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Diplom-Volkswirtin Marie-Catherine Riekhof
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Dekan: Prof. Dr. Achim Walter
Erstberichterstattender: Prof. Dr. Johannes Bröcker
Zweitberichterstattender: Prof. Dr. Martin Quaas

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Introduction

Average per capita income nearly doubled between 1970 and 2000 ([Barro and Sala-i Martin, 2004](#), p. 7), but not all people gained from this overall income growth. The economic development has been associated with a rapid rise in the use of natural resources with unintended side effects like climate change. Common observations related to climate change are more extreme weather events. These are especially devastating for the global poor, because those who did not gain from overall economic growth often rely on natural resources for an income, face lower insurance possibilities against adverse shocks and have less income alternatives mainly due to missing education.

As climate change effects and strategies human kind deal with them are not yet entirely known, restricting carbon emissions serves as an insurance against adverse shocks. So far, negotiations on the precise climate policy measures and on their timing are not yet finalized. Furthermore, to include the poor into global prosperity and to make them less vulnerable to adverse shocks from climate change, one could increase education and make income alternatives as well as insurances available. Again, the debate on successful strategies to do so is not yet completed.

This dissertation contributes to these on-going discussions in three papers. The first paper deals with the timing of climate policy. The second paper analyzes informal credit markets and their role for education with resulting income alternatives in poor economies. The third paper adds to the comprehension of risk sharing in informal credit contracts in developing countries.

As limiting emissions to reduce climate change is a global challenge, politics try to reach international agreements. International political decision making processes and bureaucratic policy implementations take time, which implies that climate policy, say a tax on emissions, can only be implemented with a certain time lag between announcement and implementation. This time lag may cause the well-intended policies to actually make matters worse such that a do-nothing policy would be preferable. Why is that? Resource owners anticipate the future restrictions on carbon emissions and increase their current resource supply at a lower price as compared to a no-intervention scenario. Thus, lagged implemented climate policy increases emissions during the ‘announcement period’, the period between the credible commitment to climate policy and its actual implementation. This effect is termed ‘announcement effect’ or ‘weak green paradox’ ([Gerlagh, 2011](#)).

The discussion on well-intended environmental policies that lead to the opposite due to market imperfections was brought up by [Sinn \(2008\)](#) a few years ago. Since then, a large body of theoretical papers emerged that found a (weak) green paradox for different settings. What really matters though is not only the existence of a weak green paradox, but the overall welfare effect of the lagged implemented policy. In principle, this adverse announcement effect could more than outweigh in welfare terms the gain from lower emissions after tax implementation. It is a priori not clear if the initially higher emissions (announcement effect) or the lower emissions once the policy takes effect compared to a no-intervention scenario dominate the overall welfare effect. This is especially true if one takes into account that climate dynamics, i.e. the diffusion of emitted carbon from the atmosphere into other reservoirs, are relatively slow. As carbon remains relatively long in the atmosphere, it may not matter if it is emitted today or tomorrow. Even though the adverse announcement effect is theoretically well established, it could turn out to be a theoretical curiosity if it is quantitatively not relevant. Furthermore, given it matters quantitatively, it may be interesting to know how much time there actually is to implement welfare enhancing climate policy after announcing it.

This is the issue of the first paper of my dissertation. It evaluates the welfare effect of announced climate policy that is only implemented with a known time lag due to political procedures. It shows for the first time that the adverse announcement effect of climate policy is not only a theoretical curiosity but also quantitatively relevant in state-of the art models. In a numerical simulation, the paper quantifies a ‘window of opportunity’ such that implementation before (after) its end is a welfare gain (loss) over the no-intervention scenario. The model is a Ramsey model extended by an exhaustible carbon resource and linked to a stylized dynamic climate model adapted from [Nordhaus \(2008b\)](#). The policy is a carbon emissions tax whose time path is chosen optimally at the time when implemented. The result is highly sensitive to assumptions on the available resource stock which is afflicted with particular empirical uncertainties. The central estimate is a window of opportunity of about 60 years. Hence, there is still time to act, but the window of opportunity may be smaller.

The paper is joint work with Johannes Bröcker. He developed the research question and the baseline model idea, while I did the literature research, the calibration and implementation of the different model versions as well as the presentation of the analysis and the results. I presented the work at the Brown Bag Seminar of the Institute of Economics of the University Kiel 2010, at the Kiel Young Researcher Conference at the Kiel Institute for the World Economy 2012, where the work was rewarded with a best-paper award, at the ‘Nachwuchsworkshop der Umwelt- und Ressourcenökonomie’ of the ‘Verein für Socialpolitik, Ausschuss für Umwelt und Ressourcenökonomie’ 2014 as well as on seminars of the Institute for Regional Research and of the Group of Environmental, Resource and Ecological Economics of the University of Kiel.

Besides avoiding climate change and its possible adverse effects, one could enable people to better deal with possible adverse effects themselves. The group most vulnerable to climate change effects are the global poor who have barely participated in prosperity growth. Education is an important input for sustained economic development ([Sen, 1999](#)). Education implies consumption abstinence today, but it enlarges future income possibilities and increases resilience.

The intertemporal dimension shows that education is closely related to credit markets, especially for the poor who often finance education with the help of loans. In poor areas, only informal credit markets with high interest rates exist. Conventional wisdom suggests that lower interest rates make education more attractive and thus foster development, but some empirical studies find negative effects of credit market improvements on education in developing countries (Islam and Choe, 2013; Maldonado and González-Vega, 2008). This shows that conventional wisdom may not hold for informal credit markets. It highlights the importance of specifying conditions under which credit market improvements really lead to more education.

The second paper of my dissertation derives these conditions by taking the peculiarities of informal credit markets into account. Frederik Noack's and my fieldwork in fishing villages in India showed that two basic loan categories exist: a low interest rate loan secured by collateral ('secured' loan) and a high interest rate loan without collateral ('unsecured' loan). The collateral takes the form of a productive investment: fish traders, for example, take fishing boats as collateral and micro finance institutions normally only allow business loans.

We include a fragmented credit market with two loan types into a two period model with a skilled and an unskilled sector. As especially many poor communities rely on harvesting common pool resources for an income, one scenario also considers how results change if the unskilled sector includes a common pool resource. Only capital investments needed for production in the unskilled sector serve as collateral because education cannot be appropriated in case of default.

It is this collateral arrangement that provokes the adverse effect of a lower interest rate leading to less education. A lowered 'secured' interest rate means that capital for the unskilled sector is available at lower costs. Investment in unskilled production increases. Unskilled labor becomes relatively scarce and opportunity costs of schooling rise. Education decreases for the relatively poorest households holding both loan types. For relatively richer households holding

only a 'secured' loan, the higher investment increases the collateral and allows to transfer a higher share of future income to the present at the low rate. Education becomes more attractive. For a large output elasticity of unskilled labor, the second effect dominates. In this case, the lower 'secured' interest rate increases education.

Lower interest rates improve the situation of the current generation, but, as the analysis shows, may have a negative effect on future generations through lower education. Future generations may become locked in the unskilled, low income sector. To promote development, education should either be supported directly or, if the support should work via the credit market, special collateral arrangements should be taken into account.

The paper is joint work with Frederik Noack. We developed the research question together, and iterated on the final writing of the paper, while I developed the modeling framework, did the calculations, and the initial writing with inputs from Frederik Noack and Johannes Bröcker. I presented the paper at the biennial conference of the International Institute of Fisheries Economics and Trade (IIFET) 2012, the summer school 'Equity and Efficiency in Fisheries' 2012, the winter seminar of the German Section of the Regional Science Association in 2013 and on seminars of the Institute for Regional Research and the Group of Environmental, Resource and Ecological Economics of the University of Kiel.

In addition to financing investments, credit markets also play an important role in consumption smoothing and in providing some kind of coverage if access to formal insurance markets is not available. The higher importance of risk in the everyday life of the poor ([Besley, 1995](#)) increases the relevance of informal credits. On informal credit markets, wholesale traders provide the lion's share of loans ([Hoff and Stiglitz, 1997](#)). Empirical studies show that they often interlink the credits with the output market. An 'interlinked contract' is a contract that jointly determines conditions for trade on several markets ([Bell, 1988](#)). [Stiglitz \(1974c\)](#) proposes that these interlinked contracts are a risk sharing mechanism. Instead of fixing interest rates, the borrower has to sell his output to the trader

at below market prices. When income is low (high), interest payments are low (high). This implies a risk transfer from the borrower to the lender, i.e. an informal insurance. [Kamstra and Shiller \(2009\)](#) propose to issue state debt with interest payments based on current GDP, which shows that the mechanism to link interest payments with an insurance component attains attention beyond development economics.

Still, the set-up of the informal interlinked contracts is problematic because income and interest payments are variable and determined by the same instance, which may lead to exploitation. [Bhaduri \(1977\)](#) calls the attention to possible usurious interest rates. [Bardhan and Rudra \(1978\)](#) do not find any evidence for exploitative behavior of the traders in East Indian Villages, but they do not compare interest rates from interlinked contracts to other interest rates.

Institutional economics would predict lower interest rates in interlinked contracts due to efficiency gains because the lender saves screening and monitoring costs. [Crow and Murshid \(1992, 1994\)](#) and [Bell et al. \(1997\)](#) in turn provide evidence that interest rates from interlinked contracts lie above other relevant rates. How is the puzzle solved? Even though interlinked contracts have a high importance for the global poor, there is no thorough empirical analysis that includes risk sharing.

The third paper of the dissertation closes this gap by including a risk measure into the empirical analysis of interest rates from interlinked contracts. The dataset used in this paper stems from fieldwork by Frederik Noack and me in Indian fishing villages in 2010 and 2011 with a household survey in 2011. We developed the sample design as well as the questionnaire and organized the data collection and processing.

The estimations in the third paper show that interest rates from interlinked contracts contain an insurance premium: borrowers pay for the risk sharing via a higher interest rate. Furthermore, calculations show that the average interest rates from interlinked contracts are of a similar size as interest rates from micro

finance institutions. The reason for this is that traders are in the special position to take the fishing boat as collateral. The interlinkages reduce transaction costs. The fishing boat as collateral reduces the interest rate and counteracts the insurance premium. The paper provides empirical evidence that in the case of missing formal insurance markets interlinked contracts are one way of providing insurance.

The paper is a single authored paper. I presented it at the ERDE-Workshop 2013 in Kiel, the joint doctoral seminar of the Institute for Regional Research of the University of Kiel and the Sonderborg University in December 2013 as well as at the seminar of the Group of Environmental, Resource and Ecological Economics of the University of Kiel in 2014.

The three papers of my dissertation and their respective research questions called for three different methodical approaches, namely model calibration with numerical simulations in the first paper, analytical calculations in the second paper as well as econometric estimations in the third paper. Still, all papers think about how to improve the situation of those with no political lobby — the currently poor as well as future generations —, either through avoiding climate change or by promoting development.

Furthermore, all papers consider ‘second best’ cases, where transaction costs call for a deviation from the standard model: political procedures impede immediate emissions tax implementation, information costs on informal markets call for productive assets as collateral that bias the credit markets against education and information costs also make interlinked credit contracts an important insurance source. All papers show that carefully designed research approaches have to include market imperfections as real life interactions are full of transactions costs.

Chapter 1

Does the Adverse Announcement Effect of Climate Policy Matter? A Dynamic General Equilibrium Analysis

Abstract: We quantify the welfare effect of a climate policy that is announced today, but implemented with a known time lag as political procedures impede immediate implementation. The policy is a carbon emissions tax whose time path is chosen optimally at the time when implemented. During the time span before implementation, the announcement induces a lower price of fossil fuel and thus higher emissions as compared to a no-intervention scenario. In principle, this adverse ‘announcement effect’ could more than outweigh in welfare terms the gain from the tax after implementation. We show this not to be just a theoretical curiosity. We quantify a ‘window of opportunity’ such that implementation before (after) its end is a welfare gain (loss) over the no-intervention scenario. The result is highly sensitive to assumptions on the resource stock which is afflicted with particular empirical uncertainties. Our central estimate is a window of opportunity of about 60 years. Hence, there is still time to act, but the window of opportunity may be smaller. Thus, the adverse announcement

effect is a worrying phenomenon deserving political awareness. The model is a Ramsey model extended by an exhaustible carbon resource and linked to a stylized dynamic climate model adapted from [Nordhaus \(2008b\)](#).

Key Words: Announcement Effect, Dynamic General Equilibrium, Climate Policy, Strong Green Paradox, Welfare Evaluation

JEL classification: Q 54, Q 32

1.1 Introduction

Policies like the Kyoto-protocol intend to reduce carbon emissions to mitigate harmful climate change, but bureaucratic and political procedures impede an immediate policy implementation. The Kyoto Protocol, for example, was agreed upon in December 1998, became effective in 2005 and was implemented in 2008 ([van der Werf and Di Maria, 2011](#)). This implementation lag leads to an adverse ‘announcement effect’. The policy will be anticipated by the owners of carbonic resources: Knowing that the policy will restrict demand in the future and thus dampen their price, they are induced to extract more resources before implementation and sell the extracted resource at a lower price as compared to a world without any climate policy. The extra emissions during the period before implementation add to global warming, so that delayed implementation means a welfare loss compared to an immediate policy implementation.

A priori, it is not clear if an announced policy that is implemented only with a certain delay is to be preferred over a do-nothing policy. There are two counteracting forces. In the case of an announced policy, emissions are lower than under a do-nothing policy once the policy is implemented, but they are higher than under a do-nothing policy before. Obviously, a policy intervention designed optimally at the point in time when it becomes effective will always be welfare improving if the implementation lag is sufficiently short. If, however,

the impossibility to implement the policy in a timely manner makes the implementation lag long enough, the second effect could dominate. Then, it turns out preferable to do nothing rather than announcing and implementing a policy with too long an implementation lag. This is so because it is the timing rather than the total amount of emissions that matters for global warming (Nordhaus, 2008b). The atmosphere warms up if the carbon enters the atmosphere at a rate higher than the rate at which it dissipates into other reservoirs. The announcement effect can make things worse because it pushes emissions up.

Sinn (2009) calls a scenario where the net welfare effect turns out to be the opposite of what was intended in the first place a 'green paradox'. Later authors (Gerlagh, 2011) refer to the adverse announcement effect as a 'weak green paradox', while 'strong green paradox' means that this adverse effect dominates positive effects, such that the policy is worse than doing nothing. Beyond lagged implementation, the literature also points to other sources of green paradox, for example 'leakage effects' (Smulders et al., 2012) resulting from an incomplete regional coverage of climate policy (see van der Werf and Di Maria (2011) for an overview).

This paper aims to analyze the strong green paradox arising from a delayed climate policy where all agents know when the policy will be implemented. The adverse announcement effect could, of course, be reduced if the time path of the announced intervention is chosen optimally from the present point of view, taking the anticipation by the market participants into consideration. Such a policy would, however, be time inconsistent and thus not credible because it would be welfare enhancing at the time of policy implementation to introduce the tax that is optimal from then on. We therefore consider the announcement of a policy that is optimally designed as to the point in time when implemented.

Our main result is the estimation of a 'window of opportunity' for a favorable climate policy. It is defined such that an intervention implemented before its end is welfare increasing but welfare reducing afterwards. It turns out that, for all scenarios studied, there exists such a window of finite length. Hence,

the strong green paradox is shown to hold if the policy is announced to be implemented after the window is closed.

We set up, calibrate and solve a dynamic general equilibrium model with perfect foresight, linking an economic Dasgupta-Heal-Solow-Stiglitz exhaustible resource model ([Dasgupta and Heal, 1974](#); [Solow, 1974](#); [Stiglitz, 1974a,b](#)) with a dynamic climate module adapted from [Nordhaus \(2008b\)](#) and [Nordhaus \(2010b\)](#). Carbon extracted from an exhaustible resource is a production input and pollutant added to the stock of greenhouse gas in the atmosphere, staying there for long and causing the mean earth temperature to increase gradually. A higher temperature reduces output as described by a damage function also adapted from [Nordhaus \(2008b, 2010b\)](#). The climate model describes how the atmospheric carbon slowly dissipates into other reservoirs. Climate policy is introduced by a tax on carbon use, which is equivalent to a tax on carbon emissions because input and emissions are related one to one. As the tax is chosen optimally at the point of implementation, immediate implementation of the tax leads to the global welfare maximum, while an implementation lag only allows for a non-optimal solution, possibly one that is worse than doing nothing. Welfare is measured by the intertemporal relative equivalent variation, a monotone transform of the utility of the perpetually living representative household. The model is written in continuous time.

Deviating from common practice in integrated climate assessment modeling, we do not run an optimization machinery but solve the dynamic market equilibrium conditions because the inefficient time paths with lagged or no policy intervention do not have an equivalent optimization representation. This is straight forward and thus, in our view, more transparent than finding inefficient market solutions by iterative applications of an optimization procedure as in [Nordhaus \(2008b\)](#).

The paper contributes to two strands of literature. The first strand analyzes the announcement effect. [Di Maria et al. \(2012\)](#) analyze the announcement effect in a model with two resource types that differ in their carbon content. They

compare emissions until an announced emissions cap is implemented to the laissez-faire development and find a weak green paradox. [Smulders et al. \(2012\)](#) develop a model with capital accumulation, and clean as well as dirty energy inputs. They show that a weak green paradox even occurs if resources are not scarce or the implementation date is uncertain. [Eichner and Pethig \(2011\)](#) analyze conditions for a green paradox in a two period three country model. The second strand of literature uses integrated assessment models to analyze policy scenarios in a second best world. [Blanford et al. \(2009\)](#) and [Bosetti et al. \(2009\)](#) consider the anticipated participation of developing countries to the climate coalition. [Bosetti et al. \(2009\)](#) explicitly consider leakage effects, but neither [Blanford et al. \(2009\)](#) nor [Bosetti et al. \(2009\)](#) discuss the response of the resource owners to announced participation. The contribution of this paper lies in the quantification of the ‘strong green paradox’. Further, to our knowledge, we are the first to solve the market equilibrium conditions in an integrated assessment model to analyze climate policies in a second best world.

