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2008

Structural Change, Economic Growth and Environmental Dynamics with Heterogeneous Agents*

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March 2008

Abstract

This paper presents a model which takes into account two main factors that have been partially neglected by the economic development literature: the environmental externalities of human activities and agents' heterogeneity in terms of asset endowment and, consequently, in terms of income source and vulnerability to depletion of natural resources. This approach permits to shed light on agents' differences in feed-back mechanisms and interactions between their choices and environmental dynamics and allow us to propose a taxonomy of structural changes on the basis of distributive, environmental and economic impact. In such context, we identify under which conditions each structural change can occur. In particular, we identify new requirements for prompting positive structural changes, i.e. a movement of labour to capitalistic activities associated with poverty reduction and the alleviation of environmental pressures.

JEL Classification: D62, O11, O13, O15, O41, Q20
Keywords: structural change, environmental externalities, economic development, poverty alleviation.

*The authors would like to thank Ramón López for the insightful conversations and discussions about the topics dealt with in this work. We are also grateful to Simone Bertoli, Giovanni Andrea Cornia, Javier Escobal and Alessandro Vercelli as well as audience to conferences in Ascona, Urbino and Wageningen for helpful suggestions and comments on a preliminary version. The usual caveats apply.

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1 Introduction

In the history of development theory, structural change, namely a movement of labor force from the traditional resource-based sector to the modern one, has been regarded by some economists as a cause and consequence of economic development and growth (see e.g. Lewis 1955, Ranis and Fei 1961, Lucas 2004): growth of the non-resource sectors may permit an unending process of labor productivity growth because they rely on assets (human capital and physical capital) that can expand over time. Lucas (2004) recently stated that 'the origins of modern economic world can be seen, in part, as a transition from a traditional agricultural society to a society of sustained growth in opportunities of human and physical capital accumulation'. Saving and investment in physical capital can produce an increase in labor productivity leading to economic expansion. In a dual framework, such vision implies that capital intensive activities are able to sustain a process of economic growth, while the production of the subsistence sector is constrained and cannot overcome a certain threshold because it relies on limited factors of production. Therefore a labor shift towards the "modern" sector leads to a structural change associated with an increase of social welfare. Actually, many middle-low income countries have experienced a structural change associated with growing problems of environmental degradation in addition to low performances in the struggle against poverty. López (2003, 2007) refers to these cases as "perverse structural changes" and he notes[1] that environmental pressures can have a role in triggering off these types of processes: pressures on natural resources can cause a decline in productivity of agricultural traditional activities and the consequent reduction of labor opportunity cost fuels a labor migration from agricultural sector. The result is a movement of labor force from the traditional resource-based sector to the modern one associated with declining or stagnant wages and with a welfare loss for labor force[2]. Two direct factors that López identifies as responsible for the emergence of perverse structural changes are natural resource degradation and processes of disenfranchisement of part of the rural poor from access to natural resources. In turn, these factors can be caused by demographic expansion, environmental externalities of economic production, expulsion of rural

[1] In particular, he refers to Latin America, but the observation is valid for many other countries too.

[2] López points out that indirect factors capable to trigger a perverse structural change are inadequate policies aiming at fostering productivity in the modern sector in addition to a complete neglect of traditional subsistence sector of the rural poor.

communities due to an expansion in commodities or manufacturing activities, large investments in hydroelectric and irrigation projects, other infrastructures or other types of enclosures of natural common goods.

In this paper, we analyze a model which follows López's approach in that we try to embody the role of environmental externalities in shaping a process of structural change by focusing on the channel of labor costs and labor productivity, but we will attempt to also adopt a distributive perspective and to abandon a classification between clean and a dirty sectors on the basis of their production function. In particular, we consider a small open economy with two sectors: a traditional resource-based sector that relies on self-employment of poor households and a sector managed by the rich. We contemplate the possibility that both sectors cause an environmental impact. In this way, our model follows a sectorial classification based on asset endowment of the two groups (that is reflected in the production function) and no assumptions on relative difference between the two sectors in the degree of environmental impact are made. On the contrary alternative scenarios will be analyzed. The purpose is to present a theoretical model aiming at contributing to the analysis of the role that the free access natural resources may play in the relationship between growth, poverty and distribution in contexts (as in several developing countries) characterized by asset concentration, presence of relevant environmental externalities and significant dependence of economic activities on natural capital. Understanding of the conditions and factors related to the environmental dynamics that influence distributional, poverty and economic outcomes may give us a clue about how to maximize benefits from the environment or, conversely, minimize its limits in the struggle against poverty. The remainder of the article is organized as follows. Section 2 discusses the main assumptions of the model and section 3 presents the model. Sections 4 and 5 analyze the model and investigate some possible dynamics that may emerge, their implications in terms of well-being and the conditions for their existence. Sections 6 and 7 draw conclusions.

2 Main assumptions of the model

2.1 Free access environmental resource and negative externalities

In the proposed model, natural resources are represented by a free access renewable resource. Actually different property right regimes (open, private, public, and common property) usually coexist, but the impossibility to introduce such a complex setting into a theoretical model compels making a choice and the assumption of stable institutions is made: property right regime does not change along the process of structural change. Given that many developing countries are affected by ill-defined property rights (and it is particularly valid for the resource endowments of the poor), open access is analyzed as an extreme case of this type of institutional failure[3]. A comprehensive review of the empirical and theoretical literature on the effects of different property right regimes in terms of distribution and sustainability is beyond the scope of this article. However some observations might be worth underlining. Firstly, different property rights regimes have been supposed to produce different environmental impacts, but empirical evidences show a high heterogeneity of outcomes[4]. Given our focus on environmental dynamics, we have preferred distinguished various scenarios in terms of environmental impact instead of property regime avoiding any schematic parallelism between the two factors. Secondly, although with some caveats, depletion of open access renewable natural resources might represent or embody several types of forces that can prompt a structural change. The role of natural resources in determining a structural change can be given by changes in quantity of natural capital or by changes in its distribution. Our model does not manage to encompass competition on resources, but it can be noted that distributional and environmental dynamics are often associated. In many cases a change in distribution of fixed resources, such as land endowments, can be partially represented by a change in a renewable natural resource, such as land quality: for example expulsion of poor rural population from their lands because of a "beef boom" often translates in migration toward fragile lands, so even if they can cultivate the same amount of land, soil quality is likely to decline. On the other hand, rich cattle owners benefit from a higher land endowment that can be represented by an increase in their total factor productivity. Thus, in this case the dynamics can be represented by an expansion of a capitalistic sector that causes environmental externalities on rural poor dwellers. To the

[3]For certain types of resources, our model can indirectly embody the transition from open to regulating access. For example, the regulation of fishery rights can be intepretated in our model as a reduction in parameters representing the degree of environmental impact produced by economic activities. However, for other environmental resource (forest, land, etc), this interpretation is not possible because different property rights can influence not only the intensity of resource extraction but also incentives to invest in natural capital.

[4]For example, the relationship between privatization of common property resources (or the formalization of individual titles) and investment in land has been challenged by many authors (Atwood 1990, Carter and Olinto 2003, de Janvry et al. 2001, Fitzpatrick 2005, Plaze and Hazell 1993, Sjaastad and Bromley 1997 and 2000).

extent that agricultural frontier can be enlarged and property rights are not well defined land is not properly a fixed resource. Also people displacements often lead not only to distributional changes but also degradation of natural resources. Large investments in mining, logging, hydroelectric projects, irrigation projects have been responsible of severe contaminations or environmental externalities harming also communities that have not been dislocated, while displaced people are often responsible of non-sustainable behaviors and practices because they settle in new and unfamiliar areas, without knowing how long they will stay and because community relations and social capital tend to deteriorate. In the light of these observations, the choice of focusing on renewable resources in a context of open access can be considered reasonable. The fact remains that the introduction of alternative property regimes and different types of natural resources might be an interesting extension for further research.

2.2 The small open economy assumption

We consider a small open economy where economic growth is supply-driven and output prices do not depend on domestic factors but they are exogenously set. The rationale for this choice is that in the last two decades, several countries have undertaken trade liberalization reforms and, consequently, the importance of the domestic demand in sustaining economic growth has diminished (at least for trade sectors) because economies are less constrained by a limited national demand. At the same time, the role of agricultural sector for poverty alleviation and economic growth is less likely to operate through the channel of food prices because this sector cannot be seen as the only supplier of food and food prices are mainly determined by global market conditions rather than by domestic factors. These observations particularly hold for developing countries where a large share of the farming sector comprises subsistence activities that usually rely on household work and poor farming techniques, use their production mainly for self-consumption and have weak backward and forward linkages with the rest of the economy (input provider sectors, food processing and service sectors).

On the contrary in open economies, a fundamental role for economic growth is played by productive competitiveness that depends, among other important factors, on labor cost that is endogenously set in our model. In this sense, we follow Matsuyama's model (1992) that shows how the growth process might be driven by different factors in a open and a closed context: he finds a negative relationship between agricultural productivity and economic growth in open economies, while he detects the inverse links in closed economies. The key to explaining this pattern is the different competition dynamics between agricultural and industrial sector for labor: in closed economies a decrease in agricultural productivity tends to hinder labor shift to manufacturing and growth of this sector because the relative prices are determined internally. In contrast, open economies with low agricultural productivity can import agricultural goods whose relative price is set in the world market while at the same time benefiting from their comparative advantage in industrial production. As a result, the industrial sector attracts cheap labor force and it grows faster than in other economies.

In conclusion, the model we propose assumes endogenous wages but it considers relative output prices as exogenous and it neglects sectorial interactions in terms of food (as wage good) price channel and backward/forward linkages. Even if the introduction of these mechanisms and links might represent an interesting extension of the model, our purpose here is to focus on the dynamics which are likely to be more relevant in today developing countries and that have been partially overlooked by economic development theory, such as environmental externalities and their role in compressing the wage rate.

2.3 Heterogeneous economic agents

In many developing countries asset distribution is highly concentrated and credit markets are segmented. Because of credit market imperfections, differences in asset endowment and composition determine differences in terms of constraints and opportunities in the choices of income generating strategies. Thus, population composition by employment status, production functions and sectorial structure of the economic systems partially reflect asset and income distribution. The poor satisfy their needs principally through their labor, very limited private capital assets and public or semi free access goods such as environmental resources. In many cases wage labor or traditional primary activities are their main source of subsistence. According to the World Resources Report 2008 (WRI, 2008), for example, despite urbanization progresses, three-quarters of the world's poorest families live in rural areas and they still depend in large measure on natural resources for their existence. On the other hand, the better-off are more able to accumulate financial, physical and human capital, they are more likely to be employer and to rely on non-farming activities even if the dependence of their activities on environmental resources varies a lot across countries and it is generally higher in economies with abundance of natural resources[5].

At the same time, vulnerability to environmental degradation is linked to the degree of dependency on natural resources and on ability to adopt defensive strategies, namely the ability to substitute environmental resources with other productive assets. That is, in societies where there is a polarization in the asset distribution, agents differ not only for their income, but also for their vulnerability to environmental depletion. As a result, the poor, especially in rural areas, tend to be more vulnerable to ecosystem degradation than the rich.

