Development in a Dual Economy: The Importance of Resource-Use Regulation

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Abstract: We study how rights-based resource management can trigger labor reallocation and development in a dual economy. Under open access, resource users may remain trapped in poverty. Regulation of resource use generates rents that can finance labor reallocation to resource-independent production. Transferability of harvest quotas broadens the scope for labor reallocation, in particular if harvest quotas are distributed unequally. Once the process of labor reallocation is started, it continues until a long-run efficient labor allocation is achieved. We use data from an Indian fishery to illustrate numerically how the design and distribution of harvest quotas affects labor, wealth, and resource dynamics in a rural economy.

JEL Codes: O13, O44, Q20, Q22, Q28

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MOST OF THE GLOBAL POOR live in rural areas and depend on natural resources such as arable soil, pastures, fish stocks, or forests for their livelihood (Millennium Ecosystem Assessment 2005; Angelsen et al. 2014). Resource overuse leads to widespread resource degradation and inefficiently low resource-based incomes (Baland and Plat-

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teau 1996; Stavins 2011; Costello et al. 2012). This is particularly problematic in poor countries in which the rest of the economy also functions imperfectly. Malfunctioning labor and capital markets can prevent poor households from leaving the impoverished rural sector and from investing in profitable income alternatives. Indeed, in most developing countries, there are large income gaps between rural and urban households (Vollrath 2009; Gollin et al. 2014) suggesting barriers to labor reallocation that trap rural households in poverty.

Development economists have suggested that improving credit reduces the barriers to labor reallocation (Banerjee and Newman 1993; Galor and Zeira 1993), and empirical studies have shown that positive income shocks or cash transfers can induce efficient labor reallocation from rural to urban production (Blattman et al. 2014; Bryan et al. 2014; Kleemans 2014; Angelucci 2015; Noack et al. 2015; Bazzi 2017).[1] In contrast, resource economists have emphasized the economic potential of managing common-pool resources to increase resource-based incomes (Gordon 1954; Wilen 2000). In particular, tradable quotas for natural resources have been shown to create economic benefits and to reduce resource degradation (Grafton et al. 2006; Costello et al. 2008).

The contribution of our paper is to show under which conditions resource regulation leads to an efficient labor reallocation, a wealthier and less resource-dependent rural population, and a healthy resource stock as a result. First, we show that the introduction of resource-use regulation increases resource rents to an extent that can be sufficient to finance labor reallocation to urban, resource-independent production. This finding implies that introducing resource-use regulation not only increases incomes in the resource sector but also increases efficiency in the whole economy by reducing labor misallocation. Second, we show that introducing tradable harvest quotas broadens the scope for development, as resource users can sell their quotas to generate additional funds for investment in urban, resource independent production. Last, we show that distributing the quotas unequally can start the development process in cases where an equal allocation of quotas does not suffice.[2]

Our analysis is based on an analytical model of a dual economy in which households work either in common-pool, resource-dependent rural production or in resource-

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[1] Conversely, Hirvonen (2016) shows that negative income shocks reduce labor reallocation.

[2] It is worth noting that the mechanism at work in our model is different from the one described by Baland and Platteau (1997) and Dayton-Johnson and Bardhan (2002), who show that an unequal distribution of wealth may increase efficiency of resource use because inequality affects the incentive of households to conserve an open access resource.

independent urban production.[3] Both sectors require initial investments and, as we assume that credit markets are absent, investments are restricted by accumulated wealth. We show that in the absence of credit markets, households can be trapped in the resource-dependent sector if they are too poor to invest in resource-independent production. Further, poor parents leave low bequests to their children, which can perpetuate the poverty trap.

Our results suggest that the introduction of harvest quotas in developing countries increases incomes in the rural sector, contributes to the protection of natural resources, and can induce a shift of labor from the unproductive rural sector to the more productive urban sector.[4] To illustrate the impact of different forms of resource regulation on resource conservation and economic development, we calibrate our model with data from a survey of fishermen at Chilika lagoon, an Indian inland fishery in the state of Odisha, which has also motivated our analysis. At Chilika lagoon, fishermen's real incomes have been weakly declining over the last 60 years, while the number of fishermen has been steadily rising. In contrast, real incomes in Odisha have been growing by 3.5% per year on average over the same time period (Government of Odisha 2015). The lack of response by the fishermen to their declining relative incomes can be explained by barriers to labor reallocation. In the spirit of Galor and Zeira (1993) and in line with our field observations, we suggest that the high costs of education prevent the fishermen from working in the urban sector. The calibration results show that the resource rents from resource regulation would not suffice to finance sufficient levels of education and to start the labor reallocation process. However, introducing tradable harvest quotas would suffice to start the development process, leading to fewer but richer resource harvesters, larger resource stocks, and higher economy-wide incomes.

Although our results indicate that introducing tradable quotas for natural resources can increase efficiency, very few quota systems have been implemented in developing countries. Possible causes for this lack of quota systems in developing countries may be their dependence on strong government capacities (Jardine and Sanchirico 2012), the high diversity of resource stocks which complicates regulation (Ahmed et al. 2007), and the large number of resource users in many developing countries, which inflates the costs of regulation. Further, our results indicate that the effect of regulation on current incomes largely depends on the transition to the optimal harvesting steady state. Temporary harvest moratoriums to build up resource stocks may be difficult to implement when households do not have the means to cope with temporary income short-

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[3] The notion of a dual economy, with low rural labor productivity and high urban labor productivity, originates from Lewis (1954) and was later formalized by Harris and Todaro (1970). In the following, we use the term "rural" to refer to resource-based production, including fisheries, forestry, and agriculture, and "urban" to describe resource-independent production such as the manufacturing and the service sectors.

[4] This process of structural change of economies is closely linked to the economic growth process (see, e.g., Duarte and Restuccia 2010).

falls. A comprehensive treatment of resource regulation in developing countries is beyond the scope of this paper and we refer interested readers to Cancino et al. (2007) and Wilen (2013). Our focus is the additional benefits of resource regulation in developing countries, which make it worthwhile to overcome the difficulties of quota implementation.

A further concern with regard to privatizing common pool resources is the distributional consequence for workers in the rural sector and for other indirectly resource-dependent individuals. Most studies predict a negative impact of privatization on the welfare of workers in the rural sector (Weitzman 1974; Baland and Francois 2005; Béné et al. 2010; Wilen 2013), although a number of studies reach opposite conclusions (De Meza and Gould 1987; Baland and Bjorvatn 2013). Taking these distributional effects into account will be important for the acceptance of resource regulation in developing countries but also lies beyond the scope of this paper, as we only consider the welfare implications of quota allocations among the directly resource-dependent individuals. This is the predominant scenario in many traditional fisheries like the Chilika fishery, where the majority of households are self-employed.

Our study is related to two strands of literature. The first analyzes the impact of resource regulation in a multi-sector economy. In two companion articles, Manning et al. (2014, 2016) use a parameterized model of a rural economy to show how resource degradation and management affects efficiency in a rural economy. In contrast to our study, the authors assume the absence of barriers to labor reallocation as well as endogenous prices and, therefore, rather describe the short-run effects of resource regulation in closed village economies. In this respect, our study is more related to Liese et al. (2007), who show that distance to markets increases the costs of nonfishing activities, with negative consequences for resource conservation. However, Liese et al. (2007) do not consider the impact of resource regulation on labor allocation and resource conservation.

The second strand of literature concerns the impact of property rights on economic development and resource use. Most studies on quota systems in fisheries find positive effects of quotas on fish stocks, resource rents, and labor reallocation (Lian et al. 2009; Abbott et al. 2010; Reimer et al. 2014). Similar effects of property rights introduction on labor mobility have been observed for land in various countries (Wang 2012; Chernina et al. 2014; Valsecchi 2014; de Janvry et al. 2015). In contrast to these studies, we focus on the impact of the design and the allocation of use rights on economic development. Our study contributes to both strands of literature by considering the long-run effects of different forms of resource regulation on occupational choices and economic development.

The paper is structured as follows. In the next section, we develop a nonoverlapping generations model. In section 2, we discuss transitional dynamics and show that different steady states may emerge, depending on the initial wealth distribution and the share of the workforce in the rural sector. Section 3 characterizes the first-best solution as a benchmark. Section 4 demonstrates how the introduction of different types of resource-use regulation can trigger a development process that leads to the first-best outcome, even in the absence of credit markets. Section 5 applies our results to the case of Chilika lagoon to give some quantitative results. Section 6 concludes.