The remainder of this paper proceeds as follows. In the next section, we introduce the model and solve for the market equilibrium as well as for the social planner’s solution. We also calculate the optimal tax path and introduce the welfare measure. The solution approach and the calibration follow in section 1.3. In section 1.4, we discuss the results. The paper closes with a conclusion.

1.2 The Model

The model connects a climate module and an economic module. The economic module describes consumption, production, capital accumulation and resource extraction based on assumptions on technologies and preferences, while the climate module translates emissions into temperature change. Temperature, in turn, affects output. As usual, dotted variables like \dot{X} denote time derivatives. Hats denote growth rates, $\hat{X} := \dot{X}/X = d \log X/dt$. Throughout the paper, Latin letters denote variables that depend on time. Exemptions are stated.

The climate module is borrowed from the DICE-model by Nordhaus (2008b)¹. It consists of two connected sub-systems: the first sub-system describes the carbon-cycle, i.e. the evolution of the carbon masses between the three carbon reservoirs atmosphere, upper ocean and lower ocean over time, while the second sub-system describes the impact of the carbon concentration in the atmosphere on the temperature (see figure 1.1).

The flows between the atmosphere and the upper ocean as well as the carbon emissions R from carbon burned in the production process and emissions from land use change E determine the mass of carbon in the atmosphere M_1 . Emissions from land use change are exogenous and decline over time at a constant rate. The carbon-transition matrix Γ consists of constant parameters and describes the flows between the three reservoirs M_1 , M_2 and M_3 by specifying the inflows and outflows of each reservoir. The columns of Γ sum up to zero reflecting the mass balance requirement. The masses in the three reservoirs add up to a constant once there are no more external carbon inflows. Over the long run, most of the carbon diffuses into the upper and then into the deeper oceans. The sub-system reads

$$\dot{M} = \Gamma M + [R + E, 0, 0]^\top \quad (1.1)$$

with $M := [M_1, M_2, M_3]^\top$. Row vectors are written as $[\dots]^\top$, $^\top$ indicates a transpose. Carbon compounds are measured in terms of their respective carbon content (stocks in giga tons of carbon GtC, flows in giga tons carbon per annum GtC/a)².

The carbon concentration in the atmosphere as well as non-CO₂ greenhouse gases influence the radiative forcing, which in turn controls the increase of the global mean surface temperature per unit of time. The function $\Pi(M_1, t)$ describes this mechanism. It is increasing in M_1 and, for the first 100 years, it is also increasing in t . The latter reflects the exogenous influence of non-CO₂ greenhouse gases. The global mean surface temperature T_1 dynamically interacts with the temperature of the lower oceans T_2 , as described by the matrix Λ .

¹We adapted his discrete time version to continuous time.

²Table A.1 in the appendix list the units. Units are printed in teletype font.

This leads to the temperature dynamics

$$\dot{T} = \Lambda T + [\Pi(M_1, t), 0]^\top \quad (1.2)$$

with $T := [T_1, T_2]^\top$. Temperatures are measured as differences from their pre-industrial (in 1900) level in °C.

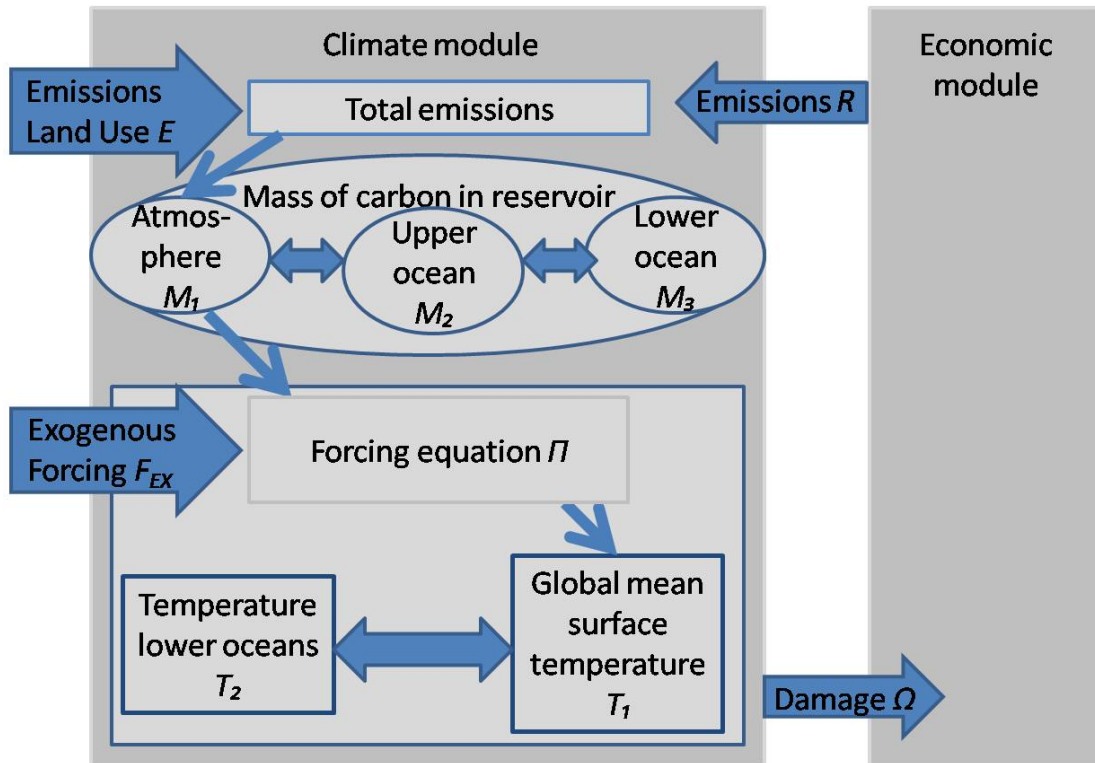


FIGURE 1.1: Interactions in the Climate Module.

The economic part of the model is a Ramsey-type growth model with exogenous technological change, where firms and households interact on competitive markets. Households consume, supply labor and own the assets of the economy consisting of the capital stock and the market value of the resource stock. Even though there is just a single representative household, the decentralized market equilibrium does not have an equivalent optimization representation due to the climate externality. This is a second best setting. We therefore first derive the equilibrium conditions for the decentralized economy with an exogenous tax imposed on carbon use. We then derive the tax rate leading to the welfare optimum.

Firms produce the final output Y with labor, capital K and the carbon flow R as inputs according to a Cobb-Douglas technology

$$Y = \Omega(T_1)K^\alpha R^\beta e^{\lambda t} \quad (1.3)$$

with partial production elasticities $\alpha > 0$ and $\beta > 0$, $\alpha + \beta < 1$. The parameter λ is the rate of technical progress. Labor is constant and therefore not displayed explicitly. Its partial production elasticity is $1 - \alpha - \beta$. Constant labor is in contrast to [Nordhaus \(2008b\)](#) who includes exogenous population growth. The carbon flow R represents a mixture of fossil fuels extracted from an exhaustible carbon resource stock S . As a common denominator, the fossil fuel inputs are measured in terms of their respective carbon content which is one-to-one emitted into the atmosphere after being burned in production. Hence, R stands for both, input and emissions, measured in GtC/a. The carbon resource stock — carbon stock in the following — also represents a mixture of fossil fuels converted into carbon, measured in GtC.

Output is scaled by the function $\Omega(T_1)$ which is decreasing in the global mean surface temperature T_1 . It represents economic damages due to higher temperatures. The specification, taken from Nordhaus and co-authors ([Nordhaus and Boyer, 2000](#); [Nordhaus, 2008b](#)), assumes the percentage loss of GDP to be a quadratic function of T_1 . Losses reflect estimates of sea-level rise costs, adverse impacts on health, non-market damages, the potential costs of catastrophic damages and negative impacts on major sectors such as agriculture due to global warming.

Due to perfect competition, input prices equal their respective marginal productivities. Taking the output good as numéraire, we obtain

$$i + \delta = \alpha Y/K, \quad (1.4)$$

$$q + r = \beta Y/R \quad (1.5)$$

with carbon price q , interest rate i , depreciation rate δ and specific tax rate r .

Imposing the tax either on the resource input or on the emissions is equivalent because the carbon extracted as a component of fossil fuel is one-to-one emitted as a component of CO₂.

The input flow R is extracted from a continuous set of privately owned carbon sources exploitable at costs per unit of flow that vary across sources. In their role as resource owners, households are price takers selling the flow on a competitive market. It is well known that under these conditions, sources are exploited in the order of ascending unit costs such that unit costs can be expressed as a non-increasing function $k(S)$ of the total carbon stock S in all yet unexploited sources, provided the interest rate is positive (see e.g. [Herfindahl \(1967\)](#); [Solow and Wan \(1976\)](#); [Laitner \(1984\)](#)).

Furthermore, resource owners collectively act like a representative owner of all sources who chooses, at any time t , an extraction path $R(\tau)$, $\tau \geq t$, as to maximize the present (as of time t) value of future net revenues from selling the flows at prices taken as given. The asset value of the remaining stock $S(t)$ at time t is thus

$$v(t, S(t)) = \frac{1}{D(t)} \max_{R(\tau), \tau \geq t} \int_t^{\infty} D(\tau) R(\tau) (q(\tau) - k(S(\tau))) d\tau \quad (1.6)$$

subject to

$$\dot{S} = -R. \quad (1.7)$$

The discount factor D has the law of motion

$$\dot{D} = -\iota D, \quad (1.8)$$

with boundary condition $D(0) = 1$.

From the current value Hamiltonian

$$\mathcal{H} = R(q - k(S)) - pR$$

with co-state p of S , we obtain the optimum conditions

$$q = k(S) + p \quad (1.9)$$

and

$$\dot{p} = \iota p + Rk'(S), \quad (1.10)$$

the augmented Hotelling rule. The transversality condition is

$$\lim_{t \rightarrow \infty} D(t)p(t)S(t) = 0. \quad (1.11)$$

The consumption side of the model is standard. An immortal representative household owns all assets a of the economy, supplies inelastically a constant stock of labor and receives the tax revenue collected by the state as a lump sum. The state has no role to play other than collecting the tax and channeling it to the household's budget. The asset value is the value of the capital stock plus the value of the resource stock,

$$a = K + v. \quad (1.12)$$

As output is transformed one-to-one into investment, capital is measured in units of the numéraire. The household chooses consumption C to maximize utility

$$U = \int_0^{\infty} u(C)e^{-\rho\tau} d\tau$$

subject to the budget constraint, with subjective discount rate ρ . As usual, u has the constant intertemporal elasticity of substitution form,

$$u = \frac{C^{1-\theta}}{1-\theta},$$

with intertemporal elasticity of substitution $1/\theta$. The flow budget constraint is

$$\dot{a} = \iota a + (1 - \alpha - \beta)Y + rR - C \quad (1.13)$$

stating that saving \dot{a} equals income minus consumption. Income has three components, interest on the asset, labor income and tax income collected by the state and paid to the household. The market prevents chain-letter credit financing such that, for $t \rightarrow \infty$, the present value of the asset must be nonnegative (Barro and Sala-i Martin, 2004, p. 92),

$$\lim_{t \rightarrow \infty} D(t)a(t) \geq 0.$$

The optimality conditions are the Keynes-Ramsey rule $\hat{C} = (\iota - \rho)/\theta$ and the transversality condition

$$\lim_{t \rightarrow \infty} D(t)a(t) = 0. \quad (1.14)$$

Integrating the Keynes-Ramsey rule, we can write optimal consumption in levels as

$$C = (e^{\rho t} B D)^{-1/\theta} \quad (1.15)$$

with an endogenous constant B . Note that, unlike the other variables in Latin letters, this one does not depend on time.

It is convenient to write the budget constraint (1.13) in a different equivalent way by inserting (1.4), (1.5) and (1.12),

$$\dot{K} + \dot{v} = \iota(K + v) + Y - (\iota + \delta)K - qR - C. \quad (1.16)$$

Taking the time derivative of (1.6), using (1.8), yields

$$\dot{v} = \iota v - R(q - k(S)). \quad (1.17)$$

Substituting this for \dot{v} in (1.16), one obtains the production balance of the economy,

$$\dot{K} = Y - \delta K - Rk(S) - C. \quad (1.18)$$

As both components of $D(t)a(t) = D(t)K(t) + D(t)v(t)$ are non-negative, for

TABLE 1.1: Overview Equilibrium Conditions Market Setting

\dot{M}	$= \Gamma M + [E + R, 0, 0]^\top$	(1.1)	$M(0)$	$= \bar{M}$
\dot{T}	$= \Lambda T + [\Pi(M_1, t), 0]^\top$	(1.2)	$T(0)$	$= \bar{T}$
Y	$= \Omega(T_1) K^\alpha R^\beta e^{\lambda t}$	(1.3)		
C	$= (B D e^{\rho t})^{-1/\theta}$	(1.15)	$\lim_{t \rightarrow \infty} D(t) K(t)$	$= 0$ (1.19)
\dot{D}	$= -\iota D$	(1.8)	$D(0)$	$= 1$
ι	$= \alpha Y / K - \delta$	(1.4)		
R	$= \beta Y / (k(S) + p + r)$	(1.5)		
\dot{p}	$= \iota p + R k'(S)$	(1.10)	$\lim_{t \rightarrow \infty} D(t) p(t) S(t)$	$= 0$ (1.11)
\dot{S}	$= -R$	(1.7)	$S(0)$	$= \bar{S}$
\dot{K}	$= Y - \delta K - C - R k(S)$	(1.18)	$K(0)$	$= \bar{K}$

(1.14) to hold, both components have to approach zero as $t \rightarrow \infty$. The transversality condition (1.14) thus implies

$$\lim_{t \rightarrow \infty} D(t) K(t) = 0. \quad (1.19)$$

This completes the model description. The equations are summarized in Table 1.1, with algebraic and differential equations in the left and boundary conditions in the right column. \bar{M} and so forth denote initial stocks. The model has thirteen unknown functions of time if we plug in (1.9) for the carbon price q , namely three carbon masses stacked in the vector M , two temperatures stacked in the vector T , output Y , consumption C , carbon flow R , carbon stock S , the marginal asset value per unit of stock p , capital K , interest rate ι as well as the discount factor D . The model also contains the integration constant B . There are eight differential equations with initial boundary conditions corresponding to the variables M , T , D , S and K . Furthermore, there are four algebraic equations for the variables Y , C , ι and R . There is an additional differential equation for p . Finally, there are two terminal boundary condition allowing for determining p as well as B , provided the differential equation system has two unstable eigenvalues. This turns out to be the case.

So far, the tax rate is taken as an exogenous policy instrument. To derive an optimal path of the tax rate, we solve the planner's problem to choose, starting at $t = 0$, a time path of consumption C and resource extraction R to maximize the representative household's utility

$$U = \int_0^{\infty} u(C)e^{-\rho\tau} d\tau$$

subject to technological, resource and climate constraints

$$\begin{aligned}\dot{K} &= \Omega(T_1)K^\alpha R^\beta e^{\lambda t} - \delta K - C - Rk(S), \\ \dot{S} &= -R, \\ \dot{M} &= \Gamma M + [E + R, 0, 0]^\top, \\ \dot{T} &= \Lambda T + [\Pi(M_1, t), 0]^\top,\end{aligned}$$

(1.20)

given inherited state variables K , S , M and T at $t = 0$.

The present value Hamiltonian is

$$\begin{aligned}\mathcal{H} &= u(C)e^{-\rho t} + \left(\Omega(T_1)K^\alpha R^\beta e^{\lambda t} - \delta K - C - Rk(S) \right) P_K \\ &\quad - RP_S + \left(M^\top \Gamma^\top + [E + R, 0, 0] \right) P_M + \left(T^\top \Lambda^\top + [\Pi(M_1, t), 0] \right) P_T.\end{aligned}\quad (1.21)$$

P_K and so forth are the costates associated with states K and so forth. P_M and P_T are column vectors. If \mathcal{H}_R and so forth denote derivatives of the Hamiltonian with respect to R and so forth, the static and dynamic efficiency conditions read,

respectively,

$$\mathcal{H}_R = 0 \quad \Rightarrow \quad 0 = P_K \frac{\beta Y}{R} - P_S + P_{M_1} - P_K k(S), \quad (1.22)$$

$$\mathcal{H}_C = 0 \quad \Rightarrow \quad P_K = C^{-\theta} e^{-\rho t}, \quad (1.23)$$

$$\mathcal{H}_K = -\dot{P}_K \quad \Rightarrow \quad -\dot{P}_K = P_K \left(\frac{\alpha Y}{K} - \delta \right), \quad (1.24)$$

$$\mathcal{H}_S = -\dot{P}_S \quad \Rightarrow \quad -\dot{P}_S = -P_K k'(S) R, \quad (1.25)$$

$$\mathcal{H}_M = -\dot{P}_M \quad \Rightarrow \quad -\dot{P}_M = \Gamma^\top P_M + \left[P_{T_1} \frac{\partial \Pi}{\partial M_1}, 0, 0 \right]^\top, \quad (1.26)$$

$$\mathcal{H}_T = -\dot{P}_T \quad \Rightarrow \quad -\dot{P}_T = \Lambda^\top P_T + \left[P_K \frac{\partial Y}{\partial T_1}, 0 \right]^\top. \quad (1.27)$$

The transversality condition is

$$\lim_{t \rightarrow \infty} Z(t)^\top P(t) = 0 \quad (1.28)$$

with $Z(t)$ and $P(t)$ denoting column vectors of states and costates in corresponding order.

