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Sustainability traps: patience and innovation

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Abstract

This paper argues that the joint relation between long-term orientation, environmental quality and innovation plays a key role in explaining environment-poverty traps. Based on empirical observations, we allow for the subjective discount rate to negatively depend on environmental quality in an R&D-driven endogenous growth model with local pollution externalities. Our model reconciles two empirical facts: i) multiple equilibria of economic and environmental development; ii) opposite responses to technological improvements depending on the initial equilibrium. Our results suggest that — in addition to traditional policies such as development aid and technology transfer — policies that aim at improving both the economic and the environmental dimension of sustainability, should also focus on changing individuals' long-term views in countries that face weak environmental conditions.

JEL classification: D90, E21, O13, O44, Q55, Q56.
Keywords: Endogenous growth, innovation, time preference, environmental poverty traps, economic poverty traps.

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1 Introduction

There is extensive literature documenting that while some countries thrive both, economically and environmentally, others stagnate in an "environmental and economic poverty trap" (Fact 1).[1] At the same time evidence shows that even if technological advances exist in countries that face such a trap – through aid, imitation, technology transfer, or actual R&D efforts – these are not capable to help those countries out of it (Fact 2).[2] Yet the views in the literature on the factors behind both Facts 1 and 2 are broad. This paper aims at narrowing this gap through a behavioral mechanism that is crucial on the intertemporal decisions of households. We present an R&D-driven endogenous growth model where patience positively depends on the quality of the local natural environment. This, in turn, affects the decisions of individuals for technological investments, which are crucial for promoting both the economic and the environmental dimension of sustainability.

Figure 1 documents the above facts in a stylized way. For a cross section of countries, it presents the average R&D expenditure (percentage of GDP) – as a proxy for economic development – for the years 1960-2016, against the Environmental Performance Index (EPI)[3] score for 2018, along with a relative measure of time preference (indicated by the size of circles around countries) as provided by Falk et al. (2018); the figure also splits the sample of countries in high income countries (orange) and non-high income countries (green), according to the UN definition. The graph shows that: i) there is a positive correlation between income per capita and both the EPI score and R&D expenditure; ii) there is a positive correlation between long-term orientation (larger circles) and both the EPI score and R&D expenditure – more patient economies are characterized, at the same time, by higher environmental performance and larger investment in developing new products or improving the technology of existing ones; iii) there is a threshold of environmental quality

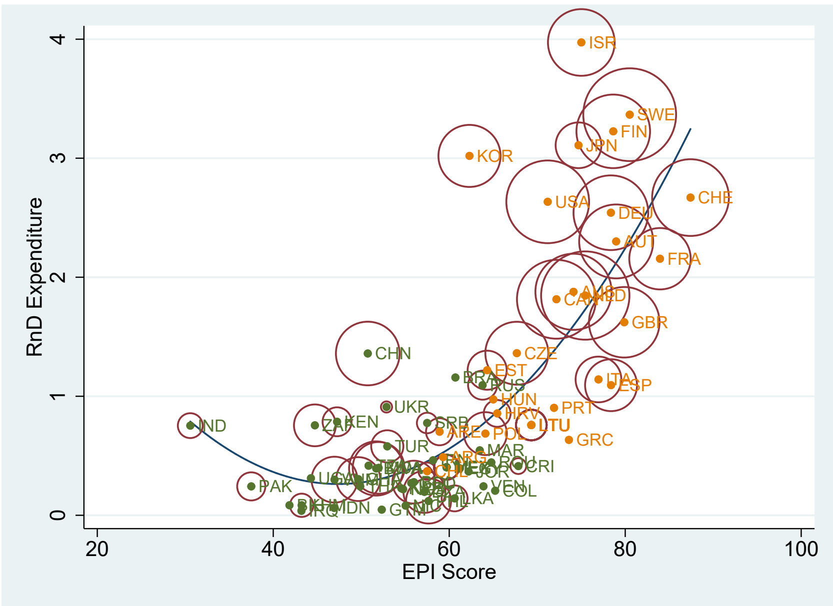
[1] Barbier (2010), Barbier and Hochard (2016, 2018, 2019), Bhattacharya and Innes (2012), Barrett and Carter (2013), Barrett and Bevis (2015).

[2] Easterly (2003), Kraay (2005), Rajan and Subramanian (2011), Ravallion (2012), Yang et al. (2013), Kraay and McKenzie (2014).

[3] The EPI is produced by the Yale Center for Environmental Law & Policy and the Center for International Earth Science Information Network (CIESIN) at Columbia University's Earth Institute, in collaboration with the World Economic Forum (WEF). The EPI ranks countries on twenty-four performance indicators across ten issue categories covering environmental health and ecosystem vitality. The EPI thus offers a sustainability score that highlights leaders and laggards in environmental performance (EPI 2018).

(around EPI 45), such that for countries that lie above it, higher R&D efforts are associated with higher environmental quality, which does not hold true for countries below this threshold.[4] Our focus lies on capturing this threshold of environmental quality that prevents certain countries from enjoying higher sustainability scores, even if technological advances exist, and we do so through the rate of time preference that is endogenous on the level of environmental quality.