In the light of these elements, in the model we consider two agent typologies, the poor and the rich, different production functions and income sources for the two groups considered and, as we shall, this differentiation will also lead to a divide in terms of feed-back mechanisms and interactions between agents' choices and environmental dynamics.

Finally, in our model agents' heterogeneity is also related to the degree of environmental impact produced by their activities, even if a dirty sector is not a priori defined. In fact, though it is recognized that poor families might lack incentives or means to adopt sustainable resource management practices, theoretical literature and empirical findings show that the vision of the poverty as a major cause of environmental degradation is too simplistic (Chopra and Gulati 2001, DFID et al. 2002, Durahiappah 1998, Ekbom and Bojo 1999, Forsyth et al. 1998, Scheer 2000, Swinton et al. 2003), while the empirical research has not reached conclusive findings about the environmental impact of an increase in household income (World Bank 2008, Vedeld et al. 2004)[6]. At the same time, many examples of unsustainable use of natural resources caused by wealthy interests can be cited (Barraclough and Ghimire 2000, Chomitz 2008, Ghai and Vivian 1992, Heath and Binswanger 1996, Martines-Alier 2002, Stonich 1989). For these reasons, in the model both types of agents cause environmental externalities and no assumptions on the degree of such impact and of resource dependence are made, but these factors are taken as exogenous and alternative scenarios are contemplated and compared.

[5] On involvement of the relatively wealthies households in resource-based activities in developing countries see Barbier, 2006.

[6] An extensive review of the debate on poverty-environment linkages is provided by Opschoor (2007).

3 The model

We consider a small open economy with three factors of production: labor, a free access renewable natural resource (E) and physical capital (K). In this economy, agents belong to two different populations: the "Rich" (R-agents) and the "Poor" (P-agents). The R-agents accumulate physical capital, hire labor force and employ all their potential work - represented by a fixed amount of entrepreneurial activity - to produce a storable private good. We call their production "capitalistic sector" or "modern sector". The P-agents are endowed only with labor and they have to choose the distribution of their labor between two activities: working as employee for the Rich in the capitalistic sector or directly exploiting natural resources to produce a non storable good. Let "subsistence sector" or "traditional sector" denote production of the Poor. Given that the Poor cannot invest and accumulate physical capital, we assume that the capital market is completely segmented and is accessible only by the Rich.

3.1 The maximization problem of the Poor and the production in the traditional sector

The population of the Poor is constituted by a continuum of identical individuals and the size of the population is represented by the positive parameter $\overline{N}$. The P-population's welfare depends on two goods:

1) A non storable good deriving directly from free access renewable natural resources, hereafter referred to as environmental good.

2) A good (hereafter denoted private good) which can be consumed as a substitute for the services coming from the environmental good.

We assume that the instantaneous utility function of each P-agent is the following

$$U_p(c_P, c_S) = \ln(c_P + ac_S) \tag{1}$$

where:

c_S : is the consumption of the produced good as a substitute for the environmental good;

c_P : is the consumption deriving from the exploitation of the environmental resource.

According to (1), c_S and c_P are perfect substitutes, with a (constant) rate of substitution equal to $a > 0$. That is, the private good produced by the Rich is able to substitute completely c_P. This is a stylized fact, but it can represent the main components of poor people's welfare: if they work in the subsistence sector in rural areas (fishing, forestry, agriculture or breeding) their standard of living strictly depends on access to and exploitation of E; while if they move to urban zones or they become wage labor force, they satisfy their needs mainly through the consumption of private goods.

Each P-agent, in each instant of time, employs all her potential labor (that we normalize to unity) in the subsistence sector or in the sector of the Rich. Thus, she cannot rely on alternative income sources at the same time. However, in the absence of inter-sectorial moving costs, significant divergences from the case with employment diversification are not a priori expected. Therefore, for the sake of analytical simplicity, the hypothesis of indivisible labor allocation will be kept.

Let us indicate with N_P and N_R the number of the Poor that work, respectively, in the subsistence sector and in the capitalist sector. Consequently, we have $N_P + N_R = \overline{N}$. The aggregate function of production in the traditional sector is given by

$$Y_P = \alpha N_P E \tag{2}$$

This specification was proposed by Schaeffer (1957) for fishery and since then it has been widely adopted in literature in modelling natural resources (Munro and Scott 1993, Conrad 1995, Brander and Taylor 1998a and 1998b, McAusland 2005, López et al. 2007). We have assumed that the Poor cannot save and that production is completely exhausted by their consumption. From equation (2), it follows that per capita output and consumption for the Poor working in this sector is equal to[7]

$$c_P = \frac{Y_P}{N_P} = \alpha E \tag{3}$$

The Poor that are hired in the sector of market goods receive a real wage equals to w (in terms of the private good produced by the Rich) that is considered as exogenously given. By (3), the Poor are indifferent between the work in the traditional sector and that in the capitalistic one if and only if

$$c_P = ac_S = aw \tag{4}$$

[7]In the traditional sector the labor payment is not based on marginal product activity, but on income sharing. Thus people that work in this sector receive the average product (Ray, 1998).

which can be re-expressed as

$$\frac{1}{a}\alpha E = w \tag{5}$$

If $\frac{1}{a}\alpha E > w$ (respectively, $\frac{1}{a}\alpha E < w$), then no Poor (respectively all Poor, i.e. $\overline{N}$) would like to work in the capitalistic sector. We assume that E is taken as exogenously given by the Poor, that is they do not internalize the impact of their production on natural resources; however, we will return to this issue later. In equation (5), the parameter a determines the difference between the wage in the capitalistic sector and the average output in the traditional sector that allow for the same level of utility. The alignment of labor income between the two sectors (from condition (5)) is consistent with the role of traditional sector as indicator of the labor opportunity cost[8] in other sectors. In the economy, labor supply is affected by two factors: on the one hand, an increase in wage rate (due for example to an augmentation in labor demand) represents a “pull” factor of labor force; on the other hand, negative externalities causing environmental depletion constitute a “push” factor of labor force.

3.2 The production in the capitalistic sector

The population of the Rich is constituted by a continuum of identical individuals and the size of the population is represented by the positive parameter $\overline{M}$. We normalize the size of the R-population by assuming $\overline{M} = 1$. As said, the representative R-agent employs all her fixed potential labor in the modern sector as entrepreneurial activity. Without loss of plausibility, we assume that the marginal product of entrepreneurial labor in the modern sector is higher than the marginal product of labor in the subsistence sector. Therefore, the possibility that the Rich work in the subsistence sector is excluded a priori and the production function of the modern sector can be specified as follows

$$Y_R = \beta K^{\gamma} E^{\delta} (N^D)^{1-\gamma-\delta} \tag{6}$$

[8] López (2003) observes that in developing countries labour remuneration in primary sector (especially traditional primary activities that use labour intensive techniques) is likely to represent the basic opportunity cost or floor wage for unskilled labour and, correcting for skill differentials, of the whole economy. López and Anriquez (2007) show that in Chile (1987-2003 period) the main channel through which agriculture growth reduces poverty is the labour market: expansion of agriculture production raises wages and employment of unskilled workers among whom poverty is more predominant, while effects on poverty through food price channel is less relevant. In a study on sectoral composition of growth and poverty in India, Datt and Ravallion (1998) find that growth in farm productivity contributes to poverty alleviation both directly and by inducing a rise in the wage rate as well as a reduction in food prices (although the price effect is lower).

where:

$\gamma > 0$, $\delta \geq 0$ and $\gamma + \delta < 1$ (i.e. the production function satisfies the constant returns to scale assumption);

K: is the physical capital accumulated by the representative R-agent;

N^D: is labor demand by the Rich;

β : is a positive parameter representing (exogenous) technical progress.

The function (6) is increasing in all its inputs, is concave and it satisfies the *Inada conditions* in K and N^D; while, as E approaches zero, its marginal output tends to infinite only if $\delta > 0$. If $\delta = 0$, environmental resources do not enter the production function of the Rich.

3.3 Asset accumulation

P and R-agents consider the effect of their choices on the environment as negligible and they do not internalize it; therefore, in their maximization problems they take the evolution of E as given; that is, they behave without taking into account the shadow value of the natural resource and so nobody has an incentive to preserve or restore natural resources. Thus, investment in natural capital does not affect the environmental stock and the dynamics of E can be described by the usual logistic function modified for human intervention

$$\dot{E} = E(\overline{E} - E) - \epsilon\alpha N_P E - \eta \overline{Y}_R \tag{7}$$

where:

$\overline{E}$ is the carrying capacity of the environmental resource, that is the maximum stock at which E stabilizes in absence of negative impacts due to P and R-agents' economic activities;

$\epsilon\alpha N_P E^{\chi}$ is the aggregate environmental impact by the subsistence sector and the parameter $0 < \epsilon < 1$ represents exploitation of the natural resource by P-agents;

$0 < \eta < 1$ is a parameter measuring the environmental deterioration caused by the aggregate production $\overline{Y}_R$ of R-agents. Assuming identical Rich agents, it follows that $\overline{Y}_R = Y_R$.

As there is no investment in natural capital, the R-agent invests in physical capital accumulation all she saves after her consumption expenditures and remuneration of the employed labor force. Therefore the stock of physical capital grows according to the following equation

$$\dot{K} = \beta K^{\gamma} E^{\delta} (N^D)^{1-\gamma-\delta} - wN^D - c_R \tag{8}$$

3.4 The intertemporal maximization problem of the representative R-agent

Preferences of the Rich are assumed to be representable by an utility function defined over the consumption of the private good. Let the R-agent's instantaneous utility be

$$U_r(c_R) = \ln c_R \tag{9}$$

Therefore U_R is twice continuously differentiable, strictly increasing and strictly concave, that is $U_R' > 0$ and $U_R'' < 0$. The representative R-agent maximizes her utility by choosing c_R and the labor demand N^D, that is she solves the following intertemporal optimization problem

$$\underset{c_R,\ N^D}{Max} \int_0^{\infty} (\ln c_R) e^{-rt} dt \tag{10}$$

under the constraints (7) and (8), where $r > 0$ is the discount rate. The solution to the R-agent's problem is found considering the following current value Hamiltonian function

$$H = \ln c_R + \lambda(\beta K^{\gamma} E^{\delta} (N^D)^{1-\gamma-\delta} - wN^D - c_R) + \theta(E(\overline{E} - E) - \epsilon \alpha N_P E - \eta \overline{Y}_R) \tag{11}$$

where λ and θ are the co-state variables associated to K and E, respectively. It is easy to verify that the dynamics of λ, K and E do not depend on θ. In fact, we have assumed that agents consider $\epsilon \alpha N_P E$ and $\overline{Y}_R$ as given in the maximization problem above and consequently the resulting dynamics are not optimal; however, the trajectories under such dynamics are Nash equilibriums (see Wirl 1997), in the sense that no (Rich or Poor) agent has an incentive to modify her choices along each trajectory generated by the model as long as the others do not modify theirs. The dynamics generated by the model are found by applying the maximum principle

$$\dot{K} = \frac{\partial H}{\partial \lambda} = \beta K^{\gamma} E^{\delta} (N^D)^{1-\gamma-\delta} - wN^D - c_R \tag{12}$$

$$\dot{E} = \frac{\partial H}{\partial \theta} = E(\overline{E} - E) - \epsilon \alpha N_P E - \eta \overline{Y}_R \tag{13}$$

$$\dot{\lambda} = r\lambda - \frac{\partial H}{\partial K} = \lambda \left[r - \beta\gamma K^{\gamma-1} E^{\delta} (N^D)^{1-\gamma-\delta} \right] \tag{14}$$

where c_R, N^D and N_P are determined by the following conditions

$$\frac{\partial H}{\partial c_R} = \frac{1}{c_R} - \lambda = 0 \qquad \text{(i.e. } c_R = \frac{1}{\lambda}) \tag{15}$$

$$\frac{\partial H}{\partial N^D} = \lambda(\beta(1-\gamma-\delta)K^{\gamma}E^{\delta}(N^D)^{-\gamma-\delta} - w) = 0 \qquad \text{(i.e. } \beta(1-\gamma-\delta)K^{\gamma}E^{\delta}(N^D)^{-\gamma-\delta} = w) \tag{16}$$