1. A MODEL OF A DUAL ECONOMY WITH COMMON POOL RESOURCES

In this section, we describe our model of a dual economy without credit markets and with resource externalities. The model setup is motivated by the small-scale Indian fishery of Chilika lagoon, which is representative for a typical village economy in a developing country, with local resource extraction (Liese et al. 2007; López-Feldman and Wilen 2008; Angelsen et al. 2014), as well as with costly labor migration to urban centers (Bryan et al. 2014; Kleemans 2014). In this setup, the village economy is small compared to the rest of the economy, and neither migration nor the selling of goods to urban centers affect price and wage levels. Households in this village economy can either earn incomes from rural resource-based production such as agriculture, fisheries, and forestry or migrate to urban centers to earn an income in the manufacturing or service sector.

The "rural," resource-based sector uses labor, sector-specific capital, and a renewable common pool resource for production. Common pool resources may include fish stocks, forests, and fertile land. The "urban" sector employs sector-specific capital and labor. The economy is inhabited by a continuum of individuals with a constant generation size normalized to one. This assumption implies that the impact of individual actions on aggregate production is very small, as they are weighted by their relative mass in the whole population.[5] Each individual lives for two periods and gives birth to a child at the beginning of the second period of her life. The total population of the economy therefore consists in each point of time of a working parent generation and their nonworking children.

Individuals are identical, except for their initial wealth level, b_t, which they inherit from their parent. They may also differ with respect to the sector they work in.

In the first period of her life, t, an individual is born, inherits initial wealth b_t from her working parent, and decides on her wealth allocation. Wealth can be consumed, bequeathed, or turned into capital specific to the rural or the urban sector. When deciding on the type of capital, the individual also chooses the sector she will work in. In the second period of her life, $t + 1$, the individual inelastically supplies one indivisible unit of labor[6] and uses the capital, which depreciates completely after the second pe-

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[5] To be precise, the weight of individual actions is zero.

[6] This means that we measure labor in units of an individual's life working time. Aggregate labor supply is equal to the amount of labor per individual times the total mass of individuals. Having normalized both to one, total labor supply—the total mass of individuals times the working life time of each individual—also equals one.

riod of her life. The individual earns income y_{t+1}, consumes a quantity c_{t+1}, and bequeaths an amount b_{t+1}.[7]

Following Banerjee and Newman (1993) and Galor and Zeira (1993), each individual appraises consumption, c_{t+1}, and the bequest to her offspring, b_{t+1}, according to the utility function:[8]

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

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

In the urban sector, revenue α is independent from its number of workers but none of our results hinge on this assumption.[9] The income y^m_{t+1} in the urban sector of an individual j born in period t is thus

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

with superscript m denoting the urban ("modern") sector. If an individual decides to work in the rural sector, she has to invest some amount $k_t > 0$ into sector-specific capital (i.e., boats and fishing gear in the case of a fishery, for instance). In contrast to β, k_t can be chosen continuously, such that individuals can always derive income from re-

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[7] In general, all these quantities, that is, $y_{t+1}(j)$, $c_{t+1}(j)$, and $b_{t+1}(j)$, differ across individuals j. In order to save notation we omit the dependency on j unless needed for clarification.

[8] Alternatively, the parent's altruism toward her child could be modeled by assuming that she draws utility from the consumption, or from the utility level, of her child. Compared to (1), an individual would then indirectly take all future generations into account when deciding on her own consumption and bequest. She may then sacrifice additional consumption if a higher bequest allows her descendants' escape from poverty. However, even in this setup, there is a level of initial wealth at which the current generation is so poor that it is indifferent between making that extra sacrifice to future generations or using that unit of wealth for its own consumption. The households' behavior changes at this point. Thus adapting a more complicated setting with a utility function that takes future consumption or utility into account would not change the households' behavior qualitatively but would complicate the analysis considerably (Galor and Zeira 1993; Matsuyama 2011).

[9] This is in contrast to the rural sector. There are two different justifications for the assumption of a constant α. One is that production in the urban sector uses capital and labor, with constant returns to scale. By choosing to work in the urban sector, households supply labor and capital in a constant ratio ($1/\beta$) and get the constant marginal returns to their capital and labor investment, α. The second justification is that the resource-based production, in contrast to the urban sector, is small relative to the economy. A discussion of endogenous fixed costs and incomes in these types of models is given by Matsuyama (2011).

source extraction, which is in line with the hypothesis of common pool resources as income source of last resort (Baland and Francois 2005; Delacote 2009).[10]

The resource-harvesting technology is described by a standard Gordon-Schaefer harvest function (Gordon 1954; Schaefer 1957),

$$h_t = qX_te_t, \tag{3}$$

where h_t is the harvest per individual, $q > 0$ is a technological parameter describing harvesting efficiency, X_t is the resource stock size, and e_t is individual harvesting effort. Alternatively, q could be interpreted as the unit price of the harvest, but we prefer the interpretation of harvesting efficiency and assume that the resource price is one. Harvesting effort is generated by means of capital k_t and labor l_t according to a Leontief production function

$$e_t = \min\{k_t, \lambda l_t\}, \tag{4}$$

with $\lambda > 0$.[11] As labor supply is inelastic, $l_t = 1$ for each individual. We assume that capital is the limiting input for all individuals who cannot afford the investment β for working in the urban sector, that is, $\lambda > \beta$—an assumption that we maintain throughout the analysis.

Renewable natural resources differ widely in the time scales of their internal dynamics. While many commercially important fish stocks reproduce in time scales that are much shorter than human generations, forests grow on time scales that span several human generations. To accommodate these differences, we describe the dynamics of the resource stock $X_t(\tau)$ in continuous time τ. We choose units of continuous time such that $\tau = 1$ is one generation, that is, τ and t are measured in the same units. Net growth of the resource stock is given by natural reproduction minus aggregate harvest.

$$\frac{dX_t(\tau)}{d\tau} = \rho X_t(\tau)\left(1 - \frac{X_t(\tau)}{\kappa}\right) - qX_t(\tau)K_t(\tau). \tag{5}$$

Natural reproduction corresponds to a logistic growth function, with the intrinsic growth rate ρ and carrying capacity κ. Aggregate harvest depends on aggregate harvesting effort, which is proportional to aggregate capital $K_t(\tau) = \int_0^1 k_t(j, \tau)dj$, where $k_t(j, \tau) \geq 0$ is the capital used in resource harvesting by individual j at time τ.[12] In

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[10] In an alternative version of the model, we included an additional low-skilled production that does not require capital investment and is independent of the resource. This assumption introduces a lower bound on income in the rural sector but does not change the qualitative results of the study. It also increases the complexity of the results.

[11] One could allow λ to differ between the different resource harvesters to account for differences in productivity. In the present paper, the focus is on capital as the limiting factor.

[12] The integral in the equation for aggregate capital goes over all individuals from 0 to 1, assuming that individuals in the modern sector do not use capital for resource harvesting.

an unregulated setting, harvest capital is constant within one period but with regulation, the invested capital k_t is only used after the resource has recovered to its optimal level, making k_t a function of τ.

In the baseline scenario, access to the renewable common pool resource is free for all individuals. As the economy consists of a constant but continuous mass of individuals, the individual impact on the resource stock is small (in fact it is zero) and each individual neglects the impact of her harvest on the resource stock. Taking the harvesting effort of the other resource users as given, each individual decides on her personal harvesting effort. In Nash equilibrium, no resource user wants to change her decision, and resource productivity depends on the aggregate harvesting effort.

As a result of the linear harvesting technology, each individual receives a fraction $k_t(j)/K_t$ of the aggregate revenues. Thus, an individual j engaged in the rural, resource-based sector earns an income

$$y^r_{t+1}(j) = \max_{k_t(j,\tau)} \int_0^1 \{qX_t(\tau)k_t(j,\tau) - k_t(j,\tau) + b_t(j)\}d\tau, \tag{6}$$

with superscript r denoting the rural or resource-based sector. For the sake of simplicity and consistency with the assumption that the alternative use of capital is consumption, we ignore discounting within one generation.