Figure 1: **R&D expenditure (%GDP) vs. Environmental Performance Index (EPI)**. The graph shows the average R&D expenditure for the years 1960-2016 vs the EPI score for 2018 for 94 countries. The circles rank countries on their rate of time preference (RTP) - large circles indicate more patient economies. The sample is also split between high-income countries (orange) and non-high income countries (green) according to the UN definition. The solid line shows the quadratic regression fit. Sources: R&D expenditure, World Bank Indicators; EPI Score, EPI (2018); RTP, Falk et al. (2018)



[4]Figure 1 shows the 94 – out of 136 countries of our sample – for which data for the rate of time preference (RTP) is available. While in Figure 1 the U-shaped relation between R&D expenditure (as a percentage of GDP) and the EPI score seems to be driven by India, the quadratic regression ($R\&DExpenditure$=3.16(0.855)-0.13(0.029)*$EPIScore$+0.001(0.0002)*$EPIScore^2$, where in parenthesis we indicate the standard errors) from the sample of 136 countries justifies the statistical significance of the displayed U-shaped correlation. The data and replication files are available at the authors' websites.

So far the literature is not unanimous in its views on the factors behind environment-poverty traps. For example, Jalan and Ravallion (2002) conclude that the most important factor is geographic location; a factor clearly rejected by Bloom et al. (2003). Acemoglu and Robinson (2012) are calling for the possibility of persistent low-quality institutions; for the same reason foreign aid does not help spur growth in developing countries in Burnside and Dollar (2000). In Djankov et al. (2008) and Rajan and Subramanian (2011) windfall profits from aid activate mechanisms found in the "resource curse" literature and result in lower growth. Climate change suppresses growth prospects unevenly across countries in Bretschger and Valente (2011), while Bretschger and Suphaphiphat (2014) find that active climate mitigation policies from developed nations are more efficient in supporting developing nations than direct foreign aid. Barbier (2010) and Barbier and Hochard (2019) connect rural poverty with ecological scarcity; poor households that rely on marginal and fragile environments face production constraints that do not allow them to escape the trap. With regards to the local environment, Greenstone and Jack (2015) propose possible explanations for the puzzling correlation between poor environmental quality and the low marginal willingness to pay for its improvement in developing countries; these range from low income levels, that make individuals value increases in income more than improvements in environmental quality, to market failures such as weak property rights and missing capital markets.

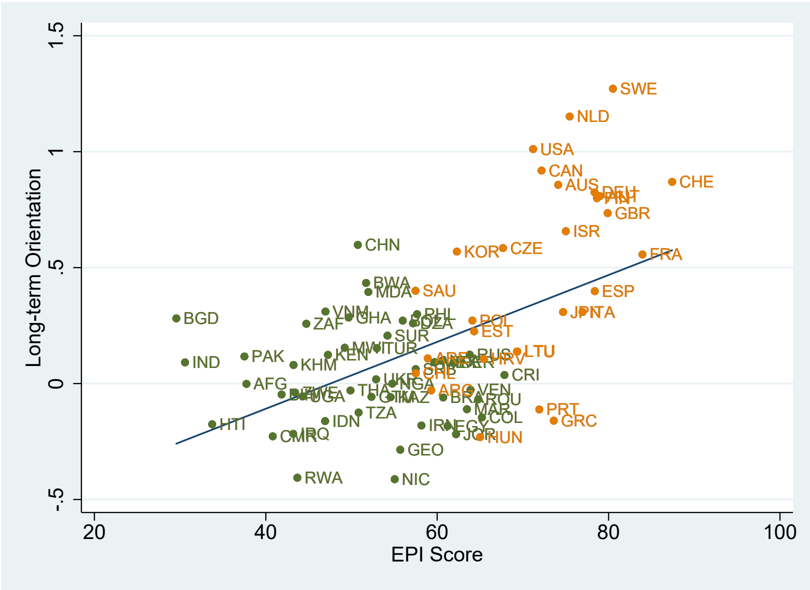
The extend to which a developing country rich in natural resources can escape a poverty trap is studied in Le Van et al. (2010) and Antoci et al. (2010). In the former paper the resource is a depletable one and the poverty trap arises due to a convex-concave production function, while in the latter the resource is renewable and the trap arises due to its logistic function and decreasing returns to scale in the production of the final good. An important contribution where the endowment of natural resources leads to two balanced growth paths is the recent work of Gars and Olovsson (2019). The authors show that, although technological progress exists through R&D efforts, differences in the endowments of primary energy sources, fossil and biofuel, along with the associated differences in the cost of improving energy efficiency of those two sources can explain divergence in countries' long-run economic performance: high growth and output per capita for countries relatively more endowed with fossil fuels and economic stagnation or sluggish growth for countries relatively more endowed with biofuels.

In this paper we keep all standard assumptions for the concavity of the production technology, instantaneous utility, and for the dynamics of the natural environment (our depletable natural resource). We contribute to the literature of environment-poverty traps by providing an endogenous growth framework that builds on the observed joint interaction between investment in R&D, patience (endogenous), and the level of environmental quality. In particular our model complements the literature in the following ways. First, we introduce a behavioral mechanism that works through intertemporal discounting. To be more precise, based on empirical observations, we allow for environmental degradation to worsen the way people value the future, and hence to affect their investment decisions. Second, our framework allows for the observed duality in balanced growth equilibria: a steady state with good environmental quality and growth and one with poor environmental quality and growth, and so we focus not only on two balanced growth paths for economic development but also on the observed two steady states in the quality of the natural environment. Last, we examine whether traditional improvements in technology can help countries escape the bad equilibrium.