The decentralized market is brought to fulfill the optimality conditions if the tax rate is

$$r = -P_{M_1} / P_K. \quad (1.29)$$

To see this, insert BD for P_K and \hat{D} for \hat{P}_K , $-r$ for P_{M_1} / P_K and $P_K p$ for P_S . Then, (1.24) becomes (1.8) with ι from (1.4), (1.23) becomes (1.15) and (1.22) becomes (1.5) with $q = P_S / P_K + k(S) P_K$. Inserting $p = P_S / P_K$ into (1.10) leads to (1.25). Equations (1.19) and (1.11) are the transversality conditions in (1.28) for K and S , respectively. The tax rule (1.29) has an obvious interpretation: $-P_{M_1}$ is the marginal utility loss from an extra unit of carbon in the atmosphere. It is translated into units of the numéraire by dividing through P_K , the marginal utility of an extra unit of the numéraire.

For welfare evaluation of policies, we use two measures, a relative and an absolute intertemporal equivalent variation. The former is the constant percentage h by which consumption \check{C} of the benchmark scenario must be changed to attain

the utility level U of the policy scenario. A relative intertemporal equivalent variation $h > 0$ ($h < 0$) indicates a welfare gain (loss) as compared to the benchmark. The relative intertemporal equivalent variation is thus implicitly defined by

$$U = \int_0^{\infty} \frac{\left((1+h)\check{C}\right)^{1-\theta}}{1-\theta} e^{-\rho\tau} d\tau.$$

Using the definition of \check{U} ,

$$\check{U} = \int_0^{\infty} \frac{\check{C}^{1-\theta}}{1-\theta} e^{-\rho\tau} d\tau,$$

one obtains

$$h = \left(\left(\frac{U}{\check{U}} \right)^{1/(1-\theta)} - 1 \right).$$

The absolute intertemporal equivalent variation is the amount of the numéraire W one would have to give to the household in $t = 0$ to make it as well off as in the policy case,

$$W = h \int_0^{\infty} \check{D}(\tau)\check{C}(\tau)d\tau. \quad (1.30)$$

The utility level U can comfortably be calculated by adding an extra differential equation with an appropriate boundary condition to the system. Define

$$V(t) := \int_t^{\infty} u(C)e^{-\rho\tau} d\tau$$

such that $U = V(0)$. Taking the time differential delivers the extra differential equation

$$\dot{V} = -u(C)e^{-\rho t}.$$

The transversality condition

$$\lim_{t \rightarrow \infty} V(z) = 0 \quad (1.31)$$

is obtained from

$$U = \lim_{t \rightarrow \infty} \left(\int_0^t u(C) e^{-\rho\tau} d\tau + V(t) \right) = U + \lim_{t \rightarrow \infty} V(t).$$

Thus, one can treat V as a forward looking variable that can be determined like the other variables in the system.

1.3 Solution Approach and Calibration

Three important issues arise when operationalizing the model. First, the system cannot be solved until infinity. Second, as the model includes externalities, the market solution does not have an equivalent optimization representation. Third, some data for calibration is afflicted with particular uncertainties.

As the system cannot be solved until infinity, operational boundary conditions holding at a finite horizon need to replace the transversality conditions. This procedure can be justified since, by discounting, the present value welfare with finite and infinite horizon become arbitrarily close to each other. To obtain viable final boundary conditions, we assume constant steady state growth rates. The following two assumptions lead to constant steady state growth rates: First, as emissions asymptotically tend towards zero, we consider the steady state system that would prevail if no more emissions entered the climate module. Second, we assume that the extraction cost component in the production balance (1.18) in the long run grows slower than the capital stock, i.e.

$$\hat{R} + \epsilon_{k:S} \hat{S} < \hat{K} \quad (1.32)$$

with the partial elasticity of extraction costs with respect to the carbon stock $\epsilon_{k:S}$. As boundary conditions, we then require a subset of the variables to already reach constant growth rates at a final point in time. This is similar to requiring some variables to reach their steady state values at a finite horizon, a method known from literature (see [Bröcker and Korzhenevych \(2013\)](#) for a discussion).

As there is some arbitrariness in fixing the finite horizon, we vary the horizon to ensure that the choice of the finite horizon does not drive results. Furthermore, we also run a model version using the stable manifold approach proposed by [Bröcker and Korzhenevych \(2013\)](#). Results do not change.

To obtain the model solution, we do not run an optimization machinery. We directly solve the dynamic market equilibrium conditions with $r = 0$ for the market outcome and $r = -P_M/P_K$ for the planner's solution. The variables are solved in log-deviations from their respective values in 2005, if data is available, or from a proxy steady state if data for 2005 is not available. The latter is the case for the shadow values. The proxy steady state is defined as the steady state but with climate as in $t = 0$. Two variables are not solved in log-deviations: V is used directly, while T is solved in absolute deviations from the respective 2005 data.

The reference year for model calibration and the starting point of the model ($t = 0$) is 2005. The calibration of the climate module is based on the 2010-Version of the RICE/DICE model ([Nordhaus, 2010b](#)) including initial values for carbon masses $M(0)$ and temperatures $T(0)$. The appendix [A.2](#) gives details. Calibration of consumption and of production including the initial capital stock as well as calibration of the resource sector relies on several data sources. It is explained in the following. Again, the appendix [A.2](#) gives details.

For the consumption side of the model, we take the elasticity of intertemporal substitution $1/\theta = 2/3$ from literature. The time preference parameter is $\rho = 0.015$ 1/a, also from literature. This yields a real interest rate in steady state of $i^* = 4.2\%$ 1/a.

To calibrate the production side, we take the capital's cost share $\alpha = 0.33$ from literature ([Barro and Sala-i Martin, 2004](#), page 58) and calculate carbon's cost share $\beta = 0.058$ from [IEA \(2007\)](#) and [EIA \(2010\)](#). The scaler of the production function at $t = 0$, $\Omega(\bar{T}_1)$, ensures $Y(0) = 45.23$ trillion \$. The rate of technical progress $\lambda = 0.0134$ 1/a is chosen to match a steady state growth rate of $g = 1.8\%$ 1/a.

Regarding the initial capital stock $K(0)$, there is no reliable data available. However, one can use the fact that the capital-output ratio is constant in steady state implying that capital and output grow at the same rate. Compared to the climate variables, this constant capital-output ratio is reached relatively fast. An initially smaller or bigger ratio approaches the steady state value in a couple of years. Thus, instead of assigning a value to $K(0)$, we require the growth rates of capital and output to be equal in $t = 0$.

To calibrate the resource sector, we first specify extraction costs as

$$k(S) = \gamma S^{-\epsilon} \quad (1.33)$$

similar to [Laitner \(1984\)](#). For condition (1.32) to hold in steady state,

$$\epsilon < \frac{\iota^*}{\iota^* - g} \quad (1.34)$$

is required with the steady state interest rate ι^* and the steady state growth rate of the economy g . To see why, use the fact that the assumption of constant steady state growth rates leads to $\hat{Y}^* = \hat{K}^* = \hat{C}^* = g$ and $\hat{S}^* = \hat{R}^* = g - \iota^*$. Furthermore, the partial elasticity of extraction costs with respect to the carbon stock $\epsilon_{k:S} = -\epsilon$. Condition (1.32) thus reads $(1 - \epsilon)(g - \iota^*) < g$, which one can rearrange to (1.34). Extraction costs are zero for $\gamma = 0$ and constant for $\epsilon = 0$. For $\epsilon = 1$, unit extraction costs double if the stock is halved. This shows the close connection between ϵ and the carbon stock.

For the initial carbon stock $S(0)$ — the sum of oil, gas and coal stocks converted into carbon —, several definitions and accordingly, different values are available with the smallest and the largest differing by a factor of 10. Larger carbon stocks imply the use of reservoirs that are more difficult to exploit such that cost developments should also differ. To reflect this, we define three scenarios with different initial carbon stocks and different ϵ :

- In one scenario, the initial carbon stock matches data on carbon reserves³, $S(0) = 612 \text{ GtC}$. We assume constant extraction cost, $\epsilon = 0$, to take into account that reserves are recoverable with current technologies ('CEC' scenario).
- In the second scenario, the initial carbon stock matches the carbon resource base (the sum of reserves and resources (UNDP, 2000, p.481)) instead. The estimated resource base amounts to roughly 3563 GtC⁴ and is 5-6 times larger than the reserves. The larger resource amount is only recoverable with rising extraction costs. We thus define a scenario with increasing extraction cost, $\epsilon = 1$, and an initial carbon stock of $S(0) = 3000 \text{ GtC}$ ('IEC' scenario).
- Since estimates of shale oil and shale gas are still not very good (World Energy Council, 2010), we include a third scenario with an even larger initial carbon stock of $S(0) = 6000 \text{ GtC}$. This is similar to the DICE model that puts an upper bound of 6000 GtC on emissions. We use $\epsilon = 1.6$, a rough estimate based on the long-term oil-supply cost curve given in IEA (2008). A parameter value $\epsilon = 1.6$ implies that extraction costs increase with the factor 3 if the resource stock is halved. This implies a sharper increase in extraction costs with declining carbon stock as compared to the IEC scenario such that the third scenario has sharply increasing extraction costs ('SIEC scenario').

To ensure compliance with constant steady state growth rates, we have to check if condition (1.34) holds. Plugging in data leads to $\epsilon < 1.75$. This is fulfilled in all scenarios.

³UNDP (2000, p. 481) define „Reserves“ and „Resources“ as follows: „Reserves: those occurrences of energy sources or mineral that are identified and measured as economically and technically recoverable with current technologies and prices“ and „Resources: those occurrences of energy sources or minerals with less certain geological and/or economic/technical recoverability characteristics, but that are considered to become potentially recoverable with foreseeable technological and economic development“.

⁴based on 5090 Gtoe from UNDP (2000, p. 116)

Furthermore, we have to calibrate γ . It is chosen to ensure an initial carbon flow of $R(0) = 7.76 \text{ GtC}$, which results in an initial carbon price of $q(0) = 0.34 \text{ \$/kgC}$.⁵ Note that the carbon price has a cost component, $k(S) = \gamma S^{-\epsilon}$, and a rent component, p . The rent component is endogenous and driven by the abundance of the resource. It is lower in the more resource abundant scenarios. Thus, γ differs across scenarios: it scales initial extraction costs to be higher in the more resource abundant scenarios to ensure the same initial resource price. In the CEC-scenario, initial resource extraction costs turn out to be $0.23 \text{ \$/kgC}$, while they are slightly higher in the IEC-scenario with $0.30 \text{ \$/kgC}$ and even higher in the SIEC-scenario with $0.31 \text{ \$/kgC}$.

Given $q(0)$, we can calculate rent to price ratios — the rent share in the price — to compare the different model results with available data. The rent to price ratios of the CEC-, the IEC- and the SIEC-scenario are 33%, 11% and 9% for 2005, respectively. [Bauer et al. \(2013\)](#) present data for 2010 with rents close to zero for natural gas and coal in Russia, but rent to price ratios around 50% for crude oil in the Middle East and North Africa, natural gas in EU27 and coal in China as well as around 30% for crude oil in the USA. The average rent to price ratio for some European countries (namely the Netherlands, Denmark, United Kingdom and Norway) in 1999 for oil and gas was 34% (calculation based on [European Commission \(2002\)](#)). If coal were included, the rent to price ratio would probably decrease. This is the case because coal with a reserve to production ratio⁶ of 224 a is relatively more abundant than oil and natural gas with reserve to production ratios of 40 and 62 a, respectively ([Feygin and Satkin, 2004](#)).⁷ The comparison suggests that currently observed scarcity rents are more in line with the CEC scenario.

To match reported data on rent to price ratios in the scenarios with a more abundant initial resource stock, the rent to price ratios in these scenarios would need

⁵Note that $\text{\$/kgC} = 10^{12}\text{\$/GtC}$.

⁶The reserve to production ratio gives the period the resource stock lasts at the current extraction rate.

⁷The reserve to production ratios in the CEC, the IEC and the SIEC scenario are 79, 387 and 773 a, respectively.

to be higher. To achieve this, one would have to assume a lower carbon flow price $q(0)$. As a consequence, the carbon flow $R(0)$ would be higher. Both would be a contradiction to reported data.

1.4 Results

1.4.1 First-best Policy

Before coming to our main point of estimating a window of opportunity, we look at the welfare gain of an instantaneously implemented optimal policy over laissez-faire. For the CEC scenario, one gains a relative intertemporal equivalent variation of $h = 0.0054\%$ corresponding to an absolute intertemporal equivalent variation of $W = 71.6$ billion \$, a share of 0.16 % of 2005 GDP, a tiny number indeed. The gain in the IEC scenario is larger, but still small. The relative intertemporal equivalent variation is $h = 0.0361\%$ corresponding to an absolute intertemporal equivalent variation of $W = 452.3$ billion \$, a share of 1.00 % of 2005 GDP. In the SIEC scenario, $h = 0.0559\%$ corresponding to $W = 694.2$ billion \$, a share of 1.54 % of 2005 GDP. This is still small, but larger by a factor of 10 as compared to the CEC scenario.

As the three scenarios are identical otherwise, differences in resource scarcity explain the range of welfare results. If carbon is scarce, markets tend to economize its use which turns out to be good for climate. All calculated global mean surface temperatures for the year 2100 are in the range of the IPCC predictions, but temperatures are lower in the scenarios with a scarcer resource (see Table 1.2). Thus, resource scarcity means less room for favorable climate policy. This result is in line with [Golosov et al. \(2014\)](#) who compare the effect of an optimal tax on scarce oil and abundant coal relative to the laissez-faire allocation. They find that the effect of the tax is large on coal use, but small on oil use.

TABLE 1.2: Comparison of the Predicted Global Mean Temperature Increases for the Year 2100

Scenario	$\Delta^{\circ}\text{C}$ from 1900
CEC	2.1
IEC	3.1
SIEC	3.3
IPCC - B1*	2.4
IPCC - A1B*	3.4
IPCC - A2*	4.2
RICE-2010**	3.6
DICE-2007***	3.1

*based on [IPCC \(2007\)](#): A1B assumes a converging world with very rapid economic growth and balanced technological change; B1 also assumes a converging world, but a rapid change towards a service and information technology; A2 considers a fragmented world with increasing population and slower technological change, **based on [Nordhaus \(2010a\)](#), ***based on [Nordhaus \(2008b\)](#).

As we base our modeling of the economy-ecology interaction on the DICE model, we compare our welfare outcomes to the DICE-2007 results. In the DICE-2007, the net economic welfare gain from optimal policy is 3,400 billion \$, about 0.17% of the discounted value of total future income ([Nordhaus, 2008b](#)). The relative equivalent variation of optimal policy as compared to laissez-faire is $h = 0.2\%$ ⁸, i.e. the net economic welfare gain from optimal policy is 0.2% of the discounted value of total future consumption. The share is slightly larger than 0.17% as it relates to consumption and not to income. The relative equivalent variation of optimal policy as compared to laissez-faire in the DICE-2007 is four times the value in our SIEC scenario and 40 times the value in our CEC scenario.

⁸We calculate h according to the formulas reported in this paper using the discount factors as well as consumption values reported in the DICE-2007.

The main explanation why our welfare results differ a lot from those of the DICE model are again differences in resource scarcity. We deviate from the DICE model as we need an explicitly modeled resource sector for the evaluation of the strong green paradox. The DICE model does not model resource extraction but places an upper limit on carbon emissions. The carbon limit in the DICE-2007 is the same as in our SIEC scenario, but the resource in the SIEC scenario is nevertheless scarce because extraction costs go up rapidly with on-going exploitation.⁹

Furthermore, different from the DICE model, we do neither allow for abatement nor include a backstop technology. In the DICE model, both options give climate policy more influence because, in addition to influencing the timing of emissions, climate policy can also influence the total amount emitted. This gives more room for welfare enhancing climate policy in the DICE model as compared to our model.

In contrast to the discussed fundamental theoretical differences between our model and the DICE model that lead to a larger welfare gain of optimal policy in the DICE model as compared to our model, differences in calibration operate the other way. Calibration between the DICE-2007 and our model differ because we mainly base calibration on the 2010 update, as e.g. the RICE-2010 model — the regionalized version of the DICE model (Nordhaus, 2010b).¹⁰ The prediction for the laissez-faire temperature in the year 2100 is higher in the RICE-2010 than in the DICE-2007 (see Table 1.2). A higher laissez-faire temperature gives more room for favorable climate policy. Everything else equal, the reported calibration differences should lead to higher future laissez-faire temperatures and a corresponding higher welfare effect of climate policy in our model as compared

⁹The predicted temperatures cannot be directly compared as differences stem to a large extent from differences in the calibration of the climate module, see the following discussion.

¹⁰There is an unchecked Excel version of the 2010 DICE model, but the solver is unreliable (Nordhaus and Sztorc, 2013, p. 49). There is a 2013 DICE version, but with a different definition of the baseline scenario. The baseline case now refers to a scenario that extends current policies (as of 2010) until infinity (Nordhaus and Sztorc, 2013, p. 24) instead of considering the laissez-faire outcome.

to the DICE-2007. Still, we expect this calibration effect to be small compared to the theoretical differences.

