Rural Environmental Degradation, Growth, and Income Distribution in a Structuralist Two-Sector Model

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Abstract

The model presented in this paper distinguishes an industrial and an agricultural sector within a developing economy. Environmental degradation results from the overexploitation of a renewable resource due to a common pool externality, which causes agricultural productivity to decline. The model considers a differentiated peasantry where land ownership and savings behaviour differ across income classes.

The analysis reveals that environmental degradation can reduce growth in the short run but increases growth (measured by the stock of industrial capital per capita) in the long run. Redistribution in favour of the poor reinforces the long-run increase but generates ambiguous short-term outcomes. These results suggest that environmental and redistributive policies involve complex trade-offs between both intergenerational and intragenerational equity.

JEL Codes: D30, E12, O11, Q20

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1 Introduction

Environmental degradation[1] has become widespread in the rural areas of many developing countries. Examples are deforestation, soil erosion, soil salinity, waterlogging, and local level declines in the groundwater table.[2] Rural environmental degradation does not only impair the general quality of life (in the sense of inflicting a disutility on individuals) but also reduces the productivity of land, labour, and capital. Furthermore, the poor are more strongly affected by these productivity declines than the rich (the non-poor) in many cases.[3]

While the microeconomic causes and effects of rural environmental degradation have been studied in a variety of settings,[4] the question arises what are their impacts on economic growth and welfare. A widely held view is that the growth process as such is unaffected by environmental degradation but preferences for a healthy environment may induce society to devote some resources to environmental quality (Beckerman 1992, p.482). A competing view is that environmental degradation represents a constraint to growth. As far as the distributive impact of environmental degradation is concerned, it is suggested that environmental degradation raises rural poverty and inequality, which in turn accelerate degradation. In this context, environmental degradation is thought to provide a new rationale for redistributive policies (Dutt and Rao 1996, pp.298-299).

This paper examines the hypothesis that rural environmental degradation reduces industrial growth in a developing country both directly (through its impact on agricultural output) and indirectly (through increased rural poverty and income inequality). To this end, it integrates a neoclassical model of renewable resource exploitation into a structuralist two-sector framework. While the former makes it possible to analyze environmental degradation as resulting from a microeconomic externality, the latter makes it possible to focus on demand linkages between industry and agriculture. This paper extends an earlier model (Chakraborty 2001) to the case of a differentiated peasantry. It considers a closed economy.[5]

The model contains three components. The *first component* is a two-sector model originally developed by Taylor (1991) that describes the relationship between industry and agriculture.[6] It reflects a vision of the growth

[1]The concept of environmental degradation employed in this paper comprises the decline of renewable resource stocks below and the increase in pollution above efficient levels. It excludes problems related to the increasing scarcity of non-renewable resources.

[2]See Dasgupta and Mäler (1995) for an overview.

[3]For empirical cases see Fernandes, Menon, and Viegas (1988); Chambers, Saxena, and Shah (1989); Nadkarni (1989); Ratna Reddy and Behera (2000).

[4]See for example Dasgupta and Heal (1979); Barrett (1991); Pagiola (1993); Baland and Platteau (1996); López (1997; 1998).

[5]Implications for open economies are briefly discussed in Section 3.1.2.

[6]The basic structure of this model dates back to Kalecki (1954/1976).

process that considers the sectoral transformation from a predominantly agrarian to an industrial economy as central to economic development. In this framework, production is assumed to be constrained by different factors in agriculture and in industry. Industrial production is constrained by effective demand while agricultural production is constrained by the scarcity of land, physical infrastructure, and 'modern' inputs. Labour is not considered as a constraint to the expansion of output.

Growth is driven by the investment demand of the two sectors. Investment determines saving through the Keynesian mechanism of effective demand. Furthermore, it is assumed that an oligopolistic market structure prevails in the industrial sector. Firms set prices by adding a fixed percentage markup to labour costs and adapt to changes in demand by varying output rather than price. Industrial wages are considered as institutionally determined. Labour supply is infinitely elastic at the prevailing wage rate. As a result, the allocation of labour between the two sectors is determined by the level of the effective demand for industrial goods.

The assumptions of price setting behaviour and investment-driven growth imply that excess capacity exists in the industrial sector even in the long run. The model's emphasis on demand permits a detailed analysis of the impact of the allocation of consumption expenditure between agricultural and industrial goods (Engel effects).

It is assumed that agricultural producers are unable to adjust their output to short-term fluctuations in effective demand. Stronger dependence on natural cycles is one empirical justification. Another is the fact that, in many developing countries, agriculture consists of numerous small producers (peasants) whose market power is small. As a result, the market for agricultural goods clears by variation of the price.

The *second component* of the model describes the causes of environmental degradation and its impact on agricultural output. It is based on a neoclassical renewable resource exploitation model that was first published by Gordon (1954). Environmental degradation results from a common pool externality which causes a renewable resource to be overexploited. It is assumed that the externality is fully internalized initially through traditional common property institutions. These institutions lose their strength as a result of (exogenous) modernization, which leads to decreasing resource stock levels. The depletion of the resource is linked to the agriculture-industry framework through its impact on agricultural output: agricultural productivity positively depends on the stock of the renewable resource.

The *third component* concerns the impact of income distribution on growth. It considers the case of a differentiated peasantry where poor farmers experience higher relative productivity declines (induced by the environmental externality) than the non-poor because they own less land both in terms of quantity and quality. Furthermore, the poor are assumed to have a lower marginal savings ratio than the non-poor. As a result, environmental degradation raises the aggregate marginal savings ratio in agriculture, which affects industrial growth because it has an impact on the demand for industrial goods.

The linkages between environmental degradation, growth, and income distribution have rarely been analyzed on a *macroeconomic* level.[7] The model therefore combines elements from three strands of the literature. The first strand analyzes the linkages between *growth and income inequality.* While Kuznets (1955) argued that income inequality rises in the early stages of the growth process, more recent neoclassical[8] and structuralist[9] contributions emphasize that the redistribution of income from the rich to the poor can accelerate growth. This paper follows the structuralist view in that rural poverty and inequality affect growth through demand linkages between agriculture and industry. The assumption of class-specific marginal savings ratios dates back to Kaldor (1955).

Second, the model builds on the literature on the relationship between *agriculture and industry in economic development.* By arguing from a supply side perspective, early contributions emphasized that the expansion of agricultural output was a precondition for industrial growth.[10] More recent contributions have emphasized the role of the level and structure of demand as a determinant of industrial growth.[11] The model presented in this paper differs from these contributions in that it explicitly considers environmental degradation. Insofar it considers investment demand rather than savings supply as the driving force of growth ("investment determines saving"), it builds upon earlier models by Rowthorn (1981) and Dutt (1984).

The third strand of the literature to which the model is related analyzes the linkages between *growth and environmental degradation.* Most contributions present neoclassical[12] growth models where the environment is either an input to or a by-product of the production of a composite commodity that can be consumed or invested. In these growth models, environmental externalities *increase* the rate or the level of growth if environmental degradation "only" inflicts a disutility on the affected individuals. Consequently, growth is reduced when these externalities are internalized.[13] In contrast, environmental externalities *reduce* the rate or the level of growth if environmental degradation reduces the productivities of the factors of production. Growth is stimulated when these externalities are internalized.[14]

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[7]For an informal discussion, see Dutt and Rao (1996).

[8]See Galor and Zeira (1993) and Murphy, Shleifer, and Vishny (1989). An overview is contained in Aghion, Caroli, and García-Peñalosa (1999).

[9]See Rowthorn (1981) and Dutt (1984).

[10]See Lewis (1954/1963); Jorgenson (1961); Fei and Ranis (1964).

[11]See Taylor (1983, 1991), Dutt (1991), Rao (1993), Storm (1993, 1997), and Skott (1999).

[12]D'Arge (1971) employs a Harrod-Domar framework.

[13]See Forster (1973); Gradus and Smulders (1993); Tahvonen and Kuuluvainen (1993).

[14]See Bovenberg and Smulders (1996); Smulders and Gradus (1996).

The model presented here differs from this literature in three respects. First, it takes the interaction between agriculture and industry explicitly into account. Second, it simultaneously considers the impact of environmentally-induced poverty and inequality on growth. Third, the model assumes that the scarcity of unskilled labour is not the binding constraint to the expansion of industrial production, which is an appropriate assumption for many countries.

The model generates the following results. *First*, environmental degradation reduces the rate of industrial growth in the short run but *raises* the level of the industrial capital stock per capita in the long run if agricultural investment is not too responsive to agricultural prices. The reason is that the decline in agricultural productivity raises agricultural prices, which reduces the consumption demand for industrial goods in the short run but increases industrial capital accumulation through increased agricultural investment demand in the long run. These results are termed *production effect* here; they differ from the predictions of the neoclassical "environment and growth" models in that an environmental externality that reduces the productivity of a factor of production increases the level of the growth path in the long run.

Second, environmental degradation raises rural inequality and increases the poverty of poor farmers and non-farming communities who depend on renewable resource extraction for their livelihoods. *Third*, if the poor have a lower marginal propensity to save than the rich, an additional effect on industrial growth arises which is termed *distribution effect*. The distribution effect is ambiguous in the short run but unambiguously weakens the production effect in the long run. These results suggest that the case for environmental or redistributive policies is not unambiguous. Rather do trade-offs need to be considered between the present and the future, the welfare of different social classes at a point in time, and between industrial growth and environmental benefits that are not considered in the model (such as the option or existence value of the environment).

The structure of this paper is as follows. Section 2 describes the model while Section 3 analyzes the impact of environmental degradation on growth and income distribution. Section 4 presents simulation results. Section 5 concludes.

2 The Model

2.1 Production and Environment

The actors in the industrial sector can be divided into capitalists and workers, who are distinguished by their endowments with factors of production: Capitalists own the sectoral capital stock while workers exclusively own their labour power. Firms employ capital and labour to produce an industrial commodity which can be used both for consumption and investment. A limitational production function is assumed for simplicity, which implies that the labour coefficient a_0 is constant. Wages are imperfectly indexed to prices; for simplicity, the nominal wage rate W is assumed to be constant. An oligopolistic market structure is assumed to prevail, which implies that firms set prices. This opens the possibility for excess capacity to exist. A representative firm in the industrial sector sets its price for the industrial good P_N by adding a constant percentage markup τ to variable labour costs Wa_0:

$$P_N = Wa_0(1+\tau) \tag{1}$$

Agricultural households pursue three types of activities: One is the production of a marketable agricultural commodity. Another is the exploitation of a renewable resource, which is harvested exclusively for self-consumption. The third activity is reproductive; it comprises the preparation of food, raising children, social and religious activities, and "leisure" activities. Furthermore, the renewable resource stock provides a flow of environmental services which is an input into the production of the agricultural commodity.

Agricultural households combine stocks of land, labour, and capital with a flow of environmental services to produce the agricultural commodity. For simplicity, a limitational relationship is assumed to exist between labour and capital. The productivity of capital depends on the area of land employed and the flow of environmental services. In contrast, a substitutional relationship is assumed between land and environmental services. The flow of environmental services is assumed to be positively related to the size of the renewable resource stock. The renewable resource may be thought of as stock of forest biomass, which generates consumption benefits when harvested (e.g. in the form of fuelwood) but also provides a flow of environmental services, as it prevents soil erosion and stabilizes the hydrological cycle (Chambers, Saxena, and Shah 1989; Chomitz and Kumari 1998, pp.16-20, 22).