The aforementioned positive relationship between environmental quality and long-term orientation, which is an important element of our theory, was recently established by Galor and Özak (2016).[5] This paper is instructive for our motivation. They document that populations exposed to good climatic conditions in the pre-industrial era developed a positive attitude towards the long-term, and, therefore, towards investments in agricultural technologies of the time. In our framework history is important as the initial situation of the physical environment matters for the uniqueness of equilibria and the differential response of economic variables to productivity shocks. Additionally, Galor and Özak (2016) confirm that these behavioral traits withstood the test of time and can be traced among descendants in the contemporary era. Figure 2 zooms in the positive relationship between the contemporary rate of time preference and the quality of the physical environment, the EPI score, of Figure 1.

[5]See also Viscusi et al. (2008), Vella et al. (2015), Dioikitopoulos et al. (2020). Relevant to our paper is also the work of Strulik (2012). He allows for the rate of time preference to depend on the level of the economy's stock of capital and gets multiple equilibria of development.

Figure 2: **Long term orientation vs. EPI**. The graph shows the std. deviation from the world mean of the rate of time preference (RTP) against the EPI score for 2018 for 94 countries; better environmental quality is associated with higher long-term orientation. The solid line shows the linear regression fit. Sources: EPI Score, EPI (2018); RTP, Falk et al. (2018)



What was once the workhorse of technological progress, investment in agriculture, is now investment in research and development. To capture the observed joined correlations of Figure 1 between the quality of the local environment, innovation, long-term orientation, and economic development in the modern era, we develop an R&D-based model of endogenous growth with technological quality improvements, where climate degradation affects the investment decisions of individuals through endogenous time preferences. In our model, agents choose to allocate their scarce resources either to modern – R&D-driven – production methods, which are clean and at the same time generate increasing returns at the aggregate level, or to polluting artisanal production at the cost of environmental degradation. When artisanal manufacturing is degrading the local natural environment and the long-term orientation of agents depends on environmental quality, two equilibria arise: a good equilibrium with high levels of environmental quality and economic development, and a bad one with low environmental quality and development. Additionally, albeit stylized, our model captures the fact that short-term increases in productivity (through e.g. technology transfer) improve the situation of economies in the good equilibrium with respect to both, the natural and the economic environment, while worsen the situation of countries in the bad equilibrium, and reproduces the non-monotonic relation that appears in Figure 1.

In terms of policy implications, the usual recommendation to help populations out of environment-poverty traps is large-scale direct foreign aid to either facilitate migration out of fragile environments or investment in improving the living conditions of the ones that remain (World Bank 2008), or both (Barbier and Hochard 2019). In our framework technological improvements alone are not enough to help countries escape an environmental and economic poverty trap under a threshold level of environmental quality. We show that investment choices of individuals towards clean R&D technologies under productivity increases can mitigate the adverse effects of economic activity on the natural environment and, in turn, generate a double dividend of higher growth and better environmental quality. This is possible only if individuals are long-term oriented so as to sacrifice ephemeral pleasure for environmental and economic gains in the future. Therefore, our model highlights the possibility of promoting both the economic and the environmental dimension of sustainability with policies that aim at changing the long-term orientation of individuals. We believe that our framework can be used as a vehicle for further research on policies that promote such behavioural changes.

The remainder of the paper is organized as follows. Section 2 presents the model. It develops the endogenous growth framework and shows the equilibrium conditions of our stylized economy. Section 3 deals with comparative statics and simulations. In this section we show the existence of multiple equilibria, perform stability analysis, and compare the development of economies based on initial conditions and long-term views, when these economies face exogenous productivity increases. Section 4 concludes.

2 The model

To establish the link between the natural environment and economic development in the modern era, we use an R&D-based endogenous growth framework in the spirit of Romer (1990) and Aghion and Howitt (1992) with research to improve the quality of firm-specific technological processes happening in-house.[6] Our model, albeit highly stylized, captures the trade-off between artisanal – and polluting – production methods, and modern technology-based production – which is clean and creates increasing returns to scale on the aggregate level. When allowing for the intertemporal discount rate of the respresentative household to depend on the quality of the environment it lives in, the model generates two equilibria of development: a good equilibrium with high environmental quality and growth, and a bad equilibrium with poor environmental quality and growth prospects. Below we present our economy in detail.

2.1 Firms

Our economy features a final good Y which combines the output from an artisanal sector R and a modern sector M in a Cobb-Douglas fashion: $Y = R^{1-\beta} M^{\beta}$, with $\beta \in (0,1)$. The artisanal good is produced using labor L_Y with a linear technology, i.e., $R = L_Y$, while the modern sector comprises a Dixit-Stiglitz CES composite of a unit mass of intermediate inputs x_j, indexed by $j \in [0,1]$; each intermediate is associated with a certain technological quality level q_j, i.e., $M = (\int_0^1 q_{jt}^{1-\kappa} x_{jt}^{\kappa} dj)^{1/\kappa}$, where $1/(1-\kappa)$ measures the elasticity of substitutions between inputs. To ease exposition we follow Acemoglu and Cao (2015) and Akcigit and Kerr (2018) – among others – and assume that $\kappa = \beta$, such that the final good is produced with the following production technology:

$$Y_t = L_{Yt}^{1-\beta} \int_0^1 q_{jt}^{1-\beta} x_{jt}^{\beta} dj, \qquad j \in [0,1]. \tag{1}$$

[6] See also Smulders and van de Klundert (1995) for a first-generation R&D model with in-house R&D. A model with induced-technical change and in-house R&D can be found in Smulders and de Nooij (2003). A more elaborate model capturing both process and product innovation aligned with many observed empirical regularities can be found in Akcigit and Kerr (2018). Here we abstract from the complexity of such dynamic models of Industrial Organization (IO) to focus on the interaction between economic development and the natural environment, when the latter shapes the long-term views of households.