The labor market is perfectly competitive and wage is flexible. The equilibrium value of N_P is given by the following labor market equilibrium condition (obtained by equalizing left sides of (4) and (16))

$$\frac{\alpha}{a} E = \beta(1-\gamma-\delta)K^{\gamma}E^{\delta}(\overline{N} - N_P)^{-\gamma-\delta} \tag{17}$$

In particular, we obtain

$$N_P = \overline{N} - \left[\frac{a\beta(1-\gamma-\delta)}{\alpha} \right]^{\frac{1}{\gamma+\delta}} E^{-\frac{1-\delta}{\gamma+\delta}} K^{\frac{\gamma}{\gamma+\delta}} \tag{18}$$

if the right side of (18) is not negative, otherwise $N_P = 0$ (i.e. $\overline{N}$ Poor work in the capitalistic sector). By substituting $N_P = 0$ in (18) and solving it with respect to K we get the curve which separates the region where $N_P > 0$ from that where $N_P = 0$ in the plane (E, K)

$$K = L(E) := \left[\frac{\alpha \overline{N}^{\gamma+\delta}}{a\beta(1-\gamma-\delta)} \right]^{\frac{1}{\gamma}} E^{\frac{1-\delta}{\gamma}} \tag{19}$$

where $\frac{1-\delta}{\gamma} > 1$.

Along and above the curve (19) it holds $N_P = 0$. By substituting N^D with the equilibrium value of $\overline{N} - N_P$ in (16) the equilibrium wage w is found and it can be used in (12).

Finally, given that (ex-post) $\overline{Y}_R$ is equal to Y_R, the dynamics generated by the model are the following

$$\dot{K} = \beta(\gamma+\delta)K^{\gamma}E^{\delta}(\overline{N}-N_P)^{1-\gamma-\delta} - \frac{1}{\lambda} \tag{20}$$

$$\dot{E} = E(\overline{E}-E) - \epsilon\alpha N_P E - \eta\beta K^{\gamma}E^{\delta}(\overline{N}-N_P)^{1-\gamma-\delta} \tag{21}$$

$$\dot{\lambda} = \lambda(r - \beta\gamma K^{\gamma-1}E^{\delta}(\overline{N}-N_P)^{1-\gamma-\delta}) \tag{22}$$

where $N_P = 0$ for (E, K) above (19) while N_P is given by (18) for (E, K) below the curve (19). The following restrictions on variables and parameters hold: K, E, $\lambda > 0$; a, α, β, γ, ϵ, η, r, $\overline{E}$, $\overline{N} > 0$; $\delta \geq 0$, $\gamma + \delta < 1$.

4 Basic mathematical results

In this section we analyze the existence ad stability of the fixed points (i.e. the stationary states) of the dynamics of the model, obtained by imposing $\dot{E} = 0$, $\dot{K} = 0$, $\dot{\lambda} = 0$ in the system (20)-(22). Note that, for $\lambda > 0$, equations $\dot{E} = 0$ and $\dot{\lambda} = 0$ depend only on E and K and consequently solving them we obtain the fixed point values of E and K. The corresponding value of λ is obtained by solving the equation $\dot{K} = 0$.

4.1 The case without specialization $\overline{N} > N_P > 0$

In the case without specialization (i.e. $\overline{N} > N_P > 0$), the condition $\dot{E} = 0$ is satisfied along the graph of the function

$$K = F(E) := E^{\frac{1-\delta}{\gamma}} \left(\frac{\overline{E} - E - \epsilon\alpha\overline{N}}{M(\beta\eta M^{-\gamma-\delta} - \epsilon\alpha)} \right)^{\frac{\gamma+\delta}{\gamma}}$$

where $M := \left(\frac{a\beta(1-\gamma-\delta)}{\alpha} \right)^{\frac{1}{\gamma+\delta}}$, and the condition $\dot{\lambda} = 0$ is satisfied along the graph of the function

$$K = G(E) := \left(\frac{\beta\gamma}{r} M^{1-\gamma-\delta} \right)^{\frac{\gamma+\delta}{\gamma}} E^{\frac{2\delta+\gamma-1}{\gamma+\delta}}$$

Therefore, the intersections between $F(E)$ and $G(E)$ identify the fixed points under the regime of no specialization. To analyze the existence and stability results about these fixed points, we define

$$\Omega := \alpha \left(\frac{\eta}{a(1-\gamma-\delta)} - \epsilon \right) \tag{23}$$

$$\Delta := \frac{r}{\beta\gamma \left(\dfrac{a\beta(1-\gamma-\delta)}{\alpha} \right)^{\dfrac{1-\gamma}{\gamma}}}$$

$$\overline{N}_1 := \Delta^{\dfrac{\gamma}{1-\gamma}} \left[\frac{\delta a}{\alpha[\eta - \epsilon a(1-\gamma-\delta)]} \right]^{\dfrac{1-\gamma-\delta}{1-\gamma}}$$

$$\overline{E}_1 := \frac{\left(1 + \dfrac{\delta}{1-\gamma-\delta}\right)}{\left[\left(\overline{N}_1\right)^{\delta} \Delta^{\gamma}\right]^{\dfrac{1}{1-\gamma-\delta}}} + \alpha\epsilon\overline{N}$$

$$\overline{E}_2 := \frac{\alpha\eta\overline{N}}{1-\gamma-\delta} + \left(\frac{1}{\overline{N}^{\delta}\Delta^{\gamma}} \right)^{\dfrac{1}{1-\gamma-\delta}}$$

According to the sign of the coefficient Ω (see 23), two regimes can be distinguished:

1. **REGIME DCS (Dirty Capitalistic Sector)** *We denote regime DCS (Dirty Capitalistic Sector) the scenario in which* η*, the rate of environmental impact caused by the capitalistic sector, is relatively high (ceteris paribus) in comparison to the environmental impact of the traditional sector, measured by* ε*. That is, it holds* $\Omega > 0$*, where* $\Omega > 0$ *if and only if* $\dfrac{\eta}{\epsilon} > a(1-\gamma-\delta)$*.*
2. **REGIME DTS (Dirty Traditional Sector)** *We denote regime DTS (Dirty Traditional Sector) the scenario in which:* $\Omega < 0$*.*

Now we can state the following proposition. The proof of such proposition requires straightforward but tedious calculations; so, due to space constraints, we omit it.

Proposition 1 *In the regime DCS (i.e. $\Omega > 0$), two fixed points with $\overline{N} > N_P > 0$ at most exist. In particular, if*

$$\overline{N} < \overline{N}_1,\ \overline{E}_1 < \overline{E} < \overline{E}_2$$

then two fixed points exist; if

$$\overline{N} \leq \overline{N}_1,\ \overline{E} \geq \overline{E}_2$$

then one fixed point exists; no fixed point exists in the remaining cases.

In the regime DTS (i.e. $\Omega < 0$), one fixed point with $\overline{N} > N_P > 0$ at most exists. In particular, if

$$\overline{E} \geq \overline{E}_2$$

then the fixed point exists; no fixed point exists in the remaining cases.

In the regime DCS (i.e. $\Omega > 0$), if there exist two fixed points, in one of these the curve $G(E)$ intersects $F(E)$ from above in the plane (E, K) (we will indicate such point by the letter A) while in the other point (that we shall indicate by B) the opposite holds; in A the value of E is lower than in B. If only one fixed point is admissible, its configuration is like a point B, namely in it $G(E)$ intersects $F(E)$ from below (see **Figure 6** of the mathematical appendix). In the regime DTS (i.e. $\Omega < 0$), in the unique fixed point the curve $G(E)$ intersects $F(E)$ from above.

Proposition 1 highlights that the fixed points with $\overline{N} > N_P > 0$ exist only when the carrying capacity $\overline{E}$overcomes certain thresholds ($\overline{E} > \overline{E}_1$ if $\Omega > 0$ and $\overline{E} > \overline{E}_2$ if $\Omega < 0$). These thresholds are positively correlated to the rate of environmental impact caused by the two sectors (ϵ and η). Thus if the economic activities are too polluting then stationary points with $\overline{N} > N_P > 0$ don't exist.

The Proposition 1 also implies that it can always be found a $\overline{E}$ or $\overline{N}$ so that there exist two fixed points if $\Omega > 0$ and one fixed point if $\Omega < 0$, namely the maximum number of admissible stationary points.

Let (E^*, K^*, λ^*) denotes the fixed point value of the variables. The stability properties of fixed points depend on the signs of the eigenvalues associated to the Jacobian matrix J of the dynamical system (20)-(22) evaluated in (K^*, E^*, λ^*). We define "reachable" a fixed point that has at least two eigenvalues with negative real parts, i.e. with a 2 or 3-dimensional stable manifold. As a matter of fact, under the perfect foresight assumption, if the fixed point has a 2-

dimensional stable manifold, given the initial values $K(0)$ and $E(0)$ of the state variables K and E, R-agents are able to fix the initial value $\lambda(0)$ of the jumping variable λ so that the growth trajectory starting from $(E(0), K(0), \lambda(0))$ approaches the fixed point. Therefore the fixed point can be reached by growth trajectories. If the fixed point has a 3-dimensional stable manifold, given the initial values $K(0)$ and $E(0)$ of state variables K and E, a continuum of initial values $\lambda(0)$ exists so that the growth trajectory starting from $(K(0), E(0), \lambda(0))$ approaches the fixed point.

