_{kk}^* \end{bmatrix}$$

and

$$H^{j,i} = \begin{bmatrix} -y_{li}^* & y_{lk}^* \\ -y_{ki}^* & y_{kk}^* \end{bmatrix}$$

with  $i \in \{\iota, \tau, \phi\}$ ,  $j \in \{TL, EL, OL, NO, SA\}$  and the Lagrangian at the optimum  $y^*$  (see equation (4.4)). A locally unambiguously defined optimum implies  $|H^j| > 0$ <sup>1</sup> such that the denominator only influences the size of the effect but not the direction and equation (4.8) determines the sign.

### B.4 Proofs for Table 4.1

We use (4.8) and (4.7) to determine the direction of change of labor reallocation to low-skilled work as a response of rising interest factors.

#### Proof of $dl^j/d\iota$ :

**TL:** For  $j = TL$  and  $f = \iota$ :

$$\text{sgn}\left(\frac{dl^{TL}}{d\iota}\right) = \text{sgn}((h_k h_{lk} - h_l h_{kk})(1 + \iota)). \quad (\text{B.2})$$

<sup>1</sup>The objective function is concave if and only if the Hessian Matrix is semi definite ( $|H^j| \geq 0$ ). We assume a locally unambiguously defined optimum. Then,  $|H^j| = 0$  occurs with probability zero.

For a linear homogenous production function the ratio of the marginal productivities is only a function of the factor input ratio such that

$$\frac{d(h_k/h_l)}{d(k/l)} \frac{k/l}{h_k/h_l} = \frac{d(h_k/h_l)}{dk} l \frac{k/l}{h_k/h_l}.$$

The inverse elasticity of substitution between capital and labor in low-skilled production,  $\sigma$ , can therefore be represented by

$$\begin{aligned} \frac{1}{\sigma} &= -\frac{d \ln(h_k/h_l)}{d \ln(k/l)} = -\frac{d \ln(h_k/h_l)}{d \ln(k)} = -\frac{d \ln(h_k)}{d \ln(k)} + \frac{d \ln(h_l)}{d \ln(k)} \\ &= k \left( \frac{h_{lk}}{h_l} - \frac{h_{kk}}{h_k} \right) = l \left( \frac{h_{lk}}{h_k} - \frac{h_{ll}}{h_l} \right). \end{aligned}$$

Using the Euler equation  $h_k k + h_l l = h$  and its first derivative with respect to  $k$  yields

$$\frac{1}{\sigma} = \frac{h_{lk} h}{h_l h_k} \quad (\text{B.3})$$

Multiplying both sides of (B.2) with  $k/[(1+\iota)h_k h_l]$  and using (B.3) gives

$$\text{sgn} \left( \frac{dl^{TL}}{d\iota} \right) = \text{sgn} \left( \frac{1}{\sigma} \right).$$

**EL,OL,NO,SA:** For  $j \in \{EL, OL, NO, SA\}$  and  $f = \iota$ ,  $y_{li}^* = y_{ki}^* = 0$  such that  $dl^j/d\iota = 0$ .

### **Proof of $dl^j/d\tau$ :**

**TL:** For  $j = TL$  and  $f = \iota$ :

$$\text{sgn} \left( \frac{dl^{TL}}{d\tau} \right) = \text{sgn}(-h_{lk}(1+\iota)).$$

**EL:** For  $j = EL$  and  $f = \tau + \lambda_3/\lambda_2$ :

$$\text{sgn} \left( \frac{dl^{EL}}{d\tau} \right) = \text{sgn} (f_\tau (h_k h_{lk} - h_l h_{kk})(1+f) - h_{lk}(1+f) - f_k h_l). \quad (\text{B.4})$$



The inverse elasticity of intertemporal substitution in consumption can be expressed by

$$\frac{1}{\eta} = \frac{d \ln(u_1/u_2)}{d \ln(c_2/c_1)} = \frac{f_{c_2} c_2}{f} = \frac{f_{c_1} c_1}{f} = -\frac{u_{22} c_2}{u_2} = -\frac{u_{11} c_1}{u_1}. \quad (\text{B.5})$$

The derivation of this expression is analogous to (B.3).