The agrarian structure consists of two classes of peasant households, who differ by their endowments with land. All "rich" farm households together own the land area L_1 while the "poor" own L_2. The land distribution (L_1, L_2) among the classes is given; it is assumed that all rich households together own more land than all poor households together, $L_1 > L_2$.[15] Land is distributed equally within each group. The ith class of farmers employs the capital input $K_{A,i}$ and the labour input $N_{A,i}$ to produce the agricul-

[15] This reflects circumstances that are typical in many developing countries. For example, available data on the distribution of operational agricultural landholdings in the Terai (lowlands) region of Nepal reveal that the sum of all agricultural holdings which are larger than one hectare accounts for 69.5% of the total agricultural land area (Central Bureau of Statistics 1994, pp.13 and 16).

tural output $X_{A,i}$.[16] The marginal productivity a_i of agricultural capital depends on the class-specific land input L_i and the renewable resource stock R, which is a common input to the production of both classes. The marginal productivity of labour ε_i positively depends on the marginal productivity of capital, $\varepsilon_i = \varepsilon_i(a_i)$. The agricultural output of each class is then

$$X_{A,i} = min[a_i(L_i, R) \cdot K_{A,i}, \quad \epsilon_i(a_i) \cdot N_{A,i}] \tag{2}$$

with $i = 1, 2$ for the rich and poor farmers, respectively. The substitution possibilites between land and environmental services are described by a CES function with constant returns to scale:

$$a_i(L_i, R) = (\beta_{1i} R^\rho + \beta_{2i} L_i^\rho)^{\frac{1}{\rho}} \qquad \text{with } \beta_{1i}, \beta_{2i} > 0 \text{ and } 0 < \rho < 1 \tag{3}$$

where $\sigma = 1/(1-\rho)$ is the elasticity of substitution. The assumption $0 < \rho < 1$ (which implies $\sigma > 1$) ensures that a given decline in R reduces the agricultural productivity of the poor more strongly than that of the rich, as will become clear in Section 3.2.1. The model allows for the possibility that the two income classes differ not only in their endowments with land quantity (as measured by L_i) but also with regard to land *quality*. It is a well-known stylized fact that the poor live in regions that are ecologically more fragile than those where the rich live.[17] These differences can be accounted for by variations in the parameters β_{ji} across income classes. For example, $\beta_{12} > \beta_{11}$ implies that a given decline in environmental services will reduce the productivity of capital for the poor more strongly than for the rich; $\beta_{22} < \beta_{21}$ implies that a given increase in the land area owned by the poor raises their productivity less than it would for the rich. The following analysis assumes that $\beta_{12} \geq \beta_{11} \wedge \beta_{22} \leq \beta_{21}$.

The capital stocks owned by the two classes of farmers are expressed as fractions of the total capital stock in agriculture K_A. The rich farmers own the capital stock $K_{A,1} = bK_A$ while the poor own the capital stock $K_{A,2} = (1-b)K_A$ with $0 < b < 1$. In case the labour constraint is not binding, aggregate agricultural output X_A can be written as

$$X_A = X_{A,1} + X_{A,2} = [a_1(L_1, R)b + a_2(L_2, R)(1-b)]K_A \tag{4}$$

$$X_A = aK_A \quad with \quad a := a_1(L_1, R)b + a_2(L_2, R)(1-b) \tag{5}$$

The change in the resource stock per unit of time $\dot{R} = dR/dt$ is[18]

$$\dot{R} = rR\left(1 - \frac{R}{c}\right) - qN_E R \qquad \text{with} \quad c, q, r > 0 \tag{6}$$

[16]The model allows for the possibility that some members of the poor farm households work as wage labourers on the fields of the rich (see next section).

[17]See Chambers, Saxena, and Shah (1989) and Leonard et al. (1989).

[18]See Clark (1976), pp.10-32.

The first term in (6) represents the self-regeneration of the resource, which is governed by the intrinsic growth rate of the resource, r, and the carrying capacity of its environment, c. The second term represents the resource harvest $E = qN_E R$, which is assumed to be a linear function of labour input N_E and the resource stock R while q is a parameter. When the resource is in biological equilibrium ($\dot{R} = 0$), the equilibrium resource stock R^0 and the equilibrium resource harvest E^0 can be expressed as functions of the equilibrium labour input N_E^0:

$$R^0 = c\left(1 - \frac{q}{r} N_E^0\right) \quad (7)$$

$$E^0 = qcN_E^0 \left(1 - \frac{q}{r} N_E^0\right) \quad (8)$$

Finally, agricultural households employ labour to produce a third good, which can be thought of as an index of reproductive services, V. The good is produced with a linear technology with labour input N_V while the labour coefficient is set to one for simplicity:

$$V = N_V \quad (9)$$

2.2 Labour Allocation

The model is based on the general view that the subsistence sector (interpreted as the aggregate amount of time devoted to reproductive services) provides "unlimited supplies of labour"[19] to industry, agriculture, and renewable resource harvesting. Therefore, the scarcity of labour is not considered as the binding constraint to the expansion of industrial and agricultural output.

The specification adopted here builds on an argument developed by Sen (1966), who has shown that the labour constraint to agricultural production can be non-binding ("surplus labour") even if the marginal productivity per hour of labour is positive. This situation prevails if the marginal utility of income or the marginal "disutility" of work is constant over a certain range. While Sen focuses on the trade-off between agricultural labour and leisure time (which is embodied in his concept of the disutility of work), this model interprets the trade-off as existing between productive activities and reproductive services. Hence, the marginal utility of the consumption of reproductive services is assumed to be constant over the relevant range. As a result, employment in market-oriented agriculture does not decline if the demand for industrial labour increases.

Peasant household members allocate time to subsistence activities (reproductive services and natural resource extraction) and market oriented agriculture (work on their own farms and wage labour). Alternatively, they

[19] Lewis (1954/1963).

may decide to leave the agricultural sector and migrate to industry.[20] Individuals derive utility from *individual* monetary (agricultural and industrial) income, $m = P_A x_{A,i} + W n_N$ with $x_{A,i} = x_{A,i}(n_{A,i})$, consumption (equals harvest) of the renewable resource, $e(n_E)$, and reproductive services, $v(n_V)$. Lower case variables denote individual income and labour inputs, respectively. The utility function is assumed to be additively separable in v, e, and m:

$$U = \kappa v + e + u(m) \tag{10}$$

Equations (10) and (9) imply that the marginal value product of the labour input to reproductive services, κ, is constant.[21] Furthermore, the marginal utility of resource consumption is assumed to be constant and equal to one for simplicity. Finally, it is assumed that the marginal utility of monetary income is positive and decreasing.

The aggregate demand for industrial labour is fixed at $a_0 X_N$ by the level of the effective demand for industrial goods, X_N. It is assumed that it is always attractive for individuals to reallocate labour from reproductive services to industry in order to earn industrial wage income, $W n_N$:

$$\frac{\partial U}{\partial m} \cdot W > \kappa$$

Utility maximization then implies that industrial employment is determined by the effective demand for industrial goods:

$$N_N = a_0 X_N \tag{11}$$

Equation (2) implies that the marginal productivity of labour in agricultural production is zero if the labour constraint is not binding. However, it is positive and constant for both classes of farmers if the labour constraint binds:

$$\frac{\partial x_{A,i}}{\partial n_{A,i}} = \frac{\partial X_{A,i}}{\partial N_{A,i}} = \begin{cases} \varepsilon_i & for \quad \varepsilon_i N_{A,i} < a_i K_{A,i} \\ 0 & for \quad \varepsilon_i N_{A,i} \geq a_i K_{A,i} \end{cases}$$

It is assumed that it is always attractive for individuals to reallocate labour from reproductive services to peasant farming if the labour constraint in (2)

[20] Strictly interpreted, the labour allocation mechanism described here refers to units of labour time. One may think of two classes of households with differing endowments of land and (labour) time who allocate their time to various activities. This may or may not coincide with individual household members devoting their entire time budget to any single activity. However, it is convenient to interpret the allocation of labour to industry as the migration of individuals from rural to urban areas.

[21] This is a simplification. For the results of the model to hold, it is only required that the marginal value product is constant over a certain range of n_V.

is binding, i.e. $\partial U/\partial m \cdot P_A \varepsilon_i > \kappa$. As a result, the equilibrium allocation of labour to agriculture is exclusively determined by the level of the agricultural capital stock as long as the resource stock and the land endowments are given:

$$N_{A,i} = X_{A,i}/\epsilon_i = \frac{a_i K_{A,i}}{\varepsilon_i(a_i)} \tag{12}$$

$$N_A = N_{A,1} + N_{A,2} \tag{13}$$

Furthermore, the model allows for the possibility that some members of the poor agricultural households work on the fields of the rich. This is the case, for example, if the labour endowment of the rich households is smaller than $N_{A,1}$. The demand for agricultural wage labour is assumed to be $N_{A,1}f$ with $0 \leq f \leq 1$ as the share of the poor peasants in total labour employed on the fields of the rich. Wage labourers are paid a constant real wage ω in terms of agricultural goods.[22] It is assumed that it is always attractive for individuals to reallocate labour from reproductive services to agricultural wage labour, i.e. $\partial U/\partial m \cdot P_A \omega > \kappa$.

The allocation of labour to all activities is subject to a labour force constraint, as the sum of all units of labour allocated to the four activities equals the total labourforce, N:

$$N_A + N_N + N_E + N_V = N \tag{14}$$

For the subsistence sector to function as a reservoir of labour, it has to be assumed that $N_V > 0$.

The renewable resource is assumed to exhibit both a stock externality and a common pool externality. The stock externality is caused by the dependence of agricultural productivity on the level of the resource stock while the common pool externality is caused by the impact of individual harvest rates on aggregate productivity in resource harvesting (Gordon 1954; Dasgupta and Heal 1979). It is assumed that users ignore the stock externality throughout but are able to internalize the common pool externality fully or partially through the establishment of common property rules. This assumption captures the stylized fact that, historically, common property rules did not necessarily achieve full internalization (Baland and Platteau 1996). Full internalization requires that resource users maximize discounted net utility from the consumption of the resource over an infinite time horizon:

$$\underset{N_E}{\text{Max}} \quad J = \int_{t=0}^{\infty} e^{-\delta t} \left(qR - \kappa\right) N_E dt \tag{15}$$

subject to (6), (14) and the constraint $N_E \geq 0$

[22] This unrealistic assumption is made to keep the algebra in Section 3.2.1 simple.

It is useful to focus on the *singular solution* (Clark 1976, pp.92-97) to the linear control problem (15). For simplicity, it is assumed that the resource users' discount rate δ is zero.[23] The singular path of the resource stock is then characterized by (details see Full Mathematical Workings)

$$\kappa = qc\left(1 - \frac{q}{r}\mu N_E\right) \tag{16}$$

The parameter μ measures the degree of internalization of the common pool externality. If the externality is fully internalized, $\mu = 2$ and the RHS of (16) is identical to the marginal productivity of equilibrium harvest with respect to labour, as can be seen from (8).[24] Under partial internalization ($1 < \mu < 2$), harvesting effort is greater than under complete internalization. If $\mu = 1$, the RHS of (16) is identical to the *average* productivity of harvest at equilibrium. The resulting equilibrium is equivalent to an open access equilibrium.