The most crucial assumption for our results is the absence of credit markets, or at least of credit markets that could finance the cost of labor allocation to the urban sector. Although credit markets do exist in many rural economies, they rarely allow large investments into intangible "goods" like education or migration, as moral hazard makes repayment unlikely in these cases. As a result, only individuals with an initial wealth level $b_t \geq \beta$ can afford the fixed investment that is necessary to work in the urban sector. We will refer to individuals with initial wealth $b_t < \beta$ as *poor* and to individuals with initial wealth $b_t \geq \beta$ as *rich*.

2. THE MARKET OUTCOME

This section describes the long-run market outcome and transitional dynamics of a rural economy in which each individual chooses the occupation that maximizes her utility subject to her initial wealth, given the occupational choices of all other individuals and under the absence of resource-use regulation.[13]

Rich individuals, who can afford the fixed investment β, will leave the rural sector as long as income is higher in the urban sector. Conversely, households in the urban sector will enter the rural sector if the income in resource harvesting exceeds the incomes in the urban sector. Poor households have no choice but to work in the rural sector.

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[13] As the consumption and production decisions are separable, maximizing utility is identical to maximizing income.

Given the occupational choices, the total mass of individuals in resource harvesting evolves according to

$$\begin{aligned} n_{t+1} &= n_t - \varepsilon \int_0^{n_t} \mathbf{1}_\beta \max\{y^m_{t+1}(j) - y^r_{t+1}(j), 0\} dj \\ &\quad + \varepsilon \int_{n_t}^{1} \max\{y^r_{t+1}(j) - y^m_{t+1}(j), 0\} dj, \end{aligned} \tag{7}$$

where $\varepsilon > 0$ is a time constant that measures the speed of labor reallocation, which we assume to be small enough such that n_{t+1} is nonnegative. In equation (7), n_t relates to the parents—using the resource at time $t + 1$—and n_{t+1} to the children—allocating capital at time $t + 1$. Whether children change the sector compared to their parents—such that $n_t \neq n_{t+1}$—depends on the expected incomes in the two sectors and whether entrance in the modern sector can be afforded. As there is no uncertainty in our model, children know their income options, that is, y^r_{t+1} and y^m_{t+1}. The description of the dynamics of migration is common in the economic geography literature (see, e.g., Krugman 1991). The indicator function $\mathbf{1}_\beta$ has the value one if $b_t \geq \beta$ and zero otherwise. It indicates whether an individual is rich and has the option to work in the urban sector.

Individuals who work in the rural sector choose a level of capital investment that maximizes incomes from resources harvesting. We measure capital in the same monetary units as bequest, such that the marginal costs of capital are unity. Provided marginal returns are larger than marginal costs, that is, if $qX_t > 1$, individuals in the rural sector choose

$$k_t = b_t, \tag{8}$$

because production is linear in individual harvesting effort, and individuals take the resource stock X_t as given when deciding on their capital investment k_t. If marginal returns were smaller than marginal costs, there would be no one in the rural sector. Further, as we have assumed that capital depreciates completely after one generation, intergenerational harvesting capital dynamics are completely driven by wealth dynamics and occupational choices. The extensive margin of harvesting effort is therefore determined by the occupational choices, while intergenerational wealth dynamics within the rural sector determine harvesting effort adjustments on the intensive margin.

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

In the urban sector, individual wealth dynamics are given by

$$b^m_{t+1} = \delta(\alpha - \beta + b^m_t), \tag{9}$$

with the steady-state bequest[14]

$$b_*^m = \frac{\delta}{1-\delta}(\alpha - \beta). \tag{10}$$

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

$$\delta\alpha > \beta, \tag{11}$$

that is, the bequest of an individual working in the urban sector is large enough for her child to be able to afford the fixed investment β.

In the rural sector, individuals bequeath

$$b_{t+1}^r = \delta q b_t \int_0^1 X_t(\tau) d\tau \tag{12}$$

to their offspring. For the sake of simplicity, we assume that all individuals in the rural sector bequeath the same amount in steady state, a result that follows endogenously if harvest technologies are strictly concave (see Noack [2013] for a version with concave harvest technology). For the rural sector, the steady state requires that the share of resource harvesters, the resource stock, and the bequest remain constant over time. The steady-state bequest in resource harvesting depends on the mass of resource harvesters in steady state $n_* \in [0, 1]$ and is given by (see app., sec. A)

$$b_*^r = \frac{\rho}{q n_*} \frac{\delta q \kappa - 1}{\delta q \kappa}. \tag{13}$$

The aggregate harvesting effort is $K_* = n_* b_*^r$. The rural sector only persists if rural households can make a living from resource harvesting, which implies $b_*^r > 0$ and therefore

$$\delta q \kappa > 1, \tag{14}$$

an assumption that we impose in the following. Equation (13) shows that the wealth of the resource harvesters in steady state increases with the altruism of the parents (δ), as well as with the productivity (ρ) and extent (κ) of the resource. Higher physical capital—driven by bequests—and higher natural capital—driven by resource productivity and its extent—increase income, bequest, and wealth. Interestingly, technology (q) has an ambiguous impact on the steady-state wealth of the resource harvesters, which is in line with the findings of Squires and Vestergaard (2013). Better technologies lower harvesting costs, but they also lower incentives to invest in natural capital. The steady state bequest in the rural sector also declines with the mass of resource harvesters in steady state, which thus also determines whether the next generation is rich or poor.

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[14] To arrive at the steady-state bequest we set $b_*^m \equiv b_{t+1}^m = b_t^m$ and solve (9) for b_*^m.

Following Galor and Zeira (1993), we call an economy *developed* if the lowest steady-state bequest is larger than or equal to β, that is, if all individuals are rich and can afford the investment that is necessary to work in the urban sector.

Next, we consider the steady-state mass of individuals in the rural sector. All resource harvesters are rich and the economy is developed in steady state if $b^r_* \geq \beta$, which is the case if and only if $n_* \leq \bar{n}$, with

$$\bar{n} \equiv \frac{\rho}{q\beta}\frac{\delta q\kappa - 1}{\delta q\kappa}. \tag{15}$$

The mass $\bar{n}$ defines the maximum amount of individuals that can harvest the resource without being considered poor. In other words, a mass of resource harvesters larger than $\bar{n}$ traps the rural households in poverty. Like the steady-state bequest in the resource sector, this threshold increases with the resource productivity, its extent and the parents' altruism. Additionally, it declines in the fixed cost of labor reallocation. If the cost for labor reallocation is lower, the income and bequest level needed to leave the sector is reached sooner and more people can share the resource without being considered poor. Once resource harvesters can afford to enter the urban sector, they will do so according to (7). They leave the rural sector until $y^r_* = y^m_*$, that is $b^r_* = b^m_*$, which is the case if and only if $n_* = \underline{n}$ with

$$\underline{n} \equiv \frac{\rho}{q(\alpha - \beta)}\frac{1 - \delta}{\delta}\frac{\delta q\kappa - 1}{\delta q\kappa}. \tag{16}$$

The mass $\underline{n}$ defines the mass of resource harvesters that equalizes income across both sectors. From assumption (11), it follows that $\bar{n} > \underline{n}$, as the steady-state bequest in the urban sector exceeds β. This implies that in both sectors, steady-state incomes can only be equal if the economy is in a developed state. In an underdeveloped economy, there is an income gap between the rural and urban sector, with low incomes in the rural sector, high incomes in the urban sector, and high labor reallocation costs that prevent poor households from choosing the activity with the highest income.

The two thresholds, (15) and (16), indirectly define the steady-state mass of resource harvesters. While any $n > \bar{n}$ is a steady-state value in an underdeveloped economy because resource harvesters cannot afford to leave, the only steady-state value for n in a developed economy is $n^* = \underline{n}$, that is, when incomes equalize across sectors.[15] Furthermore, the mass of resource harvesters in a developed economy, $\underline{n}$, decreases with the incomes of the urban sector. Increasing incomes in the urban sector of a de-

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[15] Note that there are special cases with $\bar{n} < 0$ or $\underline{n} > 1$. In the first case, the resource is so unproductive that households are always too poor to leave the rural sector. In the second case, the resource is so productive that households always prefer to stay in the rural sector. The first case is ruled out by condition (14). We also ignore the second case in the following, as it is empirically irrelevant.

veloped economy thus induce a labor reallocation from the rural to the urban sector and consequently, incomes rise as well in the rural sector. These findings are in line with the results of Hannesson (2007), who shows that the constant decline of fishermen in Norway over the last decades has helped to keep the remaining fishermen's incomes roughly on par with other occupational groups' income.

