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ARTICLE

The environment, life expectancy, and growth in overlapping generations models: A survey

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Abstract

It is widely accepted that environmental and demographic changes will significantly influence the future of our society. In recent years, an increasing number of studies has analyzed the interlinkages among economic growth, environmental factors, and a specific demographic variable, namely life expectancy, applying an overlapping generations framework. The aim of this survey is threefold. First, we review the role of life expectancy and pollution for sustainable growth. Second, we discuss the role of intervening factors like health investment and technological progress as well as institutional settings including government expenditures, tax structures, and inequality. Finally, we summarize policy implications obtained in different models and compare them to each other.

KEYWORDS
endogenous growth, environmental quality, government policy, longevity, pollution

JEL CLASSIFICATION
J10, O11, O44, Q56, Q58

1 INTRODUCTION

The interactions between economic activity, environmental change, and population growth have been disputed ever since Malthus (1798), who argued that limited natural resources are the main impediment to the compatibility of population growth and economic growth. Therefore, according to Malthus, economic output will stabilize at the subsistence level with zero population growth in the long run. Malthus' early work greatly influenced later researchers at the interface between demography and environment, with the problematic of population growth and scare natural resources remaining the main question of interest until the late 20th century (see, e.g., Pebley, 1998, who laments the limited scope of research in this area).

The past few decades, however, have been marked by a renewed interest in the interplay between the environment, demography, and economic activity. Newer data and improved methods have shown the risks to human well-being induced by environmental degradation and sparked interest in these topics while economic models have highlighted many new mechanisms at work. Recently, environmental degradation and demographic trends have even been included in a list of megatrends that shape our world and our future by the UN Economist Network (2020). The rising scientific interest can also be seen in the increasing number of economics articles associated to both demography and the environment as depicted in Figure 1. Economists started studying a broader range of demographic and environmental variables both separately and simultaneously. For instance, they increasingly included variables like endogenous fertility, morbidity, and mortality, and environmental issues like pollution, or, more recently, climate change. In particular, evidence for significant environmentally induced effects on mortality and associated economic effects (see, e.g., Landrigan et al., 2018; Watts et al., 2018) highlighted the need to focus not only on the short-term, but also the long-term interactions between the environment, mortality and economic outcomes. Following Mariani et al. (2010), who showed that there is a strong positive correlation between environmental quality (measured by the well-known environmental performance index (EPI); Yale Center for Environmental Law and Policy, 2020) and life expectancy, Figure 2 depicts an updated version of their plot. Clearly, the positive correlation between the EPI and life expectancy still persists[1]. The interlinkages between these variables and economic growth are the main focus of this review.

In addition to the wider range of variables included, the rising awareness of a two-way reciprocal relationship between demography and the environment has opened many new research avenues. Researchers now acknowledge both the influence of demography on the environment and vice versa. For economists, these acknowledgments raised many new questions: Do economic outcomes change when considering the interlinkages between demography and the environment? What are the economic effects induced by measures to improve environmental quality? How do these effects change across individuals and across time?

The aim of this review is to deepen our understanding of the interactions between the environment, mortality, and economic activity. While the empirical literature provides evidence on the importance of each of these interlinkages[2], economic models are crucial for highlighting key long-term mechanisms and contributing to their understanding. The overlapping generations (OLG) framework is particularly well-suited to analyze these questions: First, it can account for shifts in the demographic structure in a rather intuitive manner. In particular, it allows for a straightforward introduction of endogenous mortality (Blackburn & Cipriani, 2002; Chakraborty, 2004). Second, an OLG framework allows the effect of decisions of one generation on subsequent generations to be captured. This aspect is important for questions related to sustainability, as the conflict between short-lived individuals and the long-lived environment is

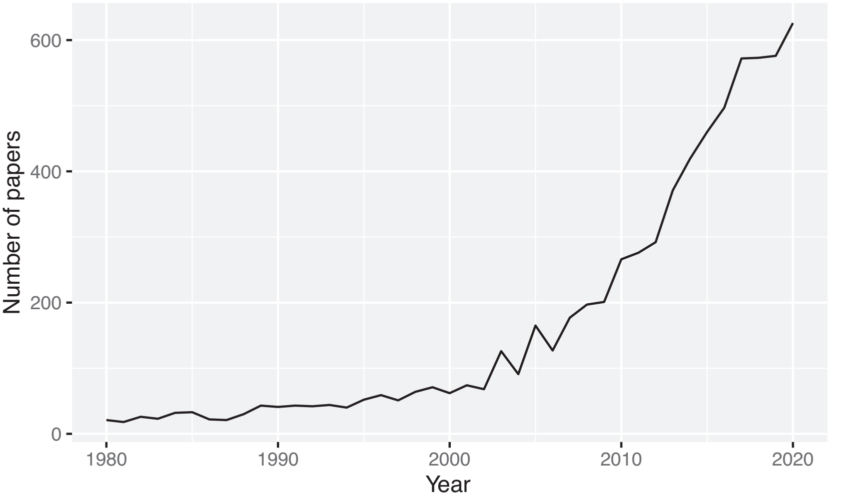

FIGURE 1 Number of economics articles associated to demography and the environment each year and referenced by Scopus. Note that while this is just a rough estimate of all relevant articles, it does clearly depict the increasing interest in these topics. The articles can be extracted using the query: (TITLE-ABS-KEY (environment*) OR TITLE-ABS-KEY(pollution) OR TITLE-ABS-KEY(emission*) OR TITLE-ABS-KEY(resource*) AND TITLE-ABS-KEY(life AND expectancy) OR TITLE-ABS-KEY(mortality) OR TITLE-ABS-KEY(longevity) OR TITLE-ABS-KEY(morbidity) OR TITLE-ABS-KEY(lifetime) OR TITLE-ABS-KEY(survival) OR TITLE-ABS-KEY(demograph*) OR TITLE-ABS-KEY(fertility) OR TITLE-ABS-KEY(migration)) AND (LIMIT-TO(SUBJAREA, “ECON”)) AND (PUBYEAR > 1979).

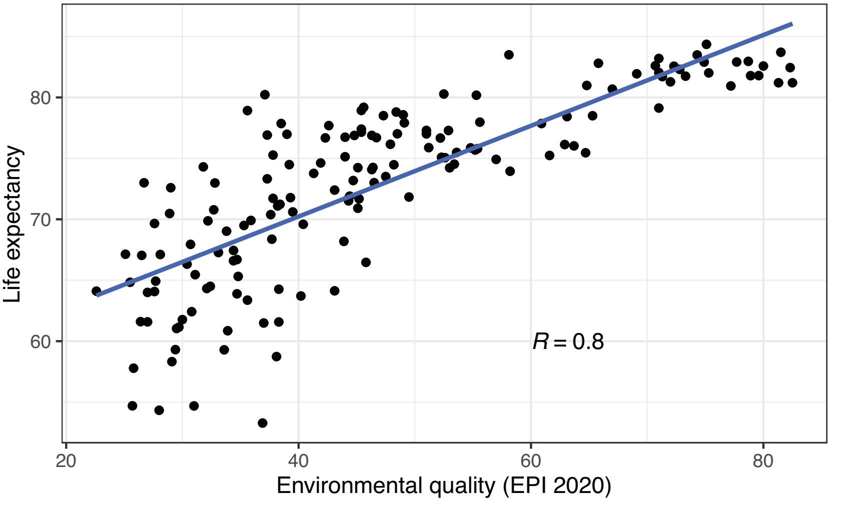

FIGURE 2 Correlation between environmental quality measured by the environmental performance index (EPI) and life expectancy.
[Colour figure can be viewed at wileyonlinelibrary.com]
Sources: Yale Center for Environmental Law and Policy (2020), World Bank (2019).

apparent in this context (John & Pecchenino, 1994). Further, OLG models are applied widely for policy analysis and the analysis of long-term dynamics. This is especially important in our context considering that environmental and demographic dynamics evolve slowly over time. We, thus, focus on articles including environmental variables and endogenous longevity in OLG frameworks. We aim at synthesizing research findings on how the reciprocal relationship between mortality and the environment can affect economic outcomes in the long run, the effects of measures to mitigate these impacts and their interactions with other policy measures.