If the resource stock is below or above its equilibrium level, singular control requires to set N_E either equal to zero or equal to the maximum level defined by (14). In the latter case, the labourforce constraint would be binding. As changes in common property rules are associated with significant transaction costs (Ostrom 1990), resource users do not change their rules very often, however. Therefore, the following analysis assumes that resource users do not alter their rules as the resource stock varies unless a parameter in arbitrage equation (16) changes. An exogenous decrease in μ then causes an instantaneous increase in harvesting effort, which results in a *gradual* decline of the resource stock over time to its new equilibrium level.

2.3 Consumption and Saving

It is assumed that both (industrial) capitalists and peasants save a constant fraction of their incomes. It is further assumed that (industrial) workers consume their entire wages. With X_N as industrial output, the profit share h in the industrial sector can be calculated as

$$h = \frac{P_N X_N - W a_0 X_N}{P_N X_N} = 1 - (W/P_N)a_0 \tag{17}$$

W/P_N is the real wage in the industrial sector, measured in terms of industrial goods. As the capitalists' savings ratio is s_N, their savings are $s_N h P_N X_N$. As far as agricultural incomes are concerned, the model allows for the possibility that saving behaviour differs across income classes. Rich

[23] An exogenous positive discount rate would not change the results of the model. See Full Mathematical Workings.

[24] Note that this solution is still inefficient because it ignores the impact of the resource stock on agricultural productivity.

farmers save the fraction $s_{A,1}$ of their income while the poor save the fraction $s_{A,2}$. Furthermore, some members of the poor peasant households may work as wage labourers on the fields of the rich. The wage income of the poor is then equal to $fN_{A,1}\omega P_A$ while the profits of the rich peasants are $P_A X_{A,1} - fN_{A,1}\omega P_A$. The sectoral savings ratio s_A is a weighted average of the savings of the two groups:

$$s_A = \frac{s_{A,1}(P_A X_{A,1} - fN_{A,1}\omega P_A) + s_{A,2}(P_A X_{A,2} + fN_{A,1}\omega P_A)}{P_A(X_{A,1} + X_{A,2})} \tag{18}$$

Aggregate agricultural savings are $s_A P_A X_A$. Aggregate consumption demand D is then

$$D = (1 - s_A)P_A X_A + (1 - s_N h)P_N X_N$$

If $\gamma_A := 1 - s_A$ and $\gamma_N := 1 - s_N h$ are defined as the marginal (equals average) propensities to consume out of agricultural and nonagricultural incomes, respectively, aggregate consumption demand can be written as

$$D = \gamma_A P_A X_A + \gamma_N P_N X_N \tag{19}$$

Following Taylor (1991), identical preferences are assumed for all consumers with regard to the allocation of their consumption demand to agricultural and industrial goods. Consumers spend ϕD on agricultural and $(1 - \phi)D$ on industrial goods with $0 \leq \phi \leq 1$. The budget share ϕ depends on consumption demand per capita D/N and the terms of trade P_A/P_N, i.e. $\phi = \phi(D/N, P_A/P_N)$. The income elasticity for agricultural goods η and the price elasticity for agricultural goods ν can be calculated as[25]

$$\eta = \frac{\partial \phi}{\partial (D/N)} \frac{D/N}{\phi} + 1 \tag{20}$$

$$\nu = 1 - \frac{\partial \phi}{\partial (P_A/P_N)} \frac{P_A/P_N}{\phi} \tag{21}$$

where ν is counted positively. It is assumed that Engel's Law applies, i.e. $0 < \eta < 1$ and $0 < \nu < 1$. It is further assumed that ϕ approaches zero (one) as D/N approaches infinity (zero) and that ϕ approaches a finite positive value as $P_A/P_N \to 0$. Consequently, the budget share ϕ of agricultural goods *rises* as the terms of trade increase and *falls* as aggregate consumption demand D increases.

[25] See Full Mathematical Workings for details.

2.4 Investment and Factor Accumulation

The investment functions are specified separately for each sector. Each investment function contains an autonomous component, which represents 'animal spirits', and a profit-related component.[26] The sectoral investment demands are expressed as shares of the sectoral capital stocks. Agricultural investment demand g_A depends on the autonomous component m_A and the level of the terms of trade P_A/P_N while α_A is a parameter. Industrial investment demand g_N depends on the autonomous component m_N and the level of industrial capacity utilization X_N/K_N while α_N is a parameter and K_N represents the industrial capital stock. Industrial firms keep excess capacity to be able to respond to unanticipated increases in demand.[27] Factor accumulation is determined by investment demand and population growth. The growth rates of the industrial capital stock K_N and the agricultural capital stock K_A are determined by the rates of investment g_N and g_A, respectively:

$$\frac{\dot{K}_A}{K_A} := g_A = m_A + \alpha_A \frac{P_A}{P_N} \tag{22}$$

$$\frac{\dot{K}_N}{K_N} := g_N = m_N + \alpha_N \frac{X_N}{K_N} \tag{23}$$

Following Taylor (1991), the rate of population growth is assumed to depend on the distribution of income between agriculture and industry, which is measured by the ratio (in value terms) of agricultural output to the industrial capital stock, $aP_AK_A/(P_NK_N)$. It is assumed that the population grows at the rate n_0 when agricultural income is zero but is reduced by the factor β as agricultural income rises relative to the industrial capital stock:

$$\frac{\dot{N}}{N} = n_0 - \beta \cdot \frac{aP_AK_A}{P_NK_N} \tag{24}$$

2.5 Equilibrium

2.5.1 Short-run Equilibrium

Population, the sectoral capital stocks, and the resource stock are considered as "slow" variables, which adjust to their equilibrium values only in the long run. Therefore, they are treated as parameters in the short run. The price of agricultural goods P_A and industrial output X_N are assumed to adjust in the short run in order to clear the markets for agricultural and industrial goods, respectively. At equilibrium, the excess demands are zero in both markets:

$$\phi D - P_AX_A = 0 \tag{25}$$

[26] This specification follows Taylor (1991).

[27] Rowthorn (1981), p.12; Dutt (1984), p.28.

$$(1-\phi)\,D + g_A P_N K_A + g_N P_N K_N - P_N X_N = 0 \tag{26}$$

The system [1-6, 9, 11-19, 22-26] determines the 20 endogenous variables P_N, h, $X_{A,i}$, a_i, X_A, a, R, V, N_A, $N_{A,i}$, N_N, N_E, N_V, s_A, D, K_A, K_N, N, X_N, and P_A. With K_A, K_N, R, and N being constant in the short run, the equilibrium values of P_N, $X_{A,i}$, a_i, X_A, a, V, N_A, $N_{A,i}$, N_E, N_V, and s_A follow directly from their definitions or from the considerations presented in the preceding sections. The equilibrium values of D, g_A, g_N, N_N and h can be computed easily once P_A and X_N are known. Hence, it is useful to focus on the solution of the system for P_A and X_N. In order to facilitate the analysis of growth in the next section, these and several other variables are normalized according to the definitions in Table 1. Dividing Equations (25)-(26) by $(P_N K_N)$ and applying these definitions yields:

$$\phi(\delta k, z) \cdot \delta - z\lambda a = 0 \tag{27}$$

$$[1 - \phi(\delta k, z)]\,\delta + \lambda g_A + g_N - u = 0 \tag{28}$$

It can be shown that a pair of values for the terms of trade $z = P_A/P_N$ and the rate of industrial capacity utilization $u = X_N/K_N$ exists which represents a unique solution to (27)-(28).[28] The system is stable if the following sufficient conditions are fulfilled:[29]

$$\Gamma_A := a(1-\gamma_A) - \alpha_A > 0 \tag{29}$$
$$\Gamma_N := 1 - \gamma_N - \alpha_N > 0 \tag{30}$$
$$\nu - \gamma_A \phi \eta > 0 \tag{31}$$

The first two conditions require that agricultural (industrial) savings respond more strongly than investment to changes in the terms of trade (effective demand). The third condition states that an increase in the terms of trade with capacity utilization held constant reduces the excess demand for agricultural goods. This imposes an upper limit on the strength of Engel effects, i.e. a lower bound on ν.

[28] Sufficient conditions are that investment demand exceeds savings supply in agriculture and (30) holds. See Chakraborty (2001) for a detailed exposition. See also Full Mathematical Workings.

[29] These conditions are identical with the stability conditions in Taylor's (1991) model. See Full Mathematical Workings for details.

$z = P_A/P_N$	Terms of trade
$u = X_N/K_N$	Industrial capacity utilization
$\lambda = K_A/K_N$	Ratio of sectoral capital stocks
$\delta = D/(P_N K_N)$ $\delta = \gamma_A z a \lambda + \gamma_N u$	Effective consumption demand per unit of the industrial capital stock
$k = P_N K_N/N$	Industrial capital stock per capita
ϕ	Share of agricultural goods in aggregate consumption demand

Table 1: Normalized variables in the model

2.5.2 Long-run Equilibrium

Population, the sectoral capital stocks, and the resource stock vary in the long run. For the following analysis, it is useful to focus on three state variables: the ratio λ of the sectoral capital stocks, the industrial capital stock per capita[30] k, and the stock of the renewable resource R. The values of the state variables are constant at long-run equilibrium. Using (22), (23), and (24), the equilibrium conditions can be formulated as

$$\frac{\dot{k}}{k} = g_N - \frac{\dot{N}}{N} = m_N + \alpha_N u - n_0 + \beta z a \lambda = 0 \quad (32)$$

$$\frac{\dot{\lambda}}{\lambda} = g_A - g_N = m_A - m_N + \alpha_A z - \alpha_N u = 0 \quad (33)$$

$$\dot{R} = rR\left(1 - \frac{R}{c}\right) - qRN_E = 0 \quad (34)$$

It can be shown that, with appropriate parameter values, a steady state exists which is locally stable.[31]

3 Environmental Degradation

Common pool externalities are an important cause of rural environmental degradation. Historically, common pool resources were managed under common property regimes in many countries.[32] Common property rules limited aggregate harvest rates by imposing restrictions on individual harvest rates, harvesting technology, or harvest times (Ostrom 1990; Baland and Platteau 1996). These traditional rules have come under pressure, as social, technological, and political changes occurred on a wide scale.[33] As a result,

[30] More precisely, k is defined as the industrial capital stock per hour of labour applied in the economy. However, the number of labour hours per person is assumed to be constant.

[31] See Chakraborty (2001) for a detailed exposition. See also Full Mathematical Workings.

[32] See Guha (1989) and Ostrom (1990) for case studies.

[33] See Fürer-Haimendorf (1982), Fernandes, Menon, and Viegas (1988), Madsen (1999), and Jeffery and Vira (2001) for case studies.

the compliance with and the enforcement of traditional common property rules have declined. Common pool externalities have become less and less internalized over time.

In the model described above, the erosion of common property institutions can be represented by a decrease in the value of the parameter μ, which measures the degree of internalization of the common pool externality. For example, μ could decline as the industrial or agricultural capital stock increases, which would reflect the impact of improved transport infrastructure or harvesting technologies on harvesting costs. Alternatively, μ could decline as the population in the reproductive services sector increases or income per capita in the non-industrial sectors falls, which would reflect poverty-induced "pressures" on the natural resource base.

To keep the analysis simple, the decline in common property rules will be represented by an *exogenous* decline in μ. The decrease in μ causes an instantaneous increase in harvesting effort, which results in a *gradual* decline of the resource stock to its new equilibrium level.

Indicators of Growth and Distribution. The following analysis considers three sets of indicators of growth and income distribution. The first set comprises the rates of growth in the two sectors, which are measured according to (22)-(23) by the levels of the terms of trade and industrial capacity utilization, respectively. The second set describes the levels of the sectoral growth paths, which are measured by the industrial capital stock per capita k and the ratio of agricultural to industrial capital λ. Furthermore, the degree of industrialization of the economy can be measured by the level of industrial output per capita $uk = P_N X_N / N$. As the industrial labour coefficient is constant, uk is also a measure of the share of industrial workers in the labourforce.