To explore the transitional dynamics, we follow Galor and Moav (2004) and consider a simplified setting with only two groups of individuals: a fraction $n^p \in [0, 1]$ of the individuals is initially poor and possesses $b_0 = b^p < \beta$, while the remaining fraction $1 - n^p$ is rich. A nondegenerate wealth distribution among the poor does not change the results, provided that the steady state in the rural sector is locally stable.[16] This is because the distribution of wealth among the individuals in the resource-dependent sector has no effect on the marginal productivity in resource harvesting, as the harvest technology is linear in individual capital investment.

The steady state in the urban sector is stable, and wealth dynamics are monotone, as the slope of (9) in b_t^m is $0 < \delta < 1$. A steady state in the rural sector is locally stable if $|db_{t+1}^r/db_t^r| < 1$, and b^p is sufficiently close to the steady-state level (Galor 2007). We show in appendix, section A, that $|db_{t+1}^r/db_t^r| < 1$ if in addition to (14)

$$\delta q \kappa < 3, \tag{17}$$

which we assume in the following.[17] Condition (17) states that the wealth dynamics need to be sufficiently slow in order to ensure monotone dynamics of the whole system. With fast wealth dynamics, a population of suddenly rich resource harvesters can overharvest the resource stock until the stock declines well below its previous level, leading to a next generation of impoverished resource harvesters.

All descendants of the rich stay rich because of assumption (11). The descendants of the poor may accumulate wealth over time, but they can only become rich if $n^P < \bar{n}$.

An economy that starts with a low share of poor individuals in the rural sector ($n^P < \bar{n}$) develops over time. The wealth of all individuals approaches $b_*^m = b_*^r$ and the share of the individuals in the rural sector approaches $\underline{n}$. An economy that starts with many poor individuals ($n^p > \bar{n}$) remains poor and resource dependent. The wealth of the poor approaches $b_*^r < \beta$, and the wealth of the rich approaches $b_*^m > \beta$. In this case, the share of individuals in the rural sector remains constant over time and the income gap between the rural and the urban population persists. The income of the poor declines with the share of the initially poor, $n^p = n$. Section 5 illustrates the wealth, resource, and labor dynamics with the calibrated model.

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[16] A formal analysis of unequal wealth distributions in the resource sector is given in Noack (2013).

[17] Economic development despite $n > \bar{n}$ as a consequence of cyclical wealth dynamics may occur if condition (17) does not hold. We illustrate this case numerically in Noack et al. (2015).

3. THE FIRST-BEST SOLUTION

In this section we briefly characterize the first-best setting. In the first-best benchmark case, capital and labor are allocated efficiently. Suppose now that any desirable intra- and intergenerational income distribution can be achieved with redistributional policies after total wealth has been maximized, that is, Kaldor-Hicks efficiency is achieved. This situation describes an economy with perfect institutions as well as perfect labor and financial markets.

The first-best benchmark therefore characterizes an economy in which credit markets work frictionlessly and in which property rights over resources are secure.[18] The steady-state efficient capital and labor allocation maximizes the aggregate income of all individuals and is described by (see app., sec. B):

$$\hat{K} = \frac{\rho}{2q}\frac{q\kappa - 1}{q\kappa} \tag{18}$$

$$\hat{n} = \hat{K}/\lambda \tag{19}$$

if labor in resource harvesting is sufficiently productive and $\lambda > \alpha - \beta$. Otherwise, all individuals would move to the urban sector and the rural sector would cease to exist. In the first-best allocation, the mass of individuals engaged in resource harvesting is the minimal amount required to operate the capital used in resource harvesting. This reflects the situation in a developed economy where very few individuals engage in capital-intense resource harvesting.[19]

4. RESOURCE REGULATION

We now turn to the analysis of resource regulation and economic development. We focus on situations without a credit market and study in this second-best setting how the introduction of use rights and their distribution affect the development of the economy. Accordingly, we start out from an initial situation of an underdeveloped economy, in which—without intervention—resource harvesters remain trapped in poverty. The other second-best setting with perfect credit markets and without property rights is analyzed in our working paper (Noack et al. 2015).

The dominant practical approach for initially allocating use rights is grandfathering (Anderson et al. 2011; Lynham 2014). Grandfathering means that use rights are distributed according to historical resource use, without charge. As we start from steady state where all individuals in the resource sector have the same wealth level and harvest

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[18] 18. Frictionless credit markets imply the absence of credit rationing and the same interest rate for borrowing and saving. This is the standard assumption in resource economic models (see, e.g., Clark 1990).

[19] 19. The result that only few individuals engage in capital-intense resource harvesting depends on our assumption of λ being large. For a small λ, the situation would be different.

the same amount, all resource users receive the same quantity of use rights. We first consider this approach but do not allow for trade of use rights. We then study a regulation that allows for trading use rights. Finally we show how an unequal distribution of use rights affects development. In each case, the children of the resource harvesters inherit the use rights from their parents.

To analyze the effect of regulation, we consider a situation in which holding a use right allows an individual to use a certain amount of harvesting capital ("capital allowances"). Under the assumptions of nonsubstitutability between capital and labor and a lack of technological progress, this approach is equivalent to limiting harvest quantities, but the mathematics is more transparent. We want to stress, however, that given the strict assumptions about technology and substitutability, the results rather apply to harvest quotas than to capital allowances in reality. We therefore use the term "harvest quotas" to refer to this type of resource-use regulation.

The limit on aggregate harvest is such that it maximizes the aggregate steady-state income of resource users, given the number n_* of individuals in the rural sector. Under our assumptions, this is equivalent to limiting individual harvesting capital to the first-best capital stock (18) divided by n_*, that is,

$$\bar{k} = \frac{\rho}{2qn_*}\frac{q\kappa - 1}{q\kappa}. \tag{20}$$

This type of regulation increases the income of poor resource users only if the resource harvesters are rich enough to buy more harvesting capital than $\bar{k}$, that is, if $b^r_* > \bar{k}$ in steady state. Only then would the resource regulation be binding and affect the resource users' behavior. Using (20) and (13), this is the case if and only if

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

If the altruistic part of the utility function is very low and condition (21) does not hold, bequests in the resource sector are low relative to the size of the resource and the accumulated capital is not sufficient to overharvest the resource. In this case, limiting individual resource use would not increase their incomes. In the following, we assume that resource users are wealthy enough to overuse the resource, that is, that (21) holds. Under this condition, resource regulation increases efficiency. This increase in efficiency happens at the intensive margin, without any shift of labor from the rural to the urban sector. If the situation is favorable enough at first, resource regulation in the form of nontradable quotas may be sufficient to trigger labor reallocation and the development process.

Proposition 1: Grandfathering nontradable harvest quotas over renewable resources in the rural sector will develop the economy if

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

Proof: The proof is given in the appendix, section C. QED

The proposition states that resource regulation is sufficient to lift resource users above the poverty line if the mass of resource users is small relative to the resource productivity and the cost of labor reallocation. This means that resource users were relatively wealthy before the regulation and a small increase in income and bequest is sufficient to pay the labor reallocation cost. The mass $n^E \leq n^R$ of resource harvesters that equalizes income across both sectors under resource regulation with nontradable quotas is obtained analogously to (16) as

$$n^E = \frac{\rho\kappa}{4(\alpha - \beta)} \left(\frac{q\kappa - 1}{q\kappa} \right)^2. \tag{23}$$

For an initial mass of resource users n with $n^R > n > n^E$, resource users will start to leave the rural sector after the regulation, until the mass of resource harvesters has declined to n^E. For an initial mass of resource users $n \leq n^E$, the resource rents generated by resource regulation are so large that resource users prefer to stay in the rural sector, and only the regulation prevents individuals in the urban sector from entering resource harvesting.