Ceteris paribus, higher technological quality of intermediate inputs translates into a higher productivity in the manufacturing of the final good. The final good is produced in competition with input prices taken as given. We normalize the price of Y to be one in every period. Hence profit maximization yields the following demand curves for labor L_Y and intermediates x_j, respectively:

$$w_t = (1-\beta)Y_t/L_{Yt}, \tag{2}$$

$$p_{jt} = \beta L_{Yt}^{1-\beta} q_{jt}^{1-\beta} x_{jt}^{\beta-1}, \tag{3}$$

where w denotes the wage rate of labor and p_j the consumer price of intermediate j.

The CES composite in (1) supports monopolistic competition in the manufacturing of intermediates. We assume that each good j is produced by one monopolistic firm and each firm produces one good; the marginal cost of producing intermediate x_j is ψ units of the final good, with $\psi > 0$ a constant. Additional to the manufacturing of intermediates, each firm j is responsible for improving upon its existing technological level by performing R&D in-house.[7] To do so it combines firm-specific technology q_j with l_j units of skilled labor with the following specification,

$$\dot{q}_{jt} = A q_{jt} l_{jt}, \tag{4}$$

with $A > 0$ a productivity parameter and $q_{j0} > 0$, given.[8] We assume that an exogenous positive change in A can occur through international technology transfers, foreign aid, imitation, or governmental spending, all promoting the productivity of R&D activity – the growth engine in this framework. The objective of each intermediate monopolist is the maximization of its discounted stream of monopoly profits ($\pi_j = p_j x_j - \psi x_j$) net of expenditure in improving its technology (wl_j) while taking into account the demand curve (3), i.e.,

[7] Prescott and Visscher (1980) define a firm by its organizational capital: a firm-specific practice or technology is an asset that affects its production possibilities and can be accumulated through investment over time. As a matter of fact, there is substantial evidence that research happens mostly in-house, and that established firms undertake incremental innovation improving their existing products (Malerba et al. 1997, Acemoglu and Cao 2015).

[8] Extending the model to include economy-wide knowledge spillovers in the spirit of Romer (1990), as in Smulders and de Nooij (2003), would not alter the results.

$$\max_{\{x_{jt},l_{jt}\}_{t=0}^{\infty}} \int_0^\infty \left[\beta L_{Yt}^{1-\beta} q_{jt}^{1-\beta} x_{jt}^{\beta} - \psi x_{jt} - w_t l_{jt}\right] e^{-\int_0^t r_s ds} dt,$$

subject to (4); r is the interest rate at which future cash flows are discounted. Without loss of generality we normalize $\psi = \beta^2$. With $V_j = \lambda_j q_j$ the stock market valuation of firm j (λ_j is the shadow price for the firm specific technology q_j), this optimization implies:

$$x_{jt} = q_{jt} L_{Yt}, \tag{5}$$

$$V_{jt} = V_t = w_t/A, \tag{6}$$

$$\frac{\pi_{jt}}{V_t} + \frac{\dot{V}_t}{V_t} = r_t. \tag{7}$$

The same valuation across firms implies that $\pi_j = \pi, x_j = x, q_j = q, l_j = L_S$ (with L_S total scientific labor), $\pi = \beta(1-\beta)qL_Y$ and $x = qL_Y$ for all j.

According to equation (7) asset markets are in equilibrium.[9] Moreover, in equilibrium total output Y is allocated to aggregate consumption C and aggregate expenditure in intermediates I, i.e., $Y = C + I$. With the above, aggregate expenditure in intermediates reads $I = \int_0^1 \psi x_j dj = \beta^2 Q L_Y$, with $Q \equiv \int_0^1 q_j dj$, the average technological level of the economy, and thus $q = Q$. From (1) and (5), final good production is $Y = QL_Y$ and from the resource constraint of this economy, aggregate consumption $C = (1-\beta^2)Y$. Equation (2) also implies $w = (1-\beta)Q$. Combining (6) and (7) gives:

$$r_t = \beta A L_{Yt} + \frac{\dot{Q}_t}{Q_t}. \tag{8}$$

2.2 Emissions and the environment

For our purposes, artisanal manufacturing R creates polluting by-products – henceforth emissions – $E = \varphi R$, which deteriorate the quality of the local natural environment N;

[9]In equilibrium, and in absence of arbitrage, adjusting for any risk and depreciation, every asset should yield the same return. Therefore, an investor should be indifferent between investing in an intermediate firm with a return $\pi/V + \dot{V}/V$, i.e., the dividend yield from monopoly profits plus the growth in the stock market value, and the return on a riskless asset, i.e., the market's interest rate r.

parameter $\varphi > 0$ measures emissions intensity. With $R = L_Y$ the law of motion for the degradation of the natural environment follows:

$$\dot{N}_t = -\varphi L_{Yt} + (1-\delta)(\bar{N} - N_t), \tag{9}$$

with a given initial level of environmental quality $N_0 > 0$, $\bar{N} > 0$ the highest attainable level of environmental quality, and $\delta \in (0,1)$ the degree of environmental persistence.[10] Similar specification to (9) has been used in Jouvet et al. (2005) and Acemoglu et al. (2012), among others. For a constant labor employment in manufacturing, L_Y^{SS}, this equation leads to a constant level of environmental quality $N^{SS} = \bar{N} - \frac{\varphi}{1-\delta} L_Y^{SS}$.

Technologically-advanced societies allocate a larger share of their scarce resources (labor in this model) to modern production which is clean and creates increasing returns in the aggregate economy. Thus, investing in new and better technologies is key to sustainable development. Importantly, this presupposes households with long-term orientation who supply liquidity to the intermediate firms that perform R&D. We now turn to the problem of households.