An obvious question is why we do not, though following Nordhaus in many other aspects, also buy his carbon abundance assumption. The answer is: it is far out because our model would conclude, and in our opinion rightly so, that the carbon use (and thus the carbon emissions) should be much larger in a laissez-faire market equilibrium without extraction costs than it actually is. The DICE model is not forced to come to this conclusion because, strangely enough, the marginal product of carbon use exceeding a certain level is zero.

Simulations with a reduced carbon limit in the DICE-2007 GAMS version (see [Nordhaus \(2008a\)](#)) support our argument that resource scarcity explains the differences in the welfare effects of optimal climate policy. With a carbon limit of 600 GtC as in our CEC scenario, the relative equivalent variation in the DICE-2007 reduces to $h = 0.0047\%$, similar to our CEC result ($h = 0.0054\%$). It is slightly lower than our CEC result due to the already mentioned differences in calibration.

The discussion suggests that resource scarcity is the main driver of the different welfare results of optimal climate policy between the DICE model and our model. The analysis indicates that resource scarcity and global warming should be considered in a joint framework as data indicates that resource rents are substantial, which implies that resources are scarce. Resource scarcity, in turn, reduces the positive welfare effect of optimal climate policy as markets economize on the resource.

1.4.2 Estimating a Window of Opportunity

To evaluate the strong green paradox, we calculate the welfare differences between scenarios with an announced policy and a do-nothing policy. The scenario with an announced policy is a scenario where, in $t > 0$, the tax is introduced that is optimal from then on. In $t = 0$, agents correctly anticipate the

introduction of the tax in $t > 0$. As mentioned before, the time path of the announced intervention starting in $t > 0$ cannot be chosen optimally from the present point of view, taking the anticipation by the market participants into consideration, because such a policy would be time inconsistent and thus not credible. Such a policy would be time inconsistent, because it would be welfare enhancing at the time of policy implementation to introduce the then optimal tax and not the initially announced tax.

We say that an announcement effect exists whenever an announced policy causes a behavior change prior to implementing the respective policy as compared to the do-nothing scenario (weak green paradox). Figure 1.2 illustrates the announcement effect for an implementation lag of 60 years. It shows the percent excess carbon emissions in the scenario with an implementation lag of 60 years compared to a do-nothing policy over time: the positive numbers indicate that emissions in the case with announced policy are initially higher than emissions in the case without policy. The difference increases over time as the extracted resource that causes emissions and capital are not perfect substitutes but exhibit a certain complementarity. After the policy is implemented, emissions are lower compared to the market outcome.

In spite of a negative announcement effect, a lagged implemented optimal policy can still be desirable if the overall welfare effect of the policy is positive. In other words, the occurrence of a weak green paradox does not imply a strong green paradox. If the length of the announcement period is zero, the optimal tax can be implemented immediately (first-best solution). Starting with a length of zero, we increase the length of the announcement period to see if welfare results change.

We find that the overall welfare effect depends on the length of the announcement period: it is positive for small periods, negative for intermediate periods and approaches zero in the very long run. A 'window of opportunity' for favorable climate policy arises. It is defined such that an intervention implemented before its end is welfare increasing, but welfare reducing afterwards. The strong

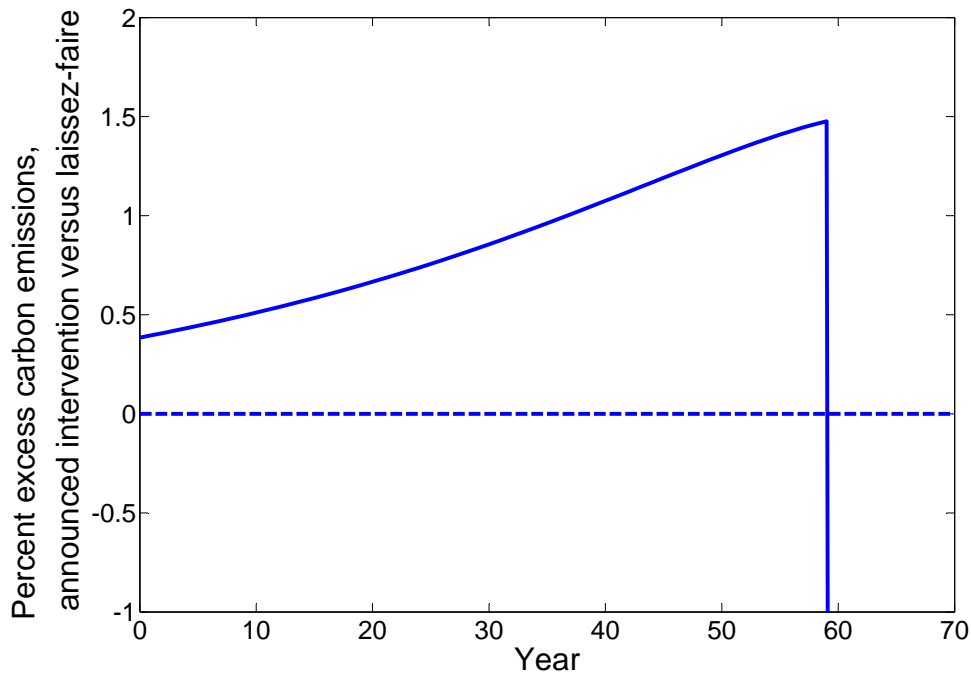


FIGURE 1.2: Emissions: Laissez-faire vs. Announcement Period of 60 Years.

green paradox arises for policies announced to be implemented after the window of opportunity closes. The window of opportunity in the CEC scenario is 12 years, while it is 66 years in the IEC scenario and 96 years in the SIEC scenario. Figure 1.3 illustrates the window of opportunity for the IEC scenario by showing the welfare gain of the (delayed) intervention as compared to no intervention over the length of the implementation lag. A positive number indicates a welfare gain, a negative number indicates a welfare loss implying that a strong green paradox arises. For an announcement period of zero, the figure displays the welfare gain of optimal policy.

Major uncertainties concern the scarcity of the carbon stock, namely its size and the extraction cost curve. Figure 1.4 shows the length of the window of opportunity for $\epsilon = 1$ and $\epsilon = 1.6$ over different initial resource stocks. It shows that the initial stock has a great influence on the window of opportunity, while the influence of ϵ , i.e. of the shape of the extraction cost curve, is small.

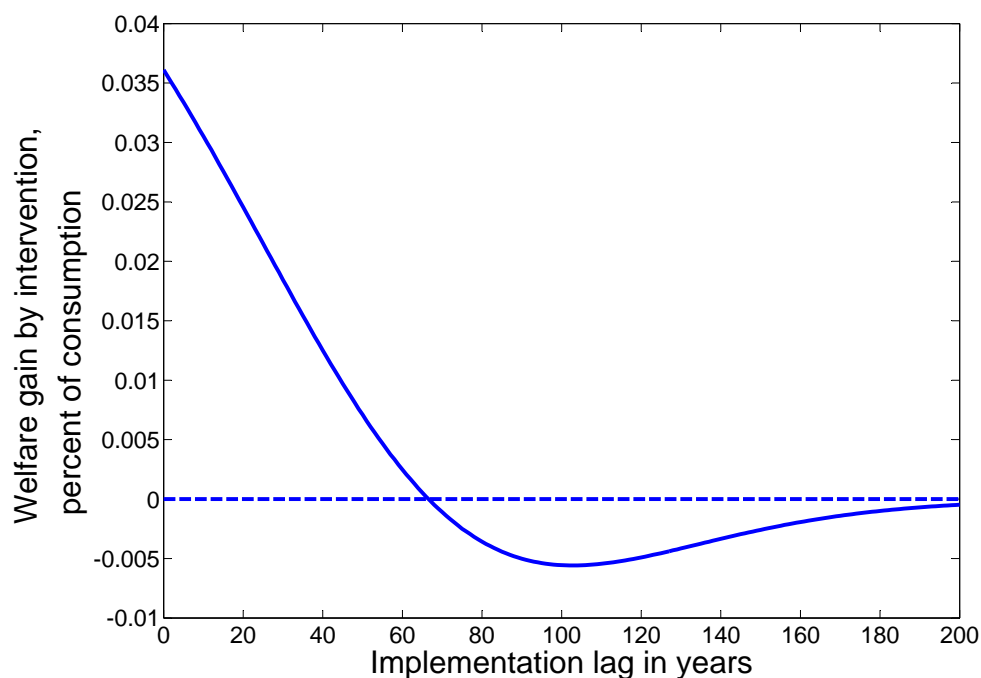


FIGURE 1.3: Window of Opportunity in the IEC Scenario: The Welfare Effect of Lagged Policy Implementation depending on the Length of the Announcement Period.

Other major uncertainties concern discounting and the damage function — 2.4% output loss if the surface temperature increases by 2°Celsius from now seems tiny. Simulations show that a larger output loss means a larger welfare effect, but it has little effect on the window of opportunity. Halving the time preference rate roughly doubles the welfare effect, but only slightly reduces the window of opportunity.

Furthermore, we do not allow for a ‘backstop’ technology that would make it possible to switch to a carbon-free production if the carbon price becomes too high. We also disregard Carbon Capture and Storage (CCS) which would cut through the one-to-one relation between carbon input and emissions. Both options would offer more room for favorable climate policy as they allow not only to influence the timing of but also the total amount of emissions.

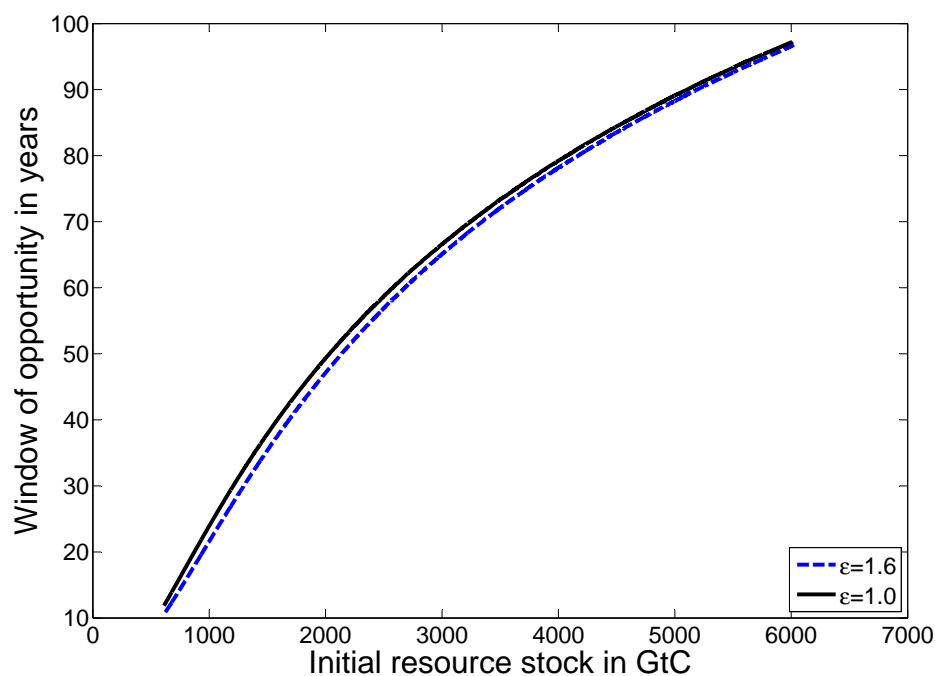


FIGURE 1.4: The Welfare Effect of Lagged Policy Implementation Depending on the Length of the Announcement Period for different initial Resource Stocks.

1.5 Conclusion

This paper is on the evaluation of the overall welfare effect of announced climate policy. The Kyoto Protocol is a prominent example for announced climate policy: between the agreement on the policy in 1998 and its implementation in 2008 was an announcement period of 10 years.¹¹ If climate policy cannot be implemented immediately due to political and bureaucratic procedures, resource owners anticipate the future emissions restrictions and increase extraction in the meantime. This negative effect is well established in the literature. Still, should the policy be implemented or not? It is a priori not clear if the reduction in emissions occurring with policy implementation can more than compensate increased emissions during the announcement period or not.

¹¹One may argue that the Kyoto protocol was not the implementation of the policy that was optimal from 2008 on as proposed in our analysis. Still, the Kyoto protocol gives an example for the existence of an announcement period.

Our analysis confirms that an announcement effect — a behavior change prior to the implementation of the policy — exists and that its effect is quantitatively relevant for the overall welfare effect in state-of-the-art models. Laissez-faire is better than intervention if the implementation lag is longer than the window of opportunity. How long is the window of opportunity? Unfortunately, this depends strongly on the carbon resource scarcity that we know little about. If the in-ground carbon stock is large (IEC or SIEC scenario), the window is long enough. But a stock that large implies tiny scarcity rents today, which seems to be at odds with the data. Hence, the window may be considerably shorter, meaning that the possibility of a strong green paradox is at least a matter of concern. Still, even within the implementation time slot, a sooner implementation is a welfare improvement compared to a later implementation.

Chapter 2

When will Higher Interest Payments Lead to More Education?

with Frederik Noack

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.

Key Words: Informal Distorted Credit Markets, Secured Loan, Human Capital, Child Labor, Education, Common Pool Resources

JEL classification: D13, D91, J24, O16, Q20

2.1 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, 2011; 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). Further, 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, 1999a](#), , Chapter 7). Credit markets are also often interlinked with other markets ([Hoff and Stiglitz, 1990a](#); [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 2.2 introduces the model framework and Section 2.3 presents the results without common pool resources. Section 2.4 introduces a common pool resource and presents the new results. Section 2.5 concludes.

2.2 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. 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.

2.2.1 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.

2.2.2 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 ϕ , the amount it borrows $v \geq 0$ constrained by the collateral k according to

$$v \leq k \tag{2.1}$$

at the fixed interest factor τ and the amount $z \geq 0$ it borrows at the fixed interest factor ι with

$$1 < \phi < \tau < \iota < \infty. \tag{2.2}$$

The investment in physical capital constrains the loan size v at the intermediate interest factor τ . 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 τ 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 ι . 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.

2.2.3 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

$$\begin{aligned} c_1 + k + s &\leq h(l, k) + \kappa + v + z \\ c_2 + \tau v + \iota z &\leq h(l, k) + w(1 - l) + \phi s, \\ v &\leq k \end{aligned} \tag{2.3}$$

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

$$\begin{aligned} y(c_1, c_2, l, k, v, z, s, \lambda_1, \lambda_2, \lambda_3) &= u(c_1, c_2) \\ &+ \lambda_1 [h(l, k) + \kappa + v + z - c_1 - k - s] \\ &+ \lambda_2 [h(l, k) + w(1 - l) + \phi s - c_2 - \tau v - \iota z] \\ &+ \lambda_3 (k - v) \end{aligned} \tag{2.4}$$

with shadow prices for consumption λ_1 and λ_2 in the first and second period, respectively, and shadow price λ_3 for the capital constraint of the secured loan. In the next section, we derive the optimal solution.

2.2.4 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

$$\begin{aligned}
u_1 - \lambda_1 &= 0 \\
u_2 - \lambda_2 &= 0 \\
\lambda_1 h_l + \lambda_2 (h_l + w_l) &= 0 \\
\lambda_1 (h_k - 1) + \lambda_2 h_k + \lambda_3 &= 0 \\
\lambda_1 - \lambda_2 \tau - \lambda_3 &\leq 0, & v \geq 0, & v(\lambda_1 - \lambda_2 \tau - \lambda_3) = 0 \\
\lambda_1 - \lambda_2 \iota &\leq 0, & z \geq 0, & z(\lambda_1 - \lambda_2 \iota) = 0 \\
-\lambda_1 + \lambda_2 \phi &\leq 0, & s \geq 0, & s(-\lambda_1 + \lambda_2 \phi) = 0 \\
h + v + z + \kappa - c^1 - s - k &\geq 0, & \lambda_1 \geq 0, & \lambda_1 (h + v + z + \kappa - c^1 - s - k) = 0 \\
h + w + s\phi - c^2 - v\tau - z\iota &\geq 0, & \lambda_2 \geq 0, & \lambda_2 (h + w + s\phi - c^2 - v\tau - z\iota) = 0 \\
k - v &\geq 0, & \lambda_3 \geq 0, & \lambda_3 (k - v) = 0
\end{aligned} \tag{2.5}$$

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

We define the household's consumption discount factor as

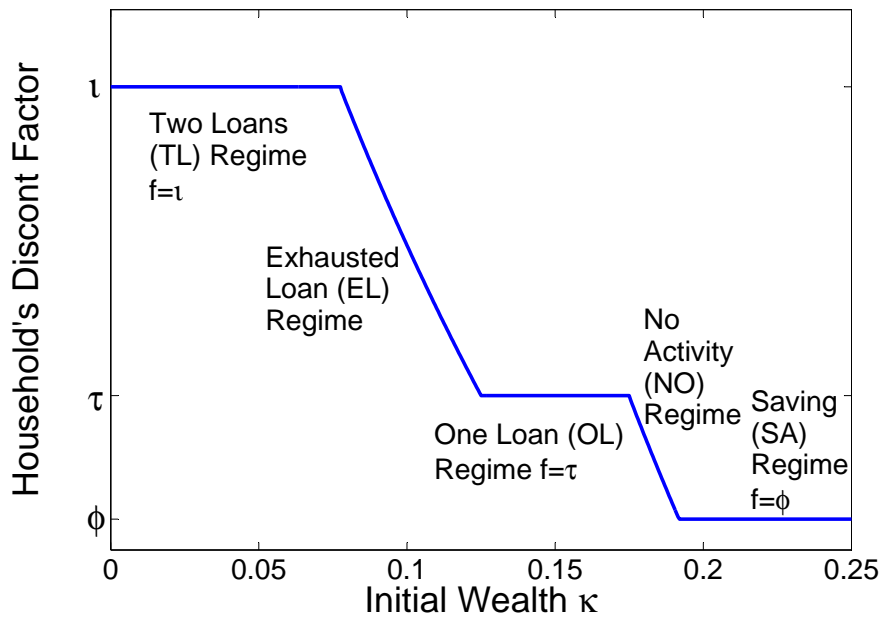
$$f := \frac{u_1}{u_2} = \frac{\lambda_1}{\lambda_2} \tag{2.6}$$

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 2.1. The different credit regimes follow from the Kuhn-Tucker conditions (see Appendix B.1) and will be described in the following.