The third set of indicators refers to the distribution of income. Industrial workers' income per capita can be measured by industrial wage income per capita. As both the wage rate and daily working hours per worker in industry are assumed to be constant, increases in industrial labour income fully take the form of additions to industrial employment. In other words, the model describes a process of "modern sector enlargement growth" (Fields 1980). Industrial capitalists' income is measured by the profit rate, $u\tau/(1+\tau)$.

Income inequality within agriculture is measured by the ratio $X_{A,1}/X_{A,2}$ of the outputs of the two income classes. Aggregate agricultural income per capita is defined as the income generated from the sale of the agricultural commodity per unit of labour in the non-industrial sector. The non-industrial sector comprises all labour that is not allocated to the industrial sector. Measured in industrial goods, agricultural income per capita A

is (details see Full Mathematical Workings)

$$A := \frac{zX_A}{N_A + N_E + N_V} = \frac{zX_A}{N - X_N a_0} = \frac{1}{a_0}\frac{za\lambda k}{W(1+\tau) - uk} \tag{35}$$

As a_0 is constant, Aa_0 is a convenient measure for changes in agricultural income per capita.

The following analysis traces the impact of environmental degradation on growth and income distribution through the model. Section 3.1 analyzes the growth impact of environmental degradation under the assumption that saving behaviour does not differ across agricultural income classes *(production effect)*. Section 3.2 considers the case where rich farmers save more than poor farmers per unit of marginal income. This gives rise to the *distribution effect*, which can weaken or reinforce the production effect.

3.1 Production Effect

3.1.1 Short-run

Population and the sectoral capital stocks can be considered as constant in the short run. It is therefore useful to focus on sectoral growth rates for *short-run analysis*. An increase in the industrial growth rate then implies an increase both in industrial output and in the share of industrial workers in the labourforce.

Consider an equilibrium $(z^0, u^0, k^0, \lambda^0, R^0)$ at time $t = t_1$ of the dynamic system [(27)-(28), (32)-(34)]. A marginal decline in μ at time $t = t_1$ raises the amount of labour allocated to resource harvesting from N_E^0 to $N_E^0 + dN_E$, as can be seen from (16). According to (6), this causes the resource stock to decline by $dR = (-qR^0 dN_E)dt$ by the time $t_2 = t_1 + dt$. As the terms of trade and the rate of industrial capacity utilization are assumed to adjust instantaneously, this causes a short-run effect which is analyzed as the impact of an exogenous decline of the resource stock at $t = t_2$ on the subsystem (27)-(28). The sectoral capital stocks and the size of the labourforce at time $t = t_2$ are considered as exogenous. The impact of an exogenous decline of the resource stock on industrial capacity utilization u and the terms of trade z can be computed from the comparative statics of the subsystem (27)-(28)(see Appendix A.2):

$$\frac{du}{dR} = \frac{du}{da}\frac{da}{dR} = \frac{\lambda^2 z}{|\mathbf{J}|}[a(1-\gamma_A)(1-\nu) - \alpha_A(1-\gamma_A\phi\eta)] \cdot \frac{da}{dR} \tag{36}$$

$$\frac{dz}{dR} = \frac{dz}{da}\frac{da}{dR} = \frac{-\lambda z}{|\mathbf{J}|}[(1-\gamma_N-\alpha_N) - \phi\eta(\gamma_A-\gamma_N) + \alpha_N\gamma_A\phi\eta] \cdot \frac{da}{dR} \tag{37}$$

$$|\mathbf{J}| = \lambda a\,[\nu(1-\gamma_N-\alpha_N) - \eta\phi(\gamma_A-\gamma_N) + \alpha_N\gamma_A\phi\eta] - \alpha_A\gamma_N\lambda\phi\eta > 0 \tag{38}$$

$|\mathbf{J}|$ is the determinant of the Jacobian of the (sub-)system (27)-(28). It is assumed that stability conditions (29)-(31) hold, which implies that $|\mathbf{J}|$ is positive. It can be seen from (5) and (3) that da/dR is positive: agricultural output falls as the resource stock declines. It follows that du/da is positive (negative) if α_A is small (large). Hence, the total derivative du/dR is also positive (negative) if α_A is small (large). As far as dz/da is concerned, the term in square brackets in (37) is positive because the term in square brackets in (38) is positive and $\nu < 1$. Consequently, dz/da is negative, and so is dz/dR.

To sum up, a decline in common property rules reduces (increases) capacity utilization, the industrial short-term growth rate and the share of the population that is employed in industry if the responsiveness of agricultural investment to the terms of trade, α_A, is small (large). At the same time, it raises the terms of trade and short-term growth (of the capital stock) in agriculture. Moreover, agricultural income per value unit of industrial capital, $za\lambda$, unambiguously rises because the terms of trade increase more strongly than agricultural productivity declines (see Full Mathematical Workings). If α_A is small, agricultural income also rises relative to industrial income because the rate of capacity utilization declines.

The short-run production effect results from the interaction of three features of the model: Engel effects, the determination of savings by investment demand, and the paradox of thrift. As agricultural prices rise as a result of environmental degradation, Engel effects cause the budget share for agricultural goods to rise, which tends to reduce consumption demand for industrial goods. This ultimately reduces investment demand, which leads to lower industrial output and growth because investment demand determines the level of aggregate savings. The decline can be weaker or stronger if the marginal savings rates are different between agriculture and industry. In this sense, the paradox of thrift applies.[34]

3.1.2 Long-run

In the long run, population and the sectoral capital stocks vary; sectoral output and capital stocks grow at the same rate as the population at equilibrium. Hence, it is useful to focus on level variables. If population growth is *exogenous*, capacity utilization and the terms of trade are fixed by (32) and (33), respectively. Consequently, the level of the industrial capital stock per capita k is a measure of industrial output and the share of industrial workers in the labourforce. The impact of a decline in the degree of internalization of the common pool externality, μ, on the industrial capital stock per capita k and the ratio of agricultural to industrial capital λ can be computed from the comparative dynamics of the system (32)-(34) (details

[34] See Chakraborty (2001) for a more detailed exposition. See also Full Mathematical Workings.

see Appendix B.2):

$$\frac{dk}{d\mu} = -\frac{ca_R g_A k\lambda N_E qz}{r\delta\phi(1-\eta)\mu}\frac{\alpha_A\alpha_N(1-\gamma_A\phi\eta)+\beta\left[a\alpha_N\lambda(1-\nu)+\alpha_A\gamma_N\phi\eta\right]}{\alpha_A\alpha_N G_A+\beta a\left(\alpha_N\lambda m_A+\alpha_A z\Gamma_N\right)} < 0 \tag{39}$$

$$\frac{d\lambda}{d\mu} = \frac{\alpha_A}{r\mu}ca_R\lambda N_E qz\frac{\alpha_N(1-\gamma_A)-\beta(\Gamma_N-\alpha_N\lambda)}{\alpha_A\alpha_N G_A+\beta a\left(\alpha_N\lambda m_A+\alpha_A z\Gamma_N\right)} \tag{40}$$

Exogenous population growth. The denominators of (39)-(40) are positive because $G_A := g_A - az(1-\gamma_A)$ and Γ_N are positive for stability reasons. Under exogenous population growth ($\beta = 0$), $dk/d\mu$ is unambiguously negative and $d\lambda/d\mu$ is unambiguously positive: a decline in common property institutions *raises* the industrial capital stock per capita and *lowers* the ratio of agricultural to industrial capital in the long run. The reason is as follows. An exogenous decline in μ lowers agricultural productivity. Agricultural prices increase as a result, which causes agricultural investment to increase, too. As agriculture now grows faster than industry, the terms of trade fall, which raises capacity utilization, the industrial growth rate, and, eventually, industrial capital per capita.[35] The ratio of agricultural to industrial capital falls because the growth impact is stronger on industrial capital than on agricultural capital. These results differ from those of neoclassical growth models in that a decline in the productivity of a factor of production raises growth.

The results just described depend on three critical assumptions. First, the structuralist assumption that excess capacity exists in the industrial sector implies that the opportunity cost of savings is zero. This leaves scope for increased agricultural investment demand to lead to a higher degree of utilization of resources in the economy. Second, optimistic substitution possibilities have been assumed in agriculture between land and the renewable resource on the one hand and between the two and capital on the other. The model may generate different results if the returns to capital were diminishing. Third, the closed economy assumption implies that the rise in the terms of trade cannot be prevented by food imports. However, the terms of trade rise even in an open economy if it is assumed that export earnings are the only source of foreign exchange and export demand for industrial goods is sufficiently inelastic. The volume of food imports is then too small to reverse the increase in the terms of trade.[36]

It is emphasized that this effect concerns the long-term *level* of the growth path but not the long-term growth rate, as the equilibrium values

[35] This result does not change if agricultural investment demand is dependent on profits rather than the terms of trade in (22), i.e. $g_A = m_A + \alpha_A \cdot (az)$. A proof is available from the author.

[36] See Storm (1997) for a numerical example.

of u and z are fixed from (32)-(33). An exogenous decline in μ alters the sectoral growth rates only during the adjustment process. In the long run, the initial growth rates are restored but the described level effects persist. As a result, the share of industrial workers in the labourforce (as measured by uk) is higher at the new equilibrium. Income from agricultural production $za\lambda/u$ unambiguously declines because λ and a are lower at the new equilibrium. However, the impact on per capita income in agriculture is ambiguous because a smaller share of the labourforce is now employed in this sector.

Endogenous population growth. The result that environmental degradation raises long-run growth is robust with regard to endogenous population growth. For if population growth responds negatively to increasing agricultural incomes ($\beta > 0$), the derivative $dk/d\mu$ is still negative. However, the sign of $d\lambda/d\mu$ is now ambiguous: the ratio of agricultural to industrial capital *increases* as μ declines if the equilibrium value of λ is small and β is large.

The comparative statics of the system (27)-(28) reveal that capacity utilization increases as λ or k rises (see Appendix A.2). As a result, the impact of a change in μ on the industrial long-run equilibrium growth rate g_N and industrial employment uk is ambiguous if k rises but λ falls.

3.2 Distribution Effect

The distribution effect arises when the assumption that the savings ratios of the rich and the poor farmers are equal is relaxed. It is now assumed that the rich save more per unit of marginal income than the poor, i.e. $s_{A,1} > s_{A,2}$. Under this condition, changes in the renewable resource stock R do not only affect agricultural productivity a but also the aggregate marginal savings ratio in agriculture s_A, as can be seen from (18). The following section derives a set of conditions which cause s_A to rise when the natural resource stock R declines. Sections 3.2.2-3.2.3 analyze the short-run and long-run effects, respectively.

3.2.1 Resource Stock Decline and Agricultural Savings

A decline in the renewable resource stock reduces both output and labour demand in agriculture. If both classes of peasants work exclusively on their own land, the aggregate agricultural savings ratio increases if the output of the poor declines more strongly than the output of the rich. If, more realistically,[37] some poor peasants work as wage labourers on the fields of the

[37]Under exogenous population growth, labour demand on the fields of the rich grows at the rate $(a_1/\varepsilon_1)\,n_0$, which may be smaller or greater than the population growth rate n_0. If $a_1/\varepsilon_1 > 1$, it is rational for rich peasants to employ the poor on their fields.

rich, the result is less obvious: the agricultural savings ratio increases only if the *incomes* of the poor (including wage income) decline more strongly than the *profits* of the rich. The following analysis relates productivity declines to changes in incomes.