2.3 Households

Following Figure 2 and our discussion in the Introduction, environmental quality is positively correlated with households' long-term orientation, and affects their investment decisions. Therefore, we consider an endogenous intertemporal discount rate $\rho(N) > 0$ (rate of impatience), that depends on the quality of the natural environment N, with $\rho'(N) < 0, \rho''(N) > 0$. Households own the assets in this economy, K, have logarithmic preferences and supply their constant labor unit L inelastically to manufacturing and R&D, i.e., $L = L_Y + L_S$. Their optimization is standard and reads:

$$\max_{\{C_t\}_{t=0}^{\infty}} \int_0^{\infty} \log(C_t) e^{-\int_0^t \rho(N_s) ds} dt,$$

[10] An alternative formulation leading to (9) could be obtained by assuming that the final good Y is polluting, while spillovers from a higher economy-wide technology reduce the emissions intensity of production – as in Bosetti et al. (2006) – i.e., $E = \phi(Q)Y$ with $\phi(Q) > 0, \phi'(Q) < 0$ and $\phi''(Q) > 0$. For a balanced growth path to exist, we could then employ $\phi(Q) = \varphi/Q$, $\varphi > 0$, such that effective emissions read $E = \varphi Y/Q$, and with $Y = QL_Y$, $E = \varphi L_Y$. Additionally, Agnolucci and Arvanitopoulos (2019) estimate a negative and significant effect of aggregate TFP of the production process on the energy intensity of the UK industrial sector which could further support this assumption.

subject to the dynamic budget constraint $\dot{K} = rK + wL - C$. Their intertemporal problem leads to the familiar Keynes-Ramsey rule:

$$\frac{\dot{C}_t}{C_t} = r_t - \rho(N_t). \tag{10}$$

In equilibrium $K = V$, that is households hold the equity in intermediate firms.

Equation (10) shows that consumption growth is positive if the market return to saving r is higher than the subjective discount rate $\rho(\cdot)$. In that case agents are willing to sacrifice current consumption – by making higher savings – in order to attain higher consumption in the future. Assume two economies with different environmental qualities N_{low} and $N_{high} > N_{low}$. Ceteris paribus, the economy with N_{low} will be characterized by higher ρ, lower savings and, according to (10), lower growth. If the economic development of this country is not sufficient to provide a high enough market compensation (through r), households will find it worthwhile to consume now rather than save and invest for the future. In our model this translates to lower investment in intermediate firms (source of growth), which in turn implies that the aggregate production depends on polluting artisanal manufacturing, further worsening development prospects, and leading to a vicious cycle of low growth and low environmental quality (environmental and economic poverty trap). We provide detailed intuition below where we analyze the general equilibrium of our economy.

2.4 Equilibrium and balanced growth

In equilibrium the return to household assets in equation (10), matches the return from investing in intermediate firms (8). Accordingly, substituting r from (10) in equation (8) above, with $\dot{C}/C = \dot{Y}/Y = \dot{Q}/Q + \dot{L}_Y/L_Y$, from $Y = QL_Y$, yields the law of motion for labor allocation:

$$\frac{\dot{L}_{Yt}}{L_{Yt}} = \beta A L_{Yt} - \rho(N_t). \tag{11}$$

Equations (9) and (11) describe the dynamic evolution of the economy in the $\{L_Y, N\}$-space. Moreover, on the balanced growth path (BGP), with $\dot{L}_Y = \dot{N} = 0$, it holds that $\hat{C} = \hat{Y} = \hat{Q} \equiv g$, the equilibrium growth rate of the economy; hats denote growth rates, i.e., $\hat{Q} = \dot{Q}/Q$. Let N^{SS} denote an equilibrium level of environmental quality. We get using (4), (10), and (11), that on the BGP the interest rate is also constant, i.e., $r(N^{SS}) = AL - \frac{1-\beta}{\beta}\rho(N^{SS})$; the long-run rate of economic growth follows from (10):

$$g(N^{SS}) = AL - \frac{1}{\beta}\rho(N^{SS}), \tag{12}$$

Other things equal, economic growth responds positively to an increase in the productivity parameter A. However, this first order (static) effect can be mitigated – or even reversed – depending on the long-term orientation of households. If the additional income from productivity increases results in subsequently increasing consumption relatively more than investing in intermediate firms, this second order (dynamic) effect can worsen the environmental quality and increase the intertemporal rate of discount, thus reducing growth prospects in the long run.

Moreover, following the properties of $\rho(\cdot)$, the long-run growth rate in (12) is an increasing and concave function in N, i.e., $g'(\cdot) > 0, g''(\cdot) < 0$. We show below that there are multiple stable equilibria of economic development: a good equilibrium with high environmental quality and growth and a bad one with low environmental quality and growth. Furthermore, in accord with the empirical facts documented in the introduction, for countries in the bad equilibrium with high rates of intertemporal discounting, productivity increases can further worsen both their environmental and economic situation.

3 Multiple equilibria and the process of development

3.1 Parametric restrictions and multiple equilibria

All along the BGP $\dot{L}_Y = \dot{N} = 0$. From (9) and (11), the steady state level of environmental quality N^{SS} is given by the solution to:

$$\frac{\rho(N^{SS})}{\beta A} = \frac{1-\delta}{\varphi}(\bar{N} - N^{SS}), \tag{13}$$

while the steady level of economic growth comes from (12). For a well defined problem we impose the following parameter restrictions:

Restriction 1. *The intertemporal discount rate for extreme environmental degradation* $N = 0$ *obeys:* $\beta A \frac{1-\delta}{\varphi}\bar{N} \leq \rho(0) \leq \beta AL$.