Our review shows that several conclusions can be drawn from this strand of literature. First, acknowledging the two-way reciprocal relationship between the environment and mortality can have significant effects on economic outcomes. In particular, the possibility of falling into an environmental poverty trap, which is defined as a state with low output, low life expectancy, and high pollution, is highlighted. Other economic effects include fluctuations in economic output and increasing inequality. Second, the literature emphasizes the relevancy of environmental policy by showing that it does not only improve environmental quality but can also have long-term economic benefits. More specifically, environmental policy can help economies escape the environmental poverty trap and reduce both fluctuations and inequality. Third, considering environmental policy simultaneously with other policy measures shows that measures such as public healthcare can reduce the negative economic effects induced by pollution. However, these policies do not constitute perfect substitutes for environmental policy, providing further evidence for its importance.

The remainder of this paper is structured as follows: We start our survey in Section 2 with a review of the seminal works by John and Pecchenino (1994) and Chakraborty (2004)[3]. While the former introduces the environment into OLG models, the latter introduces endogenous life expectancy into an OLG framework. We next introduce the paper by Mariani et al. (2010) that combines both frameworks and allows for the links between economic growth, pollution, and life expectancy. This model forms the basis for our review, with all other papers discussed building on the same basic mechanisms.[4] Section 3 focuses on the environmental poverty trap, highlighting different mechanisms that can drive an economy away from the desirable equilibrium characterized by high environmental quality, high life expectancy, and high environmental quality. In Section 4, we review the role of environmental policy, emphasizing effects on the environment, economic outcomes, and demography. Section 5 analyzes synergies and trade-offs between environmental policy and other policy options such as public healthcare. Finally, Section 6 concludes.

2 | FINITELY LIVED AGENTS, THE ENVIRONMENT, AND ENDOGENOUS MORTALITY

2.1 | Economic growth and the environment: The model by John and Pecchenino (1994)

John and Pecchenino (1994) study the trade-offs between growth and environmental quality in a dynamic general equilibrium model that is populated by overlapping generations. By assuming finitely lived agents, their framework establishes the effects of short-lived individual decisions on long-lasting environmental quality. Previous models that assumed the same life span for individuals, the economy and the environment were restricted to only consider intragenerational trade-offs while John and Pecchenino (1994) allowsthe consideration of intergenerational trade-offs as well.

In their model, agents live for two time-periods. To keep the model simple, it is assumed that agents do not derive utility from consumption in the first period of life, but only from consumption in the second period of life d_{t+1} and future environmental quality E_{t+1}:

$$U(d_{t+1}, E_{t+1}) \tag{1}$$

with $U_d(\cdot), U_E(\cdot) > 0, U_{dd}(\cdot), U_{EE}(\cdot) < 0$, and $U_{dE}(\cdot) \geq 0$.

Young agents are endowed with one unit of labor. They invest their wage w_t in saving s_t for old age consumption and environmental maintenance m_t:

$$w_t = s_t + m_t \tag{2}$$

In old age, agents earn a gross return $(1 + r_{t+1})$ on their savings:

$$d_{t+1} = (1 + r_{t+1})s_t \tag{3}$$

Environmental quality is a public good, which evolves according to

$$E_{t+1} = (1 - \eta)E_t - \beta c_t + \sigma m_t \tag{4}$$

where $\eta \in [0, 1]$ measures the speed of the autonomous change in environmental quality[5], $\beta > 0$ depicts the effect of consumption on environmental quality, and $\sigma > 0$ represents the efficiency of environmental maintenance m_t.

Final output Y_t is produced according to a constant returns to scale production function by perfectly competitive firms

$$Y_t = \psi(K_{t-1})F(K_t, L_t) \tag{5}$$

where K_t and L_t denote aggregate capital stock and total employment. $\psi(K_{t-1})$ is a technological externality that captures enhancements to productivity from last period's capital and satisfies $\psi'(\cdot) \geq 0$. This specific production function allows for increasing returns to scale from an intertemporal social perspective through the capital stock K_{t-1}. At the same time, production at any point in time exhibits constant returns for current producers since K_{t-1} is predetermined at time t[6]. The capital stock depreciates at a rate $0 \leq \delta \leq 1$. Overall, this setup implies that different generations are connected through three mechanisms: the evolution of environmental quality when environmental quality deteriorates incompletely, the accumulation of the capital stock when depreciation is incomplete and the technological externality in the production function.

In the competitive equilibrium, agents optimally choose their consumption, maintenance in environmental quality, and savings while firms maximize profits and markets clear. Solving for an interior equilibrium and ignoring the external increasing returns, the model allows for no, one, or two steady states of the capital stock and environmental quality. In the latter case, one steady state is characterized by low environmental quality and a low capital stock, while both environmental quality and capital stock are high at the other steady state. The emergence of multiple steady states can be explained as follows. When environmental quality is low, agents prioritize environmental maintenance and savings are relatively low. If, additionally, the capital stock is low, agents do not have much income. In that case, even relatively high environmental maintenance might not be enough to ensure increasing environmental quality. At the same time, low savings keep the capital stock low, perpetuating the situation. By contrast, if both environmental quality and the capital stock are high, agents are incentivized to save more, ensuring a high capital stock and enough resources to engage in effective environmental maintenance. When two interior steady states arise, the steady state with the higher capital stock and environmental quality is stable. The authors further show that zero environmental maintenance can be optimal if environmental quality is sufficiently high or the capital stock is sufficiently low. In that case, there is a negative correlation between environmental quality and the capital stock, as higher consumption deteriorates the environment more and there is no environmental maintenance to counteract it. By further allowing for increasing returns in the production function, the model allows for sustained growth of environmental quality and capital. The authors also provide a welfare analysis solving the social planner problem that takes into account the externalities of savings on the increasing returns in the production function and the externality of consumption and maintenance on future generations.

Overall, by focusing on the accumulation of capital and environmental quality, the model by John and Pecchenino (1994) is able to explain the varying correlations between environmental quality and economic growth we observe in reality.

2.2 | Economic growth and longevity: The model by Chakraborty (2004)

The relationship between longevity and economic growth is a relatively new research field. First, theoretical contributions analyzed the economic effect of changes in life expectancy in overlapping generations frameworks in the late 1990s and early 2000s (Zhang et al., 2001; De la Croix & Licandro, 1999; Kalemli-Ozcan et al., 2000; Zhang et al., 2003). They show that exogenous increases in life expectancy can significantly affect the returns on investment in physical and human capital and, thus, economic growth. However, by focusing on exogenous changes in life expectancy only, these contributions implicitly assume a one-way causal relationship from life expectancy to economic growth. Consequently, they ignore the potential effects of economic growth on life expectancy, for example, through better healthcare systems. This view was contested by several authors, who introduced endogenous longevity to study the two-way causal relationship between longevity and economic growth (Blackburn & Cipriani, 2002; Chakraborty, 2004). In the following, we will give a short overview of the baseline model introduced in Chakraborty (2004), since it includes both the household and the firm side and is, therefore, closer to the other models included in this review.