Proposition 2 *The fixed points without specialization ($\overline{N} > N_P > 0$) are characterized by the following stability properties:*

In the regime DCS (i.e. $\Omega > 0$), the fixed point A is always not reachable while the fixed point B is always reachable if $\gamma + 2\delta - 1 < 0$ while, if $\gamma + 2\delta - 1 > 0$, the fixed point can be reachable or repulsive; however, if $E^* > \frac{1}{2}\left(\overline{E} - \epsilon\alpha\overline{N} - \frac{r\delta}{\gamma}\right)$, it is reachable.

In the regime DTS (i.e. $\Omega < 0$), the unique fixed point is always reachable.

Proof. See Appendix. ■

From Proposition 2, it follows that if the gap between the value of the parameter $\overline{E}$ - denoting the carrying capacity - and E^* is not too wide (namely if $E^* > \frac{1}{2}(\overline{E} - \epsilon\alpha\overline{N} - \frac{r\delta}{\gamma})$), the fixed point B is reachable. As we will see in the following sections, this gap depends on demographic pressure and on the environmental impact of the production of the Poor and of the Rich because E^* is decreasing in ϵ, η and $\overline{N}$. As long as the parameters ϵ, η and $\overline{N}$ overcome a certain threshold, the gap is such that the fixed point cannot be reached.

4.2 The case with specialization $N_P = 0$

In this context, the condition $\dot{E} = 0$ is satisfied along the graph of the function

$$K = F_0(E) := \frac{E^{\frac{1-\delta}{\gamma}} (\overline{E} - E)^{\frac{1}{\gamma}}}{(\eta\beta\overline{N}^{1-\gamma-\delta})^{\frac{1}{\gamma}}}$$

while the condition $\dot{\lambda} = 0$ is satisfied along the graph of the function

$$K = G_0(E) := \left(\frac{\beta\gamma}{r}\overline{N}^{\frac{1}{\gamma}}\right)^{\dfrac{1}{1-\gamma}} E^{\dfrac{\delta}{1-\gamma}}$$

Therefore the intersections between $F_0(E)$ and $G_0(E)$ identify the fixed points under the regime of perfect specialization in the production of the capitalistic sector.

To state the following proposition, we define

$$\Gamma := \frac{1-\gamma-\delta}{2-2\gamma+\delta}$$

$$\overline{E}_0 := \left(\frac{\overline{N}}{\Gamma}\right)^{\theta} \left(\frac{\left(\dfrac{\beta\gamma}{r}\right)^{\dfrac{1}{1-\gamma}}}{\dfrac{\gamma}{\eta r}(1-\Gamma)}\right)^{\dfrac{1-\gamma}{2-2\gamma-\delta}}$$

$$\overline{N}_0 := \frac{\eta r}{\gamma}(1-\Gamma)\left(\frac{\beta\gamma}{r}\right)^{\dfrac{1}{\gamma}} \left(\frac{\alpha\eta\Gamma^{\Gamma}}{a(1-\Gamma)(1-\gamma-\delta)}\right)^{\dfrac{2\gamma+\delta-1}{1-\gamma}}$$

By straightforward but tedious calculations, we can prove that:

Proposition 3 *Two fixed points with $N_P = 0$ at most exist. In particular, if*

$$\overline{N} < \overline{N}_0,\ \overline{E}_0 < \overline{E} < \overline{E}_2$$

then two fixed point exist; if

$$\overline{E} \geq \overline{E}_2$$

then one fixed point exists; no fixed point exists in the remaining cases.

When two fixed points with specialization exist, in one of these points (the fixed point that we will denote by A_0) the graph of $G_0(E)$ intersects that of $F_0(E)$ from above, viceversa in the other fixed point (which we will indicate by B_0) Furthermore, in A_0 the value of E is lower than in B_0. If only one fixed point exists, its configuration is like a point A_0 namely in this point $G_0(E)$ intersects $F_0(E)$ from above (see **Figure 7** of the mathematical appendix).

We can observe that $\overline{N}_0$ depends on r but not on $\overline{N}$, while $\overline{E}_2$ depends on $\overline{N}$ but not on r. Therefore Proposition 3 implies that, given $\overline{E}$, there always exist $\overline{N}$ and r such that at least one fixed point exists.

Proposition 4 *The fixed point A_0 is always not reachable, while B_0 can be reachable; in particular, it is always the case if*

$$E^* > \frac{1}{2}\left(\overline{E} - \frac{r}{\gamma(1-\gamma)}\right)$$

Proof. See Appendix. ■

It follows that the fixed point with complete specialization can be reached only when two fixed points with specialization exist, namely demographic pressure and carrying capacity do not cross a certain threshold (respectively $\overline{N}_0$ and $\overline{E}_2$). Moreover, according to Proposition 4, E^* has to be sufficiently high, i.e. $E^* > \frac{1}{2}\left(\overline{E} - \frac{r}{\gamma(1-\gamma)}\right)$. These are sufficient conditions so that the system presents a reachable stationary state with disappearance of the traditional sector and a complete process of "proletarianization" with all the Poor employed in the capitalistic production.

We can also investigate whether the existence of fixed points with $N_P = 0$ is compatible with the existence of fixed points with $N_P > 0$. The following Proposition identifies sufficient conditions for the simultaneous existence of four fixed points A, B, A_0 and B_0.

Proposition 5 *If $\overline{N}_1 < \overline{N} < \overline{N}_0$, $max\{\overline{E}_1, \overline{E}_0\} < \overline{E} < \overline{E}_2$, $\Omega > 0$, then four fixed points exist: A_0 and B_0 with $N_P = 0$, A and B with $N_P > 0$.*

Proof. It follows from Proposition 1 and Proposition 3. ■

For a numerical example, see **Figure 1**. In a context with multiple reachable fixed points, the choice between B and B_0 depends on the initial conditions. This is a typical example of path dependence: the initial value of E and K determine the fixed point (B or B_0) that the growth trajectory will approach. These findings are clearly shown by the numerical simulations showed in **Figures 2-5**. In these Figures, the continuous (dotted) lines indicate values of E^* and K^* corresponding to reachable (respectively, unreachable) fixed points. Note that for some values of η and $\overline{E}$, the conditions set in Proposition 5 are satisfied: four fixed points exist and the initial levels of E and K determine whether B or B_0 will be reached. Moreover, as $\overline{E}(\eta\ )$ overcomes a minimum (maximum) level, only B_0-type fixed points with full specialization are compatible with the dynamic system and are approached. Thus, point B_0 can be generated as a final step of an "excessive" depletion of the stock of environmental resources.

5 Comparative statics

This section studies the role played by the variation of some significant parameters of the model in determining a structural change defined as a variation of labor allocation between the two sectors of the economy. To this end, we focus our attention on the variations of the coordinates of the reachable fixed point, in the context $\overline{N} > N_P > 0$. In particular, we are interested to study the impact on R-agent's consumption and accumulation, P-agent's consumption and labor allocation between the two sectors, as well as natural capital. The following Proposition helps to identify the most significant variables that represent dynamics of the economy.

Proposition 6 *The fixed point value of consumption c_R^* of the Rich is positively proportional to the fixed point value of physical capital K^*. More precisely, it holds: $c_R^* = \frac{(\gamma+\delta)r}{\gamma} K^*$. The fixed point values of consumption c_S^* of the Poor working in the capitalistic sector and of consumption c_P^* of the Poor working in the traditional sector are positively proportional to the fixed point value of natural capital E^*. More precisely, it holds: $c_S^* = \frac{\alpha}{a} E^*$ and $c_P^* = \alpha E^*$.*

This implies that the Rich are able to effectively face environmental degradation through physical capital accumulation. It means that exogenous changes leading to an increase in K^* ensure a growing c_R^*, even if E^* declines. This is not the case for the Poor, whose welfare is positively proportional to E^*.

The above Proposition allows to focus on equilibrium values of N_P, E^* and K^*. From these variables, Poor and Rich agents' welfare can be computed. In order to carry out some exercises of comparative statics, we study how the functions that identify the loci where $\dot{E} = 0$ and $\dot{\lambda} = 0$ move in relation to variations of parameters. The following proposition concerns the impact of a change in the more significant parameters on N_P, E^* and K^*; the proof is straightforward but tedious, so we omit it. Results are distinguished according to the relatively more environmental demanding sector DCS (i.e. $\Omega > 0$) and DTS (i.e. $\Omega < 0$) and according to the value of the expression $\gamma + 2\delta - 1$, introduced in Proposition 2, which can be interpreted as an indicator of modern sector dependency on natural capital. It holds $\gamma + 2\delta - 1 > 0$ if $\delta > \frac{1-\gamma}{2}$, where δ is the natural capital elasticity of the production function of the modern sector. So a positive value of $\gamma + 2\delta - 1$ indicates a "high" importance of natural resources in the production process of the modern sector. We will indicate by the symbol $x \uparrow$ (respectively, $x \downarrow$) an increase (respectively, a reduction) of x.

Proposition 7 *1) If $\overline{E} \uparrow$, then $N_P^* \uparrow$, $E^* \uparrow$ and $K^* \uparrow$ when $\gamma + 2\delta - 1 > 0$ while $N_P^* \uparrow$, $E^* \uparrow$ and $K^* \downarrow$ when $\gamma + 2\delta - 1 < 0$.*

2) If $\epsilon \uparrow$ or $\eta \uparrow$, then $N_P^* \downarrow$, $E^* \downarrow$ and $K^* \downarrow$ when $\gamma + 2\delta - 1 > 0$ while $N_P^* \downarrow$, $E^* \downarrow$ and $K^* \uparrow$ when $\gamma + 2\delta - 1 < 0$.

3) If $\beta \uparrow$, then:

3.1) $N_P^* \downarrow$, $E^* \downarrow$ and $K^* \downarrow$ or $K^* \uparrow$ when $\gamma + 2\delta - 1 > 0$ and $\Omega > 0$.

3.2) $N_P^* \downarrow$, $E^* \uparrow$ and $K^* \uparrow$ when $\gamma + 2\delta - 1 > 0$ and $\Omega < 0$.

3.3) $N_P^* \downarrow$, $E^* \downarrow$ and $K^* \uparrow$ when $\gamma + 2\delta - 1 < 0$ and $\Omega > 0$.

3.4) $N_P^* \downarrow$, $E^* \uparrow$ and $K^* \downarrow$ or $K^* \uparrow$ when $\gamma + 2\delta - 1 < 0$ and $\Omega < 0$.

The following sections discuss these comparative statics results.