Calculate

$$\begin{aligned} f_k &= \frac{u_2 u_{11} h_k - u_1 u_{22} (h_k - \tau)}{u_2^2} \\ &= \frac{u_{11} h_k}{u_2} - \frac{u_1 c_1}{u_1 c_1} - \frac{u_1 u_{22} (h_k - \tau) c_2}{u_2 u_2 c_2}. \end{aligned}$$

Inserting the elasticity of intertemporal substitution and  $f = \frac{u_1}{u_2}$  gives

$$f_k = -f \frac{h_k}{\eta c_1} \frac{c_2}{c_2} + f \frac{h_k - \tau}{\eta c_2}.$$

Replacing  $h_k - \tau$  by  $-f h_k$  from (4.7) yields

$$f_k = -f \frac{h_k}{\eta c_1} \frac{c_2}{c_2} - f \frac{f h_k}{\eta c_2}.$$

Inserting  $f_{c_2} = f / (\eta c_2)$  from (B.5) yields

$$f_k = -f_{c_2} h_k \left( \frac{c_2}{c_1} + f \right).$$

The derivative of the subjective discount factor with respect to the interest factor  $\tau$  can be expressed as

$$f_\tau = \frac{u_1 u_{22} k}{u_2^2} = -f_{c_2} k.$$

Multiply (B.4) by  $1/(h_l h_k)$ , use the elasticity of substitution (B.3) and insert  $f_k = -f_{c_2} h_k (c_2/c_1 + f)$  and  $f_\tau = -f_{c_2} k$  to attain

$$\begin{aligned} \text{sgn} \left( \frac{dl}{d\tau} \right) &= \text{sgn} \left( f_\tau \left( \frac{h_{lk}}{h_l} - \frac{h_{kk}}{h_k} \right) (1+f) - \frac{h_{lk}}{h_l h_k} (1+f) - \frac{f_k}{h_k} \right) \\ &= \text{sgn} \left( -f_{c_2} k \left( \frac{h_{lk}}{h_l} - \frac{h_{kk}}{h_k} \right) (1+f) - \frac{h_{lk}}{h_l h_k} (1+f) + f_{c_2} \left( \frac{c_2}{c_1} + f \right) \right) \\ &= \text{sgn} \left( -\frac{f_{c_2}}{\sigma} (1+f) - \frac{1+f}{h\sigma} + f_{c_2} \left( f + \frac{c_2}{c_1} \right) \right). \end{aligned}$$

Multiply with  $\sigma/(f_{c2}(1+f))$  and re-arrange to attain

$$\text{sgn}\left(\frac{dl}{d\tau}\right) = \text{sgn}\left(-\left(1 + \frac{1}{hf_{c2}}\right) + \sigma\frac{f + \frac{c_2^2}{c_1}}{1+f}\right) = \text{sgn}\left(\sigma\frac{f + \frac{c_2^2}{c_1}}{1+f} - 1 - \frac{\eta c_2}{hf}\right).$$

**OL:** For  $j = OL$  and  $f = \tau$ :

$$\text{sgn}\left(\frac{dl^{OL}}{d\tau}\right) = \text{sgn}((h_k h_{lk} - h_l h_{kk})(1+\tau) - h_{lk}(1+\tau)). \quad (\text{B.6})$$

Multiplying (B.6) with  $((1+\tau)h_{lk}h_k)^{-1}$  leads to

$$\text{sgn}\left(\frac{dl}{d\tau}\right) = \text{sgn}\left(1 - \frac{h_l h_{kk}}{h_{lk} h_k} - \frac{1}{h_k}\right).$$

Note that the first order condition for capital in (4.7) leads to

$$\frac{1}{h_k} = \frac{1}{\tau} + 1. \quad (\text{B.7})$$

Now insert the first derivation of the Euler equation of the production function (see (B.3)) and (B.7) to attain

$$\begin{aligned} \text{sgn}\left(\frac{dl}{d\tau}\right) &= \text{sgn}\left(\frac{h_l l}{kh_k} - \frac{1}{\tau}\right) \\ &= \text{sgn}\left(\tau - \frac{kh_k}{lh_l}\right) \\ &= \text{sgn}\left(\tau - \frac{1-\alpha}{\alpha}\right). \end{aligned}$$

**NO,SA:** For  $j \in \{NO, SA\}$  and  $f = \tau, y_{l\tau}^* = y_{k\tau}^* = 0$  such that  $dl^j/d\tau = 0$ .

**Proof of  $dl^j/d\phi$ :**

**TL,EL,OL,NO:** For  $j \in \{TL, EL, OL, NO\}$  and  $f = \phi, y_{l\phi}^* = y_{k\phi}^* = 0$  such that  $dl^j/d\phi = 0$ .