Restriction 2. *For a certain level of environmental quality* $N^* \in [0, \bar{N}]$ *that solves* $\rho'(N^*)/\beta A = -(1-\delta)/\varphi$*, the elasticity of time preference with respect to environment, i.e.,* $\epsilon_{\rho N} \equiv d\ln\rho/d\ln N$*, evaluated at* N^**, obeys:* $\epsilon^*_{\rho N} < -(\frac{\bar{N}}{N^*} - 1)^{-1}$.

From (13), the first restriction excludes the possibility of a steady state with $N < 0$ or $L_Y > L$. The second parametric restriction that comes from the condition $\frac{\rho(N^*)}{\beta A} < \frac{1-\delta}{\varphi}(\bar{N} - N^*)$ ensures existence and rules out the knife-edge tangency equilibrium.

Proposition 1. *(Multiplicity) Let Restrictions 1 and 2 hold. Then, there are two interior equilibria that solve* (13)*: one with low environmental quality and low growth – for which* $N^{SS} < N^*$*; one with high environmental quality and high growth – for which* $N^{SS} > N^*$.

Proof. Equation (13) provides the equilibrium of the economy. The LHS function, $\rho(N)/\beta A$, is decreasing and convex ($\rho'(N) < 0, \rho''(N) > 0$). With Restriction 1, it starts and ends above the RHS of (13), which is $(1-\delta)/\varphi(\bar{N} - N)$. Accordingly, we have the possibility of three cases: none, one (tangency), or two equilibria. Under Restriction 2, there exists $N^* \in [0, \bar{N}]$ that solves $\rho'(N^*)/\beta A = -(1-\delta)/\varphi$ such that at N^* the LHS of (13) is below the RHS, thus, exactly two equilibria exist $\{N_1^{SS}, N_2^{SS}\}$. With Restriction 2 it holds that $N_1^{SS} < N^* < N_2^{SS}$. Using equation (12) and the properties of $\rho(\cdot)$, we also get that $g(N_1^{SS}) < g(N_2^{SS})$. □

Proposition 1 shows that in an economy with endogenous time preference in environmental quality, two long-run equilibria arise. One with low level of environmental quality and growth (bad equilibrium), and one with high level of environmental quality growth (good equilibrium); Figure 3 illustrates the existence and multiplicity of the equilibria. In Proposition 2 below we analyze the stability properties of these equilibria along with the dynamic mechanisms that lead towards them.

3.2 Stability analysis

This section deals with the stability of the multiple equilibria. The determinant Δ of the Jacobian of the dynamic system of equations (9) and (11) evaluated at a steady state N^{SS}

reads:

$$\Delta = -\varphi L_Y^{SS} \rho'(N^{SS}) \left(1 - \frac{\rho'(N^*)}{\rho'(N^{SS})}\right), \tag{14}$$

with $\rho'(N^*) = -\beta A(1-\delta)/\varphi$ from Restriction 2 above. Using our assumptions on ρ we have three cases for Δ:

1. For $N^{SS} < N^* \rightarrow \rho'(N^*)/\rho'(N^{SS}) < 1$, which implies $\Delta > 0$,
2. For $N^{SS} > N^* \rightarrow \rho'(N^*)/\rho'(N^{SS}) > 1$, which implies $\Delta < 0$,
3. For $N^{SS} = N^* \rightarrow \rho'(N^*)/\rho'(N^{SS}) = 1$, which implies $\Delta = 0$.

Case 3 is excluded by Restriction 2. We are now ready to prove the following proposition:

Proposition 2. *(Stability) (i) The good equilibrium ($N^{SS} > N^*$) is always stable with saddle path type of stability. (ii) The bad equilibrium ($N^{SS} < N^*$) is stable if $\beta AL < 1-\delta$; the type of stability is either an attractive focus or an attractor.*

Proof. The first part comes directly from Case 2 above with $\Delta < 0$. The second part comes from Case 1 and from the fact that the trace of the jacobian matrix evaluated at the steady state, $\beta AL_Y^{SS} - (1-\delta)$, is negative for $\beta AL < 1-\delta$ (since $L_Y \in [0, L]$), i.e., a sufficient condition for a stable equilibrium. □

The proposition above establishes that the multiple equilibria of economic development are stable equilibria. Condition $\beta AL < 1-\delta$ rules out the possibility of an unstable bad equilibrium.[11] Below we discuss the dynamics of the economy under study and show that technological developments stemming from productivity increases benefit only the equilibrium with $N^{SS} > N^*$ (good equilibrium), while they can further worsen the prospects of economies with $N^{SS} < N^*$ (bad equilibrium).

[11] Following the discussion of the vicious cycle described in the previous section, this condition shows that the polluting effect of productivity from higher growth (βAL) shall be sufficiently lower than the speed of regeneration of the natural environment ($1-\delta$). Otherwise, the dynamics of the model wouldn't converge to a long-run steady-state growth rate of output for the bad equilibrium.