6 Classification of structural changes

Comparative statics in the regime without specialization $\overline{N} > N_P > 0$ has shown that a change in some parameters of the model causes an impact on the fixed point value of N_P; that is, the economy reaches an equilibrium characterized by a different labor allocation between the two sectors. Thus a structural change comes out. The analysis focuses on structural changes in which labor shifts from the traditional to the modern sector (namely with $N_P \downarrow$). These transitions can be classified in four different typologies:

1) **Immiserizing structural change (ISC)** $N_P \downarrow$, $E^* \downarrow$, $K^* \uparrow$*: labor moves out from the subsistence sector, the stationary value of environmental stock declines as well as Poor agents' consumption, while the equilibrium physical capital and the Rich agent's consumption grow. Thus, the structural change is characterized by environmental degradation and increase in inequality. Rich is not negatively affected by environmental stress because they partially substitute natural capital with physical capital and wage labor employment.*

2) **Pro-poor Structural Change (PpSC)** $N_P \downarrow$, $E^* \uparrow$, $K^* \downarrow$*: labor shift is associated with a growth in the stationary value of natural capital and with a decrease in physical capital. That is, structural change benefits the Poor to detrimental of the Rich.*

3) **Positive Structural Change (PSC)** $N_P \downarrow$, $E^* \uparrow$, $K^* \uparrow$*: in this case, the structural change leads to a Pareto improvement. Both the Rich and the Poor are benefited and environment is preserved.*

4) **Negative Structural Change (NSC)** $N_P \downarrow$, $E^* \downarrow$, $K^* \downarrow$*: in this case, environmental degradation push labor force to the capitalistic sector but both the Rich and the Poor are harmed by the reduction in natural capital endowment.*

Comparative statics results of our model have shown that alternative scenarios can emerge. Table 1 and 2 associate to variations of parameters the corresponding structural change type. The following section attempts to schematize,

Parameter	$\Omega > 0$			Typology	$\Omega < 0$			Typology
	N_p^*	E^*	K^*		N_p^*	ΔE^*	K^*	
$\overline{E} \downarrow$	$\downarrow$	$\downarrow$	$\uparrow$	ISC	$\downarrow$	$\downarrow$	$\uparrow$	ISC
$\beta \uparrow$	$\downarrow$	$\downarrow$	$\uparrow$	ISC	$\downarrow$	$\uparrow$	$\updownarrow$	PpSC / PSC
$\eta \uparrow$ or $\epsilon \uparrow$	$\downarrow$	$\downarrow$	$\uparrow$	ISC	$\downarrow$	$\downarrow$	$\uparrow$	ISC

Table 1: Comparative statics if $\gamma + 2\delta - 1 < 0$

Parameter	$\Omega > 0$			Typology	$\Omega < 0$			Typology
	N_p^*	E^*	K^*		N_p^*	E^*	K^*	
$\overline{E} \downarrow$	$\downarrow$	$\downarrow$	$\uparrow$	ISC	$\downarrow$	$\downarrow$	$\downarrow$	ISC
$\beta \uparrow$	$\downarrow$	$\downarrow$	$\updownarrow$	ISC /NSC	$\downarrow$	$\uparrow$	$\uparrow$	PSC
$\eta \uparrow$ or $\epsilon \uparrow$	$\downarrow$	$\downarrow$	$\downarrow$	NSC	$\downarrow$	$\downarrow$	$\downarrow$	NSC

Table 2: Comparative statics if $\gamma + 2\delta - 1 > 0$

highlight and discuss our findings.

7 Interpretation of results

Most of two-sectors models with environmental externalities (e.g. Eliasson and Turnovsky 2004, López et al. 2007) distinguish between a clean and non-resource sector (it comprises activities that do not employ natural capital neither pollute) and a dirty resource sector (i.e. activities that use natural resources as input of production and that cause an environmental impact). Under some assumptions on the values of parameters, our model can reflect these characterizations. Given that the traditional sector tends to be more dependent on natural resources, in our model this case occurs when $\eta = \delta = 0$ (where η and δ are respectively the environmental impact and natural capital elasticity of the capitalistic sector production) and consequently $\Omega < 0$ and $\gamma + 2\delta - 1 < 0$. However, differently from Eliasson and Turnovsky's and López's models, in our context this specification is not neutral from a distributional point of view. Indeed, it implies that the production of the Poor represents the dirty sector, while the R-agent is involved in clean production. In this context, consistently with other models, an increase in β leads to a positive structural change and the economy tends to fixed point with a higher level of natural and physical capital, so welfare of the Poor and the Rich agents increases. However, if the movement of labor is caused by an increase in environmental pressures (for example, the parameter ε measuring the environmental impact of the traditional sector or the parameter $\overline{E}$ representing carrying capacity decreases), the final result is an immiserizing structural change: the traditional sector is affected by the reduction in natural capital, while the Rich are not harmed. Indeed, the capitalistic sector is benefited by the access to labor at low cost and this, in turn, produces incentives for investment in physical capital. Both structural changes are positive for the representative Rich agent but the results in terms of the capitalistic sector output are different. Note that labor productivity in the modern sector is equal to $\beta(1-\gamma-\delta)K^{\gamma}(\overline{N}-N_P)^{-\gamma-\delta}$. Thus, even if an increase in β or in ε, or a reduction in $\overline{E}$, lead to the same labor shift, in the first scenario labor productivity grows more than in the other cases. Therefore, the immiserizing structural change leads to an expansion of the capitalistic sector associated with a lower labor productivity than in the positive structural change.

The economy represented by our model is characterized by a more complex context: both sectors produce and are affected by natural resource degradation. This context gives rise to a wider set of possible scenarios, as the following subsections attempt to illustrate.

7.1 How much the environment matters for the Poor and for the Rich

The basic hypothesis of this work is the non-homogenous distribution of assets. The model analyzes a stylized case in which physical capital is completely concentrated in the endowments of a social class (the upper class), while all agents have access to environmental capital. Although this is a highly stylized fact, it reflects the ways in which different assets (natural, physical, social, human capital) are typically distributed. Physical capital tends to have a concentrated dispersion across the population because of financial market failures. In absence of perfect information and competition, the wealthier individuals and large firms have a privileged access to capital market, because they are more endowed with collateral and they have a higher ability to exploit scale economies. Conversely, the services coming from environmental resources may be more dispersed and tend to have characteristics of public goods (in our model all agents have access to environmental capital). In this context, economic agents also differ in feed-back mechanisms and interactions between their choices of production (consumption) and environmental dynamics. The case with $\gamma + 2\delta - 1 < 0$ (namely the modern sector has a relatively low dependence on natural resources) sheds light on the consequences determined by the initial hypothesis of physical asset concentration and free access environmental capital. From Proposition 7 and Table 1 it follows that in this context the model tends to be a zero-sum game. Physical capital endowments allow the Rich to employ wage labor too and this possibility lies at the roots of a conflict between the Rich (labor employers), and the Poor (labor force providers). The Rich are more able to defend themselves from environmental degradation because they can partially substitute natural capital with physical capital or wage labor employment. Thus, the Rich are not disadvantaged by the environmental degradation because they can rely on substitution possibilities as a defensive strategy. On the contrary, they may benefit from the role played by the natural capital scarcity in accelerating human resources mobilization and shift of labor supply from the traditional sector to the modern one. Therefore they take advantage of the possibility to exploit labor at a lower cost. This, in turn, generates incentives to physical capital accumulation. On the other hand, the poor are harmed because they face a reduction in productivity of their labor, namely in their major mean of subsistence. In this context a reduction in environmental impact of the economic activities (i.e. a reduction in η or ϵ) or an increase in carrying capacity not only help preservation of environment (equilibrium stock of natural capital grows), but they have a distributive impact too.

7.2 Conditions for positive structural change

The comparative statics of an increase in β pinpoints the consequences of considering environmental dynamics. According to the mainstream view, an increase in total factor productivity of the modern sector is always seen as a positive factor leading to growth and, at least in the long term, poverty reduction. On the contrary, the model shows that this scenario might occur only if the modern sector has a relatively low environmental impact in comparison to the traditional one (i.e. $\Omega < 0$). In this case, a rise in β determines an increase in labor productivity in the modern sector leading to a growth in wage of workers employed by the Rich as well as an augmentation of c_R^*. At the same time, the movement of labor caused by an increase in labor demand reduces the demographic pressures on natural resources with positive effect on labor productivity in the subsistence sector too. Therefore, in both cases ($\gamma+2\delta-1 < 0$, $\gamma+2\delta-1 > 0$) a labor shift towards the capitalistic sector is associated to a Pareto improvement and to an increase in natural capital (i.e. a positive structural change) only if $\Omega < 0$.

Other variations of the parameters (for example an increase in carrying capacity or a reduction in rates of environmental impact ϵ or η) lead to higher level of natural and physical capital but they are not accompanied by a process of proletarianization. The above Proposition highlights a novel requirement for positive structural changes: labor reallocation towards the modern sector can lead to poverty reduction only if this sector is not too polluting, namely it produces relatively low environmental externalities in comparison to the traditional activities. The positive structural change also represents the labor transition associated with the highest level of labor productivity because it occurs when there is a growth in total factor productivity as well as of all productive inputs. Therefore the positive structural change also insures the best economic performances of the capitalistic sector in comparison to the other typologies of SC. Looking at policy implications, we can conclude that, in a country with high income and asset concentration and where the capitalistic sector is quite polluting or environment demanding, measures to control environmental externalities of these activities are necessary not only for sustainability, but also for economic growth and poverty alleviation. Therefore policies aiming to promote a positive structural change require that government support to modern sector productivity (such as incentives, direct and indirect subsidies for capital accumulation, financial grants, tax exemptions, public credit, favorable regulations, financing of infrastructures and so on) does not include measures too permissive in terms of environmental externalities[9].

[9]Environmental externalities can be represented by resource contamination or depletion but also, adopting a broader definition, by expulsion of other users from the access to natural resources.

7.3 Undesirable economic growth

Not only an increase in β might fail to trigger off positive structural change, but it can also cause an immiserizing structural change (refer to Tables 1 and 2). In particular, we focus on the effects of an increase in β in a DCS regime. This case clearly shows that, when we consider distributive and environmental dynamics in a joint framework, some scenarios neglected by the literature can emerge. The economic literature in general agrees that economic growth is a not a sufficient condition for reducing poverty, but distributional dynamics play a decisive role in shaping effects of economic growth on poverty rates. A stylized fact commonly accepted is that negative rates of economic growth tend to disproportionately hit lower income quintiles, but at the same time a positive performance may neglect the poorest. However, in practice, economic growth remains one of the main goals pursued by national governments and international institutions and, though a positive trend in GDP growth does not insure per se an increase in welfare of the Poor, it is seen as a necessary condition. This entails that actions to stimulate economic growth are consistent with objectives of poverty reduction that, in turn, might relieve pressures on natural resources. In contrast, the consequences of an increase in β when $\Omega > 0$ raise doubts about this expected virtuous relationship between economic growth, poverty reduction and preservation of ecosystems. Indeed, in this scenario the environmental externalities may contribute to generating an undesirable and self-reinforcing path of expansion of the modern sector associated with a process of impoverishment[10]: the capitalistic sector grows producing push forces on the Poor due to the environmental pressures, labor moves out the subsistence sector and the capitalistic sector further expands. This unexpected result may be explained by the fact that positive impact of a growing β on the wage is overcome by down pressures on w because of the environmental degradation caused by the modern sector's expansion. Thus, an increase in β may reduce welfare of the Poor if it is not accompanied by counterbalancing factors such as a rise in α (i.e. total factor productivity of the traditional sector) or a reduction

[10]Models that predict scenarios with undesirable economic processes are not new in literature. Actually, Antoci and Bartolini (1999, 2004), Antoci et al. (2005, 2008) and Antoci (2008) propose models in which negative externalities may constitute an engine of economic growth. In their models, economic growth produces negative externalities that reduce the capacity of natural or social environment to provide free goods. Agents try to defend themselves from welfare losses by increasing their labor supply in order to rise their consumption of private goods that are substitute of free access goods. This, in turn, leads to economic growth. As result, defensive strategies generate a growth path that is Pareto dominated in terms of well-being.

in η (i.e. environmental impact of the capitalistic sector). The parameters α and β can be affected by public investments. Therefore, looking at the policy implications of these findings, it could be argued that governments should take into account the possibility of such perverse mechanisms in their decisions about allocation of public expenditure. If the public funds focus only on the modern sector neglecting productivity of the subsistence sector, the result may be an immiserizing growth, namely an output growth that worsens income distribution [11].