In a two-period overlapping generations model, agents gain utility from consumtpion in both periods of life, c_t and d_{t+1}. Consumption in the second period of life is discounted by the endogenous longevity in the second period of life π_t[7], which depends on public health expenditure G_t. Agents earn a wage w_t in their first period of life, but have to pay taxes equal to an exogenously given share $\tau < 1$ of their income to the government, which is used for public health spending. Agents divide the remainder of their wage between first period consumption c_t and savings s_t. In old age, agents earn the gross return $1 + r_{t+1}$ on their savings, which is used for second period consumption. The agents' maximization problem reads:

$$\max_{c_t} ln(c_t) + \pi_t ln(d_{t+1}) \tag{6a}$$

$$c_t = (1 - \tau)w_t - s_t \tag{6b}$$

$$\pi_t d_{t+1} = (1 + r_{t+1}) s_t \tag{6c}$$

$$\pi_t = \pi(G_t) = \pi(\tau w_t) \tag{6d}$$

Optimal consumption and savings are given by

$$c_t = \frac{1}{1+\pi_t}(1-\tau)w_t \tag{7}$$

$$s_t = \frac{\pi_t}{1+\pi_t}(1-\tau)w_t \tag{8}$$

While we see the usual positive relationship between income and savings and income and consumption, Equations (7) and (8) further show the importance of life expectancy for microeconomic decisions: The lower life expectancy is, the lower is the weight of future consumption in the utility function. Thus, agents facing a low life expectancy will consume relatively more while young, while high life expectancy leads to relatively higher savings.

Final output Y_t is produced by perfectly competitive firms using two factors, capital (K), and labor (L), according to a Cobb–Douglas production function. Output per worker is given by

$$y_t = Ak_t^{\alpha} \tag{9}$$

The capital stock depreciates at a rate $0 \leq \delta \leq 1$. Labor and capital are paid according to their marginal products:

$$w_t = w(k_t) = (1-\alpha)Ak_t^{\alpha} \tag{10}$$

$$r_t = \alpha A k_t^{\alpha-1} - \delta \tag{11}$$

Intertemporal equilibrium is given by

$$k_{t+1} = s_t = \frac{\pi_t}{1+\pi_t}(1-\tau)w_t \tag{12}$$

together with Equations (10) and (11), $\pi_t = \pi(G_t)$ and $G_t = \tau w_t$. Plugging equilibrium prices and health investments into Equation (12) characterizes the general equilibrium by one single equation

$$k_{t+1} = \frac{\pi(\tau(1-\alpha)Ak_t^{\alpha})}{1+\pi(\tau(1-\alpha)Ak_t^{\alpha})}(1-\tau)(1-\alpha)Ak_t^{\alpha} \tag{13}$$

This equation shows how life expectancy affects growth depending on initial capital k_0. Low k_0 means low health investments and, thus, low life expectancy, which in turn leads to high discounting of the future, low savings rates, and low economic growth. Therefore, low income and low life expectancy tend to reinforce each other. The opposite holds true for economies starting from a high capital stock. These differences can persist in the long run, when multiple positive steady states arise. The author highlights the role of the output elasticity of capital, α, for the determination of the number of positive steady states: When $\alpha < 0.5$, there is only one interior steady state in addition to the steady state with zero per capita capital. Thus, in the long run, there will be no difference in capital stock and income between two economies starting at different levels of capital. However, when α exceeds 0.5, two interior steady states arise in addition to the steady state with zero per capita capital. Out of these, the highest and the lowest steady states are asymptotically stable while the third one is not. Thus, depending on the level of initial capital, the economy can either approach the highest steady state or fall into a poverty trap. This is the case because with a large output elasticity of capital small changes in the capital stock lead to relatively large increases in wages, which in turn influence health investments and longevity. Thus, when α is large enough, differences in initial capital become more important, leading to multiple steady states.

However, it is important to acknowledge that even though the potential for multiple steady states exists within this framework, the observed empirical evidence challenges the notion of α being greater than 0.5 (Vollrath, 2021). Nonetheless, economies with the same initial conditions might still converge to different steady states if their productivities in health expenditure (i.e., the function $\pi(\cdot)$) differ. This channel also becomes relevant when different population groups face varying exposure to pollution, for example, Schaefer (2020).

2.3 | Economic growth, the environment, and longevity: The model by Mariani et al. (2010)

To analyze the interplay among the environment, life expectancy, and growth, Mariani et al. (2010) combine aspects from both models presented above into one consistent framework. In particular, they introduce environmental quality as in John and Pecchenino (1994) and endogenous longevity as in Chakraborty (2004). However, in contrast to Chakraborty (2004), life expectancy now depends on environmental quality instead of health investments. Thus, life expectancy and environmental quality dynamics are jointly determined, allowing for a two-way causal relationship between both variables. In the following, we present the model enhanced by physical capital presented in Appendix B of Mariani et al. (2010). This paper is the baseline model for our survey, since all studies included in our survey rely on endogenously determined environmental quality/pollution influencing life expectancy to investigate the interdependencies between the environment, life expectancy, and growth.

The model describes an infinitely lived economy populated by overlapping generations of agents living for two periods: adulthood and old age[8]. All decisions are taken in the adult period of life. Agents gain utility from consumption in the first period of life c_t, consumption in the second period of life, d_{t+1}, and environmental quality in the second period of life E_{t+1}. Utility gained in the second period of life is discounted by longevity π_t. The agents' utility is described by the utility function

$$U_t = \ln(c_t) + \pi_t(\rho \ln(d_{t+1}) + \gamma \ln(E_{t+1})) \tag{14}$$

where $\rho, \gamma \in (0, 1)$ represent the relative weights of old age consumption and environmental quality. Life expectancy is endogenous and depends on inherited environmental quality E_t. In particular, life expectancy can either be low $\underline{\pi}$ or high $\bar{\pi}$ depending on whether the environmental quality is below or above a threshold $\tilde{E}$[9]. Agents earn a wage w_t in their first period of life, which they can spend on consumption c_t, savings s_t, and environmental maintenance m_t. Note that in both John and Pecchenino (1994) and Mariani et al. (2010), environmental maintenance is privately financed. However, this assumption is somewhat controversial, as it is not a priori clear why agents would want to invest in environmental maintenance if they are just one agent in a continuum of agents. Thus, many later contributions have instead opted for public environmental maintenance financed through taxes. A version of the model by Mariani et al. (2010) with public environmental maintenance can be found in Appendix B.

The agents' budget constraint reads

$$w_t = c_t + m_t + s_t \tag{15}$$

Savings are used to finance old age consumption according to

$$d_{t+1} = \frac{s_t(1+r_{t+1})}{\pi_t} \tag{16}$$

where $(1+r_{t+1})/\pi_t$ denotes the actuarially fair interest factor at time $t+1$ accounting for life expectancy, that is, lower life expectancy inflates the interest factor. This specification is consistent with the assumption of perfect annuity markets as in Chakraborty (2004)[10].

The setup on the production side is the same as in Chakraborty (2004) with a Cobb–Douglas production function and a depreciation rate of $\delta \in [0,1]$.

Environmental quality is reduced by both consumption and production (represented by the capital stock), but can be improved through environmental maintenance. It evolves according to

$$E_{t+1} = (1-\eta)E_t + \sigma m_t - \beta c_t - pk_t \tag{17}$$

where $\eta \in (0,1)$ is the natural rate of deterioration of the environment and $\sigma > 0$ determines the effectiveness of environmental maintenance. $\beta > 0$ and $p > 0$ denote the environmental impact of one unit of consumption and one unit of physical capital, respectively.