3.3 Dynamics and comparative development

In this section we investigate the effect of exogenous technological improvements (e.g. through international technology transfers, foreign aid, imitation, or government spending) on the equilibrium rate of economic growth and level of environmental quality. Let $\epsilon_{NA}^{SS} \equiv d\ln N^{SS}/d\ln A$ measure the relative change in the steady state level of environmental quality following a relative increase in productivity, and $\epsilon_{\rho N}^{SS}$ denote the elasticity $\epsilon_{\rho N}$ defined in Restriction 2 above, evaluated at the steady state. We then have:

Proposition 3. *(Technological improvements) (i) An increase in productivity A improves at the same time the equilibrium level of environmental quality and economic growth in the good equilibrium ($N^{SS} > N^*$). (ii) In the bad equilibrium ($N^{SS} < N^*$) it unambiguously worsens environmental quality; it also worsens growth prospects when $\rho(N^{SS})\epsilon_{\rho N}^{SS}\epsilon_{NA}^{SS} > \beta AL$.*

Proof. Totally differentiating equation (12), the relative change in equilibrium growth $\tilde{g} \equiv dg/g$ following a relative increase in productivity $\tilde{A} \equiv dA/A > 0$ reads:

$$\tilde{g} = \frac{1}{g}\left(AL - \frac{1}{\beta}\rho(N^{SS})\epsilon_{\rho N}^{SS}\epsilon_{NA}^{SS}\right)\tilde{A}, \tag{15}$$

From manipulating (13) with $N^{SS} = N^{SS}(A)$ we get that:

$$\epsilon_{\rho N}^{SS}\epsilon_{NA}^{SS}\left(1 - \frac{\rho'(N^*)}{\rho'(N^{SS})}\right) = 1. \tag{16}$$

Since $\epsilon_{\rho N}^{SS} < 0$, the sign of ϵ_{NA}^{SS} for the above to hold and following our assumptions on ρ proves the proposition. We showed in Case 2 of section 3.2 that $\rho'(N^*)/\rho'(N^{SS}) > 1$ for $N^{SS} > N^*$, such that $\epsilon_{NA}^{SS} > 0$ and thus from (15) $\tilde{g} > 0$. For $N^{SS} < N^*$ we always get $\epsilon_{NA}^{SS} < 0$, while $\tilde{g} < 0$ when $\rho(N^{SS})\epsilon_{\rho N}^{SS}\epsilon_{NA}^{SS} > \beta AL$. □

Technological improvements are key to sustainable development. However, the literature seems to agree on the fact that when these occur exogenously, through aid or technology transfer, these are not always sufficient to help countries escape the environment-poverty trap. Yet there is no consensus on the mechanisms behind this fact. Proposition

3 above shows that endowments of environmental quality play a crucial role for the effectiveness of development policies, when environmental quality works through the subjective discount rate of individuals.

The proposition above highlights the interplay between long-term orientation, environmental quality, and growth, and matches the stylized facts of Figure 1. An exogenous increase in A has a first-order effect on household budget by increasing the income of individuals through the return on equity ($r(N^{SS}) = AL - \frac{1-\beta}{\beta}\rho(N^{SS})$). Societies with very good environmental quality, exhibit higher patience (low ρ) and thus can reap the benefits of such a productivity increase to further invest in R&D firms that advance both their economic and environmental situation. On the other end of the spectrum, societies with poor environmental quality are oriented towards the short-term (high ρ). Provided that their ρ is high and their productivity level A is already low (such that $\rho(N^{SS})\epsilon_{\rho N}^{SS}\epsilon_{NA}^{SS} > \beta AL$ is satisfied), a productivity increase would trigger relatively more consumption rather than investment, thus worsening both their economic and environmental development prospects.

The above can be studied in the following phase diagram of Figure 3 which depicts the dynamics of the economy in the $\{L_Y, N\}$-space. For a given productivity level A there are two equilibria: the good equilibrium with high level of environmental quality and innovation (high labor in R&D, L_S, and thus low in manufacturing, L_Y), steady state SS_G, and the bad equilibrium with low environmental quality and innovation, SS_B. Equilibrium SS_G is saddle stable as we already established; the figure also depicts its stable arm. For the chosen parameter values[12], equilibrium SS_B is an attractor locally (two real and negative eigenvalues of the Jacobian matrix evaluated at SS_B). Studying the phase diagram, we also see that an increase in the productivity parameter to a level $A' > A$ improves the situation in the good equilibrium (SS'_G) while it worsens, both, environmental and growth prospects for economies in the bad steady state (SS'_B); the dynamic evolution depending on the initial equilibrium is depicted by the red dots. Figures 4 and 5 show, respectively, the dynamic evolution of economies in the good and the bad equilibrium, when productivity increases at $t = 50$. For both figures the first graph shows the scientific labor force $L_S = L - L_Y$, the second the level of environmental quality N, and the third the rate of economic growth,

[12]For figures 3-5 we assume that $\rho(N) = \rho_0 \exp(-\eta N), A = 0.05, A' = 0.06, L = 1, \bar{N} = 1, \delta = 0.8, \varphi = 0.3, \rho_0 = 0.023, \eta = 2.3$, and $\beta = 0.5$ such that $C/Y = 1 - \beta^2 = 0.75$, a standard value in the literature.

i.e., $\hat{Y} = \hat{Q} + \hat{L}_Y = AL_S + \beta AL_Y - \rho(N)$ – from equations (4) and (11) .

Overall, while both economies grow endogenously over time, the demand for consumption is relatively higher (lower) in the impatient (patient) economy resulting in higher (lower) pollution and lower (higher) level of environmental quality and growth. This result is line with Figure 1 where for economies that lie above a threshold level of environmental quality, R&D spending is higher, the level of patience is higher and the level of environmental quality is higher.