7.4 Consequences of a high dependence on natural resources

¿From Proposition 7 and Table 2 it follows that if the modern sector is more resource-based (i.e. $\gamma + 2\delta - 1 > 0$) the Rich are more vulnerable to environmental degradation. In this context, a change in parameters produces an impact with the same sign to the Rich and the Poor, namely their utility are positively correlated. Thus, a reduction in E, due to a decrease in the carrying capacity or to an increase in η or ϵ, leads the economy to fixed points characterized by lower level of welfare both for the Poor and for the Rich because natural resources are relevant for their consumption levels. Therefore, in the long run, environmental policies may be win-win strategies. In this context there is not a trade-off between goals of poverty alleviation, economic growth and environmental preservation, but they require similar interventions (such as measures for raising carrying capacity or legislation, controls and incentives for adoption

[11] Claims of representatives of organisations of peasants, fisher peoples, victims of tsunami (Via Campesina, World Forum of Fisher Peoples) can be interpreted also in the light of these findings. In the final declaration of Regional Conference on Rebuilding Peasants' and Fisherfolk's Livelihoods After the Earthquake and Tsunami Catastrophes (Medan-Indonesia, 17-19 February 2005) the following statements can be read: After the terrible destruction caused by the quake-induced tsunami, hundreds of thousands of victims have had to flee their homes, their fishing grounds and farmlands and shift to relief camps, leading to a great sense of despair and despondency in having to depend on charity and others for their living. This condition has only been worsened by the attempts of governments in some tsunami-hit countries to clear the beaches and coastal areas in the name of tsunami-preparedness, preventing coastal communities from exercising control of, and access to, traditional sources of beach-based economic activities, while simultaneously planning to hand them over to corporate and business interests in the tourism, industrial fisheries and aquaculture, and maritime industries....... Rehabilitation and reconstruction activities in the affected coastal areas should give utmost priority to traditional, artisanal, small-scale communities relying on beach-based fishing activities, and not to large scale mechanized fishing vessels or industrial aquaculture farms.......We reject aid for the affected coastal fishing communities that are not locally appropriate or designed to suit the needs of beach-based labor-intensive fishing practised by most coastal fishing communities in the affected regions, in contrast to the harbour-based fishing prevalent in the donor countries (www.viacampesina.org).

of sustainable practices or technologies that reduces η or ϵ).

7.5 Effects of resource abundance and environmental preservation

Figure 6 provides information on the relationship between resource abundance and structural change. According to these findings, in all scenarios we have that $\overline{E} \uparrow$, $\epsilon \downarrow$ or $\eta \downarrow$ lead to $E^* \uparrow$ and $N_P \uparrow$. Thus, scarcity of natural resources represents a push force of labor force towards the capitalistic sector, while natural capital abundance (given by a high endowment of natural capital stock or a low environmental impact of human action) tends to delay labor shift to the modern sector and physical capital accumulation while at the same time reducing poverty. If the modern sector is seen as engine of growth, our results are consistent with "resource curse hypothesis". At the same time, unlike this literature, in our model agents' welfare and economic growth are not always coincident: natural capital abundance is not a curse but a resource against processes of impoverishment even if it can be an obstacle to economic growth. However, though our findings recall this literature, some differences have to be considered. Studies on "resource curse" have focused on settings that are not likely to be represented by high $\overline{E}$. In our model, the environmental resources are public goods that all agents have access to, while well resource endowed countries have been identified according to per capita land (Wood and Berge 1997), primary export share (Sachs and Warner 1997) or abundance of point resources (mining, oil and, in a certain measure, plantations)[12]. However the use of per capita land as a proxy of resource wealth does not capture distributive aspects, while point resources are more likely to be appropriated by a narrow élite, and export oriented primary activities can be assimilated to what we have called "modern" sector: they often adopt capital intensive techniques of production, employ wage workers and are managed by the rich. In these cases environmental resources are not public but excludible goods that are mainly enjoyed by the rich. Therefore it can be concluded that, even if our results are not tested by the studies on performance of resource-rich countries in terms of poverty and inequality, they are not in opposition to this literature. Moving to change in labor allocation, we observe that the positive (negative) relationship between ϵ and η

[12] Mineral resources, oil, plantations which require immediate processing can be considered examples of "point" resources because their rents and sources are not diffuse. These sectors are typically characterized by concentrated ownership and capital intensive production processes.

(respectively, $\overline{E}$) and immiserizing process of "proletarianization" is consistent with the empirical evidences in many countries. Chopra and Gulati (2001) show that, in India's arid and semiarid regions, environmental degradation tends to force people to move to urban areas during time of distress, especially during droughts, while measures reducing environmental pressures lead to a decrease in migration flows. In Nepal, out-migration to seek wage employment is one of the strategies adopted by farmers in the hills to cope with soil erosion and land degradation that is due to bad land use practices and to natural factors (World Bank, 1995). The investigations on environmental degradation and migration between the US and Mexico (Schwartz and Notini 1994) confirmed that the inability to make living from the land due to dry conditions and processes of soil erosion contribute to the decision of rural people to migrate. Similar evidences are found also in Africa where climate variability, climate change and unsustainable human activities (overcultivation, overgrazing, deforestation, and poor irrigation practices) lead to an increasing process of desertification that forces people to emigrate both in other rural and urban areas (UNCCD 2005). Finally, a cross-country analysis, conducted by Shandra et al. (2003) on a panel of fifty-eight developing countries, finds that deforestation exerts a positive effect on over-urbanization whereas environmental sustainability produces a negative impact on over-urbanization. According to these results, developing countries suffering environmental degradation would be prone to over-urbanization. If $\gamma + 2\delta - 1 < 0$, this may exacerbate the increase in income distribution inequality: c_P declines, while the consumption level of the Rich is not negatively affected by environmental pressures because they can rely on physical capital accumulation and employment of wage labor.

8 Conclusions

Nowadays no development strategy can avoid considering environmental dynamics, externalities of human activities under a distributive perspective. Environmental problems (the depletion of marine stocks, soil erosion, land degradation, lost of forests and biodiversity, air contamination, global warming effects and ocean acidification) have become a major concern in the international agenda, while the poor, not only tend to rely more than the rich on natural resources but they also are less able to defend themselves from environmental degradation.

This article has attempted to study the linkage between open access environmental resources and labor and output composition by taking into account two main factors that have been partially neglected by the economic development literature: agent's heterogeneity in terms of asset endowment and, consequently, in terms of income source and vulnerability to depletion of natural resources.

The proposed model have shown that the introduction of these factors adds new elements in the analysis of these link and permits to shed light on agents' differences in feed-back mechanisms and interactions between their choices and environmental dynamics.

We have proposed a taxonomy of structural changes on the basis of distributive, environmental and economic impact and we have attempted to identify under which conditions each SC can occur. Firstly, the work has identified new requirements for prompting positive structural changes, i.e. a movement of labor to capitalistic activities associated with poverty reduction and alleviation of environmental pressures. In particular, the capitalistic sector has to produce a relatively low impact on natural resources. Secondly, we have found that the existence of counter-intuitive results cannot be excluded: an increase in total factor productivity of the capitalistic sector (or other factors leading to the growth of this sector) might stimulate a self-reinforcing and immiserizing growth, namely an output growth that results in a further impoverishment of the poor and in a worsening of income distribution. This finding suggests that proper caution is to be adopted in designing government measures which emphasize only physical capital accumulation or expansion of the capitalistic sector with the purpose to fight poverty via economic growth. Indeed, some "collateral" effects may jeopardize the benefits of economic growth causing environmental degradation and impoverishment processes.

9 Appendix

9.1 Proof Proposition 2

Recalling the definition of M and noticing that $N_P = \overline{N} - MK^{\frac{\gamma}{\gamma+\delta}} E^{\frac{\delta-1}{\gamma+\delta}}$ the dynamic system becomes

$$\dot{K} = \beta(\gamma+\delta) K^{\frac{\gamma}{\gamma+\delta}} E^{\frac{2\delta+\gamma-1}{\gamma+\delta}} M^{1-\gamma-\delta} - \frac{1}{\lambda} \tag{24}$$

$$\dot{E} = E(\overline{E} - E) - \epsilon\alpha\overline{N} + K^{\frac{\gamma}{\gamma+\delta}} E^{\frac{\delta-1}{\gamma+\delta}} M(\epsilon\alpha - \eta\beta M^{-\gamma-\delta}) \tag{25}$$

$$\dot{\lambda} = \lambda \left(r - \beta\gamma K^{-\frac{\delta}{\gamma+\delta}} E^{\frac{2\delta+\gamma-1}{\gamma+\delta}} M^{1-\gamma-\delta} \right) \tag{26}$$

Let (K^*, E^*, λ^*) denotes the fixed point values of (K, E, λ). Remember that fixed points of our system correspond to the intersections between the graphs of the functions $K = F(E)$ and $K = G(E)$ occurring below the curve $K = L(E)$ in the plane (E, K) (see **Figure 6**) It is easy to check that **Figure 6** shows all possible configurations of curves $K = F(E)$ and $K = G(E)$; in such figure, $E_1 := \frac{1-\delta}{1+\gamma}(\overline{E} - \epsilon\alpha\overline{N})$ indicates the value of E maximizing $F(E)$; furthermore, when the curve $K = L(E)$ is not drawn, this means that both the intersections between $K = F(E)$ and $K = G(E)$ occur below $K = L(E)$; that is, both intersections give rise to fixed points in the regime $\overline{N} > N_P > 0$.