In this economy, agents choose consumption c_t, savings s_t, and environmental maintenance m_t to maximize their lifetime utility. Their first-order conditions with respect to consumption in the first and second period of life are given by

$$\frac{\partial U_t}{\partial c_t} = (\beta+\sigma)\frac{\partial U_t}{\partial E_{t+1}} \tag{18}$$

$$\frac{\partial U_t}{\partial d_{t+1}} = \frac{\sigma\pi_t}{(1+r_{t+1})}\frac{\partial U_t}{\partial E_{t+1}} \tag{19}$$

Abstracting from corner solutions, the optimal choices are given by

$$c_t = \frac{(1-\eta)E_t - pk_t + \sigma w_t}{(\beta+\sigma)[1+(\rho+\gamma)\pi_t]} \tag{20}$$

$$s_t = \frac{\rho\pi_t[(1-\eta)E_t - pk_t + \sigma w_t]}{\sigma + (\rho+\gamma)\sigma\pi_t} \tag{21}$$

$$m_t = \frac{[pk_t - (1-\eta)E_t][\sigma + \rho(\beta+\sigma)\pi_t] + \sigma[\beta + \gamma(\beta+\sigma)\pi_t]w_t}{\sigma(\beta+\sigma)[1+(\rho+\gamma)\pi_t]} \tag{22}$$

All three variables are increasing in income, w_t, through an income effect. In particular, environmental maintenance positively depends on physical capital, k_t, due to two effects: The first one is an income effect (as $w_t = w(k_t)$), the second one stems from the fact that more production (higher k_t) requires more maintenance. Current environmental quality has a positive effect on consumption and investment in physical capital (savings), but a negative effect on environmental maintenance, since it is less needed if the environment is less degraded.

In the long run, the interplay between the stock and the choice variables leads to a positive correlation between physical capital and environmental quality. In particular, plugging Equation

(21) and the capital accumulation equation into Equation (19) and taking steady state values yields

$$\gamma\delta\sigma k^* = \rho E^* \tag{23}$$

where the asterisk denotes steady state values. Using this identity, the capital accumulation equation and the fact that $w_t = f(k_t) - k_t f'(k_t)$ yields

$$k^* = \left(\frac{A\rho\sigma(1-\alpha)\pi}{\delta\sigma + [p\rho + \delta\sigma(\gamma\eta + \rho)]\pi} \right)^{\frac{1}{1-\alpha}} \tag{24}$$

with $\pi = \underline{\pi}$ or $\pi = \bar{\pi}$ depending on the steady state value of environmental quality E^*, which can be calculated as $E^* = (\gamma\delta\sigma/\rho)k^*$.

If $E^*(\underline{\pi}) < \tilde{E} < E^*(\bar{\pi})$, both $E_L := E^*(\underline{\pi})$ and $E_H = E^*(\bar{\pi})$ are steady states. Since $\frac{\partial k^*}{\partial \pi} > 0$ and, thus, $\frac{\partial E^*}{\partial \pi} > 0$, the steady state with the lower environmental quality, E_L, is associated with the lower level of capital. $(E_L, k(E_L))$ is, thus, an environmental poverty trap, which is characterized by low life expectancy, low capital stock, and low environmental quality.

3 | THE ENVIRONMENTAL POVERTY TRAP

One of the main results of the literature on endogenous longevity and pollution, already presented in Mariani et al. (2010), is the emergence of multiple equilibria. The first (desirable) equilibrium is characterized by high environmental quality, high life expectancy, and high economic growth, the second one is a poverty trap with low environmental quality, high mortality, and low economic growth. This second equilibrium was termed an environmental poverty trap by Mariani et al. (2010)[11]. The core mechanism that leads to the emergence of multiple equilibria is the two-way causal relationship between environmental quality and life expectancy: When initial environmental quality is high, so is life expectancy. Agents, thus, have high incentives to save for future consumption (leading to higher levels of physical capital) and to invest in environmental maintenance (leading to high levels of environmental quality). Increasing wages and good environmental quality result in high savings and high environmental maintenance in the next period, ultimately letting the economy converge to a steady state with a high capital stock and high environmental quality. However, the opposite is true when initial environmental quality and life expectancy are low. In that case, agents prefer to consume relatively more in their first period of life instead of investing in the environment or savings. This leads to low environmental quality and income in the next period, perpetuating a spiral of low environmental quality, low life expectancy, and low capital stock.

While the dynamics described above represent the only mechanism driving the economy into the environmental poverty trap in some contributions (Mariani et al., 2010; Ngami & Seegmuller, 2021; Raffin & Seegmuller, 2014; Varvarigos, 2010), over the years, several other mechanisms that can reinforce these dynamics have been highlighted. We will summarize them briefly in the following. Section 3.1 focuses on the emergence of environmental poverty traps in the context of endogenous technological choice. Section 3.2 examines the mechanisms at play when human capital accumulation is endogenized. Section 3.3 focuses on differences in the nature of pollution, that is, whether the pollutant considered is local or global. Finally, Section 3.4 details how careless policy design can drive an economy into an environmental poverty trap.

3.1 | Endogenous technological choice

Varvarigos (2014) highlights that endogenous technological choice might lead to the emergence of an environmental poverty trap. He proposes a model with two sectors, intermediate production by so-called entrepreneurs and a final goods market. Entrepreneurs can choose between a dirty technology and a clean technology, which they can implement for a fixed cost. Government intervention consists of taxing pollution to incentivize investment in the clean technology. Without government intervention, entrepreneurs do not switch to the clean technology as the negative effect of pollution on the health of the agents is not taken into account in the entrepreneurs' profit maximization problem. Thus, there is only a single steady state. Since production is dirty, the pollution stock is high and the life expectancy of households is low. Therefore, they choose to consume in their first period of life instead of saving, resulting in a steady state with a low capital stock, low environmental quality, and low life expectancy. With government intervention, however, multiple equilibria can emerge as the tax incentivizes entrepreneurs to switch to the green technology when the initial capital stock is high enough. This, in turn, leads to improved longevity of households, resulting in larger savings and consequently a higher capital stock. Thus, an initially wealthier economy can converge to a steady state with higher environmental quality and a higher capital stock. However, when the initial capital stock is low, entrepreneurs keep producing using the dirty technology. This is the case because the cost of switching to the clean technology is fixed while the environmental tax is proportional to the firms' emissions and, thus their revenues. When the capital stock is low—which results in low production—investing in the clean technology does not pay off for the firms and entrepreneurs keep producing using the dirty technology, driving the economy into the environmental poverty trap. In most models, the fact that both environmental quality and the capital stock are larger at the high steady state compared to the low steady state is due to environmental maintenance being high enough to counteract the negative effects of pollution at some point. This is not the case in Varvarigos (2014): Here, the emergence of an environmental poverty trap solely depends on the endogenous technological choice.

Dao and Edenhofer (2018) also consider a framework with endogenous technological choice while abstracting from environmental maintenance. In their model, the additional assumption of nonlinear recovery of the environment that can lead to the emergence of an environmental poverty trap. This means that the regeneration rate η varies with the level of environmental quality. In particular, it is assumed to be a hump-shaped function of environmental quality, implying that the regeneration rate is low when the state of the environment is very bad but also slows down when environmental quality is close to its maximum level. By contrast, the regeneration rate is high at intermediate levels of environmental quality. The economy then might be trapped in an environmental poverty trap as low initial environmental quality negatively affects the agents' life expectancy and discourages savings. While the resulting low capital stock might lead to low emissions, the hump-shaped regeneration rate implies that the environmental quality might not regenerate quickly enough to ensure increasing life expectancy, thus, relegating the economy to an environmental poverty trap. The feature of endogenous technological choice comes into play when the authors investigate fiscal strategies that allow the economy to escape the environmental poverty trap. They show that a combination of taxing the dirty production technology and subsidizing the clean production technology can be enough to help the economy escape the environmental poverty trap.

3.2 | Human capital

While most contributions focus on the accumulation of physical capital, environmental poverty traps can also emerge when human capital accumulation is considered instead of/in addition to physical capital (Constant, 2019; Mariani et al., 2010, 2019).