**SA:** The derivation of  $dl^{SA}/d\phi$  is equivalent to  $dl^{OL}/d\tau$ , i.e.

$$\text{sgn}\left(\frac{dl}{d\phi}\right) = \text{sgn}\left(\phi\frac{1-\alpha}{\alpha}\right).$$

## B.5 Proofs for Table 4.2

We use (4.8) and (4.13) to determine the direction of change of labor reallocation to low-skilled work as a response of rising interest factors.

### Proof of $dl^j/d\iota$ :

**TL:** For  $j = \text{TL}$  and  $f = \iota$ :

$$\begin{aligned} \text{sgn} \left( \frac{dl^{\text{TL}}}{d\iota} \right) &= \text{sgn} (h_k x (h_{lk} x + h_l x_k) (1 + \iota) - h_l x (h_{kk} x + h_k x_k) (1 + \iota)) \\ &= \text{sgn} ((h_k x h_{lk} x - h_l x h_{kk} x) (1 + \iota) + (h_k x h_l x_k - h_l x h_k x_k) (1 + \iota)) \\ &= \text{sgn} ((h_k x h_{lk} x - h_l x h_{kk} x) (1 + \iota)), \end{aligned}$$

which is equivalent to

$$\text{sgn} \left( \frac{dl^{\text{TL}}}{d\iota} \right) = \text{sgn} \left( \frac{1}{\sigma} \right).$$

**EL, OL, NO, SA:** For  $j \in \{EL, OL, NO, SA\}$  and  $f = \iota, y_{li}^* = y_{ki}^* = 0$  such that  $dl^j/d\iota = 0$ .

### Proof of $dl^j/d\tau$ :

**TL:** For  $j = \text{TL}$  and  $f = \tau$ :

$$\text{sgn} \left( \frac{dl^{\text{TL}}}{d\tau} \right) = \text{sgn} (-h_{lk} x (1 + \iota) - h_l x_k (1 + \iota)).$$

Multiplication with  $k/[(1 + \iota)h_l x]$  gives

$$\text{sgn} \left( \frac{dl^{\text{TL}}}{d\tau} \right) = \text{sgn} \left( -h_{lk} \frac{k}{h_l} - x_k \frac{k}{x} \right).$$

Expansion by  $hh_k/(hh_k)$  yields

$$\text{sgn} \left( \frac{dl^{\text{TL}}}{d\tau} \right) = \text{sgn} \left( -h_{lk} \frac{k}{h_l} \frac{hh_k}{hh_k} - x_k \frac{k}{x} \frac{hh_k}{hh_k} \right).$$

Replacing  $x_k$  by  $x_h h_k$ , multiplying by  $h/(h_k k)$  and using the elasticity (B.3) and (4.14) gives

$$\begin{aligned}\operatorname{sgn}\left(\frac{dl^{TL}}{d\tau}\right) &= \operatorname{sgn}\left(h_k \frac{k}{h} \left(-\frac{hh_{lk}}{h_1 h_k} - x_h \frac{h}{x}\right)\right) \\ &= \operatorname{sgn}\left(-\frac{1}{\sigma} + \varepsilon\right)\end{aligned}$$

**EL:** For  $j=EL$  and  $f = \tau + \lambda_3/\lambda_2$ :

$$\begin{aligned}\operatorname{sgn}\left(\frac{dl^{EL}}{d\tau}\right) &= \operatorname{sgn}\left(-f_\tau h_l x [(1+f)(h_{kk}x + h_k x_k) + f_k h_k x] + (h_k x f_\tau - 1)[(1+f)(h_{lk}x + h_l x_k) + f_k h_l x]\right) \\ &= \operatorname{sgn}\left(-f_\tau h_l x (1+f) h_{kk} x - f_\tau h_l x (1+f) h_k x_k - f_\tau h_l x f_k h_k x + h_k x f_\tau (1+f) h_{lk} x \right. \\ &\quad \left. + h_k x f_\tau (1+f) h_l x_k + h_k x f_\tau f_k h_l x - (1+f) h_{lk} x - (1+f) h_l x_k - f_k h_l x\right) \\ &= \operatorname{sgn}\left(-f_\tau h_l x (1+f) h_{kk} x + h_k x f_\tau (1+f) h_{lk} x - (1+f) h_{lk} x - (1+f) h_l x_k - f_k h_l x\right) \\ &= \operatorname{sgn}\left(-f_\tau x^2 (1+f)(h_{kk} h_l - h_k h_{lk}) - (1+f) h_{lk} x - (1+f) h_l x_k - f_k h_l x\right).\end{aligned}\tag{B.8}$$