A binding regulation implies that individuals do not fully use their bequest for investment in harvesting capital. It implies further that resource users are willing to buy additional quotas to extend their harvesting effort. A market for quotas may evolve where some individuals sell their quotas, and others buy them. Allowing to trade individual quotas may broaden the scope for development. Allowing to trade quotas can improve efficiency, as compared to nontradable quotas, only if individuals who sell their quotas become sufficiently wealthy to enter the urban sector. Otherwise, no market transactions will occur, as no individual can improve her initial situation by selling her quota. In our case, trade is entirely driven by the opportunity to leave the sector and not by differences in the efficiency of resource harvesting. Differences in skills could be introduced by allowing λ to differ between resource users.

Consider the situation in which nontradable quotas are insufficient to make everybody rich, and additional income from selling the quotas will be needed to afford β. An individual who is willing to buy additional quotas would bid up to the value of the marginal product of harvesting capital, minus its costs.[20]

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[20] From the specification of the utility function (1) it follows that individuals only value their own consumption and the amount they bequeath to their descendants—but neither consumption nor utility of their descendants (see n. 8 for a discussion of the utility function)—and

Thus, the market price p of the quotas in steady state would be equal to $q\hat{X} - 1$ with $\hat{X}$ defined in (A3), that is,

$$p_* = \frac{q\kappa - 1}{2}. \tag{24}$$

Since credit markets are absent, the bequest limits the amount of harvest capital and the additional quotas an individual can buy. This imposes a limit to the overall demand for quotas, and thus to the mass of individuals who can leave the rural sector in each generation. However, once trade in quotas has started, it is only a matter of time until the economy develops.

> **Proposition 2**: Resource regulation with tradable quotas will develop the economy if
>
> $$n_* \leq \frac{1}{1-\delta}\frac{\rho\kappa}{4\beta}\left(\frac{q\kappa - 1}{q\kappa}\right)^2 = n^T. \tag{25}$$
>
> *Proof*: See the appendix, section D. QED

Proposition 2 states that the economy develops in response to the introduction of tradable quotas if selling the quotas at one point in time generates sufficient wealth to finance the entry into the urban sector. The additional per capita wealth generated by the quota system depends directly on the mass of resource users relative to the productivity of the resource, as we have so far assumed an equal distribution of quotas.[21]

The threshold level n^T specified in proposition 2 is larger than $\bar{n}$ (see app., sec. D). This means that tradable quotas will facilitate development for an economy that would not develop otherwise, when initially $n_* \in (\bar{n}, n^T]$. Furthermore, $n^T > n^R = \delta n^T$, which means that allowing quota trade allows a larger mass of initially poor individuals to escape the poverty trap and thus broadens the scope for development.

Proposition 2 does not make any statement about the timing of labor reallocation. Dynasties may need to accumulate wealth through efficiency gains achieved by regulation before they become rich enough to sell their quotas and leave the rural sector. If the economy is initially in a steady state without regulation, implementing resource regulation with tradable quotas enables some individuals to immediately leave the rural sector if

$$n_* \leq \bar{n} + (1-\delta)(1-\tau_*)n^T, \tag{26}$$

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therefore do not take the impact of quotas on the next generations' consumption into account. The marginal product of harvesting capital can be calculated based on (3), with $e_t = k_t$ and $X_t = \hat{X}$.

[21] This result does not necessarily hold when the government captures the resource rents.

where τ_* is the time the resource needs to recover from X_* to $\hat{X}$, which is independent of n_* (for the proof, see app., sec. E).

Under condition (26), some individuals are able to immediately leave the rural sector by selling their harvest quotas. In that generation, remaining individuals' net revenues from resource use will remain unaffected by labor reallocation, as the aggregate effort remains constant and the increased revenues from resource harvesting equal the costs for buying additional quota and capital. However, each generation's descendants will be better off, as they not only inherit the same wealth in terms of capital as their parents, but also the extra wealth in terms of inherited quotas. The market value of total quotas per individual increases over time, while the price of the quotas remains constant (cf. eq. [24]). Thus, condition (26) will always be fulfilled for the next generation of resource users as well, and further individuals will leave the rural sector (as also stated in proposition 2). This development process will end when resource harvesters have no more incentives to leave the rural sector. Compared to the regulation with nontradable quotas, fewer individuals remain in the resource sector, as the revenues from selling the quota provide additional incentives to leave resource harvesting. In steady state, the resource harvesters are indifferent between staying and leaving when

$$y_*^r = y_*^m + p_*\bar{k}_*, \tag{27}$$

with the steady-state quota price p_* and the steady state capital allowance per capita $\bar{k}_* \geq \bar{k}$. This shows that owners of resource-use rights are better off than workers in the urban sector in a steady state with tradable quotas. Intersectoral migration ends when labor limits resource production and harvesting capital is at its first-best level. In that state, harvesters have no incentives to buy further quotas, as their harvesting effort is constrained by their labor.

So far, the discussion centered around a situation in which resource users leave the resource sector after a regulation has been introduced, that is, after resource rents were created and the returns to resource use were increased. This may seem counterintuitive at first sight. The reason they leave the resource sector is because the incomes in the urban sector exceed the incomes in the rural sector. A transferable quota creates an additional incentive to leave the resource sector, as it transforms the resource rent into a tangible asset. The resource user can cash in on part of the resource rent and still gain from the higher income in the modern sector.

Up to now, we have studied the case where all individuals initially receive equal quantities of harvest quotas. An unequal initial allocation of quotas may facilitate economic development in cases where an equal distribution of harvesting quotas fails to solve the poverty trap. The most promising candidate for an unequal distribution of quotas is the one where a mass $\nu < n_*$ of resource users is endowed with quotas that are just valuable enough after the resource stock has reached its optimal size to allow the harvesters to afford the capital β needed to move to the urban sector. However, this extra endowment is only possible by reducing the quotas of all $n_* - \nu$ other resource users. We will refer to the resource users that have an above-average endowment of quotas as the "advantaged" and the others as the "disadvantaged" users. The value of the quotas that needs to be given to the advantaged, $p\bar{k}_*^+$, is indirectly defined as

$$b_*^+ + p_* k^+ = \beta, \tag{28}$$

where b_*^+ is the bequest of the advantaged in the resource sector after the resource has reached its optimal state as defined by (A3) and p_* is the quota price as defined in (24). Condition (28) states that the total wealth of the advantaged, after the resource stock has transitioned to its optimal state, equals the cost of labor reallocation. However, the disadvantaged will only buy the quota of the advantaged if their wealth is sufficient to finance the total regulated harvesting capital and additionally to pay the price for the quota, that is,

$$(n_* - \nu) b_*^- = \nu p_* k^+ + \hat{K}, \tag{29}$$

where b_*^- denotes the bequests of the disadvantaged after the resource has reached its optimal state but before the advantaged have left the resource sector, while $\hat{K}$ is the optimal harvesting capital (18). After the advantaged have left the rural sector, the disadvantaged resource users may also become rich if their mass is small enough, that is, if $n_* - \nu \leq n^T$. The advantage of unequal distribution over equal distribution of quota is that it allows a sequential development, that is, the advantaged escape the poverty trap first, which leaves the disadvantaged with enough resource wealth to leave the poverty trap in a second iteration, given $n_* - \nu \leq n^T$. This process of sequential development is summarized in the following proposition.

> **Proposition 3**: An unequal distribution of tradable quota that satisfies (28) and (29) ultimately moves the economy to a developed state if
>
> $$n_* < n^T + \nu = \left(1 + \frac{\delta(q\kappa + 1) - 2}{q\kappa - 1}\right) n^T. \tag{30}$$
>
> *Proof*: See the appendix, section F. QED

The finding that unequal allocation of quotas can lead to a developed economy rests on the result that the advantaged leave the rural sector. In our modeling framework, this is only true for underdeveloped economies with poor resource harvesters. For developed economies in which households are unconstrained in their occupational choices, the advantaged may not leave the rural sector and occupational choices may be based on skills and preferences.

Unequal allocations of quotas can be perceived as unfair. However, most quotas are grandfathered according to past harvests, which may differ across resource harvesters either because of different effort levels or by chance. Proposition 3 then states that these unequal allocations can lead to a development of the economy that eventually makes all individuals better off than equal distribution.

Unequal distributions of quotas can be Pareto improving for all generations compared to the status quo if the resource dynamics are sufficiently fast and the increase of resource rents already compensates the first generation of disadvantaged for their low quota endowments (Noack 2013). This may be the case for many fast-growing fish stocks or rangelands. In contrast, slow-growing resources such as whales or forests may need several human generations to recover with long-term harvesting moratoriums. Additional policies mitigating the effect of temporary income shortfalls may be required to support households during the rebuilding of the stocks. In the next section, we discuss the transitional dynamics for the case of Chilika lagoon.