An extended version of the baseline model presented in Mariani et al. (2010) investigates the mechanisms at work when human capital accumulation is endogenized instead of physical capital[12]. In that case, parents, who now additionally care about their childrens' human capital, can invest in consumption c_t, environmental maintenance m_t, or the education of their children e_t. Human capital h_t evolves according to

$$h_{t+1} = z h_t^{\zeta}(e_0 + e_t)^{\mu} \tag{25}$$

where $e_0 \geq 0$ is an exogenously given baseline education level, which allows for corner solutions with zero expenditures in education even when applying a utility function that satisfies the Inada conditions. $\zeta, \mu > 0$ specify the importance of "nature" (i.e., the spillover of human capital from parents to children) versus "nurture" (i.e., investment in education), respectively. $z > 0$ denotes the productivity of human capital accumulation[13]. The authors show that a similar mechanism to the case with physical capital applies: Low initial environmental quality now leads to decreased returns on investment in education instead of decreasing the returns on savings, which can again lead to the emergence of two steady states. The lower one is an environmental poverty trap, now characterized by low environmental quality, low life expectancy, and low levels of human capital.

Mariani et al. (2019) extend the framework of Mariani et al. (2010) by endogenizing fertility decisions to highlight another possible mechanism leading to an environmental poverty trap. Like in Mariani et al. (2010), environmental poverty traps can be induced by low initial environmental quality. However, in this framework, they can also arise when initial environmental quality is high if initial human capital is low. This is due to the fact that low initial human capital leads to parents preferring to invest in the quantity (instead of the quality) of their offspring. Thus, parents do not invest in their children's education, slowing down human capital accumulation. Lower levels of human capital induce lower levels of production and, thus, taxes, which in turn result in low environmental maintenance. These mechanisms lower environmental quality even if it is initially high, resulting in low life expectancy and relegating the economy to an environmental poverty trap.

A specific kind of environmental poverty trap is highlighted by Constant (2019) who introduces two types of agents differing in their initial human capital into a framework with both physical and human capital. Agents can invest in consumption, savings, and their children's education. Importantly, life expectancy depends on pollution and the human capital of the agents, which means that rich agents have a higher life expectancy. Human capital of the agents of type i now additionally depends on the average human capital in the economy $\bar{h}_t$

$$h_{t+1}^i = z(e_t^i)^{\mu}(h_t^i)^{\zeta}\bar{h}_t^{1-\zeta} \tag{26}$$

In this setting, the author shows that there is always an equilibrium without inequality, but depending on the initial conditions of the capital stock and inequality, the economy might be caught in an environmental poverty trap characterized by increasing inequality, high pollution, and low growth rates of average human capital. This environmental poverty trap can arise due to two divergent forces in Equation (26). First, the dependence of human capital of agents i on their parents' human capital, h_t^i, presents one divergent force. However, this channel alone would not be enough to cause multiple equilibria. They can arise due to the combination with a second divergent mechanism: Pollution disproportionately harms unskilled agents more, who therefore have a lower return on education investment. If these differential impacts are strong enough, inequality in terms of life expectancy and human capital can widen over time.

3.3 | The nature of pollution

The only paper explicitly modeling more than one region, Wu (2017), focuses on the interactions between developing and developed countries when pollution affects life expectancy in both regions. The author considers two versions of the model differing in the nature of the pollutant: The first version includes a global pollutant, which affects agents in both regions irrespective of where it is emitted. In the second version, the pollutant is local, meaning that pollutants emitted in one country do not affect agents in the other country.

The author shows that the long-term environmental quality is lower in the model with the shared pollutant in both regions. This is due to the fact that with a shared environment, each region also benefits from the environmental maintenance from the other region. However, while agents do consider the benefits from the environmental maintenance from the other region, they do not internalize the positive impact of their own environmental maintenance. This leads to free riding, that is, both regions underinvest in environmental maintenance. Therefore, life expectancy is also lower with a shared environment. Both countries are stuck in a steady state with lower environmental quality and lower life expectancy than they would be if the pollutant was local, which the author defines as an environmental poverty trap.

3.4 | Policy design

So far, we have explored several economic mechanisms, which can lead to the emergence of environmental poverty traps, but we have not touched upon the role of policymakers. While the ability of environmental policy to help an economy escape the environmental poverty trap is examined in Section 4, careless policy design itself can relegate an economy into an environmental poverty trap.

In this context, Wei and Aadland (2021b) highlight the difference between taxes and pollution permits to finance environmental maintenance. Using a model where emissions enter the production function as an additional production factor, the authors find that an environmental poverty trap with a low capital stock and a high pollution stock can emerge with pollution permits, but not with a green tax. This is due to the fact that with pollution permits, the flow of pollution is essentially fixed. Since the authors show that the optimal price of permits increases in the capital stock, the price and consequently the public funds to invest in environmental maintenance are low when the level of capital is low. This causes the pollution stock to rise, lowering life expectancy and consequently further disincentivizing savings. These mechanisms can lead to a downward spiral, relegating the economy to an environmental poverty trap. If, on the other hand, the capital stock is initially high, environmental maintenance is enough to mitigate the negative effects of pollution, resulting in an increasing capital stock and a decreasing pollution stock. With a green tax, the mechanisms leading to the environmental poverty trap are not possible, since emissions are not fixed but tend to be low when the capital stock is low. Thus, the downward spiral described above cannot emerge, leading to a single steady state equilibrium. The authors conclude that green taxes might be preferable, but emphasize that the environmental poverty trap can be avoided if the government manages to incentivize savings even with pollution permits.

Fodha and Seegmuller (2014) and Clootens (2017) study the impact of financing environmental maintenance through public debt, arguing that introducing public debt corresponds to the beneficiary-pays principle, which means that those benefiting from the measure (future generations) pay for it. The setup is similar in both models, with governments using both public debt and a lump-sum tax on labor income to finance environmental maintenance. Further, per capita public debt and per capita envrionmental maintenance are assumed to be fixed at B and M over the whole time horizon in both contributions, respectively. The government's budget constraint becomes

$$B + \tau_t = M + (1 + r_t)B \tag{27}$$

where the left-hand side denotes the funds available to the government, consisting of newly issued debt of B and tax income raised through a lump-sum tax τ_t on households. The right-hand side denotes the uses of public budget, which is the sum of environmental maintenance M and debt repayments $(1 + r_t)B$. In addition to the government, in Clootens (2017) households can engage in private environmental maintenance and are incentivized to do so because environmental quality in their second period of life is added to their utility function. This addition has important implications for the results.

In both models, the economy either converges to a steady state with positive environmental quality and capital stock or falls into a poverty trap with a decreasing capital stock. However, this poverty trap is not characterized by low environmental quality and low life expectancy in Fodha and Seegmuller (2014). Instead, environmental quality and life expectancy are higher compared to the steady state with the higher capital stock. This is due to the fact that since public expenditure per capita is fixed and the government uses its funds only for environmental maintenance, environmental maintenance per capita is fixed as well. Thus, the environmental impact of production and associated impacts on life expectancy increase when the capital stock is higher, but environmental maintenance does not. Therefore, a higher capital stock means lower environmental quality and lower life expectancy. The crucial difference between Clootens (2017) and Fodha and Seegmuller (2014) lies in the modeling of the utility function: While environmental quality enters the utility function in Fodha and Seegmuller (2014) only indirectly though longevity, agents directly gain utility from old-age environmental quality in Clootens (2017). Therefore, agents are incentivized to engage in private environmental maintenance, preventing the above-mentioned trade-off between capital stock and environmental quality at the steady states.

Regarding the role of public debt, both studies find that raising per-capita public debt ceteris paribus increases the probability of the economy falling into the poverty trap due to a crowding-out effect from private assets toward public bonds. Such an increase in public debt also leads to a lower capital stock at the positive steady state for the same reason.