As far as agricultural production on the land of the rich is concerned, it is assumed that the burden of adjustment falls entirely on wage labour: the rich respond to declines in labour demand by reducing wage labour rather than their own labour input as long as the share f of wage labour in employment on the fields of the rich is greater than zero. Hence, the change in agricultural wage employment $N_{A,1}f$ caused by a marginal change in the resource stock is

$$\frac{\partial\left(N_{A,1}f\right)}{\partial R} = \xi f \frac{\partial N_{A,1}}{\partial R} \quad \text{with } \xi := \begin{cases} 1/f \text{ for } f > 0 \\ 0 \text{ for } f = 0 \end{cases}$$

From (12), $N_{A,1} = X_{A,1}/\varepsilon_1 = a_1 K_{A,1}/\varepsilon_1$ with $\varepsilon_1 = \varepsilon_1(a_1)$. The derivative $\partial N_{A,1}/\partial R$ can then be computed as (details see Full Mathematical Workings)

$$\frac{\partial N_{A,1}}{\partial R} = \frac{1-\chi}{\varepsilon_1}\frac{\partial X_{A,1}}{\partial R} \quad \text{with } \chi := \frac{\partial \varepsilon_1}{\partial a_1}\frac{a_1}{\varepsilon_1}$$

χ is the elasticity of agricultural labour productivity (on the fields of the rich) with regard to changes in the productivity of capital. It is reasonable to assume that $0 \leq \chi \leq 1$. The total derivative of s_A with respect to the resource stock can be calculated as (details see Full Mathematical Workings)

$$\frac{ds_A}{dR} = \frac{s_{A,1} - s_{A,2}}{X_A^2}\left\{\left[X_{A,2} + \omega f\left(N_{A,1} - \xi X_A \frac{1-\chi}{\varepsilon_1}\right)\right]\frac{\partial X_{A,1}}{\partial R} - \left[X_{A,1} - f\omega N_{A,1}\right]\frac{\partial X_{A,2}}{\partial R}\right\} \quad (41)$$

$ds_A/dR < 0$ if the term $\{.\}$ is negative, which yields

$$B \cdot \left[1 + \frac{\omega f}{\varepsilon_1}\left(\frac{X_{A,1} - \xi X_A\left(1-\chi\right)}{X_{A,2}}\right)\right] < \left(1 - \frac{f\omega}{\varepsilon_1}\right) \quad (42)$$

with

$$B := \frac{\partial X_{A,1}/\partial R}{\partial X_{A,2}/\partial R}\cdot\frac{X_{A,2}}{X_{A,1}} = \frac{\beta_{11}}{\beta_{12}}\cdot\frac{\beta_{12}R^\rho + \beta_{22}L_2^\rho}{\beta_{11}R^\rho + \beta_{21}L_1^\rho} = \frac{\beta_{11}}{\beta_{12}}\cdot\left(\frac{a_2}{a_1}\right)^\rho \quad (43)$$

B is the ratio of the elasticities of production of the resource for the two income classes. If both classes of farmers work exclusively on their own land ($f = 0$), inequality (42) simplifies to $B < 1$, which is satisfied if (see Full Mathematical Workings for details):

$$B < 1 \Leftrightarrow \frac{L_2}{L_1} < \left(\frac{\beta_{21}}{\beta_{22}}\cdot\frac{\beta_{12}}{\beta_{11}}\right)^{\frac{1}{\rho}} \quad (44)$$

A marginal decline in the resource stock raises the aggregate agricultural savings ratio if agricultural wage employment is zero and inequality in land distribution is strong. If the two income classes differ only in their endowments with land area ($\beta_{11} = \beta_{12} \wedge \beta_{21} = \beta_{22}$), the condition $L_1 > L_2$ is *both necessary and sufficient* for the agricultural savings ratio to rise when the resource stock declines. The condition $B < 1$ has a straightforward interpretation, as it implies

$$\frac{\partial X_{A,1}/\partial R}{X_{A,1}} < \frac{\partial X_{A,2}/\partial R}{X_{A,2}} \tag{45}$$

The relative decline in agricultural output has to be greater on the landholdings of the poor than on the landholdings of the rich. If agricultural wage employment is positive ($0 < f \leq 1$), it is useful to rewrite (42) as (details see Full Mathematical Workings)

$$F(B,\Omega) := B \cdot [1-(1-\chi)\,\Omega] + \frac{f-(1-\chi)}{B^{\frac{1-\rho}{\rho}}}\frac{b}{1-b}\left(\frac{\beta_{11}}{\beta_{12}}\right)^{\frac{1}{\rho}}\Omega < 1 - f\Omega := G(\Omega) \tag{46}$$

$\Omega := \omega/\varepsilon_1$ is the ratio of the agricultural wage rate and labour productivity. It can be shown that a set of values of B exists which satisfy inequality (46).[38]

The agricultural savings rate would rise more strongly than described by (41) if the wage rate was fixed in nominal rather than in real terms because profits would be higher and the income of the poor would be lower after the productivity decline.

Redistribution. If the two income classes differ only in their endowments with land quantity, redistribution in favour of the poor raises L_2 in the production function of the poor and lowers L_1in the production function of the rich. However, if the income classes also differ in land quality, it would be inappropriate to apply the parameters of the production function of the poor (β_{12}, β_{22}) to the redistributed land area. A simple alternative is to apply the parameters of the production function of the rich (β_{11}, β_{21}) to this land, which, however, strongly complicates the analytical treatment of redistribution. This route will therefore be pursued by means of simulation in Section 4; the subsequent analysis assumes that land endowments differ only with regard to quantity ($\beta_{11} = \beta_{12} := \beta_1 \wedge \beta_{21} = \beta_{22} := \beta_2$).

Redistribution of land from the rich to the poor reduces the aggregate agricultural savings ratio s_A (see Full Mathematical Workings for details). Furthermore, it increases the ratio of the elasticities of production of the resource, B. It can be shown that ds_A/dR becomes positive if redistribution raises the value of B above a certain limit.[39]

[38] See Appendix C.1 for a proof.
[39] See Appendix C.1 for a proof.

3.2.2 Short-run

This section demonstrates that the distribution effect is ambiguous in the short run. In this context, it is again useful to focus on the impact of a marginal decline in the resource stock R on industrial capital utilization u and the terms of trade z:

$$\frac{du}{dR} = \frac{\partial u}{\partial a}\cdot\frac{\partial a}{\partial R}+\frac{\partial u}{\partial \gamma_A}\cdot\frac{\partial \gamma_A}{\partial s_A}\cdot\frac{\partial s_A}{\partial R} \tag{47}$$

$$\frac{dz}{dR} = \frac{\partial z}{\partial a}\cdot\frac{\partial a}{\partial R}+\frac{\partial z}{\partial \gamma_A}\cdot\frac{\partial \gamma_A}{\partial s_A}\cdot\frac{\partial s_A}{\partial R} \tag{48}$$

With $\gamma_A = 1 - s_A$, $\partial\gamma_A/\partial s_A = -1$. The derivative $\partial s_A/\partial R$ is given by (41) while the derivatives $\partial u/\partial a$, $\partial z/\partial a$, $\partial u/\partial\gamma_A$ and $\partial z/\partial\gamma_A$ can be calculated from the comparative statics of the system (27)-(28). $\partial u/\partial a$ and $\partial z/\partial a$ have already been computed in (36) and (37). $\partial u/\partial\gamma_A$ can be calculated as

$$\frac{\partial u}{\partial \gamma_A} = \frac{za\lambda^2}{|\mathbf{J}|}\left[a\left(\nu-\phi\eta\right)+\alpha_A\phi\eta\right] \gtrless 0 \tag{49}$$

The sign of $\partial u/\partial\gamma_A$ depends on the relative size of ν and $\phi\eta$. From stability condition (31), ν has to exceed $\gamma_A\phi\eta$. As $\nu \to \gamma_A\phi\eta$, the term in square brackets in (49) approaches $-\phi\eta\left[a\left(1-\gamma_A\right)-\alpha_A\right]$, which is negative by (29). As ν rises, $\partial u/\partial\gamma_A$ increases and finally becomes positive. The ambiguity of the sign of $\partial u/\partial\gamma_A$ can be given the following interpretation. An exogenous increase in γ_A raises food demand, which tends to increase the terms of trade. The increase in the terms of trade gives rise to two contradictory effects. First, it raises the excess demand for industrial goods because it raises agricultural incomes (income effect). Second, it lowers the excess demand for industrial goods because it causes a reallocation of consumption expenditure towards agricultural goods (substitution effect). $\partial u/\partial\gamma_A$ is positive when the income effect dominates. It is negative when the substitution effect dominates.

The first term in (47) represents the production effect, which can be positive or negative depending on the value of α_A. The second term represents the distribution effect. It is assumed that (42) holds, which implies that $ds_A/dR < 0$. Given $\partial\gamma_A/\partial s_A = -1$, the sign of the distribution effect depends only on the sign of $du/d\gamma_A$. The distribution effect reinforces (weakens) the production effect if $\partial u/\partial a$ and $\partial u/\partial\gamma_A$ have identical (opposite) signs. The overall effect critically depends on the value of the agricultural investment parameter α_A. The production and distribution effect point into the same direction if agricultural investment demand is *moderately* responsive to changes is the terms of trade, i.e. if $\widetilde{\alpha_A} := a\left(\phi\eta-\nu\right)/\phi\eta < \alpha_A < \overline{\alpha_A} := a\left(1-\gamma_A\right)\left(1-\nu\right)/\left(1-\gamma_A\phi\eta\right)$. Industrial capacity utilization falls more strongly than it would if the savings ratio of the rural rich was equal to that of the rural poor. The reason is that the transfer of income from industry to agriculture which is caused by the decline in agricultural productivity generates more savings per unit of agricultural income than in the case where $s_{A,1} \leq s_{A,2}$.

In contrast, the distribution effect weakens the production effect if agricultural investment demand is either *weakly* or *strongly* responsive to the terms of trade, i.e. $0 < \alpha_A < \widetilde{\alpha_A} \vee \alpha_A > \overline{\alpha_A}$. A discussion of these cases is contained in Appendix C.2.1. If redistribution in favour of the poor is sufficiently strong, the sign of $\partial s_A / \partial R$ becomes positive, which reverses the sign of the distribution effect.

Agricultural prices. As far as dz/dR is concerned, dz/da is unambiguously negative. $\partial z / \partial \gamma_A$ can be calculated as

$$\frac{\partial z}{\partial \gamma_A} = \frac{za\lambda\phi\eta}{|\mathbf{J}|}\left(1 - \alpha_N\right) > 0 \tag{50}$$

Given (30), $\partial z / \partial \gamma_A$ is unambiguously positive. A marginal increase in γ_A raises the terms of trade and agricultural income az. Hence, the production effect on z in (48) is negative while the distribution effect is positive. The terms of trade rise less sharply the more the aggregate agricultural savings ratio increases as the resource stock declines. It can be shown that the distribution effect is never strong enough to exceed the production effect (details see Appendix C.2.2).