5. A NUMERICAL ILLUSTRATION

In this section, we parameterize the model to illustrate the impact of quota design and quota allocation on economic development as well as to discuss transitional dynamics. To parameterize the model, we use data from a fishery survey that we conducted in 2011 at Chilika lagoon, a large Indian inland fishery. However, we want to stress that the parameterization is only for illustrative purposes and we do not mean to make precise predictions.

To parameterize the model, we use the total number of Chilika fishermen in 2011 as the number of resource users, such that $n_* = 32{,}500$. We abandon the normalization of the total mass of individuals to one in order to facilitate interpretation. We further set the period length to 30 years, such that an individual would live 60 years, which is in line with the life expectancy in many developing countries. The income in the urban sector is set to $\alpha = 0.52$ million Rupees, which was the average income a Chilika fisherman with higher education would earn over 30 years after leaving the fishery. The fixed costs to enter the urban sector are assumed to be $\beta = 0.033$ million Rupees, which equals the costs of higher education and opportunity costs in the form of forgone fishing income during the education period. The parameters describing the resource dynamics (ρ, κ), as well as the catchability parameter (q), are estimated from simulations using fish catch histories following Martell and Froese (2013). Last, we set $\delta = 0.10$, to ensure a locally stable steady state according to (17). Table 1 lists the parameter values, while a detailed description of the calibration is given in Noack et al. (2015).

With the parameter values presented in table 1, the steady state bequest is $b^r_* = 0.022$ million Rs in the rural sector and $b^m_* = 0.054$ million Rs in the urban sector. The bequest in the urban sector exceeds educational costs β such that condition (11) is fulfilled and the urban sector can persist. For the present choice of parameter values, the fishermen are trapped in poverty, as their steady state bequest is well below the educational costs, $b^r_* = 0.022 < 0.033 = \beta$. This result mirrors the lack of labor reallocation to the urban sector that we observed in our field survey.

Table 1. Values Used in the Case Study

	Symbol						
	α	β	q	κ	ρ	δ	n
Value	.52	.033	.0005	1,680	.6	.10	32,500

Note. The values for α, β, and κ are given in million Rs; q is measured in 1 over the units of effort (here: 1/Rs); ρ is per year and has to be multiplied by the period length; the period length is set to 30 years; δ is dimensionless.

Resource regulation enables development as shown in the previous section. Taking the number of resource harvesters as given, resource regulation in the form of nontradable use rights limits harvesting capital to $\bar{k} = 0.018 < 0.022 = b^r_*$ million Rs. This raises the steady-state bequest to $\overline{b^r_*} = 0.024$ million Rs, which is still well below the educational costs. Regulating the resource stock in this way is not sufficient to develop the economy. Allowing trade with quotas broadens the scope for development considerably. The threshold population below which tradable use rights lead to development of the local economy rises to 234,744. This is more than seven times the current number of fishermen. Distributing the quotas unequally increases the number of fishermen who can escape poverty further to 261,780.

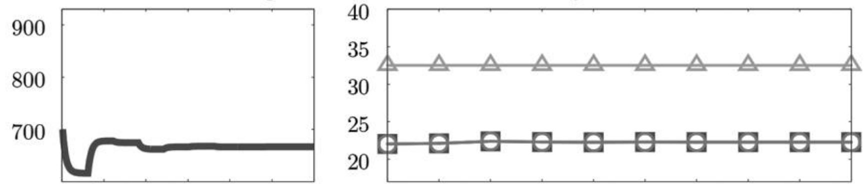
These numerical results show that making the quotas tradable and distributing them unequally broadens the scope for development considerably, as the number of fishermen that can escape the poverty trap increases by an order of magnitude compared to the nontradable regulation. Table 2 summarizes the numerical results by listing the threshold number of resource harvesters that can escape the poverty trap under different resource regulations.

Table 2. Threshold Values for Development

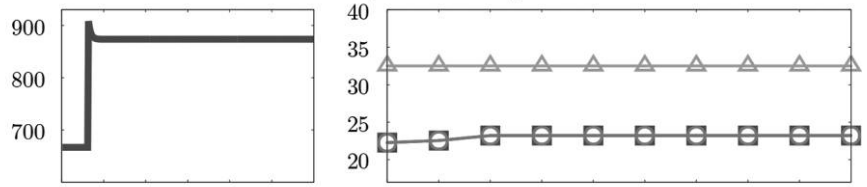
Economy developed in steady state	Eq. (15)	$n_* \leq \bar{n} = \frac{\rho}{q\beta}\frac{\delta q\kappa 30-1}{\delta q\kappa 30} = 21{,}933$
Steady-state bequests equal in rural and urban sectors	Eq. (16)	$n_* = \underline{n} = \frac{\rho}{q(\alpha-\beta)}\frac{1-\delta}{\delta}\frac{\delta q\kappa 30-1}{\delta q\kappa 30}$ $= 13{,}376$
Regulation with nontradable, grandfathered use rights develops the economy	Prop. 1	$n_* \leq n^R = \frac{\delta}{1-\delta}\frac{\rho\kappa 30}{4\beta}\left(\frac{q\kappa 30-1}{q\kappa 30}\right)^2$ $= 23{,}474$
Steady-state bequests equal in rural and urban sectors under regulation above	Eq. (23)	$n_* \leq n^E = \frac{\rho\kappa 30}{4(\alpha \vdash \beta)}\left(\frac{q\kappa 30-1}{q\kappa 30}\right)^2$ $= 14{,}316$
Regulation with tradable equally distributed quotas develops the economy	Prop. 2	$n_* \leq n^T = \frac{1}{\delta} n^R = 234{,}744$
Regulation with tradable unequally distributed quotas develops the economy	Prop. 3	$n_* \leq n^T + \frac{\frac{\delta}{1-\delta}\hat{K}(q\hat{X}-1)-1}{\beta}$ $= 261{,}780$

The numerical model also illustrates the transitional dynamics with the dynamics of fishermen according to (7). We first consider the convergence to the steady state when resource users are identical and start with a bequest level and an initial resource stock slightly above the steady-state level to illustrate that this will not be sufficient to trigger a development process (scenario 1). The first row of figure 1 illustrates this scenario. The graph on the left shows the dynamics of the resource stock, while the graph on the right shows the bequest in the resource sector, the number of resource users, and the mean income of the initial resource users over time. The above-steady-state level of bequest leads to overfishing, which, in turn, lowers the amount bequeathed to the next generation. This allows the resource stock to recover. The steady-state values are reached without resource users leaving the rural sector.

Scenario 1: No regulation, start above steady state



Scenario 2: Non-tradable quotas from generation 2 onwards



Scenario 3: Tradable quotas equally distributed in generation 2

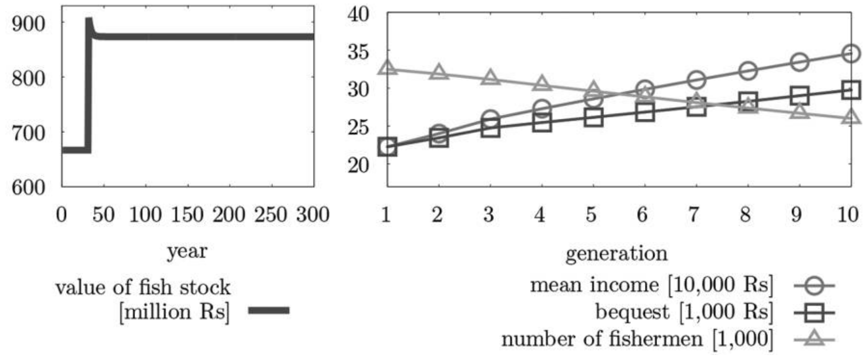


Figure 1. Simulation resource dynamics. Rs = Indian Rupees; parameter values as reported in table 1.