4 | THE ROLE OF ENVIRONMENTAL POLICY

In both the model by John and Pecchenino (1994) and Mariani et al. (2010) presented in Section 2, environmental maintenance is privately financed. While this approach allows for exploring issues related to trade-offs between consumption and environmental maintenance in the households' preferences, most later contributions have instead focused on the trade-off between consumption at young age and savings when life expectancy endogenously depends on the environmental quality. To explore how environmental policy might affect this trade-off and the resulting dynamics, environmental policy is often modeled as public environmental maintenance financed by an exogenously given tax rate. Note, however, that we use a broad notion of environmental policy including any type of governmental policy that reduces pollution. The literature on the interlinkages between the environment, life expectancy, and growth emphasizes many potential benefits of environmental policy. In particular, it shows that it cannot only improve environmental quality, but help achieve economic targets which are often considered separately from environmental issues. Thus, environmental policy is shown not to be an end in itself, but to provide additional benefits to society, such as increasing economic stability or reducing inequality. Section 4.1 details the different ways in which environmental policy can contribute to achieve environmental objectives, while Section 4.2 highlights potential economic benefits. Section 4.3 summarizes the impacts of environmental policy on demographic variables.

4.1 | Environmental outcomes

Many of the papers presented in Section 3 (Clootens, 2017; Dao & Edenhofer, 2018; Fodha & Seegmuller, 2014; Mariani et al., 2010; Raffin & Seegmuller, 2014; Varvarigos, 2010) do not only analyze the conditions for the emergence of an environmental poverty trap, but also the ability of governments to help escape it through implementing environmental policies. Since households do not internalize the negative effect of pollution on life expectancy, policy tools are relevant to improve both environmental and economic outcomes. Mostly financed through taxes on polluting activities such as production, environmental policy consisting of public environmental maintenance has two opposing effects. First, it reduces the income for investment in consumption, savings, and education. Second, it increases longevity and, thus, welfare through decreasing pollution. Depending on initial conditions, environmental policy can either completely eliminate the possibility of falling into an environmental poverty trap (Dao & Edenhofer, 2018; Fodha & Seegmuller, 2014; Mariani et al., 2010) or reduce the range of parameter values for which the economy would converge to an undesirable equilibrium (Clootens, 2017; Raffin and Seegmuller, 2014; Varvarigos, 2010), thus, reducing the probability of falling into an environmental poverty trap. Note, however, that escaping the environmental poverty trap is not a purely environmental target, many studies show that it also comes with positive effects on life expectancy, the capital stock, and welfare.

While environmental maintenance is an *end-of-pipe* solution, other contributions show that environmental policy can also encourage switches to cleaner production technologies. As described in Section 3.1, in Varvarigos (2014) and Varvarigos and Zakaria (2017), a clean technology can be implemented by the producers in the intermediate goods market for a fixed costs. However, without government intervention, they have no incentive to do so. Thus, environmental policy is crucial to induce the switch to cleaner production technologies, ultimately decreasing pollution and increasing the capital stock. In Dao and Edenhofer (2018), firms employ clean and dirty capital simultaneously to produce intermediate goods, which are then used to produce a final good. Without environmental policy, an environmental poverty trap can arise due to non-linear recovery of the environment (see Section 3.1). Environmental policy, consisting of taxes on dirty production and subsidies to clean production can induce a switch to the cleaner production technology, ultimately helping the economy escape the environmental poverty trap.

4.2 | Economic outcomes

Escaping the environmental poverty trap is not only beneficial for the environment, but also increases economic activity[14], thus also serving economic objectives. Nonetheless, escaping the environmental poverty trap and switching to cleaner production technologies can still be considered to be "environmental" objectives. However, environmental policy can also help achieve "purely economic" objectives, which are usually considered separately from environmental issues, such as economic stability or reducing inequality.

Several studies highlight the destabilizing role of pollution on the economy, either along the transition pathway (Varvarigos, 2013; Wei & Aadland, 2021a) or in the form of limit cycles (Palivos & Varvarigos, 2017; Raffin & Seegmuller, 2017). The intuition behind this volatility is that if the capital stock is high, so is pollution. Since the effect of pollution on mortality is high, savings are reduced substantially. This directly reduces capital, but also implies that pollution decreases. Next period's life expectancy and savings increase, which promotes capital accumulation. This sequence of events can become self-repeating, generating an equilibrium with persistent cycles or volatility along the transition pathway. The studies further highlight the importance of environmental policy to mitigate this volatility, which can in certain cases be eliminated through increased investment in public environmental maintenance.

The impact of environmental policy on wealth/human capital inequality is investigated in several contributions (Constant, 2019; Schaefer, 2020; Schaefer & Prskawetz, 2014). Interestingly, the effect of environmental policy seems to depend on whether the effects of pollution differ between agents or not. In particular, public policy seems to be more efficient in reducing inequality when the health effects of pollution differ between agents, which reinforces inequality. In Schaefer and Prskawetz (2014), agents differ in terms of their initial wealth, but face the same life expectancy. Depending on their initial wealth, households converge to either a steady state with low relative human capital, or a steady state with high relative human capital. An increase in taxes on pollution increases welfare for both skilled and unskilled agents, but more so for skilled agents, thus increasing inequality. This result is turned upside down when the differential impact of pollution is considered as done by Schaefer (2020) (where unskilled agents live in more polluted areas) and Constant (2019) (where unskilled agents are more adversely affected by pollution). In that case, a rise in taxes on pollution increases the life expectancy of all agents, leading them to invest more in the education of their children. However, since unskilled agents are more adversely affected by pollution than skilled agents, they benefit more from the taxation of pollution, reducing inequality.

4.3 | Demographic outcomes

While we have already discussed the positive environmental and economic effects of escaping the environmental poverty trap, it comes with an additional benefit in most cases: increased longevity. Since environmental policy can reduce the probability of an economy falling into an environmental poverty trap as discussed in Section 4.1, it can clearly have beneficial effects on life expectancy.

Policy objectives regarding the optimal fertility rate, however, are not that clear-cut: While some—mostly developed—countries struggle with low fertility rates, other—mostly developing—countries are experiencing increasing demographic pressure. Nonetheless, knowing about the potential effects of different policy instruments on fertility rates is crucial for making informed decisions. Varvarigos and Zakaria (2017) and Mariani et al. (2019) extend their previous frameworks (Mariani et al., 2010; Varvarigos, 2014) by endogenous fertility choices to provide a more holistic picture. Interestingly, the results differ substantially. In Varvarigos and Zakaria (2017), environmental taxation eventually leads to a switch to cleaner production technologies, improving environmental quality, and increasing life expectancy. As a result, households attach higher importance to consumption in old age, leading to lower fertility rates as households try to increase consumption by increasing labor supply and reducing time for child rearing. In Mariani et al. (2019), on the other hand, environmental policy has multiple effects. First, it reduces output and, thus, the environmental impact of production. Second, it reduces the opportunity cost of having children compared to educating them due to lower wages. Therefore, parents decide to have more children, increasing fertility rates.

5 | COMPLEMENTARITY AND TRADE-OFFS BETWEEN ENVIRONMENTAL POLICY AND OTHER PUBLIC SERVICES

The previous section has shown that environmental policy is a powerful tool that can improve economic and health outcomes in addition to environmental quality. However, environmental policy alone is not enough to achieve favorable outcomes in all cases. Therefore, exploring interactions with other public services is crucial. In particular, as pollution affects economic activity through the longevity channel, health expenditure seems to be a natural extension of the benchmark model. Several questions worth analyzing arise in this context: What are the interactions between environmental policy and other public services? Are there other uses for government revenue that can achieve the same outcomes as environmental policy at a lower cost? What are the consequences of investing in “mitigation” measures like environmental maintenance versus investing in “adaptation” measures like increasing public health expenditure? The OLG framework is especially suited for answering these questions, as it allows for analyzing not only intragenerational trade-offs, but also intergenerational trade-offs. Since the effects of individual policies differ between agents from different generations (for instance, old individuals tend to benefit more from public health expenditure than young ones), this feature significantly widens the conclusion that can be drawn. Section 5.1 focuses on the effects of public health services, while Section 5.2 is concerned with the provision of other public services.

5.1 | Public health expenditure

Health investments are one of the earliest and most studied extension of the benchmark model by Mariani et al. (2010). As opposed to the benchmark model, where longevity depends only on environmental quality, it is now also positively affected by health expenditure G_t[15]

$$\pi_t = \pi(E_t, G_t) \tag{28}$$

Furthermore, the costs of health investments have to be considered in the government's budget constraint, which changes to $\tau w_t = M_t + G_t$[16].