Before calculating the Jacobian matrix, we note that from (25) and (26) it follows that in the fixed point it holds

$$\frac{1}{\lambda} = \frac{r(\gamma+\delta)}{\gamma} K^* \tag{27}$$

and

$$\overline{N} - N_P = \frac{\overline{E} - E^* - \epsilon\alpha\overline{N}}{\Omega}$$

By straightforward calculations we now find the Jacobian matrix evaluated at the steady state (J^*)

$$J^* = \begin{pmatrix} h^*_K & h^*_E & h^*_\lambda \\ f^*_K & f^*_E & f^*_\lambda \\ g^*_K & g^*_E & g^*_\lambda \end{pmatrix}$$

where

$h^*_K = r$

$h^*_E = \dfrac{r(\gamma + 2\delta - 1)K^*}{\gamma E^*}$

$h^*_\lambda = \dfrac{1}{\lambda^2} = \left(\dfrac{r(\gamma+\delta)K^*}{\gamma}\right)^2$

$f^*_K = -\dfrac{\gamma}{\gamma+\delta}\dfrac{E^*(\overline{N} - N_P)\Omega}{K^*}$

$f^*_E = \dfrac{1+\gamma}{\gamma+\delta}\left(E_1 - E^*\right)$

$f^*_\lambda = 0$

$g^*_K = \dfrac{\gamma\delta}{(\gamma+\delta)^2(K^*)^2}$

$g^*_E = -\dfrac{\gamma}{(\gamma+\delta)^2}\dfrac{\gamma+2\delta-1}{E^*K^*}$

$g^*_\lambda = 0$

Therefore, h^*_K, h^*_λ and g^*_K are always positive, h^*_E and $\rho := \gamma + 2\delta - 1$ have the same sign, g^*_E and ρ have opposite sign, f^*_K and $E_1 - E^*$ have the same sign, f^*_K and Ω have the opposite sign.

In order to study the stability properties of fixed points, we apply the methodology proposed by Wirl (1997). The eigenvalues of the system are the roots of the following characteristic polynomial

$$P(z) = z^3 - z^2 tr(J^*) + zM_2 - |J^*|$$

where

$$tr(J^*) = k^*_k + f^*_E + g^*_\lambda \qquad |J^*| = h^*_\lambda(f^*_K g^*_E - f^*_E g^*_K) \qquad M_2 = -h^*_\lambda g^*_K + h^*_K f^*_E - h^*_E f^*_K$$

Therefore, the following results can be easily proved.

Lemma 1 *If $E^* < E_1$, then $tr(J^*) > 0$.*

Lemma 2 *If $\Omega > 0$, then $|J^*| < 0$ in A and $|J^*| > 0$ in B.*

If $\Omega < 0$, in the unique admissible fixed point it holds $|J^*| > 0$.

Lemma 3 *If $\rho < 0$, then $M_2 < 0$.*

If $\rho > 0$ *and* $\Omega < 0$*, then* $M_2 < 0$.
If $\rho > 0$ *and* $\Omega > 0$*, a sufficient condition for* $M_2 < 0$ *is* $E^* > \frac{1}{2}\left(\overline{E} - \epsilon\alpha\overline{N} - \frac{r\delta}{\gamma}\right)$.

It is now possible to discuss stability properties of A and B, in the regime $\Omega > 0$, and of the unique admissible point in the regime $\Omega < 0$. As explained in the main text, we define "reachable" those fixed points with at least two eigenvalues with negative real parts, i.e. with a 2 or 3-dimensional stable manifold.

9.1.1 Stability analysis of A

In A, it holds $|J^*| < 0$; therefore, such fixed point may be unreachable (a saddle point with two positive eigenvalues) or locally attractive (i.e. a sink). Conditions for local attractivity are (Wirl, 1997): $tr(J*) < 0$, $|J^*| < 0$ and $M_2 < 0$. **Figure 6** shows that the fixed point A can assume two possible configurations. In the cases (a) and (b), it holds $\rho < 0$; thus, from Lemma 3, it follows that $M_2 < 0$, therefore A cannot be attractive. This implies that A is unreachable. In the cases (e) and (f), in A it holds $E^* < E_1$; this implies, by Lemma 1, that $tr(J*) > 0$. Thus A cannot be attractive and it is unreachable. In short, the fixed point A is always not reachable.

9.1.2 Stability analysis of B and of the fixed point in the regime $\Omega < 0$

In B and in the fixed point in the regime $\Omega < 0$ it holds $|J^*| > 0$; therefore, such fixed points can be repulsive or reachable (Wirl 1997). Wirl finds that a positive determinant and a negative coefficient M_2 are sufficient conditions for saddle point stability (i.e. for reachability). Given Lemma 2 and Lemma 3, this happens when $\rho < 0$ (**Figure 6**, cases a-d) or when $\rho > 0$ and $\Omega < 0$ (**Figure 6**, case h). If $\rho > 0$ and $\Omega > 0$, the sign of M_2 is not univocally determined. Consequently, in this case, B can be repulsive or reachable. However, by Lemma 3, $E^* > \frac{1}{2}\left(\overline{E} - \epsilon\alpha\overline{N} - \frac{r\delta}{\gamma}\right)$ is a sufficient condition for saddle point stability (**Figure 6**, cases e-g); this completes the proof of Proposition 2.

9.2 Proof of Proposition 4

In order to study the stability proprieties of fixed points in the regime $N_P = 0$, we calculate the Jacobian matrix J_0^* evaluated at a fixed point (K^*, E^*, λ^*) with

$N_P = 0$

$$J_0^* = \begin{pmatrix} h_{0K}^* & h_{0E}^* & h_{0\lambda}^* \\ f_{0K}^* & f_{0E}^* & f_{0\lambda}^* \\ g_{0K}^* & g_{0E}^* & g_{0\lambda}^* \end{pmatrix}$$

Remembering that $r - \beta\gamma K^{\gamma-1} E^{\delta} \overline{N}^{1-\gamma-\delta} = 0$, we have

$h_{0E}^* = \dfrac{r\delta(\gamma+\delta)K^*}{\gamma E^*} > 0$

$h_{0K}^* = (\gamma+\delta)r > 0$

$h_{0\lambda}^* = \dfrac{r^2(\gamma+\delta)^2(K^*)^2}{\gamma^2} > 0$

$f_{0E}^* = \overline{E}(1-\delta) - (2-\delta)E^* > 0$, if $E^* < E_M := \dfrac{\overline{E}(1-\delta)}{2-\delta}$

$f_{0K}^* = -\eta r < 0$

$f_{0\lambda}^* = 0$

$g_{0E}^* = -\dfrac{\gamma\delta}{(\gamma+\delta)K^*E^*} < 0$

$g_{0K}^* = \dfrac{\gamma(1-\gamma)}{(\gamma+\delta)(K^*)^2} > 0$

$g_{0\lambda}^* = 0$

Let us first consider $tr(J_0^*) = h_{0K}^* + f_{0E}^*$.

Figure 7 shows all possible configurations of the fixed points with $N_P = 0$. Remember that fixed points correspond to the intersections between the graphs of the functions $K = F_0(E)$ and $K = G_0(E)$ occurring above the curve $K = L(E)$ in the plane (E, K). In such figure, E_M indicates the value of E maximizing $F_0(E)$; furthermore, when the curve $K = L(E)$ is not drawn, this means that both the intersections between $K = F_0(E)$ and $K = G_0(E)$ occur above $K = L(E)$; that is, both intersections give rise to fixed points in the regime $N_P = 0$.

Note that in A_0 it holds $E^* < E_M$; therefore $f_{0E}^* > 0$ and $tr(J_0^*) > 0$ (see cases a-b in **Figure 7**).

In **Figure 7a**, in B_0 it holds $E^* < E_M$; therefore $f_{0E}^* > 0$ and $tr(J_0^*) > 0$. In **Figure 7b**, in B_0 it holds $E^* > E_M$; therefore $f_{0E}^* < 0$ and the sign of $tr(J_0^*)$ is not univocally determined.

Let us now analyze the sign of $|J_0^*| = h_{0K}^*(f_{0K}^* g_{0E}^* - f_{0E}^* g_{0K}^*)$. We can observe that in A_0 it holds $F_{0E} > G_{0E}$, while in B_0 it holds $F_{0E} < G_{0E}$, where $F_{0E} = -\dfrac{f_{0E}}{g_{0K}}$ and $G_{0E} = -\dfrac{g_{0E}}{g_{0K}}$. It follows that $|J_0^*| < 0$ in A_0 while $|J_0^*| > 0$ in B_0. If only one fixed point exists (**Figure 7c**), then in such point it holds $F_{0E} < G_{0E}$ and consequently $|J_0^*| > 0$.

Let us consider

$$M_{02} = -h^*_{0\lambda} g^*_{0K} + h^*_{0K} f^*_{0E} f^*_{0K} = -\frac{r^2(\gamma+\delta)}{\gamma(1-\gamma)} + r(\gamma+\delta)(\overline{E}(1-\delta)-(2-\delta)E^*) + \frac{\delta\eta r^2(\gamma+\delta)K^*}{\gamma E^*}$$

Replacing $K^* = \dfrac{\gamma(\overline{E}-E^*)}{r\eta}$, we obtain

$$M_{02} = -\frac{r^2(\gamma+\delta)}{\gamma(1-\gamma)+(\overline{E}(1-\delta)-(2-\delta)E^*)+\delta(\overline{E}-E^*)} > 0$$

if $E^* > \dfrac{1}{2}\left(\overline{E} - \dfrac{r}{\gamma(1-\gamma)}\right)$.

9.2.1 Stability analysis of A_0

Since in A_0 it holds $|J^*_0| < 0$, such fixed point can be a saddle point with two positive eigenvalues or a sink. Given that $tr(J^*_0) > 0$, local attractivity is excluded and the fixed point A_0 is always not reachable.

9.2.2 Stability analysis of B_0

In B_0 we have $|J^*_0| > 0$; therefore such fixed point can be repulsive or reachable (Wirl 1997). If $E^* > \frac{1}{2}(\overline{E} - \frac{r}{\gamma(1-\gamma)})$ then $M_{02} < 0$ and the fixed point cannot be repulsive. That is $E^* > \dfrac{1}{2}\left(\overline{E} - \dfrac{r}{\gamma(1-\gamma)}\right)$ is a sufficient condition for saddle point stability.

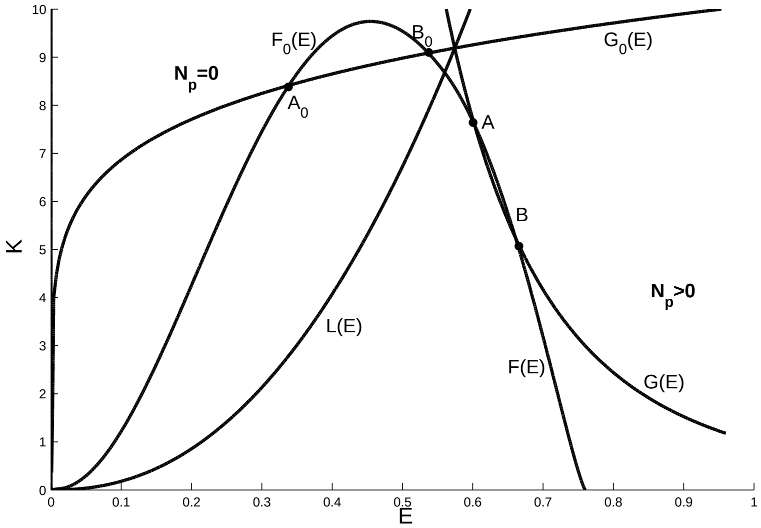


Figure 1: Four fixed points: A_0 and B_0 with $N_p = 0$, A and B with $N_p > 0$. The parameters' values are: $\alpha = 2$, $\beta = 1$, $\gamma = 0.4$, $\delta = 0.1$, $\epsilon = 0.1$, $\eta = 0.1$, $a = 1$, $r = 0.1$, $\overline{E} = 0.96$, $\overline{N} = 1$.