3.2.3 Long-run

For the long run, it is useful to focus on the impact of an increase in μ on the stock of industrial capital per capita k:

$$\frac{dk}{d\mu} = \frac{dk}{dR} \cdot \frac{dR}{d\mu} = \frac{\partial k}{\partial a} \cdot \frac{\partial a}{\partial R} \cdot \frac{dR}{d\mu} + \frac{\partial k}{\partial \gamma_A} \cdot \frac{\partial \gamma_A}{\partial s_A} \cdot \frac{\partial s_A}{\partial R} \cdot \frac{dR}{d\mu} \tag{51}$$

where the derivatives $\partial k / \partial a$ and $\partial k / \partial \gamma_A$ can be calculated from the comparative dynamics of the (2×2)-subsystem (32)-(33) (details see Full Mathematical Workings). The first term on the RHS of (51) is the production effect, which is negative by (39). The second term represents the distribution effect. Again, $\partial \gamma_A / \partial s_A = -1$. It can be shown that $dR/d\mu$ is positive. A decline in μ raises harvesting effort, which reduces the equilibrium resource stock R. The derivative $\partial k / \partial \gamma_A$ can be computed as (see Full Mathematical Workings)

$$\begin{aligned}\frac{\partial k}{\partial \gamma_A} = {} & \frac{a\alpha_A\alpha_N}{|\mathbf{K}_{33}|\,|\mathbf{J}|}k\lambda^2 z\left[g_A\phi\eta + az\left(1 - \phi\eta\right)\right] + \beta\frac{a^2}{|\mathbf{K}_{33}|\,|\mathbf{J}|}k\lambda^2 z \cdot \\ & \cdot \left[\alpha_N\lambda m_A\phi\eta + \alpha_N\lambda az\left(1 - \nu\right) + \alpha_A z\phi\eta\left(1 - \alpha_N\right)\right] > 0\end{aligned} \tag{52}$$

$$|\mathbf{K}_{33}|\,|\mathbf{J}| = \delta\lambda\phi(1-\eta)\left[\alpha_A\alpha_N G_A + \beta a\left(\alpha_N\lambda m_A + \alpha_A z\Gamma_N\right)\right] > 0$$

The derivative $dk/d\gamma_A$ is positive both under exogenous and endogenous population growth because $G_A := g_A - az(1-\gamma_A)$ and Γ_N are positive for stability reasons and (30) implies $(1-\alpha_N) > 0$. A marginal increase in γ_A raises the terms of trade in the short run, which increases the rate of agricultural investment. As a result, the terms of trade fall again, which raises industrial growth and industrial capital per capita in the long run.

This implies that the distribution effect is positive if $\partial s_A/\partial R$ is smaller than zero, which is assumed here. The distribution effect then weakens the production effect. It can be shown that the distribution effect never exceeds the production effect under exogenous population growth ($\beta = 0$) (details see Appendix C.3). If redistribution in favour of the poor is sufficiently strong, the sign of $\partial s_A/\partial R$ becomes positive, which reverses the sign of the distribution effect. The distribution effect now reinforces the production effect: industrial capital per capita is higher in the new equilibrium.

4 Simulation Results

A discrete time version of the model presented in Section 2 was used for simulation. Two sets of runs were undertaken. The first set *("Before Redistribution")* assumed a land ownership structure where the rich own 59% of the land area, which reflects the pattern of land distribution in India in 1970.[40] The second set of runs *("After Redistribution")* assumed that 30% of the land area L_1 owned by the rich was redistributed to the poor.

Within each set of runs, two sets of parameter values were distinguished. The first assumed that the two income classes differ not only in their endowments with land quantity but also with land quality (cf. Section 2.1). It was assumed that $\beta_{12}/\beta_{11} = 2 \wedge \beta_{22}/\beta_{21} = 0.5$, i.e. the poor are more dependent on the renewable resource and own the less fertile soils. The second set represents the simpler case where the two income classes differ only with regard to land quantity, i.e. $\beta_{12} = \beta_{11} \wedge \beta_{22} = \beta_{21}$. In both sets, full internalization of the common pool externality ($\mu = 2$) was compared to the case where $\mu = 1$.

The distribution of the agricultural capital stock was treated as identical in all runs. It was assumed to be roughly equal to the pattern of land distribution before redistribution ($b = 0.6$). The budget share ϕ was parametrized as $\phi = (\delta k)^{\eta-1} z^{1-\nu}$ with $\nu = 0.4$ and $\eta = 0.89$.[41] The other parameters are listed in Table 2. The software package employed was *Mathematica 3.0*.

[40]Data from Agrawal, Varma, and Gupta (1995), p.126. Farmers who operate landholdings of at least four hectares size were classified as "rich".

[41]This specification does not satisfy all restrictions imposed on ϕ in Section 2.3, which restricts the range of equilibria the simulation model is able to generate. See Full Mathematical Workings for a complete description of the simulation model.

	Before Redistribution ($L_2 = 0.7L_1$)				**After Redistribution** ($L_2 = 1.4L_1$)			
	Differing land area and quality ($\beta_{12} = 2\beta_{11}, \beta_{22} = 1/2\beta_{21}$)							
	Unequal Savings Rates ($s_{A,1} = 0.3, s_{A,2} = 0$)							
	a	γ_A	uk	Aa_0	a	γ_A	uk	Aa_0
$\mu = 2$	0.082	0.821	453	0.0004	0.089	0.868	683	0.0065
$\mu = 1$	0.050	0.794	5711	0.0050	0.053	0.847	11525	0.0101
	Production Effect: Equal Savings Rates							
$\mu = 1$	0.050	0.821	9410	0.0083	0.053	0.868	17005	0.0149
	Distribution Effect as a Percentage of Production Effect							
$\mu = 1$			-39%	-40%			-32%	-32%
	Differing land area only ($\beta_{12} = \beta_{11}, \beta_{22} = \beta_{21}$)							
	Unequal Savings Rates ($s_{A,1} = 0.3, s_{A,2} = 0$)							
	a	γ_A	uk	Aa_0	a	γ_A	uk	Aa_0
$\mu = 2$	0.075	0.805	573	0.0005	0.072	0.836	1336	0.0012
$\mu = 1$	0.052	0.802	5109	0.0045	0.050	0.839	13882	0.0121
	Production Effect: Equal Savings Rates							
$\mu = 1$	0.052	0.805	5377	0.0048	0.050	0.836	13115	0.0115
	Distribution Effect as a Percentage of Production Effect							
$\mu = 1$			-5%	-6%			+6%	+5%

Before Redistribution: L_1=982900, L_2=683400
After Redistribution: L_1=688030, L_2=683400+294870
Other parameters:
γ_N=0.83, ν=0.4, η=0.89, α_A=0.001, α_N=0.02, m_A=0.02, m_N=0.015, b=0.6, f=0, $\kappa/(dU/de)$=1, $\beta_{11}=\beta_{21}$=0.00025, ρ=0.48, β=0.07, n_0=0.03, c=555180, r=0.3, $q=9\cdot 10^{-6}$, W=170000, τ=1.92

Table 2: Simulation results: Long-run equilibria

For an analysis of the results, it is useful to distinguish between long-run equilibria and transitional dynamics.

Long-run equilibria. Table 2 shows the long-run equilibrium values of several variables of interest. Consider first the runs before redistribution. With differing land area and quality and unequal savings rates (base case), a decline in μ from two to one reduces the marginal (equals average) productivity of capital in agriculture, a, by 39% from 0.082 to 0.050. At the same time, it raises the aggregate agricultural savings ratio from $1 - \gamma_A = 17.9\%$ to 20.6%. Industrial employment and agricultural income per capita rise approximately twelvefold to $uk = 5711$ and $Aa_0 = 0.0050$, respectively. The relative size of the production and distribution effects can be determined by comparing the base case with an equilibrium where savings rates are identical for both income classes and equal to the aggregate savings ratio in the base case for $\mu = 2$, i.e. $s_A = 17.9\%$. For $\mu = 1$, industrial employment and agricultural income per capita rise to 9410 and 0.0083, respectively (production effect). This confirms the analytical result from Section 3.2.3 that the distribution effect weakens the production effect in the long run. As far as industrial employment is concerned, the distribution effect reduces the impact of the production effect by 39%.

These effects are smaller if the two rural income classes differ only in their endowments with land area. The productivity of capital in agriculture now falls by 31% only, which causes industrial employment and agricultural income per capita to rise less than in the base case. As the aggregate agricultural savings ratio rises only by 0.3 percentage points (as opposed to 2.7 percentage points in the base case), the distribution effect is small now; it reduces the impact of the production effect by only 5-6%.

Redistribution raises the land area owned by the poor by 294870 units. If both land area and quality differ (as they did in the base case), the parameters β_{11} and β_{21} of the rich need to be applied to the redistributed land area.[42] The right side of Table 2 reveals that agricultural productivity increases from 0.082 to 0.089 as a result of redistribution whereas the savings rate falls, both of which raise industrial employment and agricultural income per capita. As common property regimes degrade, agricultural productivity declines at approximately the same rate as in the base case (40%). However, the savings ratio increases by only 2.1 percentage points, which indicates that the distribution effect is weaker now. This is confirmed by comparison with the Equal Savings Rates case, which shows that the distribution effect is still negative but accounts for only 32% of the production effect. The distribution effect is still negative because the extent of redistribution is not high enough to make B greater than one. Given the other parameter values, a redistribution rate as high as $0.9 \cdot L_1$ is required for the distribution effect to reverse its sign.

If the income classes differ only in land quantity, the assumed redistribution rate of $0.3 \cdot L_1$ reverses the sign of the distribution effect. The savings rate *declines* now from 16.4% to 16.1% as μ falls from two to one. However, the decline is small, which causes the distribution effect to reinforce the production effect by only 5-6%.

Transitional dynamics. Transitional dynamics were analyzed by starting from a capital stock of $k = 1000$ units (which is below its long-run equilibrium value) and a value of $\lambda = 2.6$ (which is above its equilibrium value), which were chosen to reflect the characteristics of a predominantly agricultural economy. The initial renewable resource stock was set at $R = 333146$ units, which is equal to its dynamic equilibrium value under full internalization. The values for μ were set in the first time period and left unchanged thereafter. Hence, the simulations compare two time paths of adjustment

[42] That is, the productivity of the agricultural capital stock owned by the poor is now $a_2 = (\beta_{12} R^\rho + \beta_{22} \cdot 683400^\rho)^{\frac{1}{\rho}} + (\beta_{11} R^\rho + \beta_{21} 294870^\rho)^{\frac{1}{\rho}}$.

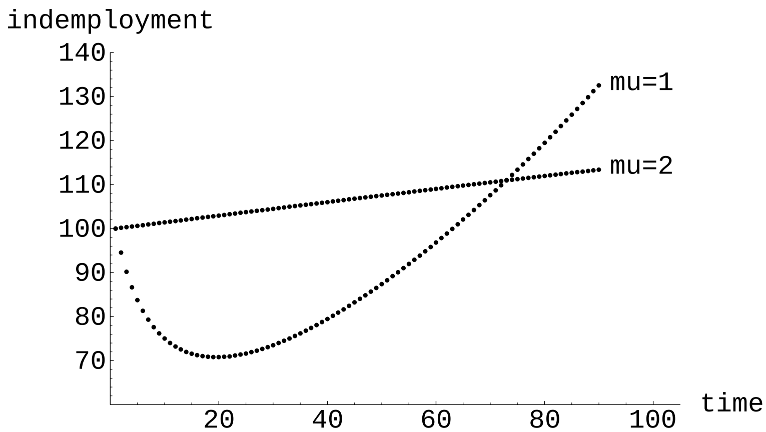

Figure 1: Industrial employment (uk) under unequal savings rates $(s_{A,1} = 0.3, s_{A,2} = 0)$ with differing land area and quality $(\beta_{12} = 2\beta_{11}, \beta_{22} = \frac{1}{2}\beta_{21})$, before redistribution

to long-run equilibrium under full internalization and under $\mu = 1$, respectively.