At first glance, public environmental maintenance and public health investments seem to play a similar role: both tools increase longevity. However, while environmental maintenance increases longevity indirectly through the reduction of detrimental pollution, health investments improve longevity directly. The trade-offs between environmental maintenance and health investments can, thus, be seen as a decision between "mitigation" and "adaptation" measures. Several conclusions can be drawn on their interplay.

First, most studies highlight that even in the presence of health investments, environmental maintenance is crucial for long-term economic growth. Thus, health investments do not constitute a perfect substitute for environmental maintenance. The importance of environmental maintenance becomes especially apparent when environmental quality/pollution is modeled as a stock (e.g., Raffin & Seegmuller, 2014, 2017). In that case, environmental maintenance does not only affect the current generations, but also all future generations through changes in environmental quality/the pollution stock. Second, striking a balance between both policy tools is important. An increase of environmental maintenance at the expense of health investments has two opposing effects. It directly reduces longevity through the decrease in health expenditure, but at the same time improves environmental quality, which positively affects longevity. Depending on which effect dominates, increasing the share of public expenditure devoted to environmental maintenance can be beneficial or detrimental. Third, the use of overlapping generations models allows for analyzing issues of intergenerational equity, which turn out to be important considerations to understand the effects of different policy measures. While interactions between different generations are important in determining the long-run behavior of the economy, this is all the more true when focusing on the trade-offs between short- and long-term effects of policies (Balestra & Dottori, 2012; Ponthiere, 2016). In particular, increasing investments in environmental maintenance at the expense of health investments might be beneficial in the long run, but harmful to current generations. This becomes especially problematic when political economy considerations are introduced. Balestra and Dottori (2012) show that in that case, there are large differences between the political economy solution and the social planner solution. This is due to the fact that old individuals prefer health investments, because they benefit less from environmental maintenance and do not internalize the positive effects on future generations.

5.2 | Other public services

While public health expenditure is by far the most studied public service in addition to environmental maintenance, some studies investigate the interactions with other public policies.

Ngami and Seegmuller (2021) extend a special case of the model presented in Raffin and Seegmuller (2014) by a pay-as-you-go pension system and investigate its effects and its interactions with public health expenditure and environmental policy. Regarding the role of the public pension system, the authors find that an increase in taxation to finance a more generous public pension system increases the probability of falling into an environmental poverty trap. This is due to two effects which both disincentivize savings: guaranteed pension income at old age, which leads to a drop in the savings rate and the reduction of the remaining available income. Additionally, even when the economy is not relegated to an environmental poverty trap, a larger pension system decreases the steady state capital-pollution ratio through disincentivizing saving. The authors further investigate how an increase in the pension system

TABLE 1 Main features of studies included in this review.

Paper	Environment	Abatement	Health investments
		Environmental poverty trap	
Varvarigos (2010)	P,F	Public	Public
Raffin and Seegmuller (2014)	P,S	Public	Public
Ngami and Seegmuller (2021)	P,S	Public	Public
		Endogenous technological choice	
Varvarigos (2014)	P,S	Public	Public
Dao and Edenhofer (2018)	E,S		
		Human capital	
Mariani et al. (2010)	E,S	Private	
Mariani et al. (2019)	E,S	Private	
Constant (2019)	P,F	Public	
		The nature of pollution	
Wu (2017)	E,S	Public	
		Policy design	
Fodha and Seegmuller (2014)	E,S	Public	
Clootens (2017)	E,S	Public and Private	
Wei and Aadland (2021b)	P,S	Public	
		The role of policy	
		Stabilizing properties of environmental poliy	
Varvarigos (2013)	E,S	Public	Public
Raffin and Seegmuller (2017)	P,S	Public	Private and Public
Palivos and Varvarigos (2017)	E,F	Public	Public
Wei and Aadland (2021a)	P,S	Public	
		Reducing inequality	
Schaefer and Prskawetz (2014)	P,S	Public	Public
Constant (2019)	P,F	Public	
Schaefer (2020)	P,S	Public	Private
		Optimal taxation	
Goenka et al. (2020)	P,F	Public	
		Interactions with fertility	
Varvarigos and Zakaria (2017)	P,S		
Mariani et al. (2019)	E,S	Private	
		Interactions with pension systems	
Ngami and Seegmuller (2021)	P,S	Public	Public
		Overinvestment in health	
Jouvet et al. (2010)	P,S		Private
		Intergenerational equity	
Balestra and Dottori (2012)	E,S	Public	Public
Ponthiere (2016)	P,S		Public

Note: The second column specifies how the environment is modeled. We differentiate between environmental quality (*E*) being modeled explicitly and pollution being modeled instead (*P*). Further, we specify whether the environment is modeled as a stock (*S*) or as a flow (*F*) variable.

affects the trade-off between environmental maintenance and health expenditure. To do so, they hold the tax revenues allocated to the combined expenses of environmental maintenance and health expenditure constant and explore the effects of varying the shares devoted to each policy instrument depending on the level of the pension income. At every level of pension income, an increase in the share of public expenditure devoted to health expenditure has two effects: First, it directly increases longevity. Second, the decrease in environmental maintenance increases the pollution stock, negatively affecting the longevity of future generations. The authors find that an increase in the pension paid to retired households strengthens the importance of the first effect compared to the second effect. Thus, increasing public health expenditure at the expense of environmental maintenance might be a suitable policy even for economies converging to the high steady state when the level of pension payments is high enough. This finding contrasts with the results derived in contributions that do not consider a pension system (e.g., Raffin and Seegmuller, 2014) and, thus, emphasize the importance of considering multiple policy measures.

Mariani et al. (2019) investigate how taxes on production or educational subsidies can help economies to escape the environmental poverty trap (see Section 3.2). Taxes on production induce two conflicting effects on pollution. They reduce the level of pollution by reducing output levels. At the same time, they reduce the opportunity costs of having children, which incentivizes parents to favor the quantity over the quality of their children, additionally hampering environmental maintenance. The authors emphasize that if the second effect dominates, environmental policy in the form of a tax on production might even be harmful to environmental quality. Educational subsidies, on the other hand, encourage parents to invest in the quality of their children. Human capital accumulation is accelerated, while population growth slows down. Since increased human capital accumulation results in higher environmental maintenance, educational subsidies can, thus, be an effective tool to improve environmental quality and help economies escape the environmental poverty trap.

6 | CONCLUSIONS AND OUTLOOK

The past two decades have been marked by an increasing awareness of the interconnections between long-term environmental and demographic processes. In particular, it is now widely acknowledged that population dynamics do not only influence the environment, but that the environment can have significant effects on demographic processes by influencing mortality, fertility, and migration (Muttarak, 2021; Millock, 2015). However, due to the complex and slow dynamics of demographic and environmental change, the mechanisms connecting them and linking them to economic growth are not obvious. In this study, we reviewed papers that analyze the interplay among economic growth, environmental factors, and a specific demographic variable, namely life expectancy. More specifically, we synthesized the strand of literature that models the two-way causal relationship between life expectancy and the environment in models of economic growth that build on the framework of overlapping generations. Table 1 provides an overview of the studies included in this review and their main characteristics.

Our review shows that several conclusions can be drawn from this strand of literature:

(i) Combining environmental degradation, endogenous longevity, and economic growth in one consistent framework can highlight important mechanisms that explain real world phenomena. In particular, the literature provides explanations for the observed positive correlation between environmental quality and life expectancy by introducing the concept of the environmental poverty trap, characterized by low life expectancy, low environmental quality, and low economic growth.

(ii) There is a broad consensus on the importance of environmental policy to achieve both favorable environmental and economic outcomes. It is shown that environmental policy can have significant co-benefits, such as reducing fluctuations in economic output and reducing inequalities.