The second row of figure 1 illustrates a scenario (scenario 2), in which, starting out from steady state in the first generation, nontradable harvesting quotas are introduced before the second generation starts fishing. As the graph on the left shows, the regulation leads to a recovery of the resource stock during the second generation. Without harvest, the resource stock reaches its first-best level in less than a year. As the fishing ban in the simulation is implemented for a whole year, the resource stock even grows above its optimal level. The regeneration of the resource stock is also visible in the bequest of the resource users, which increases marginally in the following generations. The bequest is not sufficient to leave the sector and the number of resource users, shown in the graph on the right, is constant. Still, compared to the situation without regulation, the average income of all resource users increases.

The third row of figure 1 illustrates the introduction of tradable quotas before the second generation starts fishing (scenario 3). The resource stock behaves as under a nontradable harvest quotas. The bequest, in turn, increases over time. The increase is initially around 5% and later about 3% from generation to generation. As the illustration shows, once trade in quotas starts, the economy will develop, but relying on this mechanism alone means that it will take over 100 years.

6. CONCLUSION

We have shown that the introduction of harvest quotas for common pool resources in developing economies does not only increase efficiency and incomes of the resource harvesters but may help to trigger a development process in a dual economy with imperfect labor and capital markets. The extra wealth created by rights-based regulation can facilitate labor reallocation from rural to urban production.

The type of regulation used plays an important role. Allowing trade with quotas broadens the scope of development compared to regulation by means of nontradable quotas, as an individual tradable quota is an asset that can be sold to cover fixed costs of labor reallocation. Moreover, unequal initial allocation of quotas induces a sequential reallocation of labor that enables first the better-off and then the worse-off to escape the poverty trap, and thus eventually makes the descendants of all individuals better off.

This article is primarily concerned with the long-term outcomes of resource regulation. Introducing resource regulation for overharvested resource stocks, however, implies that harvesting must be reduced temporarily to allow the resource to recover. Resource incomes therefore fall initially after the introduction of regulations, before the harvesters start to benefit from the rebuilt resource stocks. The length of the period needed to rebuild the resource stocks largely depends on the resource growth and the level of depletion. For slowly growing and severely depleted resources with long regeneration periods, additional policies are needed to overcome the temporary income shortfalls. These additional efforts and costs may be warranted, however, as resource regulation not only increases resource rents but also yields efficiency gains from labor reallocation, which can be both large and lasting.

APPENDIX

A. Steady State in the Traditional Sector

In steady state, all n_* individuals engaged in resource harvesting have the same initial wealth b^r_*, and all invest this into resource harvesting. Using this, and $b^r_{t+1} = b^r_t \equiv b^r_*$ in (12) leads to the steady-state condition

$$b^r_* = \delta q X_* b^r_* \quad \Leftrightarrow \quad X_* = \frac{1}{\delta q}, \tag{A1}$$

for $b^r_* > 0$. From (5), the steady-state condition for the resource stock is

$$q n_* b^r_* = \rho\left(1 - \frac{X_*}{\kappa}\right) = \rho\left(1 - \frac{1}{\delta q \kappa}\right). \tag{A2}$$

Rearranging leads to (13).

To study stability of wealth dynamics, consider the resource stock size as a function of bequest, $X_*(b^r_t)$.

$$\begin{aligned}\frac{db^r_{t+1}}{db^r_t} &= \frac{d}{db^r_t}\delta q b^r_t X_*(b^r_t) = \delta q X_*(b^r_t) + \delta q b^r_t \frac{dX_*(b^r_t)}{db^r_t} \\ &= 1 + \delta q b^r_t \frac{dX_*(b^r_t)}{db^r_t} < 1,\end{aligned}$$

as the resource stock must decrease with the amount of capital employed in resource harvesting, $dX_*(b^r_t) < 0$. In the extreme where the resource stock adjusts to harvesting pressure within one generation, the resource stock is given by the following expression (from [A2]):

$$X_*(b^r_t) = \frac{\kappa}{\rho}(\rho - q n_* b^r_t).$$

Thus, $db^r_{t+1}/db^r_t > -1$ only if condition (17) holds.

B. First Best

To determine the first-best allocation, we first determine the optimal amount of resource harvesting for a given labor allocation n_t, and then optimize over n_t, taking the potential feedback on optimal resource harvesting into account. Optimal resource harvesting is found by maximizing the present value of resource income over capital used in resource harvesting, over a finite time horizon T which we assume to be very large compared to generation time, $T \gg 1$.

$$\max_{\{k(j,\tau)\}} \int_0^T \int_0^1 \{qX(\tau)\min\{k(j,\tau),\lambda\} - k(j,\tau)\}djdt$$

$$\text{subject to } \frac{dX(\tau)}{d\tau} = \rho X(\tau)\left(1 - \frac{X(\tau)}{\kappa}\right) - qX(\tau)\int_0^1 \min\{k(j,\tau),\lambda\}dj.$$

Assuming $k(j, \tau) < \lambda$ and using $K(\tau) = \int_0^1 k(j, \tau)dj$, the current-value Hamiltonian for this optimization problem is

$$\mathcal{H} = qXK - K + \mu\left(\rho X\left(1 - \frac{X}{\kappa}\right) - qXK\right),$$

with the shadow price μ. As the Hamiltonian is linear in the control variable, the optimal solution is to choose $K(\tau) = 0$ or $K(\tau)$ at the maximal level until a steady-state solution is reached where resource stock size, capital, and the shadow price of the resource stock are constant at levels given by

$$\begin{aligned}\frac{\partial\mathcal{H}}{\partial K} &= qX(1 - \mu) - 1 = 0,\\ \frac{\partial\mathcal{H}}{\partial X} &= qK + \mu\left(\rho\left(1 - 2\frac{X}{\kappa}\right) - qK\right) = 0,\\ \frac{\partial\mathcal{H}}{\partial \mu} &= \rho X\left(1 - \frac{X}{\kappa}\right) - qXK = 0.\end{aligned}$$

Solving leads to

$$\begin{aligned}\hat{X} &= \frac{1 + q\kappa}{2q},\\ \hat{K} &= \frac{\rho}{2q}\frac{q\kappa - 1}{q\kappa},\\ \hat{\mu} &= \frac{q\kappa - 1}{q\kappa + 1},\end{aligned} \tag{A3}$$

with "^" indicating first best.

The optimal labor allocation at each point in time is found by maximizing aggregate income with respect to n and implementing an income tax to achieve redistributive objectives,

$$\max_n\left\{nq\hat{X}\min\left\{\hat{K}/n, \lambda\right\} - \hat{K} + (1 - n)(\alpha - \beta)\right\}.$$

For $n > \hat{K}/\lambda$, the objective function becomes $q\hat{X}\hat{K} - \hat{K} + (1 - n)(\alpha - \beta)$, which is monotonically decreasing with n. Thus, the optimal mass of resource users must fulfill $\hat{n} \leq \hat{K}/\lambda$. The objective function is $nq\hat{X}\lambda - \hat{K} + (1 - n)(\alpha - \beta)$, which is monotonically increasing with n if

$$q\hat{X}\lambda = \frac{\lambda}{2}(1 + q\kappa) > \alpha - \beta,$$

which is true due to the assumed condition $\lambda > \alpha - \beta$. Thus, the optimal mass of resource users is

$$\hat{n} = \frac{\hat{K}}{\lambda} = \frac{\rho\kappa}{2\lambda}\frac{q\kappa - 1}{(q\kappa)^2}.$$

C. Proof of Proposition 1

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

$$\begin{aligned} \frac{\rho}{2qn_*}\frac{q\kappa - 1}{q\kappa} &< \frac{\rho}{qn_*}\frac{\delta q\kappa - 1}{\delta q\kappa} \\ \Leftrightarrow \qquad \delta q\kappa - \delta &< 2\delta q\kappa - 2 \\ \Leftrightarrow \qquad 2 &< \delta(1 + q\kappa), \end{aligned}$$

which holds if and only if (21) holds.

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

$$\begin{aligned} \bar{b}^r &= \frac{\delta}{1-\delta}(qX_* - 1)\bar{k} = \frac{\delta}{1-\delta}\left(q\frac{1+q\kappa}{2q} - 1\right)\frac{\rho}{2qn_*}\frac{q\kappa - 1}{q\kappa} \\ &= \frac{\delta}{1-\delta}\frac{\rho\kappa}{4n_*}\left(\frac{q\kappa - 1}{q\kappa}\right)^2. \end{aligned} \tag{A4}$$

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

$$\frac{\delta}{1-\delta}\frac{\rho\kappa}{4n_*}\left(\frac{q\kappa - 1}{q\kappa}\right)^2 > \beta. \tag{A5}$$

Rearranging with respect to n_* and taking into account that individuals can leave the sector as soon as they inherit β leads to (22).