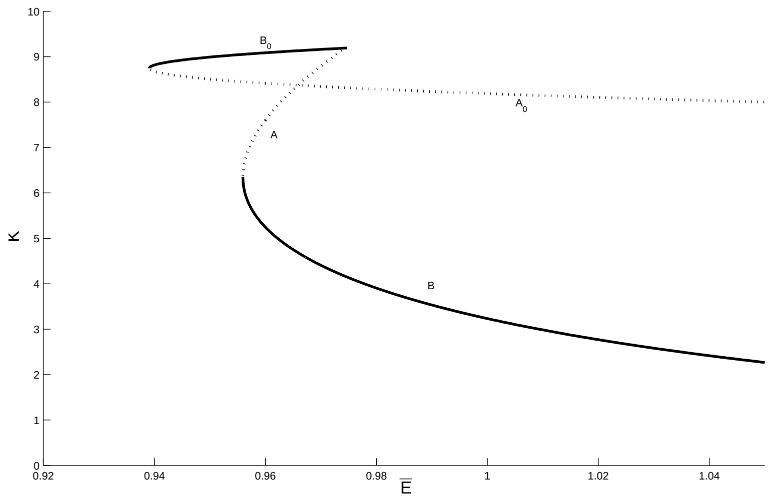


Figure 2: The value of K, evaluated at the fixed points with $N_p > 0$ and $N_p = 0$ varying $\overline{E}$. The dotted lines represent the unreachable fixed points, while the continuous lines represent the reachable fixed points.

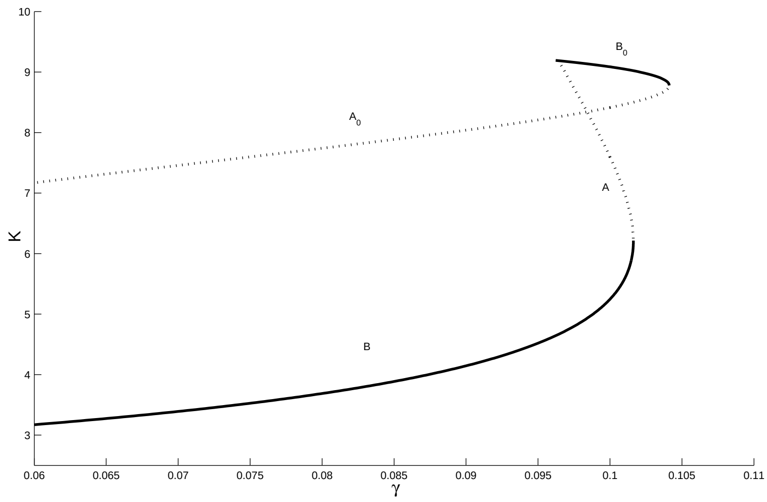


Figure 3: The value of K, evaluated at the fixed points with $N_p > 0$ and $N_p = 0$ varying η. The dotted lines represent the unreachable fixed points, while the continuous lines represent the reachable fixed points.

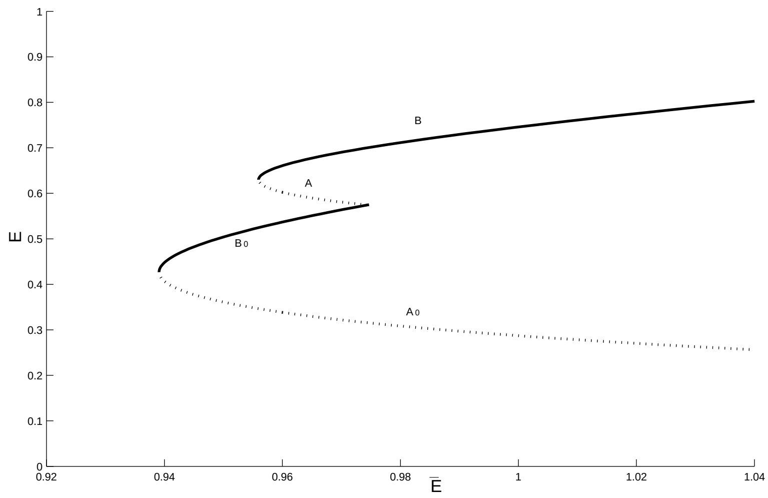


Figure 4: The value of E, evaluated at the fixed points with $N_p > 0$ and $N_p = 0$ varying $\overline{E}$. The dotted lines represent the unreachable fixed points, while the continuous lines represent the reachable fixed points.

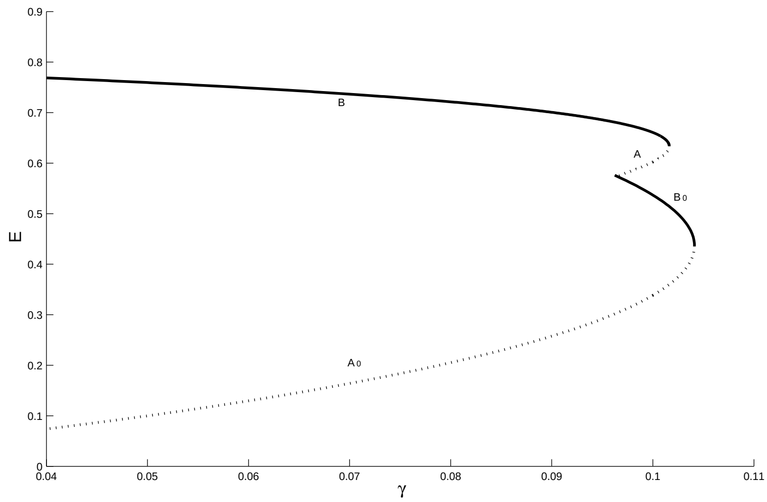
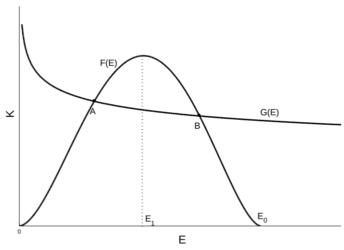
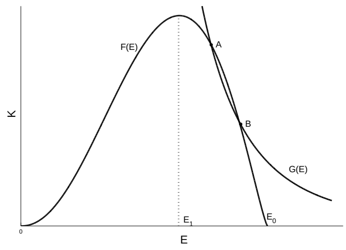


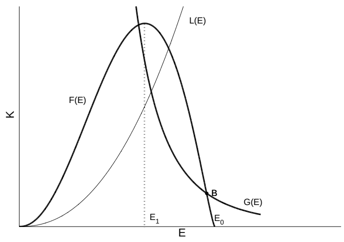
Figure 5: The value of E, evaluated at the fixed points with $N_p > 0$ and $N_p = 0$ varying η. The dotted lines represent the unreachable fixed points, while the continuous lines represent the reachable fixed points.



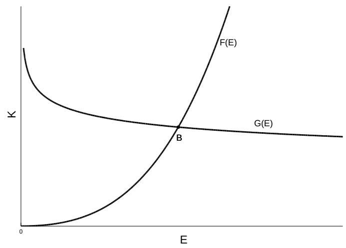
(a) $\gamma + 2\delta - 1 < 0$, $\Omega > 0$



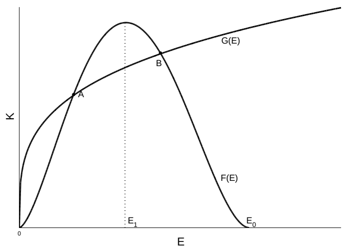
(b) $\gamma + 2\delta - 1 < 0$, $\Omega > 0$



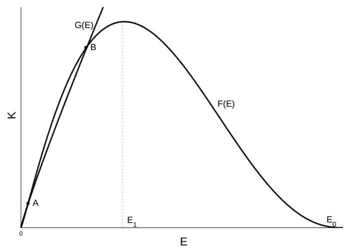
(c) $\gamma + 2\delta - 1 < 0$, $\Omega > 0$



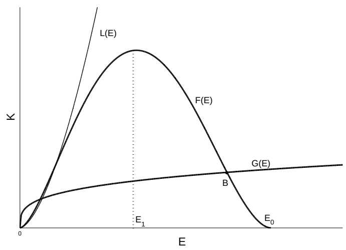
(d) $\gamma + 2\delta - 1 < 0$, $\Omega < 0$



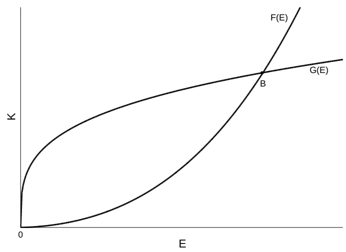
(e) $\gamma + 2\delta - 1 > 0$, $\Omega > 0$



(f) $\gamma + 2\delta - 1 > 0$, $\Omega > 0$

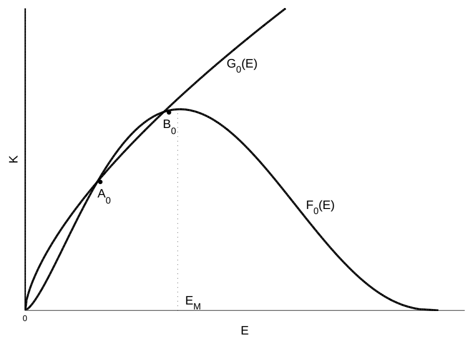


(g) $\gamma + 2\delta - 1 > 0$, $\Omega > 0$

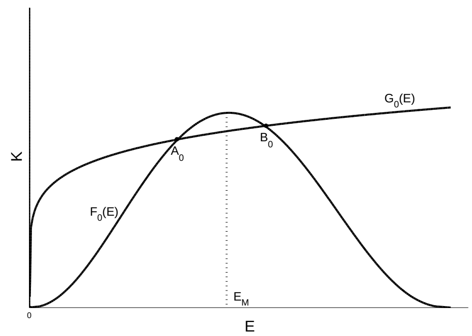


(h) $\gamma + 2\delta - 1 > 0$, $\Omega < 0$

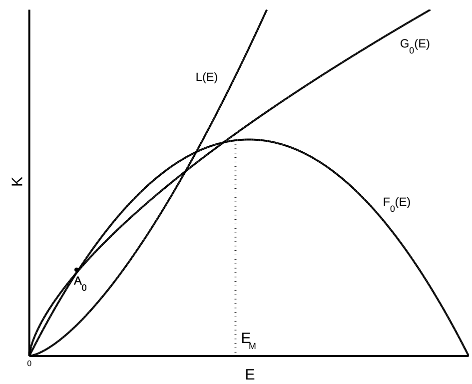
Figure 6: Fixed points with $N_p > 0$.



(a)



(b)



(c)

Figure 7: Fixed points with $N_p = 0$.

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