FIGURE 2.1: 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 2.1). 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

$$\begin{aligned}
 h_l(1 + f) - w_{1-l} &= 0, \\
 h_k(1 + f) - \tau &= 0 \quad \text{for the TL-, EL- and OL- regimes and} \\
 h_k(1 + f) - f &= 0 \quad \text{for the NO- and SA-regimes.}
 \end{aligned} \tag{2.7}$$

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 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.

2.3 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 ι , τ and ϕ 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

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

TABLE 2.1: 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.

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 (2.7) and reduce it to

$$\text{sgn}\left(\frac{dl^j}{di}\right) = \text{sgn}(-y_{li}^*y_{kk}^* + y_{ki}^*y_{lk}^*), \quad (2.8)$$

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 2.1 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 τ (in the TL-,EL-,OL-regimes) or opportunity costs

ϕ (in the SA-regime). If the interest factor for saving ϕ increases, saving becomes more attractive relative to investment in the low-skilled sector. If capital costs τ or opportunity costs of capital ϕ 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 τ . Using (2.8) to evaluate the impact of an increasing unsecured interest factor ι 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 result. A change in the unsecured interest factor ι does not affect capital costs τ (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 affected. Thus, the intertemporal effect determines the overall change. The time allocations in all other credit market regimes are unaffected by a change of ι because capital costs and subjective discounting are independent of ι in all but the TL-regime.

If the secured interest factor τ 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 τ are affected, the productivity effect is present and determines the overall change.

All three effects occur if the secured interest factor τ 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 (2.8) yields

$$\text{sgn} \left(\frac{dl^{EL}}{d\tau} \right) = \text{sgn} \left(\underbrace{f_\tau}_{\text{c. constr. e.}} \underbrace{(h_k h_{lk} - h_l h_{kk})(1+f)}_{\text{intertemp. e.}} \underbrace{-h_{lk}(1+f)}_{\text{prod. e.}} \underbrace{-f_k h_l}_{\text{c. constr. e.}} \right), \quad (2.9)$$

which becomes

$$\text{sgn} \left(\sigma \left(\frac{f + \frac{c_2}{c_1}}{1+f} \right) - 1 - \frac{\eta c_2}{fh} \right) \quad (2.10)$$

after some calculus (see Appendix B.4 for details). Expression (2.10) is positive for a small elasticities of intertemporal substitution η or a large elasticities of substitution in low-skilled production σ . It is negative for a large η and a small σ . 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 τ , 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 τ represents the discount factor as well as capital costs and

$$\text{sgn} \left(\frac{dl^{OL}}{d\tau} \right) = \text{sgn} \left(\underbrace{(h_k h_{lk} - h_l h_{kk})(1 + \tau)}_{\text{intertemporal effect} \quad >0} \underbrace{-h_{lk}(1 + \tau)}_{\text{productivity effect} \quad <0} \right), \quad (2.11)$$

which becomes

$$\text{sgn} \left(\frac{dl^{OL}}{d\tau} \right) \text{sgn} \left(\tau - \frac{1 - \alpha}{\alpha} \right) \quad (2.12)$$

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 (2.12) 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 ϕ represents the discount factor as well as the opportunity costs of capital.

2.4 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

$$\begin{aligned} h_l(1 + f)x - w_{1-l} &= 0, \\ h_k(1 + f)x - \tau &= 0 \quad \text{for the TL-,EL- and OL- regimes and} \\ h_k(1 + f)x - f &= 0 \quad \text{for the NO- and SA-regimes.} \end{aligned} \tag{2.13}$$

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

$$\varepsilon = -\frac{x_h h}{x}. \quad (2.14)$$

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. 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 2.1.

The direction of the overall effect of interest factor changes on time allocation is still determined by (2.8), but with the first order conditions (2.13) instead of (2.7). Although the individual harvester neglects his impact on the resource, his marginal productivity of capital and labor in (2.13) 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 2.2 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 2.2: 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	$= 0$	$= \text{sgn}\left(\sigma\left(\frac{f+c_1^2}{1+f}\right) - 1 - \frac{\eta c_2}{fhx} + \varepsilon\sigma\left(\frac{\eta c_2}{fhx} + \frac{1-c_1^2}{1+f}\right)\right)$	$= 0$
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	$= 0$	$= 0$	$= \text{sgn}\left(\phi - \frac{1-\alpha}{\alpha} + \varepsilon\frac{\sigma(1+\phi)(1-\alpha)}{\alpha}\right)$

The results of Table 2.2 differ from the results of Table 2.1, 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 as well as 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

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

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 that 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

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

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 σ or a large stock elasticity ε .

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

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 ε , 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.

2.5 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 dominates, 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 if 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.

Chapter 3

Estimating the Insurance Premium in Interlinked Credit-Output Contracts

Abstract: On informal credit markets, one often observes a type of credit that does not base interest payments on the loan amount, but on income flows (interlinked credit-output contract). This can be understood as a risk sharing mechanism where interest payments include an insurance premium. This paper shows that the premium increases with the income volatility. Based on observations from small-scale fishing communities around Chilika lagoon, India, the paper also confirms the finding empirically. Furthermore, in contrast to pure credit contracts, interlinked contracts allow fishing boats as collateral around Chilika lagoon. This reduces their interest rate. It explains why interlinked interest rates turn out to be of similar size as micro finance interest rates even though the former include an insurance component.

Key Words: Informal Credit Markets, Credit-Output Interlinkages, Regression Analysis, Risk Sharing, Small-Scale Fishery, India

JEL classification: O16, O17, Q22

3.1 Introduction

Credit markets have the important role of financing investment, of smoothing consumption and, in the case of incomplete insurance markets, of providing some kind of coverage. The need for credit transactions is strongest where households are poorest (Bardhan and Udry, 1999b), and risk has a higher importance in the everyday life of the poor (Besley, 1995). Formal credit and insurance is low in poor areas as formal institutions are rarely existent. Informal arrangements close the gap. One example are credits with interest payments based on income flows, which are often offered by wholesale traders. These credit contracts do not have explicit interest rates, but the borrowers sell their output to the wholesale trader at below market prices. Crow and Murshid (1992, 1994) document these arrangements for the agricultural sector in Bangladesh, while Minten et al. (2012) and Bell and Srinivasan (1989) do so for India. This paper reports similar arrangements for small-scale fishing communities around Chilika lagoon, India. Contracts that jointly determine the transaction conditions in at least two markets are called ‘interlinked’ contracts (Bell, 1988). These interlinked contracts constitute a risk sharing arrangement (Stiglitz, 1974c). In the case of credit-output interlinkages, interest payments are lower (higher) when income flows are lower (higher). As traders provide the lion’s share of informal credit (Hoff and Stiglitz, 1997), this practice deserves attention, especially with respect to the implicit interest rate. One would expect this interest rate to somehow reflect the risk sharing element of the interlinked contracts. One would also expect the interest rate to account for transaction cost savings due to the interaction of borrower and lender on more than one market.

Crow and Murshid (1992, 1994) and Bell et al. (1997) provide evidence that interest rates from interlinked contracts lie above other relevant rates, but regression analyses only exist for interest rate formation of money lenders (e.g. Mallick (2012); Iqbal (1988)) and micro finance institutions (e.g. Baquero et al.

(2012))¹. [Minten et al. \(2012\)](#) are one exemption in that they use a regression analysis to compare interlinked contracts to non-interlinked contracts. They do not calculate implicit interest rates, but compare prices on the output markets: they include a dummy that is one for loan use in the last five years in a regression to explain output prices. The coefficient of the dummy is insignificant, thus, they conclude that interlinkages do not lead to lower implicit output prices. However, this result could also stem from the fact that borrowers already repaid their loan. No study considers a possible effect from sharing income risk on interlinked interest rates even though that is the main theoretical explanation for interlinked contracts, and risk is an important element in the everyday life of the poor.

This paper is to test empirically if the interest rates from interlinked contracts increase with the borrower's income volatility. The idea is that a higher income volatility reflects higher income risk. This constitutes a test of the theoretical prediction that interlinked credit-output contracts are a risk sharing mechanism and that this contract form provides some kind of insurance leading to consumption smoothing. The analysis is based on observations from small-scale fishing communities around Chilika lagoon, India. Furthermore, to my knowledge, this paper is the first one to calculate implicit interest rates from interlinked credit-output contracts for a small-scale fishery and not for agriculture.

Regression results show that borrowers pay the lender for sharing the risk through an insurance premium that takes the form of an interest rate markup. The insurance premium increases with the borrower's income volatility. A theoretical model underpins the empirical results. Furthermore, the interaction of lender and borrower on the credit and the fish market allow the lender to take the fishing boat as collateral. As collaterals lead to lower interest rates, the

¹Further, [Ghatak \(1983\)](#) analyzes rural interest rates on the state level. [Hatlebakk \(2009\)](#) only takes one loan per household and explicitly excludes interlinked contracts.

overall interest rate level in interlinked contracts compares to that of micro finance rates even though the former includes an insurance premium. Sensitivity analysis confirms results.

The paper proceeds as follows: The next section (section 3.2) discusses informal credit markets with interlinked credit-output contracts and presents a theoretical model on interlinked credit contracts. Section 3.3 describes data collection and the fishing villages around Chilika lagoon. It also characterizes the local informal credit markets and calculates the implicit interest rates of interlinked credit-output contracts. Section 3.4 estimates the insurance premium in the interlinked contracts and section 3.5 concludes the paper.

3.2 Interlinked Credit-Output Contracts with Insurance Premium

3.2.1 Informal Credit Markets and Interlinked Credit-Output Contracts

Most theoretical literature on informal credit markets focuses on the explanation of credit constraints and high interest rates (see e.g. [Stiglitz and Weiss \(1981\)](#)) as yearly interest of 40 - 80 % are common on informal credit markets ([Duflo and Banerjee, 2010](#)). The dominant explanations went from monopoly power or perfect competition with high rates due to a high default probability to the imperfect information view ([Hoff and Stiglitz, 1990b](#)).

Asymmetric information implies that adverse selection and moral hazard may lead to involuntary or strategic default. Adverse selection relates to the problem that the lender generally cannot monitor well how the borrower is using the loan. In the end, the borrower may not be able to repay the lender. In the case of moral hazard, the borrower may not even want to repay the credit, even though

he could, because enforcement mechanisms are weak. On markets with well-developed institutions, legal mechanisms or the use of a well-defined collateral ensure repayment.

On informal credit markets, formal enforcement mechanisms are weak, property rights are often poorly defined and wealth put up as collateral is normally not sufficient (see [Ray \(1998\)](#) for further discussions). Thus, lenders on informal markets have to find other ways to ensure loan repayment.

Sometimes, informal lenders can accept collaterals that are not approved by the formal sector ([Ray, 1998](#)). This is especially true for lenders who also do business on other markets (see [Bell \(1988\)](#) and [Bardhan \(1980\)](#) for an overview on interlinked contracts). They already know the borrower which reduces transaction costs. Furthermore, they are in the special position to take specialized production assets or future income flows as collateral, as e.g. discussed in [Riekhof and Noack \(2014\)](#) and [Hoff and Stiglitz \(1997\)](#), respectively. In addition, if default is defined as an interruption in serving interest obligations, interlinked credit-output contracts also reduce the default probability. This obviously suits the lender, but also the borrower as a good credit history is important for future loan supply.

As an interlinked credit generally involves that the borrower has to sell his output to the lender, the trader also benefits from a more productive borrower in the case of a productive investment. The trader has the first right to buy the fish, but for whatever reason, he has no obligation to buy the whole output. An interlinked contract is thus one way for traders to secure the quality of supply.

Traders do not employ the producer to keep up incentives, but as already mentioned, they share the risk. Risk-sharing allows a risk neutral lender to extract payments in addition to credit costs as risk averse borrowers are willing to pay an insurance premium for reduced income risk. The model in the next section illustrates this. The insurance can also be interpreted as a consumption smoothing mechanism as it reduces the income volatility over time.

3.2.2 A Model with Interlinked Credit Contracts

The following model shows that risk averse borrowers always prefer an interlinked contract to a pure credit contract if interest payments are the same. This allows traders to extract additional payments from the lender by offering interlinked credit-output contracts, or in other words, by offering credit contracts with an insurance component. The model further shows that the insurance premium is increasing in the borrower's income volatility.

Consider a small-open economy in which two credit contract types are offered that only differ with respect to their interest payment arrangements. One contract is the standard credit contract that implies interest payments α , the α -contract. Assume that the α -contract is always offered and that its interest rate is fixed, i.e. determined in the rest of the economy. The other contract is an interlinked contract where interest payments occur in the form of the income share $1 - \beta$, the β -contract. The β -contract calls for a monitoring of the borrower's income as the borrower has an incentive to hide income parts to reduce interest payments. Only traders can easily observe the borrower's income and therefore have a monopoly on β -contracts. As the α -contracts are competitive and represent the exit option for the borrower, the trader will choose a limit price policy. He will set β so that the household just prefers the β - to the α -contract.

Now consider credit demand. Assume a risk averse, expected utility maximizing household i who faces stochastic income g_i with expected income $E(g_i) = \mu_i$ and variance $\sigma_i^2 = E(g_i^2) - \mu_i^2$. I omit the subscript whenever this does not lead to confusion. Furthermore, I assume $\mu - \sigma$ preferences. The $\mu - \sigma$ approach is compatible with expected utility maximization if all distributions in the choice set of the household belong to the same linear class or if the utility function is quadratic (Sinn, 1990). For the first result, either of the two conditions may hold.

The household can choose between the two different credit contracts, the α -contract and the β -contract. The household is indifferent between the two contracts if

$$E[u(\beta g)] = E[u(g - \alpha)] \quad (3.1)$$

with u denoting the utility function representing the borrower's preferences.

Assume the trader chooses β such that expected interest payments are equal to α , i.e.

$$(1 - \beta) E[g] = \alpha. \quad (3.2)$$

In this case

$$g - \alpha = g - (1 - \beta)E[g]. \quad (3.3)$$

Using this in (3.1) yields:

$$E[u(\beta g)] \geq E[u(g - (1 - \beta) E[g])]. \quad (3.4)$$

Considering μ - σ preferences, one only has to consider mean and variance

$$E[\beta g] = E[g] - (1 - \beta) E[g] = \beta E[g] \quad (3.5)$$

$$\text{var}[\beta g] = \beta \text{var}[g] \quad (3.6)$$

$$\text{var}[g - (1 - \beta) E[g]] = \text{var}[g]. \quad (3.7)$$

Both contracts have the same mean (by construction), but the β -contract has the lower variance. Thus, a risk-averse borrower who has mean-variance preferences will strictly prefer the β -contract. The trader can increase total payments in the β -contract such that they are higher than in the α -contract. This gives the first result: the borrower is willing to pay an insurance premium in addition to the pure credit costs α .

In case of $\text{var}(g) = 0$, the trader has to set β such that interest payments are equal to α . This implies $\partial(1 - \beta)/\partial\sigma > 0|_{\text{var}(g)=0}$. The insurance premium is increasing in the variance.

To derive analytical results concerning the influence of the variance on β for $\text{var}(g) > 0$, I assume preferences represented by the quadratic utility function $u(g) = g - \lambda g^2$. Its form is problematic because the marginal utility turns negative as incomes become large. I therefore presume that marginal utility turns negative only beyond the range in which g varies: I assume that $u'(\tilde{g}) > 0$ with $\tilde{g} = \beta\mu(1 + \sigma^2/\mu^2)$, i.e.

$$\Delta := 1 - 2\lambda\beta\mu(1 + \sigma^2/\mu^2) > 0.$$

Then, $u'(g) > 0$ for all $g < \tilde{g}$.

The household is indifferent between the two contracts if

$$\begin{aligned} E[u(g - \alpha)] &= E[u(\beta g)] \\ \Leftrightarrow \mu - \alpha - \lambda(\sigma^2 + (\mu - \alpha)^2) &= \beta\mu - \lambda\beta^2(\sigma^2 + \mu^2). \end{aligned} \quad (3.8)$$

Again assume $\beta > 0$, i.e. a positive income of the household after interest payments. It follows from (3.8) that $\beta < 1$ for $\alpha > 0$, $\mu - \alpha = \beta\mu$ for $\sigma = 0$ and $\mu - \alpha > \beta\mu$ for $\sigma > 0$. The last inequality shows the existence of the insurance premium in interlinked contracts. Further,

$$\frac{d\beta}{d\sigma^2} = \frac{\lambda(\beta^2 - 1)}{\Delta\mu} < 0,$$

i.e. the trader's share $(1 - \beta)$ increases with the variance of the income.