D. Proof of Proposition 2

When the resource stock is at its optimal level, the steady-state price of the resource-use right is (24), and the value of the right to use a capital input (20) is

$$p_*\bar{k} = \frac{q\kappa - 1}{2}\frac{\rho}{2qn_*}\frac{q\kappa - 1}{q\kappa} = \frac{\rho\kappa}{4n_*}\left(\frac{q\kappa - 1}{q\kappa}\right)^2.$$

Under regulation and without labor movement, a resource user obtains a steady-state bequest given by (A4). Thus, total wealth of one resource user is greater than β, $\bar{b}^r + p_*\bar{k} \geq \beta$, if

$$\frac{1}{1-\delta}\frac{\rho\kappa}{4n_*}\left(\frac{q\kappa - 1}{q\kappa}\right)^2 \geq \beta. \tag{A6}$$

Rearranging leads to (25). Under this condition, some resource users will leave the rural sector. This increases the incomes of the remaining resource users, thus enabling further development in the next generation. This development process continues until the economy has reached a "developed" state.

We next show that $\bar{n} < n^T$.

$$\begin{aligned} & \bar{n} = \frac{\rho}{q\beta}\frac{\delta q\kappa - 1}{\delta q\kappa} < n^T = \frac{1}{1-\delta}\frac{\rho\kappa}{4\beta}\left(\frac{q\kappa - 1}{q\kappa}\right)^2 \\ \Leftrightarrow \quad & 4(1-\delta)(\delta q\kappa - 1) \leq \delta(q\kappa - 1)^2 \\ \Leftrightarrow \quad & 4\delta q\kappa - 4\delta^2 q\kappa - 4 + 4\delta \leq \delta q\kappa^2 - 2\delta q\kappa + \delta \\ \Leftrightarrow \quad & 6\delta q\kappa + 3\delta \leq \delta q\kappa^2 + 4\delta^2 q\kappa + 4 \\ \Leftrightarrow \quad & \delta\left(6q\kappa + 3 - q\kappa^2 - 4\delta q\kappa\right) \leq 4. \end{aligned}$$

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

E. Proof of Equation (26)

Some individuals can immediately leave the rural sector if the sum of their initial wealth b^r_* and the value of their resource-use right exceeds β. Starting with a steady-state stock size X_* the individual quota may be used under the optimal policy once the resource stock has reached $\hat{X}$ (cf. app., sec. B), without harvesting and logistic resource growth in between. Thus, the quota may be used after a period of time

$$\begin{aligned} & \hat{X} = \frac{\kappa X_* e^{\rho\tau_*}}{\kappa + X_*(e^{\rho\tau_*} - 1)} \\ \Leftrightarrow \quad & \hat{X}\kappa + \hat{X}X_* e^{\rho\tau_*} - \hat{X}X_* = \kappa X_* e^{\rho\tau_*} \\ \Leftrightarrow \quad & (\kappa - X_*)\hat{X} = \left(\kappa - \hat{X}\right)X_* e^{\rho\tau_*} \\ \Leftrightarrow \quad & \frac{(\kappa - X_*)\hat{X}}{\left(\kappa - \hat{X}\right)X_*} = e^{\rho\tau_*} \\ \Leftrightarrow \quad & \tau_* = \frac{1}{\rho}\ln\left(\frac{(\kappa - X_*)\hat{X}}{\left(\kappa - \hat{X}\right)X_*}\right) \qquad \text{(A7)} \\ & = \frac{1}{\rho}\ln\left(\frac{\left(\kappa - \frac{1}{\delta q}\right)\frac{1+q\kappa}{2q}}{\left(\kappa - \frac{1+q\kappa}{2q}\right)\frac{1}{\delta q}}\right) \\ & = \frac{1}{\rho}\ln\left(\frac{(\delta q\kappa - 1)(1 + q\kappa)}{2q\kappa - 1 - q\kappa}\right) \\ & = \frac{1}{\rho}\ln\left(\frac{(\delta q\kappa - 1)(1 + q\kappa)}{q\kappa - 1}\right). \end{aligned}$$

The market price of the quota thus is

$$p = (1-\tau_*)p_* = (1-\tau_*)\frac{q\kappa - 1}{2}, \tag{A8}$$

and its market value is

$$p\frac{\rho}{2n_* q}\frac{q\kappa-1}{q\kappa} = (1-\tau_*)\frac{\rho\kappa}{4n_*}\left(\frac{q\kappa-1}{q\kappa}\right)^2. \tag{A9}$$

Resource users can immediately leave the traditional sector if their total wealth—quota value and inheritance—exceeds β, that is, if

$$\frac{\rho}{qn_*}\frac{\delta q\kappa-1}{\delta q\kappa} + (1-\tau_*)\frac{\rho\kappa}{4n_*}\left(\frac{q\kappa-1}{q\kappa}\right)^2 \geq \beta$$

$$\Leftrightarrow \qquad n_* \leq \underbrace{\frac{\rho}{q\beta}\frac{\delta q\kappa-1}{\delta q\kappa}}_{=\bar{n}} + (1-\tau_*)\underbrace{\frac{\rho\kappa}{4\beta}\left(\frac{q\kappa-1}{q\kappa}\right)^2}_{=(1-\delta)n^T}.$$

F. Proof of Proposition 3

Proof: Consider an unequal distribution of quota such that it satisfies

$$b_*^+ + p_* k^+ = \beta \quad \text{and} \tag{A10}$$

$$(n_* - \nu)b_*^- = \nu p_* k^+ + \hat{K}, \tag{A11}$$

where p_* is given by (24) and ν denotes the mass of advantaged resource users. The first condition states that the advantaged have just enough wealth to pay β. The second condition states that aggregate wealth of resource harvesters is sufficient to provide the capital $\hat{K}$ used in resource harvesting and the total cost for a maximum mass ν of people to enter the modern sector.

The steady-state bequest of the advantaged is $[\delta/(1-\delta)](q\hat{X}-1)k^+ = [\delta/(1-\delta)]p_* k^+$. Using this in (A10) and solving for $p_* k^+$ yields

$$p_* k^+ = (1-\delta)\beta.$$

The quota endowment of the disadvantaged is simply given by dividing the remaining quota by the number of disadvantaged,

$$k^- = \frac{\hat{K} - \nu k^+}{n_* - \nu},$$

and their steady-state bequest is

$$b_*^- = \frac{\delta}{1-\delta} p_* k^- = \frac{\delta}{1-\delta} \frac{p_* \hat{K} - \nu(1-\delta)\beta}{n_* - \nu}.$$

Using these results in condition (A11) leads to

$$\begin{aligned} \frac{\delta}{1-\delta}\left(p_* \hat{K} - \nu(1-\delta)\beta\right) &\geq \nu(1-\delta)\beta + \hat{K} \\ \frac{\delta}{1-\delta} p_* \hat{K} - \nu\delta\beta &\geq \nu(1-\delta)\beta + \hat{K} \\ \frac{\delta}{1-\delta} p_* \hat{K} &\geq \nu\beta + \hat{K}. \end{aligned}$$

The resulting restriction on ν is

$$\begin{aligned} \nu &= \left(\frac{\delta}{1-\delta} p_* - 1\right)\frac{\hat{K}}{\beta} = \frac{\delta(q\kappa - 1) - 2(1-\delta)}{2(1-\delta)}\frac{\hat{K}}{\beta}, \\ &= \frac{\delta(q\kappa + 1) - 2}{2(1-\delta)}\frac{\hat{K}}{\beta} = \frac{\delta(q\kappa + 1) - 2}{q\kappa - 1}\frac{1}{1-\delta}\frac{\rho\kappa}{4\beta}\frac{(q\kappa - 1)^2}{q^2\kappa^2}, \\ &= \frac{\delta(q\kappa + 1) - 2}{q\kappa - 1} n^T. \end{aligned}$$

By (21), the right-hand side of this condition is positive. It is thus always possible to endow some resource harvesters with sufficient quota, so that they can afford to move to the modern sector. That the disadvantaged can eventually become rich follows directly from proposition 2. QED

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