Figure 1 shows the evolution of industrial employment during the years (periods) 1-90 under full internalization and under $\mu = 1$ *(base case)*. Industrial employment is smaller under $\mu = 1$ than under full internalization for the first 70 years. The relative sizes of the production and distribution effects cannot be easily measured during the adjustment process because the aggregate agricultural savings ratio varies from period to period. Figure 2 therefore shows their relative size in terms of the short-run *derivatives* of industrial capacity utilization with respect to the resource stock, i.e. it shows the second term in Equation (47) as a percentage of the first term. Note that the distribution effect is positive in the first period; it reinforces the production effect by approximately one per cent. It is negative during the years 2-90 and weakens the production effect at rates of up to 12%. That is, the short-run decline in industrial employment would be stronger in the absence of the distribution effect. If the land endowments of the two income classes differ only with regard to quantity, the distribution effect is much smaller: it weakens the production effect at rates up to only 1.5%.

Redistribution both aggravates and shortens the decline in industrial employment compared to the base case with unequal savings rates, as Figure 3 shows. As the distribution effect is weaker now, the short-run decline is stronger than in the base case. However, agricultural prices and, hence, agricultural growth rise more strongly, which tends to shorten the decline.

Welfare implications. When long-run equilibria are compared for the base case, a decline of the productivity of capital in agriculture from 0.082 to

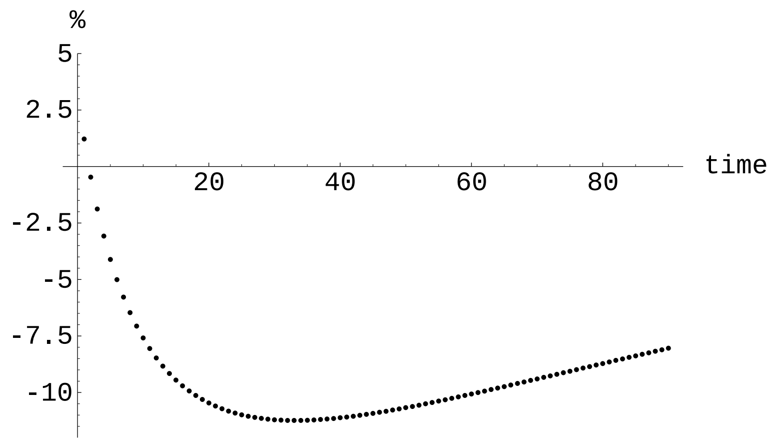

Figure 2: Marginal distribution effect as a percentage of the marginal production effect under $\mu = 1$, unequal savings rates ($s_{A,1} = 0.3, s_{A,2} = 0$) and differing land area and quality ($\beta_{12} = 2\beta_{11}, \beta_{22} = \frac{1}{2}\beta_{21}$), before redistribution

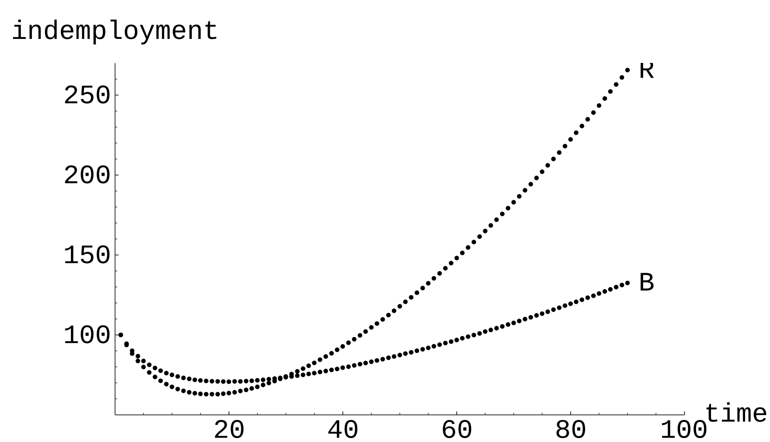

Figure 3: Industrial employment (uk) before (B) and after (R) redistribution under $\mu = 1$, unequal savings rates ($s_{A,1} = 0.3, s_{A,2} = 0$) and differing land area and quality ($\beta_{12} = 2\beta_{11}, \beta_{22} = \frac{1}{2}\beta_{21}$).

0.050 raises the share of industrial employment in the labourforce by 1161%, (aggregate) agricultural income per capita by 1150%, and the industrial profit rate by 5%. On the other hand, consumption (equals harvest) of the resource declines by 33% (details see Full Mathematical Workings).

The increase in aggregate agricultural income per capita is caused by the fact that a significant proportion of agricultural labour migrates to industry as industrial labour demand rises. This can be seen from the fact that aggregate *income from agricultural production* per unit of agricultural capital, az, *falls* by 11% because agricultural productivity declines more strongly than agricultural prices increase. This figure, however, conceals significant differences across income classes. Class-specific income from agricultural production per unit of agricultural capital, $a_i z$, *rises* by 6% for the rich but falls by 31% for the poor.

These results can be interpreted in various ways which depend on the type of ownership structure that is assumed for various types of labour.[43] In the case with two classes of rural households, rich farm households own the labour they apply to their own land and a fraction of the labour allocated to reproductive services and renewable resource harvesting, i.e. their labour endowment is $N_{A,1} + \theta N_V + \vartheta N_E$ with $\theta, \vartheta \in [0, 1]$. The labour endowment of the poor farm households is then $N_{A,2} + (1 - \theta) N_V + (1 - \vartheta) N_E$.

Two polar cases can be distinguished. If the rich own all labour units allocated to reproductive services while the poor own all labour units allocated to resource harvesting ($\theta = 1, \vartheta = 0$), the rich gain and the poor lose. The relative gains of the rich are weaker if ϑ rises above zero, i.e. if they own a fraction of the labour allocated to resource harvesting. Alternatively, the poor can be assumed to own all labour units allocated to reproductive services while the rich own all labour units allocated to resource harvesting ($\theta = 0, \vartheta = 1$). If it is assumed that the proportion of rich farmers in the population is 20% and constant, the agricultural income per capita of the poor rises eightfold, as the effect of migration exceeds the decline in income from their agricultural activity, $a_2 z$. The rich may or may not improve their welfare depending on their marginal rate of substitution between agricultural (market) income and consumption of the resource.

A third case can be distinguished where all labour allocated to reproductive services and resource harvesting is owned by a third class of rural households ("subsistence sector"). One may think of these households as representing an indigenous community who has been (largely) excluded from land ownership due to a complex set of historical factors. At long-run equilibrium, N_A and N_N grow at the same rate as total population N, and so does the sum of $N_V + N_E$. At the same time, the resource harvest is constant because N_E is constant at equilibrium, which implies that resource

[43] Recall that the labour allocation pattern described in Section 2.2 was defined in terms of units of labour, not in terms of individuals.

harvest per capita of the subsistence population declines even under $\mu = 2$. As common property regimes erode, N_E increases and equilibrium harvest ultimately declines. It follows that the *level* of the decline in subsistence income per capita is reduced as μ declines to one. In this sense, the model is able to generate growth paths where industrial growth is consistent with the impoverishment of parts of the rural population.

Even when increasing the share of industrial employment in the labourforce is considered as *the* relevant welfare criterion, the welfare improvement suggested by the comparison of long-run equilibria becomes less obvious once transitional dynamics are taken into account. It was shown above that industrial employment is smaller under $\mu = 1$ than under full internalization for the first 70 years of adjustment. Although employment under $\mu = 1$ rises thereafter and converges to a much higher equilibrium value than under full internalization (cf. Table 2), discounting the employment indicator values (uk) at a rate of 3% over a time horizon of 1000 years reveals that the present value of the $\mu = 2$ path exceeds the present value of the $\mu = 1$ path.

5 Conclusion

The preceding analysis has revealed that rural environmental degradation generates ambiguous effects on industrial growth. If agricultural investment is moderately responsive to the terms of trade $(\widetilde{\alpha_A} < \alpha_A < \overline{\alpha_A})$, environmental degradation reduces growth in the short run but *increases* the level of the growth path in the long run. The long-run increase in the stock of industrial capital per capita is the outcome of the interaction of two types of market imperfections. A coordination failure between producers and purchasers of industrial goods (more generally: between savers and investors) leads to the emergence of excess capacity in the industrial sector while a market failure in the management of the common property resource causes a decline in agricultural productivity. The increase in the terms of trade that is caused by the latter creates incentives for increased investment in agriculture, which reduces the extent of the former imperfection.

Rural environmental degradation was found to have complex effects on the intragenerational income distribution. Its immediate impact is to raise rural inequality. Moreover, it causes a transfer of real income from industry to agriculture in the short run. In the long run, environmental degradation decreases the incomes of poor farmers from agriculture and of rural nonfarming communities from renewable resource extraction.

Environmentally induced rural inequality unambiguously reduces growth in the long run but has ambiguous effects on growth in the short run. If agricultural investment is moderately responsive to the terms of trade $(\widetilde{\alpha_A} < \alpha_A < \overline{\alpha_A})$, the *distribution effect* reinforces the decline in the short run;

however, it weakens the decline if agricultural investment is only weakly responsive to the terms of trade. The simulation experiment revealed that the sign of the short-run distribution effect can change over time. Strong redistribution in favour of the poor reverses the sign of the distribution effect.

The results suggest that the case for environmental or redistributive policies is not unambiguous. Instead, various trade-offs need to be considered with regard to policy. The first trade-off concerns intergenerational equity. Simulation experiments demonstrated that the long-run benefits of environmental degradation may materialize only a after an extended period of time. It was shown that the share of industrial employment in the labourforce under $\mu = 1$ can be lower than under complete internalization ($\mu = 2$) for a period of seventy years. If a discounted welfare approach is adopted, the short-run costs outweigh the long-run benefits under plausible discount rates. Furthermore, reduced incomes from agriculture can lead to a continuous decline of common property institutions over time (as was suggested in Section 3), which would further shift the gains to the future.

Another trade-off concerns *intra*generational equity. Although environmental degradation raises industrial employment and the incomes of rich farmers in the long run, it can lead to further impoverishment for poor peasants and groups who are excluded from land ownership and depend on the extraction of the renewable resource for their subsistence (as many indigenous communities do).

A third class of trade-offs needs to be considered between growth and environmental benefits that are not reflected in the model. The latter include utility gained from the very existence of an intact rural environment, the option value of natural resources (e.g. uncertain future benefits from biodiversity), and the function of renewable resources as a sink for industrial emissions (e.g. carbon sequestration by forests).

Appendix

A Short-run equilibrium

A.1 Stability

The system (27)-(28) is linearized around the equilibrium values of $z = z^0$ and $u = u^0$:

$$\begin{pmatrix} \lambda a(\gamma_A \phi\eta - \nu) & \gamma_N \eta\phi \\ \lambda a[\gamma_A(1-\eta\phi) + \nu - 1] + \lambda\alpha_A & \gamma_N(1-\eta\phi) + \alpha_N - 1 \end{pmatrix} \cdot \begin{pmatrix} z - z^0 \\ u - u^0 \end{pmatrix} = 0 \tag{53}$$

The first matrix on the LHS represents the Jacobian of the system. The system is locally stable if the determinant of the Jacobian is positive and its trace is negative. The determinant can be computed as

$$|\mathbf{J}| = \lambda\gamma_N\eta\phi\,[a(1-\gamma_A) - \alpha_A] + \lambda a(\nu - \gamma_A\phi\eta)\,(1 - \gamma_N - \alpha_N)$$

The determinant is positive if conditions (29)-(31) are satisfied. These conditions also imply that the trace of $\mathbf{J}$ is negative. It can be seen by inspection that $J_{11} < 0$. As $1 - \phi\eta < 1$, condition (30) implies that $J_{22} < 0$, too.