Calculate

$$f_\tau = \frac{ku_{22}u_1}{u_2^2} = -\frac{kf}{\eta c_2}\tag{B.9}$$

and

$$\begin{aligned}f_k &= \frac{u_2 u_{11}(h_k x + h x_k) - u_1 u_{22}(h_k x + h x_k - \tau)}{u_2^2} \\ &= \frac{u_{11}(h_k x + h x_k) u_1 c_1}{u_2 u_1 c_1} - \frac{f u_{22}(h_k x + h x_k - \tau) c_2}{u_2 c_2} \\ &= -\frac{f}{\eta} \frac{(h_k x + h x_h h_k)}{c_1} + \frac{f}{\eta} \frac{(h_k x + h x_h h_k - \tau)}{c_2} \\ &= \frac{f h_k}{\eta} (x + h x_h) \left(-\frac{1}{c_1} + \frac{1}{c_2}\right) - \frac{f \tau}{\eta c_2}.\end{aligned}\tag{B.10}$$

Multiply (B.8) with  $(h_l h_k x^2 (1+f))^{-1}$ , rearrange (B.3) to get  $h_{kk} h_l - h_k h_{lk} = -h h_{lk}/k$  and (4.13) to obtain  $h_k x (1+f) = \tau$  and insert both expressions together with (B.10)

and (B.9) in (B.8), replace  $x_k$  by  $x_h h_k$  and rearrange (B.8) to obtain

$$\begin{aligned}
\text{sgn} \left( \frac{dl^{EL}}{d\tau} \right) &= \text{sgn} \left( \frac{f_\tau h h_{lk}}{h_l h_k k} - \frac{h_{lk}}{h_l h_k x} - \frac{x_k}{h_k x^2} - \frac{f_k}{(1+f)h_k x} \right) \\
&= \text{sgn} \left( -\frac{f h h_{lk}}{\eta c_2 h_l h_k} - \frac{h_{lk}}{h_l h_k x} - \frac{x_k}{h_k x^2} - \frac{f h_k}{\eta(1+f)h_k x} (x + h x_h) \left( -\frac{1}{c_1} + \frac{1}{c_2} \right) + \frac{f \tau}{\eta c_2 (1+f)h_k x} \right) \\
&= \text{sgn} \left( -\frac{f}{\eta c_2 \sigma} - \frac{1}{\sigma h x} + \frac{\varepsilon}{x h} - \frac{f(x + h x_h)}{\eta(1+f)x} \left( -\frac{1}{c_1} + \frac{1}{c_2} \right) + \frac{f \tau}{\eta c_2 (1+f)h_k x} \right) \\
&= \text{sgn} \left( -\frac{f}{\eta c_2 \sigma} - \frac{\sigma^{-1} - \varepsilon}{h x} - \frac{f(1-\varepsilon)}{\eta(1+f)} \left( \frac{c_1 - c_2}{c_1 c_2} \right) + \frac{f}{\eta c_2} \right) \\
&= \text{sgn} \left( \frac{f}{\eta c_2} \left( -\frac{1}{\sigma} - \frac{1-\varepsilon}{1+f} \left( \frac{c_1 - c_2}{c_1} \right) + 1 \right) - \frac{\sigma^{-1} - \varepsilon}{h x} \right). \tag{B.11}
\end{aligned}$$

Multiply with  $\sigma \eta c_2 / f$  and 'isolate'  $\varepsilon$  to attain

$$\text{sgn} \left( \sigma \left( \frac{f + \frac{c_2}{c_1}}{1+f} \right) - \frac{\eta c_2}{f h x} - 1 + \varepsilon \sigma \left( \frac{\eta c_2}{f h x} + \frac{1 - \frac{c_2}{c_1}}{1+f} \right) \right).$$