To compare different households, it may be more appropriate to consider relative income volatility. A useful measure for relative income volatility is the coefficient of variation, $V_i := \sigma_i/\mu_i$. Divide (3.8) by μ_i to obtain

$$1 - \frac{\alpha_i}{\mu_i} - \lambda\mu_i(V_i^2 + (1 - \frac{\alpha_i}{\mu_i})^2) = \beta_i - \lambda\beta_i^2\mu_i(V_i^2 + 1)$$

as well as

$$\frac{d\beta_i}{dV_i} = \frac{\lambda\mu_i 2V_i(\beta_i^2 - 1)}{\Delta_i} < 0.$$

This is the second result: borrowers with a higher coefficient of variation, i.e. higher volatility relative to their expected income, pay a higher insurance premium given equal preferences.

In the next section, I describe the data used to test if the theoretical result that borrowers with a higher coefficient of variation pay a higher insurance premium holds empirically.

3.3 A Small-scale Fishery and Informal Credit Markets

3.3.1 Data Collection

The dataset used in this analysis is based on a household survey Frederik Noack and I conducted with an interviewer team in 17 fishing villages around Chilika lagoon, Orissa, India, from February 21st to April 12th, 2011. Chilika lagoon is located at the Bay of Bengal and is the largest coastal wetland ecosystem on the Indian sub-continent (Mohapatra et al., 2007). The survey is part of the ‘Integrated Coastal Zone Management’ Program funded by the World Bank.

The area is particularly interesting for this study because most households are indebted and interlinked credit-output contracts exist next to ‘pure’ credit contracts. Furthermore, fishing income varies daily as well as across seasons, which allows to test if a higher income variation leads to higher interlinked interest rates.

To collect the information, we stratified the whole fishing community according to ecological regions and village size. Within villages, we interviewed a total of 509 randomly chosen household heads. In addition to the interviews,

we conducted group discussions and spoke to local stakeholders like money lenders, micro finance organizations and teachers. The data is particularly rich in information on households' fishing activities and on credit markets.

I take the credit contracts as observation units because one household can have several loans. The dataset includes information on 727 credit contracts. Excluding outliers, observations with missing information and credit contracts taken out before 2006 yields 450 observations for 316 households. Outlier detection follows [Barnett and Lewis \(1984, page 159\)](#). The cut-off year 2006 is a decent choice in the trade-off between a high number of observations and a short time lag between raising the credit and the survey.

3.3.2 Chilika Lagoon Fisheries

Chilika lagoon is a brackish water body with salt water inflows from the sea and fresh water inflows from rivers. This leads to four distinct ecological zones that differ in their salinity level, their species diversity and their productivity ([Mohapatra et al., 2007](#)). These zones are geographically separated into the Northern, the Central, the Southern and the Outer Channel sector. The Chilika Development Authority reports 32,530 active fishermen in 2010/11. Total annual catches 2010/11 of fish, crab, shrimp and prawn were 13 thousand metric tonnes ([Directorate of Fisheries, 2013](#)).

Predominantly male members go fishing in groups and share the catch. These so-called 'fishing units' have, on average, three members. If not all members belong to the same household, they use different remuneration systems. In most cases, the catch is divided into equal shares. The number of shares depends on the remuneration of capital: each member receives one share, but often, the boat owner receives an additional share. Sometimes, the net owner also receives an additional share. This implies that the catch is divided into n , $n + 1$ or $n + 2$ equal shares with n displaying the number of fishing unit members. Paying

TABLE 3.1: Remuneration of Fishing Collaborators Within Fishing Units.

	Same family	Equal shares	Add. share boat owner	Add. share boat & net owner	Pay wage	Other/ no answer
Share of households with a certain remuneration system in their fishing unit (in %)	44.0	10.1	19.0	8.2	3.8	14.9

TABLE 3.2: Share of Households that Belong to a Certain Subcaste.

Subcaste	Keuta	Kandara	Khartia	Pandu	Nolia	Other
Share	58.0	16.1	10.8	9.2	3.8	1.9

wages to collaborators is not very common. Table 3.1 gives an overview over the frequency of the different remuneration systems.

Fishermen use different methods to target different species. Fishing methods used to be related to the subcastes of the fishermen (see Table 3.2 for the different subcastes), but that system is not in place anymore. Most households (82.3%) go fishing by boat. Fishing trips last on average two days. The caught fish is usually brought to so-called landing centers, where fish traders buy the fish and either transport it to national or international markets or re-sell it on local markets.

Incomes are low and vary across the three seasons — summer, monsoon and winter — as shown in Table 3.3. There is no lean season as e.g. in agriculture. The average of the coefficient of variations of all households for the fishing income in the different seasons is 0.52 with a standard deviation of 0.35 across households.

Few households have an additional income source besides fishing. In those

TABLE 3.3: Monthly Fishing Incomes Per Fishing Unit for the Three Seasons.

Season	Summer	Monsoon	Winter
Average monthly catch (Indian Rupees) per fishing unit (\approx \$)	5436.8 (108.7)	6114.2 (122.3)	3616.0 (72.3)

cases, fishermen usually work as unskilled laborer to supplement fishing income.

3.3.3 Interest Rates of Interlinked Credit-Fish Contracts

Fish traders provide credits without direct interest payments, but with special agreements about buying the fish from the borrower at a lower price. Calculations based on the borrower's income loss due to selling the fish at a lower price to the fish trader make these implicit interest rates explicit. To distinguish a trader that lends money to a fisher from a trader that does not, I call the former a 'trader-lender'.

Calculations of the interlinked interest rates are either based on income forgone per day due to selling to the trader-lender instead of to another trader or on the amount of Indian Rupees per kg per day the fisher loses due to selling to the trader-lender instead of to another trader. In the first case, I multiply the income forgone per day with the fishing days per month differentiated for the three seasons and then sum over all months to attain the yearly interest payments. In the second case, I multiply the amount lost with the catch in kilograms. The catch in kilograms means the catch of the total fishing unit times the share the household receives according to the sharing mechanisms (see Table 3.1). Then again, I multiply the amount lost per day with the fishing days per month differentiated for the three seasons and then sum over all months to attain the yearly interest payments. The principal is repaid separately. One could say that interest is paid in fish and the principal is paid in money.

Relating the resulting total yearly interest payments to the yearly fishing income of the household gives the share the trader-lender receives as interest payments. On average, the trader-lender receives 23.6%. Relating the yearly interest payments to the loan amount gives the yearly interest rate. The average interest rate for a loan from a trader-lender is 28.0% p.a.

One difficulty is that possible repayments change the loan amount during the year. The dataset only provides the initial loan amount and the amount that still needs to be repaid, but these two values only differ in 25% of the cases. The average debt from those loans that report a change is still close to 85% of the initial amount. This suggests that relating the yearly interest payments to the currently outstanding debt does not lead to a severe overestimation of the interest rate. Furthermore, it is not unusual that the repayment of larger investments takes several years. In the next section, I relate the information on the trader-lender to other lender types.

3.3.4 Informal Credit Markets around Chilika Lagoon

Several lender types are available on the credit markets around Chilika lagoon, which is typical for rural credit markets in less developed economies (see e.g. [Menkhoff et al. \(2012\)](#)). Besides trader-lenders, who provide 24.2% of all loans, money lenders, who provide 27.7% of all loans, and micro finance institutions, who provide 26.4% of all loans, are important loan sources. Other loan sources include cooperatives and banks as well as friends, neighbors and relatives.

Loan conditions vary a lot between the different lender types. In general, micro finance organizations only allow business loans. For fishermen, this implies loans for fishing purposes. It may be difficult to ensure this restriction. Our data shows that loans are indeed not only used for fishing purposes. One peculiarity about micro finance loans is the rigid repayment structure that lowers administration costs ([Duflo and Banerjee, 2010](#)). Around Chilika lagoon, over

TABLE 3.4: Business Models of Different Lender Types.

Lender type	Business model
Money lenders	Individual screening, customized loan
Micro finance	Standardized procedure
Fish traders	Interlinked contracts, fishing asset and harvest as collateral
Friends, ...	Everyday interaction, personal ties
Banks	Individualized screening, formal collateral
Cooperatives	

90% of the micro finance loans are repayed on a weekly basis. There are no special conditions to attain a loan from a money lender. In addition, money lenders seem to offer very customized loans. Banks normally require formal collateral, like land, that most households cannot provide. Cooperatives used to be rather active on the credit markets around Chilika lagoon, but at the moment, most of them do not function anymore. Borrowing from and lending to people one knows is very typical when other credit sources are rare. For an overview on the different business models of the lender types see Table 3.4.

As it is also typical for many rural credit markets in less developed economies, interest rates are high and loan amounts comparably small. Table 3.5 depicts the average yearly interest rate as well as the average loan amount for the different lender types. Interest rates are nominal and calculated as of 2011. The inflation rate is around 10% p.a. based on the consumer price index for agricultural laborers in Orissa ([Government of Orissa, 2011](#)). On average, cooperatives charge lowest and money lenders charge highest rates. The average yearly interest rate obtained from fish traders lies between interest rates from banks and from micro finance institutions. Superficially, it seems that, on average, the insurance premium is not shown in form of an interest rate mark-up as postulated by the theoretical model in section 3.2.2. The empirical analysis in section 3.4 will, however, reveal that an insurance premium in form of an interest rate mark-up does exist, but that other effects reduce the interest rate from interlinked loans as compared to other loans. The average loan amount is lowest from cooperatives and highest from banks, but the average amount lent by banks is still

TABLE 3.5: Data on Credit Markets.

Lender type	Share in total number of loans	Average amount	Mean interest rate p.a.
Micro finances	30.7%	16355.1 Rs	32.8%
Money lenders	26.7%	35700.0 Rs	47.6%
Fish traders	23.8%	30773.0 Rs	28.0%
Friends, ...	7.3%	45666.7 Rs	42.8%
Banks	4.0%	54722.2 Rs	25.5%
Cooperatives	3.8%	13558.8 Rs	18.0%

small, roughly 1100 \$. The average amount lent by fish traders is similar to the amount lent by money lenders, roughly 620 \$.

The most prominent mechanism to ensure repayment is violence (in 62.5% of all loans). Further mechanisms include social sanctions and the threat to cut off future credit supply. Only 2.5% of all loans are secured by formal collateral. The secured loans are mainly loans from banks and cooperatives. In nearly all cases, the collateral is in the form of land.

A share of 34.7%, 21.6%, 31.1% and 12.7% of the loans are by households living in the Southern, the Northern, the Central and the Outer Channel sector, respectively. This roughly represents the distribution of the surveyed households, which is based on the proportions of fishing households living in the respective sectors.

Fishermen are self-employed such that households demand credit for productive as well as consumptive purposes. In the former case, one sometimes differentiates between fixed and working capital (Ray, 1998). In the small scale fishery, the need to finance fixed capital, like boats and nets, is relatively more important because fishermen normally sell the fish the same day they catch it such that the need for financing working capital is only relevant if they go on longer fishing trips. Still, some households have working options outside of fisheries where the financing of working capital may be important. Demand for consumptive credit arises if income falls, for example due to seasonality in

TABLE 3.6: Importance of Loan Purposes.

Loan purpose	Share that has certain purpose as main purpose	Share that has certain purpose as second purpose
Fishing activities	53.8%	1.2%
Consumption needs	19.6%	-
Ceremonies	12.7%	1.2%
To pay other debts	2.7%	-
Education of Children	2.4%	0.3%
Emergencies	1.5%	0.3%

Note that not all loans have more than one purpose. Less important purposes are not reported in detail.

fish catches, a decrease in prices or fish stocks, or if consumption needs increase, for example due to weddings, illness or death (Ray, 1998).

Most households (86.1 %, n=316) around Chilika lagoon are indebted and about half of the indebted households have more than one loan. The main purposes for taking out a loan for the fishery households around Chilika lagoon are fishing activities as well as consumption needs (see Table 3.6). Education is not a major loan purpose. Literacy levels around Chilika lagoon are low, only 65.5% of all people older than 10 years are literate, still almost all (96%) households have a literate household head.

3.4 Empirical Estimation of the Insurance Premium in Credit-Fish Contracts

3.4.1 Baseline Results

This section empirically examines the hypothesis that interlinked credit-output contracts include an insurance component. To be precise, the empirical model examines if the interest rate of an interlinked contract increases with the borrower's income volatility as proposed by the theoretical model. This would be

evidence for an insurance premium and for risk sharing in interlinked contracts as suggested by [Stiglitz \(1974c\)](#).

For information on usual interest payments I include the interest rates from 'pure' credit contracts, i.e. α -contracts, in the analysis. The derivation of the implicit interest rates of the interlinked contract, i.e. the β -contract, is described in section [3.3.3](#).

To measure income volatility, I use the coefficient of variation V . This is in line with the theoretical model of section [3.2.2](#). The measure implies that relative and not absolute income variation matters, which fits with the observation that different households face different needs and different income levels. The coefficient of variation is calculated for the households' fishing incomes over the three seasons. The theoretical model in section [3.2.2](#) postulates that the coefficient of variation is below one. This is the case in 93% of the contracts.

To test if interest rates from interlinked contracts increase with the relative income variation, I interact the coefficient of variation V with a fish trader dummy. The fish trader dummy is one if the credit contract is an interlinked contract. I also include V and the fish trader dummy on their own to control for their individual effects on the interest rate.

Furthermore, to analyze the special role of the fish trader with respect to transaction costs saving, I include a boat dummy interacted with a fish trader dummy. The resulting dummy is one if the household has a boat and the loan is from a fish trader. It tests if fish traders have a special position in allowing a fishing boat as collateral. I also include a dummy that is one if the household has a boat to control for the individual effect of boat ownership.

To sum up, I regress the interest rates from interlinked and pure credit contracts on V , V interacted with a fish trader dummy, a fish trader dummy, a boat dummy, the boat dummy interacted with a fish trader dummy as well as on several controls. I control for the income level, loan properties, household characteristics as well as the lender type.

As fishing income volatility is correlated with the fishing income level, I include the yearly fishing income level, i.e. the catch value of the fishing unit weighted by the share the household receives, to control for this effect. This leads to two additional problems. First, income may be endogenous as the loan could be used to increase productivity and thus income. The included dummy that equals one if the household owns a fishing boat controls for this effect. Second, the cross-sectional data does not give income information for earlier years. Income data is based on 2010/11, while loans are taken out between 2006 and 2011 such that especially the conditions for earlier loans may be based on different incomes. As incomes seem to vary more between the sectors than over the years, I include sector dummies. The sector may be more relevant than the income of an individual year as incomes are uncertain and a certain year may have been especially good or bad for the household so that the general productivity of the fishing grounds may matter more. The sector effects are estimated as deviation from their mean, i.e. the sum of all sector effects is constrained to equal zero.

In terms of loan properties, I include the loan size, the maturity and whether a formal collateral secures the loan. The signs of the coefficients of the loan size and of maturity are not clear. In the case of repeated lending or fixed costs, the interest rates fall with the loan size and with maturity. Small loans with short maturity are used as initial test on the credibility of a new borrower. Furthermore, for smaller loans or shorter maturity, fixed costs are distributed over a smaller amount or a shorter time period, respectively. Contrary to that, a larger amount and a longer maturity increase the default risk which leads to a positive relation. Maturity is measured in years and is only greater than zero if a fixed repayment date exists such that the coefficient measures both the effect of the length of the maturity and whether a fixed repayment date exists. I include a dummy that equals one if the household provides formal collateral for the loan. Its coefficient should have a negative sign as a collateral reduces the default risk. Still, some authors propose a positive relationship because lenders increase the interest rate to appropriate the collateral in case of default.

Household characteristics include literacy and subcaste. As the data does not give information on whether any or how many literate people were part of the household the year the loan was taken out, the dummy considers only the literacy of the household head. The dummy equals one if the household head is literate. I further include dummy variables for the three most important subcastes as a measure for social networks.

Individual data on the specific lender is not available, but the survey gives information on the lender type, i.e. if the loan is from a money lender or a micro finance institution. As the discussion in section 3.3.4 shows, business models between the lender types differ substantially. The main variation in lender specific effects may thus depend more on the lender type and less on the individual person. Given the available data, I therefore control for the lender type by introducing fixed effects.

As one household can have more than one loan, certain regressors only vary with the household level. To take the group structure of the error terms into account, I use clustered error terms for the computation of standard errors. The estimated coefficients are not affected.

The first column of Table 3.7, 'OLS', gives the results of the ordinary least square (OLS) estimation with clustered error terms at the household level. The effect of the coefficient of variation on the interest rate is in general negative and insignificant, but positive and significant for interest rates from loans taken out from a fish trader. First, this shows that income volatility only matters for the interest rates of interlinked credit contracts. Second, it confirms the hypothesis that interest rates from fish traders contain an insurance premium that is increasing in the borrower's income volatility. If the coefficient of variation is increased by 1, the interlinked interest rate increases by 13.3 percentage points. If the coefficient of variation is increased by its standard deviation of 0.35, the interlinked interest rate increases by 4.7 percentage points. The results provide empirical evidence for the theoretical result that interlinked contracts are a risk sharing arrangement.

TABLE 3.7: Estimation Results.