A.2 Comparative statics

The system (27)-(28) is totally differentiated at its short-run equilibrium:

$$\begin{aligned} \mathbf{J} \cdot \begin{pmatrix} dz \\ du \end{pmatrix} = &- \begin{pmatrix} (\eta-1)\phi\delta/k \\ (1-\eta)\phi\delta/k \end{pmatrix} dk - \begin{pmatrix} za(\gamma_A\eta\phi - 1) \\ \gamma_A za(1-\eta\phi) + g_A \end{pmatrix} d\lambda \\ &- \begin{pmatrix} za\lambda\phi\eta \\ za\lambda(1-\phi\eta) \end{pmatrix} d\gamma_A - \begin{pmatrix} z\lambda(\gamma_A\phi\eta - 1) \\ \gamma_A z\lambda(1-\phi\eta) \end{pmatrix} da \end{aligned} \tag{54}$$

The total derivatives of u and z with regard to k, λ, γ_A and a can be computed by applying Cramer's rule.

B Long-run equilibrium

B.1 Stability

The system (32)-(34) is linearized at its equilibrium (k^0, λ^0, R^0). Its Jacobian is $\mathbf{K} = (K_{ij}) =$

$$\begin{pmatrix} (\alpha_N u_k + \beta z_k a\lambda)\,k & [\alpha_N u_\lambda + \beta a\,(z_\lambda\lambda + z)]\,k & [\alpha_N u_a + \beta\lambda\,(z_a a + z)]\,a_R k \\ (\alpha_A z_k - \alpha_N u_k)\,\lambda & (\alpha_A z_\lambda - \alpha_N u_\lambda)\,\lambda & (\alpha_A z_a - \alpha_N u_a)\,a_R\lambda \\ 0 & 0 & -\frac{r}{c}R \end{pmatrix}$$

The equilibrium can be shown to be locally stable for $\beta \geq 0$ if the static stability conditions (29)-(31) hold and the following sufficient conditions are satisfied:

$$G_A := g_A - az\,(1-\gamma_A) > 0 \tag{55}$$

$$m_A > \alpha_A z\,(1-\nu)\,/\,(\nu - \gamma_A \phi \eta) \tag{56}$$

$$\alpha_N \delta \phi\,(1-\eta)\,\Gamma_A + \alpha_A \gamma_N \phi \eta G_A < az\alpha_A \Gamma_N\,(1-\gamma_A \phi \eta) + \beta a \delta \phi\,(1-\eta)\,\Gamma_N \tag{57}$$

B.2 Comparative dynamics

The system (32)-(34) is totally differentiated at its long-run equilibrium point:

$$\mathbf{K} \cdot \begin{pmatrix} dk \\ d\lambda \\ dR \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -qR\frac{N_E}{\mu} \end{pmatrix} d\mu - \begin{pmatrix} (\alpha_N u_{\gamma_A} + \beta z_{\gamma_A} a\lambda)\,k \\ (\alpha_A z_{\gamma_A} - \alpha_N u_{\gamma_A})\lambda \\ 0 \end{pmatrix} d\gamma_A \tag{58}$$

The total derivatives of interest can be calculated by applying Cramer's rule to the linearized system (58). The derivatives of k and λ with respect to μ and γ_A were computed by using the software package *Mathematica 3.0.* A file with computations is available from the author.

C Derivation of the distribution effect

C.1 Resource Stock Decline and Agricultural Savings

Existence of values of B. The term in square brackets in (46) and $G(\Omega)$ are positive because the agricultural wage rate ω cannot exceed the marginal productivity of labour ε_1 and f cannot exceed one. If $f-(1-\chi)<0$, $F \to -\infty$ for $B \to 0$ and $F \to \infty$ for $B \to \infty$. As F is continuous and rising for all $B>0$, a value of $B=\tilde{B}$ must exist with $F(B,\Omega) \lesseqgtr G(\Omega)\;\forall\, B \lesseqgtr \tilde{B}$.

If $f-(1-\chi)>0$, $F \to \infty$ for $B \to 0$ and $F \to \infty$ for $B \to \infty$. The function F attains a global minimum at a positive value $F=F_{\min}$ which may lie above $G(\Omega)$. However, inequality (46) is satisfied for certain values of B if Ω is small enough. To see this, consider the limiting case where $\Omega \to 0$. F then converges to B while G converges to one, which implies that $F(B,0) < G(0)\;\forall\, B<1$. In the more general case where Ω is "small", a pair of values (B_1, B_2) exists with $F\,(B,\Omega) < G(\Omega)$ for $B_1 < B < B_2$ and $F\,(B,\Omega) > G(\Omega)$ for $B < B_1 \vee B > B_2$. Note that $F(B_1) = F(B_2) = F_{\min}$ in the limiting case where $B_1 = B_2$.

Redistribution. If the members of each class work exclusively on their own land, the sign of ds_A/dR changes as B exceeds one, i.e. if $L_2 > L_1$.

With wage employment, the condition for $ds_A/dR > 0$ is $F(B,\Omega) > G(\Omega)$. This is the case for $B > \tilde{B}$ if $f - (1-\chi) < 0$ and $B < B_1 \vee B > B_2$ if $f - (1-\chi) > 0$. Both redistribution in favour of the poor (increasing B above B_2) and redistribution against the poor (decreasing B below B_1) then cause ds_A/dR to become positive.

However, values of $B > \tilde{B}, B_2$ may not be attainable, for given a fixed land area, B can assume only a limited range of values $\Im = [B_{\min}, B_{\max}]$ under all feasible patterns of land distribution. If the total land area is fixed and equal to $L := L_1 + L_2$, it follows from (43) that $\Im = [1/(1+E), (1+E)]$ with $E := \beta_2 L^\rho/(\beta_1 R^\rho)$. For redistribution in favour of the poor to change the sign of ds_A/dR, it has to be assumed that $B_{\max} > \tilde{B}, B_2$.

C.2 Short-run effect

C.2.1 The sign of du/dR

With (5) and (41), equation (47) can be written as

$$\frac{du}{dR} = \frac{\partial u}{\partial a} \cdot \left(b\frac{\partial a_1}{\partial R} + (1-b)\frac{\partial a_2}{\partial R} \right) - \frac{\partial u}{\partial \gamma_A} \frac{s_{A,1} - s_{A,2}}{a X_A} \cdot$$
$$\cdot \left\{ \left[X_{A,2} + \omega f \left(N_{A,1} - \xi X_A \frac{1-\chi}{\varepsilon_1} \right) \right] b \frac{\partial a_1}{\partial R} - \left(X_{A,1} - f\omega N_{A,1} \right)(1-b)\frac{\partial a_2}{\partial R} \right\} \tag{59}$$

$\partial u/\partial a > 0, \partial u/\partial \gamma_A < 0$ This case occurs if $0 < \alpha_A < \widetilde{\alpha_A}$; it is meaningful only if the substitution effect in (49) dominates ($\nu < \phi\eta$). In this case, the distribution effect weakens the production effect. It can be shown that, in this case, the distribution effect is never strong enough to exceed the production effect as long as the static stability conditions (29)-(31) hold. This will be shown by contradiction. The second term of the expression in square brackets in (59) represents agricultural wage income, which cannot fall below zero. Hence, the second term in $\{.\}$ is the only negative term in (59), the value of which has to exceed the sum of all other (positive) terms. Hence, a necessary condition for $du/dR < 0$ is that it exceeds any of the other terms. For example,

$$\frac{\partial u}{\partial a}(1-b)\frac{\partial a_2}{\partial R} + \frac{\partial u}{\partial \gamma_A}\frac{s_{A,1} - s_{A,2}}{a X_A}\left(X_{A,1} - f\omega N_{A,1} \right)(1-b)\frac{\partial a_2}{\partial R} < 0 \tag{60}$$

Given that $1 - \gamma_A = s_A$ is a function of $s_{A,1}$ and $s_{A,2}$, it can be shown that the second term in (60), which is negative, attains its minimum value if $s_{A,1} = 1 \wedge s_{A,2} = 0$. The expression $(X_{A,1} - f N_{A,1}\omega)/X_A$ is then equal to the aggregate agricultural savings ratio $s_A(s_{A,1} = 1, s_{A,2} = 0) = 1 - \gamma_A$. Inequality (60) then simplifies to

$$\frac{\partial u}{\partial a} + \frac{\partial u}{\partial \gamma_A}\frac{1}{a}(1 - \gamma_A) < 0 \tag{61}$$

Inserting (36) and (49) into (61) yields the condition $a(1-\gamma_A)-\alpha_A<0$, which contradicts stability condition (29). Hence, du/dR must be positive.

$\partial u/\partial a<0, \partial u/\partial\gamma_A>0$ This case occurs when $\alpha_A>\overline{\alpha_A}$. The distribution effect is now positive and weakens the (negative) production effect. It exceeds the production effect if $\alpha_A\to\overline{\alpha_A}$ from above. Technically, $\partial u/\partial a\to 0$ as $\alpha_A\to\overline{\alpha_A}$ while $\partial u/\partial\gamma_A$ attains a finite positive value. Inserting $\overline{\alpha_A}$ into (49) and requiring $\partial u/\partial\gamma_A>0$ yields the condition $\nu>\gamma_A\phi\eta$, which is satisfied for stability reasons, as (31) shows.

The reason is as follows. $\partial u/\partial a<0$ implies that a decline in the resource stock raises industrial capacity utilization because the increase in the terms of trade raises investment demand more than it reduces the consumption demand for industrial goods. At the same time, $\partial u/\partial\gamma_A>0$ implies that the demand for industrial goods falls because the downward pressure on the terms of trade caused by declining demand for agricultural goods reduces investment demand more than consumption demand for industrial goods is raised. As the latter effect is stronger than the former, capacity utilization falls.

C.2.2 The sign of dz/dR

A necessary condition for the distribution effect to exceed the production effect can be formulated in analogy to (60), which yields

$$\frac{\partial z}{\partial a}+\frac{\partial z}{\partial\gamma_A}\frac{1}{a}(1-\gamma_A)>0 \tag{62}$$

Inserting (37) and (50) into (62) yields the condition $1-\gamma_N-\alpha_N<0$, which contradicts stability condition (30).

C.3 Long-run effect: The overall effect for $\beta=0$

A necessary condition for the distribution effect to exceed the production effect can be formulated in analogy to (60), which yields

$$\frac{\partial k}{\partial a}+\frac{\partial k}{\partial\gamma_A}\frac{1}{a}(1-\gamma_A)>0 \tag{63}$$

Equation (51) implies that

$$\frac{\partial k}{\partial a}=\left.\frac{dk}{d\mu}\right|_{s_A=const}\cdot\left(\frac{\partial a}{\partial R}\frac{\partial R}{\partial\mu}\right)^{-1} \tag{64}$$

Inserting (3), (64), (52) and $\partial R/\partial\mu$ (as calculated in the previous section) into (63) and setting $\beta=0$ yields the condition $g_A-az(1-\gamma_A)<0$, which contradicts stability condition (55).

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