**OL:** For  $j = EL$  and  $f = \tau$

$$\begin{aligned}
\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) &= \text{sgn} (-h_l x (h_{kk} x + h_k x_k) (1 + \tau) + (h_k x - 1) (h_{lk} x + h_l x_k) (1 + \tau)) \\
&= \text{sgn} ((-h_l x h_{kk} x - h_l x h_k x_k + h_k x h_{lk} x + h_k x h_l x_k - h_{lk} x - h_l x_k) (1 + \tau)) \\
&= \text{sgn} ((-h_l x h_{kk} x + h_k x h_{lk} x - h_{lk} x - h_l x_k) (1 + \tau)) \\
&= \text{sgn} (-[x^2 (h_l h_{kk} - h_k h_{lk}) + h_{lk} x + h_l x_k] (1 + \tau)).
\end{aligned}$$

Use then the relationship  $h_{kk} h_l - h_k h_{lk} = -h h_{lk} / k$  from (B.3) and the elasticity of substitution, insert  $x_k = x_h h_k$  and divide by  $h_l x$ ,  $h_k x$  and  $(1 + \tau)$  to obtain

$$\begin{aligned}
\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) &= \text{sgn} \left( \frac{h h_{lk}}{h_k h_l k} - \frac{h_{lk}}{h_l h_k x} - \frac{x_k}{h_k x^2} \right) \\
&= \text{sgn} \left( \sigma^{-1} \left( \frac{1}{k} - \frac{1}{h x} \right) - \frac{x_k}{h_k x^2} \right) \\
&= \text{sgn} \left( \left[ \sigma^{-1} \left( \frac{h x}{k} - 1 \right) - \frac{x_h h_k h x}{h_k x^2} \right] \right) \\
&= \text{sgn} \left( \left[ \sigma^{-1} \left( \frac{h x}{k} - 1 \right) + \varepsilon \right] \right).
\end{aligned}$$

Using the output elasticity of capital  $1 - \alpha$  and the relation  $h_k x = \tau / (1 + \tau)$  from (4.13) yields

$$\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) = \text{sgn} \left( \frac{1}{\sigma} \left( \frac{\tau}{(1 - \alpha)(1 + \tau)} - 1 \right) + \varepsilon \right).$$

Multiply with  $\sigma$  to attain

$$\text{sgn} \left( \frac{dl^{OL}}{d\tau} \right) = \text{sgn} \left( \frac{\tau}{(1 - \alpha)(1 + \tau)} - 1 + \varepsilon \sigma \right).$$

**NO,SA:** For  $j \in \{NO, SA\}$  and  $f = \tau, y_{l\tau}^* = y_{k\tau}^* = 0$  such that  $dl^j/d\tau = 0$ .

### **Proof of $dl^j/d\phi$ :**

**TL, EL, OL, NO:** For  $j \in \{TL, EL, OL, NO\}$  and  $f = \phi, y_{l\phi}^* = y_{k\phi}^* = 0$  such that  $dl^j/d\phi = 0$ .

**SA:** The derivation of  $dl^{SA}/d\phi$  is equivalent to  $dl^{OL}/d\tau$ , i.e.

$$\text{sgn}(dl^{SA}/d\phi) = \text{sgn}(\phi / [\sigma(1 - \alpha)(1 + \phi)] - \varepsilon).$$

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# Eidesstattliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich meine Doktorarbeit „Structural Change in Resource-Abundant Economies“selbständig und ohne fremde Hilfe angefertigt habe und dass ich alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Unterschrift:

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Datum:

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# Lebenslauf

## Frederik Noack

### Curriculum vita

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Diplomarbeit: The Bioeconomics of Livestock Rearing and  
Timber Production in the Caspian Forest.  
Abitur: Freie Waldorfschule Hannover Bothfeld, 2000.

#### Berufserfahrung

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2008-heute Wissenschaftlicher Mitarbeiter am Lehrstuhl für Umwelt-,  
Ressourcen- und Ökologische Ökonomik der CAU Kiel.  
2006-2011 Berater für die Weltbank in Uganda und Indien.  
2006-2007 Berater für die Michael-Succow-Stiftung in Aserbaidschan.

- 2005 Gastwissenschaftler an der Fakultät für Natürliche Ressourcen der Universität Therean.
- 2001-2002 Wissenschaftliche Hilfskraft bei Danida und dem WWF in Malaysia.
- 2000-2001 Zivildienst beim WWF auf Langeness, Deutschland.

### **Publikationen**

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- Noack, F.**, Manthey, M., Ruitenbeek, J. and Mohajer R.M., 2010. Separate or mixed production of timber, livestock and biodiversity in the Caspian Forest. *Ecological Economics*. 70 (1): 67-76.
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