Figure 3: **Phase diagram** $\{L_Y, N\}$. Dashed $\dot{L}_Y = 0$ line is for $A' > A$. The two stable equilibria of development SS_G (good) and SS_B (bad) correspond to A, while SS'_G and SS'_B to $A' > A$. The good equilibrium is saddle stable; the bad equilibrium is an attractor. The continuous arrow lines show the stable arms for SS_G and SS'_G.

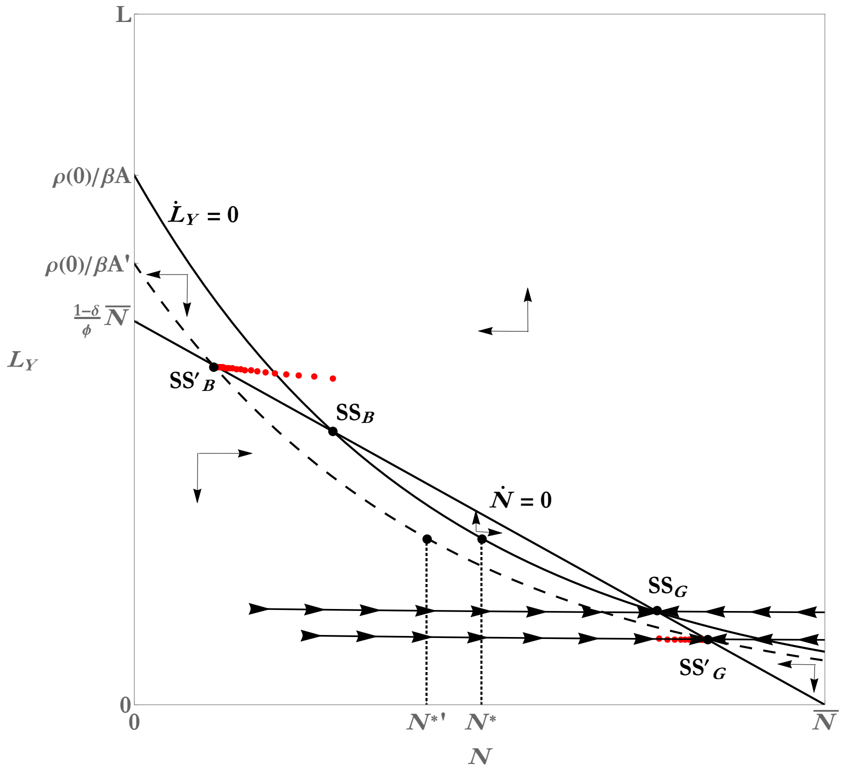


Figure 4: **Dynamics for the good steady state**. Starting at the good steady state, a small technological increase ($A \rightarrow A' > A$) at $t = 50$ improves development prospects.

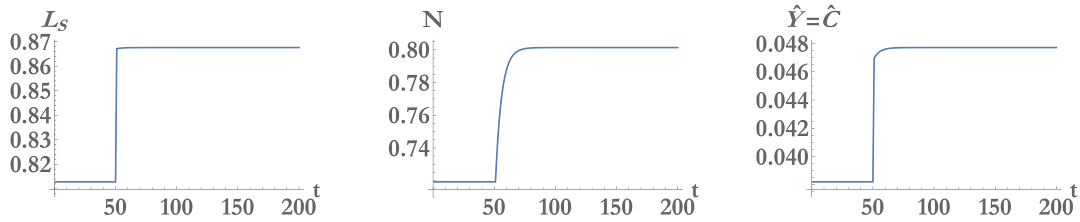
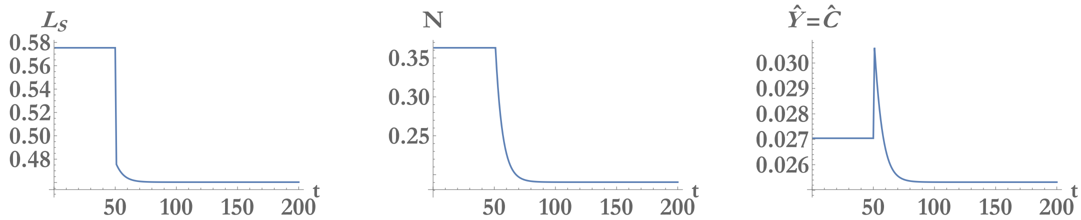


Figure 5: **Dynamics for the bad steady state**. Starting at the bad steady state, a small technological increase ($A \rightarrow A' > A$) at $t = 50$ eventually worsens development prospects.



4 Conclusion

We contribute to the environment-poverty nexus a new mechanism that builds on the joint relation between long-term orientation, environmental quality and innovation. Based on empirical evidence that links long term orientation with the quality of the natural environment, we assume a negative relationship between the subjective discount rate and environmental quality in an endogenous growth model with local pollution externalities. The economy's final good can be produced by labor-intensive artisanal manufacturing – which is degrading the local environment – and by R&D-driven modern production methods – which are clean and generate increasing returns to scale at the aggregate level. Therefore, investing in new and better manufacturing methods is key to sustainable development. However, this presupposes that households' long-term views are not distorted by the poor natural environment they live in, which – on the contrary – is what we assume.

In line with empirical observations, in this setup two equilibria arise: a bad equilibrium, with low environmental quality and low economic development, and a good equilibrium with good environmental quality and economic development. It is also well documented that exogenous technological improvements do not help societies escape the bad equilibrium, while benefit those with good sustainability scores, which is also captured by our model. Our results suggest that conventional development policies should be complemented by fundamental behavioral changes towards the long-term. This calls for further research on behavioral policies – e.g. educational programmes – that help households improve their long-term orientation in countries that face environmental constraints.

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