Interest rate p.a.	OLS	OLS(2)	OLS(3)	OLS(4)	Treatreg	> 2008
V	-0.0156 (0.0285)	-0.0170 (0.0284)	-0.0152 (0.0285)	-0.0183 (0.0286)	-0.0157 (0.0276)	-0.0431 (0.0342)
V × Fish Trader	0.1327** (0.0648)	0.1327** (0.0650)	0.1316** (0.0642)	0.1363** (0.0647)	0.1320** (0.0633)	0.1228 (0.0918)
Boat	-0.0179 (0.0411)	-0.0173 (0.0413)	-0.0189 (0.0420)	-0.0214 (0.0409)	-0.0198 (0.0404)	-0.0178 (0.0491)
Boat × Fish Trader	-0.1963** (0.0840)	-0.1970** (0.0840)	-0.1960** (0.0842)	-0.1936** (0.0840)	-0.1947** (0.0819)	-0.2118** (0.1007)
log(Fishing Income)	-0.0318*** (0.0118)	-0.0321*** (0.0118)	-0.0320*** (0.0117)	-0.0302** (0.0119)	-0.0319*** (0.0115)	-0.0330** (0.0136)
Sector 1	-0.0623*** (0.0167)	-0.0635*** (0.0167)	-0.0622*** (0.0167)	-0.0620*** (0.0167)	-0.0615*** (0.0163)	-0.0475** (0.0200)
Sector 2	-0.0213 (0.0196)	-0.0195 (0.0198)	-0.0204 (0.0191)	-0.0226 (0.0196)	-0.0203 (0.0190)	-0.0184 (0.0224)
Sector 3	-0.0089 (0.0221)	-0.0072 (0.0222)	-0.0098 (0.0223)	-0.0096 (0.0221)	-0.0092 (0.0215)	0.0180 (0.0244)
Sector 4	0.0925*** (0.0249)	0.0902*** (0.0250)	0.0924*** (0.0249)	0.0943*** (0.0245)	0.0911*** (0.0245)	0.0480* (0.0246)
log(Maturity)	-0.0320** (0.0145)		-0.0320** (0.0145)	-0.0264* (0.0143)	-0.0318** (0.0144)	-0.0425** (0.0189)
log(Loan Size)	-0.0029 (0.0090)	-0.0029 (0.0090)		-0.0038 (0.0091)	-0.0027 (0.0088)	-0.0049 (0.0118)
if Collateral	-0.0934* (0.0498)	-0.0771 (0.0488)	-0.0945* (0.0495)		-0.0896* (0.0491)	-0.1053** (0.0524)
Literacy	0.0134 (0.0202)	0.0124 (0.0203)	0.0133 (0.0202)	0.0107 (0.0203)	0.0137 (0.0197)	0.0041 (0.0235)
Keuta	0.0634** (0.0274)	0.0639** (0.0279)	0.0630** (0.0272)	0.0724*** (0.0274)	0.0622** (0.0271)	0.0423 (0.0279)
Kandara	0.0562 (0.0460)	0.0567 (0.0466)	0.0565 (0.0460)	0.0641 (0.0465)	0.0563 (0.0449)	0.0467 (0.0467)
Khartia	-0.0492 (0.0354)	-0.0446 (0.0357)	-0.0504 (0.0355)	-0.0385 (0.0354)	-0.0487 (0.0344)	-0.0865** (0.0371)
Money Lender	0.0086 (0.0638)	0.0223 (0.0646)	0.0063 (0.0638)	0.0155 (0.0653)	0.0103 (0.0636)	0.0068 (0.0723)
Fish Trader	-0.0730 (0.1111)	-0.0578 (0.1110)	-0.0740 (0.1116)	-0.0689 (0.1122)	-0.0424 (0.1262)	-0.0659 (0.1340)
Friends, ...	-0.0243 (0.0686)	-0.0097 (0.0689)	-0.0266 (0.0687)	-0.0164 (0.0699)	-0.0211 (0.0688)	0.0030 (0.0764)
Bank	-0.1541* (0.0788)	-0.1616** (0.0805)	-0.1563** (0.0783)	-0.1631** (0.0804)	-0.1547** (0.0771)	-0.0932 (0.0972)
Micro Finance	-0.0966 (0.0622)	-0.1139* (0.0640)	-0.0976 (0.0622)	-0.0951 (0.0634)	-0.0964 (0.0614)	-0.1017 (0.0703)
Cooperative	-0.2051*** (0.0709)	-0.2117*** (0.0722)	-0.2048*** (0.0707)	-0.2335*** (0.0712)	-0.2039*** (0.0701)	-0.2213*** (0.0787)
Constant	0.8432*** (0.1757)	0.7994*** (0.1726)	0.8200*** (0.1541)	0.8191*** (0.1787)	0.8365*** (0.1726)	0.9197*** (0.2090)
n/Clusters	450/316	450/316	450/316	450/316	450/316	336/241
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Clustered standard errors in parenthesis, ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

The ownership of a boat reduces the interest rate in general, but the effect is only significant if the loan is from a fish trader. This highlights the special role of the fish trader as credit provider and his ability to take a productive asset as collateral. This may also explain why the average interest rate for interlinked loans reported in Table 3.5 does not differ a lot from micro finance rates, even though the former includes an insurance premium.

In general, securing the loan by a collateral significantly reduces the interest rate. A higher fishing income - which can be interpreted as a collateral - also significantly reduces the interest rates. The important role of collaterals and especially of non-formal collaterals are in line with [Menkhoff et al. \(2012\)](#).

The negative signs of the 'log loan size'-coefficient (not significant) and the 'log maturity'-coefficient (significant) imply that a larger loan amount and a larger maturity reduce the interest rate. This fits the interpretation that fixed costs play an important role and that distributing the fixed costs over a larger loan amount and a longer repayment period reduces unit costs and thus the interest rate.

Other than expected, a literate household head increases the interest rate, but the effect is insignificant. A reason for this may be that literate people have better job opportunities outside of fisheries, which may increase the probability to migrate with default as an attractive option. If a household belongs to the subcaste 'Keuta', it faces a significantly higher interest rate.

Only the sector dummies for sector 1 and 4, the Central and the Outer Channel sector, respectively, are significant. Based on an F-test, the Null hypothesis that all four coefficients are the same can be rejected ($F(2,428)=1.99$ with $p=0.000$). This result means that the interest rates in the Central sector are significantly higher than the average. Interest rates in the Outer Channel sector in turn are significantly lower. As the Outer Channel sector seems to be the relatively less connected and most backward sector with an average yearly fishing income of less than 65% of the Central sector - the sector with the highest average yearly fishing income - , this result fits the findings of [Bhattacharjee and Rajeev \(2010\)](#)

that less developed areas face higher interest rates and of [Shami \(2012\)](#) that more connected areas reduce the exploitive nature of interlinkages.

The constant can be interpreted as the yearly interest rate from non-specified sources, all dummies being zero, while the effects of maturity, loan amount and of the fishing income still have to be subtracted. In the OLS estimation, the base-line interest rate is 84.3% p.a., which is above the mean interest rates reported in [Table 3.5](#), as the effects just mentioned have not yet been incorporated.

The lender fixed effects capture all unobserved lender dependent influences. In other words, they report the lender specific interest rate differences that can not be attributed to one of the included regressors.

3.4.2 Alternative Model Specifications

The particular concern with the estimation is that the data gives equilibrium outcomes. It is not clear if one observes the credit supply or the credit demand curve or a combination of both such that a simultaneous equation model of credit supply and demand may be more appropriate. As the focus is on the interest rate formation based on the supply side, the concern is the possible endogeneity of the loan amount. One could argue that the specification of the collateral as well as the loan maturity are also simultaneously determined with the interest rate and the loan amount. To check results, I estimate the model by consecutively leaving out 'maturity', 'loan amount' and 'collateral'. As results do not change a lot (see [Table 3.7](#) columns OLS(2), OLS(3), and OLS(4)), endogeneity of the variables does not seem to cause problems.

To confirm that a possible endogeneity of the loan amount does not cause problems, I additionally estimate a model where I use the loan purposes as instruments for the loan amount. The loan purposes are exogenous variables on the demand side that do not appear on the supply side. The estimation procedure and results are given in [Appendix C.1](#). Again, results do not provide evidence

for an endogeneity problem. Furthermore, the evidence for an insurance premium remains, namely, the effect of the coefficient of variation if the loan is from a fish trader is still positive and significant.

One could argue that the Heckit method (Heckman, 1976; Wooldridge, 2010) should be applied because interest rates of debt free households are not observed. If the aim of the study was to explain a household specific interest rate, one should indeed take the possibility of a selection bias into account. Households may not hold loans because no one is willing to lend to them. In this study, I explicitly want to explain different interest rates for the same household such that I take the credit contracts and not the households as observation units. As there are infinitely many credit contracts that did not materialize and with no available information I concentrate on observed credit contracts.

Another concern is that the households self-select into an insurance, i.e. into an interlinked credit-fish contract. If the insurance choice is endogenous, it should be modeled directly. Otherwise, the impact of the insurance on the interest rate will be biased. For contracts that entail insurance, households may be willing to pay a higher interest rate. I re-estimate the model with a treatment effect where the insurance choice is explained with a probit model. As one household may have multiple loans, the question is not if the household chooses insurance in general but why it chooses insurance in combination with a specific loan.

To explain why the household chooses insurance in combination with a specific loan, I include the following variables in the probit model:

- One important reason may be the loan purpose. If a loan is taken out in case of an emergency, insurance probably does not matter. In turn, investment in fishing activities may lead to unforeseeable changes in income flows calling for insurance. I thus include one dummy variable that equals one if the loan purpose is fishing activities and a second dummy variable that equals one if the loan was taken out due to emergencies.

- To consider the role of income volatility for an insurance choice, I also include V even though it is not loan but household specific. I thus expect its effect on the insurance choice to be low.

Estimation results are similar to the OLS results (see Table 3.7 column 'treatreg'). The correlation between the error of the regression equation and the error of the selection equation is $\rho = -0.1158$. The likelihood ratio tests that the equations are independent ($\rho = 0$) indicates that there is no problem of endogenous selection ($\text{Prob} > \text{Chi}^2 = 0.5666$). Furthermore, the effect of the coefficient of variation on the probability to choose an interlinked contract is positive, but insignificant.

To check if the time difference between income information and receipt of the credit matters, I estimate the model by only using loans taken out more recently, i.e. after 2008. The coefficient of the relative income variation if the loan is from a fish trader is still positive and of a similar size as before, but not significant anymore (see Table 3.7 column '>2008'). This means that the effect within the sample is as before, but that the result does not carry over to the whole population. This may be due to the smaller sample size.

As a last robustness check, I include a dummy that is one if the household head has an alternative income source in addition to fishing. This is relevant for 19.3% of the credit contracts. An additional income source may depict another way of smoothing income flows making an insurance via an interlinked contract unnecessary. Appendix C.2 reports results, which are similar to the baseline results. The effect of the dummy is positive, but insignificant. The sign is unexpected, as one would assume that income alternatives reduce default risk. Around Chilika lagoon though, incomes outside of fisheries may rather be a sign for low fishing incomes and thus a sign for a higher default risk.

3.5 Conclusion

Even though traders provide the lion's share of informal credits, their interest rate formation has received little empirical attention. The main theoretical explanation for interlinked credit-output contracts is risk sharing. This paper provides empirical evidence for that hypothesis by showing that income risk matters for interest rates from interlinked contracts. It calculates the implicit interest rates of interlinked credit-fish contracts. Empirical estimations show that these interest rates contain an insurance premium. In other words, borrowers pay an interest rate mark-up to the lender for sharing the risk. The insurance premium increases with the borrower's income volatility.

In addition, the analysis shows that fish traders are able to take fishing boats as collateral, while other lenders are not. This stresses the special position of the traders and illustrates transaction costs savings. It further explains why the level of interlinked interest rates compares to micro finance rates, even though interlinked rates include an insurance premium.

The results highlight that interlinked credit contracts in contrast to pure credit contracts provide an important additional service in the case of missing markets, namely insurance. Still, the theoretical model showed that pure credit contracts have an important role for limiting interest rates of interlinked contracts because they exhibit the exit option to interlinked contracts.

Appendix A

Appendix to Chapter 1

A.1 Overview Units

TABLE A.1: Overview Units.

Abbreviation	Explanation
\$	2005 US dollars
GtC	giga tons carbon
kgC	kilograms carbon
Gtoe	giga tons oil equivalent
kgoe	kilograms oil equivalent
a	annum
°C	degree Celsius
Δ°C from 1900	degree Celsius difference from temperature level in the year 1900

Note that $\$/\text{kgC} = 10^{12}\$/\text{GtC}$.

A.2 Calibration

TABLE A.2: Overview Variables

Symbol	Explanation	Value	Unit	Source
C	consumption		10^{12} \$ /a	endogenous
E in 2005	emissions from land use change	1.1	GtC/a	Nordhaus (2008b) , see note 1
R in 2005	extracted car- bon resource flow = emis- sions	7.7578	GtC/a	EIA (2010) , IEA (2007) , see note 2
M_1 in 1750	carbon mass in atmosphere	596.4	GtC	Nordhaus (2008b) , Nordhaus (2010b)
M_1 in 2005	carbon mass in atmosphere	808	GtC	Nordhaus (2010b)
M_2 in 2005	carbon mass in upper ocean	1600	GtC	Nordhaus (2010b)
M_3 in 2005	carbon mass in lower ocean	10010	GtC	Nordhaus (2010b)
P_M	shadow prices carbon stocks		utils/GtC	endogenous
P_T	shadow prices of tempera- tures		utils/ $\Delta^\circ\text{C}$ from 1900	endogenous
P_K	shadow price of capital stock		utils/ 10^{12} \$	endogenous
P_S	shadow price of carbon stock		utils/GtC	endogenous

q in 2005	carbon flow price	0.3415	\$/kgC	EIA (2010) , see note 3
v	netto carbon flow price		\$/kgC	endogenous
l^*	steady state interest rate	0.042	1/a	see note 4
S in 2005	carbon stock	612; 3000; 6000	GtC	see section 1.3
T_1 in 2005	global mean surface temperature	0.83	$\Delta^\circ\text{C}$ from 1900	Nordhaus (2010b)
T_2 in 2005	temperature lower ocean	0.0068	$\Delta^\circ\text{C}$ from 1900	Nordhaus (2010b)
U	overall utility		present value utils	endogenous
u	instantaneous utility		utils/a	endogenous
Y in 2005	GDP	45.23	$10^{12}\$/\text{a}$	Worldbank (2009)
r	tax rate		\$/kgC	endogenous
h	relative intertemporal equivalent variation		1	endogenous
W	absolute intertemp. equiv. variation		$10^{12}\$$	endogenous

TABLE A.3: Parameters Taken from Literature

Symbol	Explanation	Value	Unit	Source
Γ	carbon transition matrix	$\begin{bmatrix} -0.0120 & 0.0047 & 0 \\ 0.0120 & -0.0052 & 0.0001 \\ 0 & 0.0005 & -0.0001 \end{bmatrix}$	1/a	Nordhaus (2010b), see note 5
δ	depreciation rate	0.05	1/a	Barro and Sala-i Martin (2004)
α	income fraction capital	0.33	1	Barro and Sala-i Martin (2004, page 58)
θ	inverse of the intertemporal elasticity of substitution	1.5	1	Nordhaus (2010b)
Λ	temperature interaction matrix	$\begin{bmatrix} -0.0345 & 0.0066 \\ 0.0050 & -0.0050 \end{bmatrix}$	1/a	Nordhaus (2010b), see note 7
ρ	time preference rate	0.015	1/a	Nordhaus (2010b)

TABLE A.4: Calibrated Parameters

Symbol	Explanation	Value	Unit	Source
K in 2005	capital stock		$10^{12}\$$	Calibration: $\hat{K}(2005) = \hat{Y}(2005)$
β	income fraction resource	0.058	1	Calibration: $\frac{q_{2005}R_{2005}}{Y_{2005}}$, see note 2

λ	rate of technological progress	0.0134	1/a	Barro and Sala-i Martin (2004) (page 13), see note 8
γ	scaler extraction costs			see section 1.3
ϵ	exponent extraction costs	0; 1; 1.6	1	see section 1.3

TABLE A.5: Functions

Symbol	Explanation	Value	Unit	Source
$\Pi(M_1, t)$	radiative forcing	$\eta_1 \log\left(\frac{M_1(t)}{M_1 \text{ in } 1750}\right) + \eta_2 F_{EX}$	$^{\circ}\text{C/a}$	Nordhaus (2010b) , see note 6
$\Omega(T_1)$	damage function	$\frac{b}{1 + \xi_1 T_1 + \xi_2 T_1^{\xi_3}}$		Nordhaus (2008b) , see note 9
$k(S)$	extraction cost function	$\gamma S^{-\epsilon}$	$\$/\text{kgC}$	see section 1.3

Notes

1. Total emissions in GtC/a are $R + E$ with $E = E(0)e^{-.0101t}$. The value of carbon emissions from land use change in $t = 0$, i.e. in 2005, is 1.1 GtC/a ([Nordhaus, 2008b](#)). Division by 10 adjusts the original value 11 GtC from per decade to per year. The yearly shrinking rate of the emissions from land use change is also taken from [Nordhaus \(2008b\)](#) and transformed into its continuous time yearly counterpart, i.e. from $(1 - 0.1)^{t-1}$ to $\log(1 - 0.01) = -.0101$.

2. Data on resource flows and stocks as well as on emissions are based on [IEA \(2007\)](#). Because the model uses only one carbonic resource, we merge the data on oil, coal and gas, and convert units into giga tons of carbon, GtC.
3. The resource price q in 2005 is a weighted average of the average 2005 prices for oil, steam coal and natural gas in \$/kgoe, 0.3562, 0.0964 and 0.3109, respectively. The coal and gas price are roughly estimated average prices 2005 from [IEA \(2007\)](#), while the oil price is the average of the 'Weekly All Countries Spot Price FOB Weighted by Estimated Export Volume' ([EIA, 2010](#)). We take the shares of each resource in total resource consumption 2005 as weights and convert the units into \$/kgC. The calculation yields $q = 0.3415$ in \$/kgC.
4. The steady state interest rate of the model is $i^* = 0.042$ 1/a. This is close to the average interest rate of the countries listed at [Inter-Agency Group on Economic and Financial Statistics \(IAG\) \(2010\)](#). [Barro \(1987\)](#) finds an average interest rate of 3.45 % 1/a for the UK for 1729-1918, [Eurostat \(2011\)](#) states an average interest rate of 4.33 % 1/a for 2001-2010, [Mendoza \(1991\)](#) and [Oviedo \(2005\)](#) use 4 % 1/a as a world interest rate, but [Oviedo \(2005\)](#) cites studies that use an interest rate up to 14.9 % 1/a. The interest rate in the DICE model is 5-6 % 1/a. Thus, our model yields a sensible steady state interest rate.
5. We calculate the carbon transition matrix according to $\Gamma = \frac{B_1 - I}{10}$ using its discrete time counterpart, say B_1 , in [Nordhaus \(2010b\)](#), with

$$B_1 = \begin{bmatrix} -0.0120 & 0.0047 & 0 \\ 0.0120 & -0.0052 & 0.0001 \\ 0 & 0.0005 & -0.0001 \end{bmatrix},$$

I is the identity matrix. $B_1 - I$ is divided by 10 because one period in the DICE model corresponds to a decade.

6. F_{EX} is the exogenous radiative forcing in watt/m². It linearly increases from -0.06 to 0.3 watt/m² within 100 years and stays constant afterwards. The parameter values $\eta_1 = 0.1206$ °C/a and $\eta_2 = 0.022$ (°C/a) (m²/watts) are based on Nordhaus (2008b, 2010b) and adjusted to the time scale, i.e. the value given by Nordhaus divided by 10.
7. We calculate the temperature interaction matrix according to $\Lambda = \frac{B_2 - I}{10}$ using its discrete time counterpart, say B_2 , in Nordhaus (2010b), with

$$B_2 = \begin{bmatrix} .6553 & .0660 \\ .05 & 0.95 \end{bmatrix}.$$

As before, we divide by 10 because one period in the DICE model corresponds to a decade.

8. The rate of technological progress is calibrated to match a steady state growth rate of 1.8 % 1/a. Barro and Sala-i Martin (2004) (page 13) find an average per capita growth rate of 1.9% 1/a for major developed countries for over a century. For $g = 0.018 = \frac{\lambda - \rho\beta}{1 - \alpha - \beta + \beta\theta}$ based on $\hat{q}^* = \iota^*$ meaning that $k(S)$ grows slower than p in the long run, the rate of technological progress is $\lambda = 0.018(1 - \alpha - \beta + \beta\theta) + \rho\beta = 0.0134$ 1/a.
9. We take the parameters $\xi_1 = 0.0018$, $\xi_2 = 0.0023$ and $\xi_3 = 2$ from Nordhaus (2010b), while we use the scaler b to ensure $Y(0) = \bar{Y}$.

Appendix B

Appendix to Chapter 2

B.1 Derivation of the Five Credit Regimes

From the Kuhn-Tucker conditions (2.5) and definition (2.6) 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.

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 κ . The rest follows from the credit regimes definition.

B.3 Derivation of Equation (2.8)

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

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

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 (2.4)). A locally unambiguously defined optimum implies $|H^j| > 0^1$ such that the denominator only influences the size of the effect but not the direction and equation (2.8) determines the sign.

B.4 Proofs for Table 2.1

We use (2.8) and (2.7) 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 $f = \iota$:

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

¹The 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, σ , 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 (2.7) 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 τ 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

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

Multiply with $\sigma/(f_{c_2}(1+f))$ and re-arrange to attain

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

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

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

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

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

Note that the first order condition for capital in (2.7) 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

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

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 2.2

We use (2.8) and (2.13) 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 $j = TL$ and $f = \iota$:

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

which is equivalent to

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

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 $f = \tau$:

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

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

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

Expansion by $hh_k/(hh_k)$ yields

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

Replacing x_k by $x_h h_k$, multiplying by $h/(h_k k)$ and using the elasticity (B.3) and (2.14) gives

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

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

$$\text{sgn} \left(\frac{dl^{EL}}{d\tau} \right) \tag{B.8}$$

$$\begin{aligned} &= \text{sgn}(-f_\tau h_l x[(1 + f)(h_{kk}x + h_k x_k) + f_k h_k x] + (h_k x f_\tau - 1)[(1 + f)(h_{lk}x + h_l x_k) + f_k h_l x]) \\ &= \text{sgn}(-f_\tau h_l x(1 + f)h_{kk}x - f_\tau h_l x(1 + f)h_k x_k - f_\tau h_l x f_k h_k x + h_k x f_\tau(1 + f)h_{lk}x \\ &\quad + h_k x f_\tau(1 + f)h_l x_k + h_k x f_\tau f_k h_l x - (1 + f)h_{lk}x - (1 + f)h_l x_k - f_k h_l x) \\ &= \text{sgn}(-f_\tau h_l x(1 + f)h_{kk}x + h_k x f_\tau(1 + f)h_{lk}x - (1 + f)h_{lk}x - (1 + f)h_l x_k - f_k h_l x) \\ &= \text{sgn} \left(-f_\tau x^2(1 + f)(h_{kk}h_l - h_k h_{lk}) - (1 + f)h_{lk}x - (1 + f)h_l x_k - f_k h_l x \right). \end{aligned} \tag{B.9}$$

Calculate

$$f_\tau = \frac{ku_{22}u_1}{u_2^2} = -\frac{kf}{\eta c_2} \tag{B.10}$$

and

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

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 (2.13) to obtain $h_k x (1 + f) = \tau$ and insert both expressions together with (B.11) and (B.10) in (B.8), replace x_k by $x_h h_k$ and rearrange (B.8) to obtain

$$\begin{aligned}
&\text{sgn} \left(\frac{dl^{EL}}{d\tau} \right) \tag{B.12} \\
&= \text{sgn} \left(\frac{f_\tau h h_{lk}}{h_l h_k k} - \frac{h_{lk}}{h_l h_k x} - \frac{x_k}{h_k x^2} - \frac{f_k}{(1+f) h_k x} \right) \\
&= \text{sgn} \left(-\frac{f h h_{lk}}{\eta c_2 h_l h_k} - \frac{h_{lk}}{h_l h_k x} - \frac{x_k}{h_k x^2} - \frac{f h_k}{\eta (1+f) h_k x} (x + h x_h) \left(-\frac{1}{c_1} + \frac{1}{c_2} \right) + \frac{f \tau}{\eta c_2 (1+f) h_k x} \right) \\
&= \text{sgn} \left(-\frac{f}{\eta c_2 \sigma} - \frac{1}{\sigma h x} + \frac{\varepsilon}{x h} - \frac{f(x + h x_h)}{\eta (1+f) x} \left(-\frac{1}{c_1} + \frac{1}{c_2} \right) + \frac{f \tau}{\eta c_2 (1+f) h_k x} \right) \\
&= \text{sgn} \left(-\frac{f}{\eta c_2 \sigma} - \frac{\sigma^{-1} - \varepsilon}{h x} - \frac{f(1 - \varepsilon)}{\eta (1+f)} \left(\frac{c_1 - c_2}{c_1 c_2} \right) + \frac{f}{\eta c_2} \right) \\
&= \text{sgn} \left(\frac{f}{\eta c_2} \left(-\frac{1}{\sigma} - \frac{1 - \varepsilon}{1 + f} \left(\frac{c_1 - c_2}{c_1} \right) + 1 \right) - \frac{\sigma^{-1} - \varepsilon}{h x} \right). \tag{B.13}
\end{aligned}$$

Multiply with $\sigma \eta c_2 / f$ and 'isolate' ε 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 $f = \tau$

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

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

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

Using the output elasticity of capital $1 - \alpha$ and the relation $h_k x = \tau / (1 + \tau)$ from (2.13) yields

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

Multiply with σ to attain

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

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.

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

Appendix C

Appendix to Chapter 3

C.1 Instrumental Variable Estimation

As additional robustness check, I estimate a model where I use the loan purposes as instruments for the loan amount to check for simultaneity. The loan purposes are exogenous variables on the demand side that do not appear on the supply side. Statistical tests support the validity of the instruments: First, as suggested by [Baum et al. \(2007\)](#) for clustered error terms, I use the Wald F-statistic based on the Kleibergen-Paap rk statistic to test for weak identification. Following the ‘rule of thumb’ that the F-statistic should be at least 10 to avoid weak instruments ([Baum et al., 2007](#); [Staiger and Stock, 1997](#)), the evidence suggest that the model does not have a problem of weak instruments (see [Table C.1](#)). Second, the instrumental variables should be independent from the unobservable error process, which in the case of intra-cluster correlation can be tested with the J-statistic ([Baum et al., 2003](#)). Based on the calculated J-statistic (see [Table C.1](#)), the Null-hypothesis that all instruments are exogenous cannot be rejected. I conclude that all instruments are valid.

I now estimate the model with the Two-Stage Least Square (2SLS) technique as well as the 2-step GMM approach proposed by [Baum et al. \(2007\)](#) for efficient

	n	450
Kleinbergen-Paap rk Wald F-statistic		34.276
Overidentification test all instruments		
Hansen J-statistic		2.578
Chi sq (12) p-value		0.8597
Test of endogeneity (h0: variables exogenous)		
Robust regression F	F(1,315)	=2.178
P-value		0.141

TABLE C.1: Statistics Instrumental Variable Estimations

estimates. I again adjust standard errors for clustering. If the loan amount is exogenous, the instrumental variable estimation is still consistent, but inefficient relative to OLS estimation. As the statistical test suggests a valid instrumental variable estimation, I can now test if 'loan amount' is indeed endogenous. Based on a regression based test ([StataCorp., 2013](#); [Rao et al., 1995](#)), the Null-hypothesis that all variables are exogenous cannot be rejected (see [Table C.1](#)).

The first column of [table C.2](#) again gives the OLS results and the next two columns (GMM and 2SLS) give the instrumental variable estimation results. Other than before, sector specific effects are not constraint to sum up to zero, such that one sector dummy is omitted, i.e. its effect is part of the constant. The effect of income volatility on the interlinked interest rate is similar to the OLS-results.

TABLE C.2: OLS, GMM and 2SLS Estimation Results.

Interest rate p.a.	OLS	GMM	2SLS
V	-0.0156 (0.0285)	-0.0289 (0.0264)	-0.0255 (0.0280)
V × Fish Trader	0.133** (0.0648)	0.162** (0.0754)	0.162** (0.0778)
Boat	-0.0179 (0.0411)	-0.00450 (0.0366)	0.00625 (0.0394)
Boat × Fish Trader	-0.196** (0.0840)	-0.205** (0.0840)	-0.205** (0.0847)
log(Fishing Income)	-0.0318*** (0.0118)	-0.0284** (0.0119)	-0.0262** (0.0126)
Sector 1	-0.155*** (0.0345)	-0.153*** (0.0329)	-0.157*** (0.0334)
Sector 2	-0.114*** (0.0375)	-0.129*** (0.0374)	-0.140*** (0.0426)
Sector 3	-0.101** (0.0407)	-0.0884** (0.0392)	-0.0817** (0.0403)
log (Maturity)	-0.0320** (0.0145)	-0.0339** (0.0144)	-0.0315** (0.0150)
log (Loan Size)	-0.00286 (0.00904)	-0.0562 (0.0277)	-0.0754 (0.0500)
if Collateral	-0.0934* (0.0498)	-0.0765 (0.0564)	-0.0664 (0.0599)
Literacy	0.0134 (0.0202)	0.0162 (0.0208)	0.0163 (0.0210)
Keuta	0.0634** (0.0274)	0.0720** (0.0288)	0.0737** (0.0301)
Kandara	0.0562 (0.0460)	0.0511 (0.0469)	0.0465 (0.0480)
Khartia	-0.0492 (0.0354)	-0.0220 (0.0390)	-0.0194 (0.0427)
Money Lender	0.00856 (0.0638)	0.0599 (0.0674)	0.0660 (0.0757)
Fish Trader	-0.0730 (0.111)	-0.0526 (0.112)	-0.0499 (0.115)
Friends, ...	-0.0243 (0.0686)	0.0241 (0.0713)	0.0337 (0.0793)
Bank	-0.154* (0.0788)	-0.108 (0.0816)	-0.0965 (0.0888)
Micro Finance	-0.0966 (0.0622)	-0.0755 (0.0623)	-0.0723 (0.0661)
Cooperative	-0.205*** (0.0709)	-0.208*** (0.0715)	-0.211*** (0.0744)
Constant	0.936*** (0.180)	1.377*** (0.270)	1.526*** (0.439)
n/Clusters	450/316	450/316	450/316
(Centered) R ²	0.2789	0.2338	0.1963

Clustered standard errors in parenthesis, ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

C.2 Estimation Results with Extra-Activity Dummy

TABLE C.3: Results with Extra-Activity Dummy

Interest rate p.a.	OLS Coeff.	(Std. Error)
V	-0.0184	(0.02969)
V × Fish Trader	0.1338**	(0.0653)
Boat	-0.0198	(0.0414)
Boat × Fish Trader	-0.1957**	(0.0841)
log(Fishing Income)	-0.0307**	(0.0124)
Sector 1	-0.0619***	(0.0168)
Sector 2	-0.0226	(0.0193)
Sector 3	-0.0073	(0.0223)
Sector 4	0.0918***	(0.0253)
log(Maturity)	-0.0316**	(0.0145)
log(Loan Size)	-0.0027	(0.009)
if Collateral	-0.0929*	(0.0496)
Literacy	0.0124	(0.0206)
Keuta	0.0627**	(0.0272)
Kandara	0.0553	(0.0461)
Khartia	-0.051	(0.0353)
Money Lender	0.0073	(0.0641)
Fish Trader	-0.0762	(0.1119)
Friends, ...	-0.0272	(0.0695)
Bank	-0.1558**	(0.0791)
Micro Finance	-0.0992	(0.0629)
Cooperative	-0.2076***	(0.0718)
Dummy Activity	0.0102	(0.024)
Constant	0.8334***	(0.1781)
n/Clusters	450/316	

Clustered standard errors in parenthesis, ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$.

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Eidesstattliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich meine Doktorarbeit „Essays in Resource and Development Economics“ 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 anlehenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Unterschrift:

Datum:

CV

Personal Data

Marie-Catherine Riekhof, born 21 May 1984 in Hamburg, Germany

Education

2014	Doctoral Program "Quantitative Economics", CAU Kiel
2008	Diploma in Economics, CAU Kiel
2005-2006	Semester at the Universidad Autónoma de Madrid/Spain
2003	Abitur, Gymnasium Lerchenfeld, Hamburg
2000-2001	High school year in New York State/USA

Positions

2014-	Research Assistant, Chair for Environmental, Resource and Ecological Economics (Prof. Dr. Quaas), CAU Kiel, BMBF-project ECCUITY
2008-2014	Research Assistant, Institute for Regional Research (Prof. Dr. Bröcker), CAU Kiel, EU-Project TEN-CONNECT: Estimation of border barriers; Teaching: - tutorials economic growth (Diploma and Master) - tutorial microeconomics (Bachelor) - tutorials CGE-Analysis (PhD) - Co-Trainer CGE-Analysis INFRATRRAIN summer school (Jönköping/Sweden, 2009)
2008-2012	Consultant at UNICconsult Strategieentwicklung GmbH, Goettingen
2010-2011	World Bank Consultant for the Intergrated Coastal Zone Management Project in Orissa/India

Research Fields

- Resource and environmental economics with a special focus on climate change (green paradox, dynamic general equilibrium model) and resource use in low income countries
- Development economics with a special focus on informal credit markets, risk sharing and structural change

Selected Presentations

- 06/2010 IUCN Brown Bag Lunch, Gland/Switzerland
- 07/2010 Brown Bag Seminar of the Institute of Economics CAU Kiel
- 11/2012 Kiel Young Researcher Conference "Did you know that your research is on Green Growth?"
- 07/2012 IIFET Conference "Visible Possibilities: The Economics of Sustainable Fisheries, Aquaculture and Seafood Trade", Dar es salaam/Tanzania
- 02/2013 Winter seminar of the German Section of the Regional Science Association, Matrei/Austria
- 11/2013 Seminar in Environmental, Resource and Development Economics, Kiel
- 02/2014 AURÖ-Nachwuchsworkshop (Umwelt- und Ressourcenökonomie), Kiel
- 06/2014 Monte Verità Conference on Sustainable Resource Use and Economic Dynamics (SURED), Ascona/Switzerland
- 6/2014 6th Edition of the Summer School in Development Economics (SSDEV), Ascea/Italy
- 06/2014 Jahrestagung des Ausschusses für Entwicklungsländer des Vereins für Socialpolitik, Passau
- 07/2014 World Congress of Environmental and Resource Economists, Istanbul/Turkey

Awards and Scholarships

- Best Paper Award at the Young Researcher's Conference on Green Growth in Kiel for the paper "Does the Adverse Announcement Effect of Climate Policy Matter", 2012
- PROMOS scholarship for the course "The Economics of Marine Resources: Ecological Modelling and Management of the Marine Environment", University of Southern Denmark, 2011
- DAAD funding for an Internship in León/ Nicaragua, 2007

Kiel, July 2014