(iii) Regarding synergies and trade-offs between different policy instruments, this strand of literature shows that other instruments such as public healthcare can complement, but not perfectly substitute environmental policy.

While the literature on the interplay among the environment, longevity, and growth has grown over the last years, our review clearly shows that there is still scope for further exploration of these topics. In particular, more research is needed on the interaction of longevity with other demographic variables. While there have been first attempts to include fertility (Mariani et al., 2019; Varvarigos & Zakaria, 2017), the topic of migration deserves particular attention in the light of climate change (Millock, 2015). Moreover, there is still large potential to improve our understanding of how governments can optimally design policies to achieve favorable environmental, economic, and demographic outcomes at the same time. This is especially true for the case of global environmental problems, where global political economy considerations become essential. While there is a large literature on cooperation between regions in the International Environmental Agreement literature, these considerations are neglected in the studies covered by this survey with only Wu (2017) introducing more than one region. Furthermore, all models included in this survey are deterministic. Yet, uncertainty is a central feature of many environmental problems and consequently environmental policy (Pindyck, 2007). The environmental economics literature has acknowledged this in a growing number of publications applying stochastic frameworks[17]. However, to the best of our knowledge, none of these publications has investigated the interplay between the environment, life expectancy, and economic growth. Since uncertainty could be introduced at multiple points in these models (e.g., the build-up of the pollution stock, the health damages of pollution, the effectiveness of environmental and health policies, etc.), it would certainly be a complex but particularly interesting area for future research. Finally, in the light of the current pandemic, introducing epidemics into an economic framework of environment and life expectancy might be a fruitful research avenue, especially considering the empirical evidence on the interactions between climate change and infectious diseases. First steps in that direction have been taken by Davin et al. (2021).

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DATA AVAILABILITY STATEMENT

No new datasets were generated or analyzed during the current study. Data used for figures and data on publications were obtained from the sources cited in the manuscript.

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ENDNOTES

[1] The Pearson correlation coefficient is equal to 0.8 and statistically significant at the 1% level.

[2] A large body of literature has focused on the empirical relationship between the environment and economic growth, see, for example, Grossman and Krueger (1995), Dasgupta et al. (2002), Friedl and Getzner (2003). For the link between life expectancy and economic growth, see, for example, Kalemli-Ozcan (2002), Bloom et al. (2004), Oster et al. (2013). Finally, the impact of pollution on mortality is analyzed, for example, in Evans and Smith (2005), Pope III et al. (2009), Hanlon and Tian (2015), Lelieveld et al. (2020). A few studies even include all three variables, as, for example, Ebenstein et al., 2015.

[3] A table with all variables and parameters is provided in Appendix A.

[4] We chose Mariani et al. (2010) as our benchmark model due to several reasons: (i) It is one of the earliest contributions that combines environmental factors with endogenous longevity in an overlapping generations model. (ii) In contrast to contributions like Pautrel (2008) and Pautrel (2009), it builds on an OLG model à la Diamond (1965) instead of a continuous model à la Blanchard (1985). We deem these models more useful for our purpose since they allow for differential mortality along the life cycle. Furthermore, most subsequent contributions build on a framework à la Diamond. (iii) The framework is more tractable than in other early contributions such as Jouvet et al. (2010) and Varvarigos (2010), making it better suited to build upon.

[5] Note that while some contributions model environmental quality, others opt for modeling pollution instead. In that case, Equation (4) becomes $P_{t+1} = (1-\eta)P_t + \beta c_t - \sigma m_t$. With a pollution stock, η can be interpreted as "self-cleaning" of the environment. Instead, in models that include environmental quality, the environment deteriorates at rate η.

[6] The production function is motivated by the literature on external increasing returns in growth models, see, for example, Arrow (1962) who introduced increasing returns through learning by doing and Romer (1986) who introduced knowledge as a capital good with increasing marginal product.

[7] Note that by weighting the second period of life by survival probability, mortality acts as a discount factor. When life expectancy is high, the discount rate is low and vice versa.

[8] The third period of life in Mariani et al. (2010), childhood, was omitted here as we do not include human capital in the benchmark model and childhood is, thus, not relevant.

[9] Note that the results do not depend on life expectancy being a step function. While it is an analytically appealing functional form, later contributions derive similar results using continuous life expectancy functions.

[10] The assumption of perfect annuity markets is standard in these models. While it is certainly nontrivial, introducing imperfect annuity markets requires the introduction of a redistribution mechanisms (e.g., through unintended bequests), making it more difficult to disentangle the effects of the interplay between environment, life expectancy, and economic growth. Thus, most contributions rely on perfect annuity markets, with only Balestra and Dottori (2012) investigating the implications of imperfect annuity markets.

[11] Note that there are cases where a poverty trap emerges, that is not characterized by low environmental quality, for example, Fodha and Seegmuller (2014).

[12] Note that we chose to present the version extended by physical capital accumulation in Section 2.3.

[13] This human capital accumulation function goes back to Tamura (1991) and Glomm and Ravikumar (1992). It has since been widely applied in studies on human capital inequality, for example, De La Croix and Doepke (2003).

[14] With Fodha and Seegmuller (2014) being an exception to this rule, as the equilibrium with the higher capital stock is associated with lower environmental quality.

[15] Note that in models that consider pollution instead of environmental quality, longevity is now given by $\pi_t = \pi(P_t, G_t)$ where P_t denotes the pollution stock. Typical examples of longevity functions include $\pi_t = G_t^{\phi} E_t^{\xi}$, or, equivaltently $\pi_t = G_t^{\phi}/P_t^{\xi}$ and $\pi_t = \frac{a+bG_t/P_t}{G_t/P_t}$ with $\phi, \xi, b > 0$ and $a \geq 0$.

[16] From $\tau w_t = M_t$, see Equation (B.8) in Appendix B.

[17] See, for example, Bretschger and Vinogradova (2019) for a broadly applicable framework of stochastic environmental damages or Cai and Lontzek (2019) for a stochastic extension of the well-known DICE model (Nordhaus, 1992).

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APPENDIX A: OVERVIEW OF VARIABLES AND PARAMETERS

Variable/parameter	Description
$F(\cdot)$	Aggregate production
$U(\cdot)$	Utility function
Y, y	Output
K, k	Capital stock
L	Labor force
N	Population size
H, h	Human capital
$\pi(\cdot)$	Life expectancy/longevity/survival probability
$\bar{h}$	Average human capital
c	Consumption in first period of life
d	Consumption in the second period of life
s	Savings
E	Environmental quality
P	Pollution
M, m	Environmental maintenance
x	Per-capita available space
G, g	Health expenditure
e	Per-child educational expenditure
n	Number of children per adult

(Continues)

Variable/parameter	Description
q	Quality of children
b	Bequests per child
τ	Tax share
δ	Depreciation
w	Wage
r	Interest rate
A	Productivity parameter
α	Output elasticity of capital
η	Rate of environmental regeneration
σ	Effectiveness of environmental maintenance
β	Emissions per unit of consumption
p	Emissions per unit of capital/production
γ, ρ	Weight parameters for utility functions
$\underline{\pi}, \bar{\pi}$	Longevity depending on environmental quality
ϕ	Elasticity of longevity with respect to health expenditures
ξ	Elasticity of longevity with respect to pollution/environmental quality
λ	Elasticity of pollution with respect to environmental maintenance
a, b	Parameters of the longevity function
ϵ	Elasticity of pollution with respect to emissions
χ	Share of private investments in total health expenditure
z	Efficiency of human capital accumulation
ζ	Elasticity of human capital with respect to education expenditures
μ	Importance of parents' human capital in human capital accumulation

Note: If not specified otherwise, we denote per capita variables by lowercase letters and aggregate variables by uppercase variables. Further, we use horizontal bars above variables to indicate mean values (e.g., $\bar{h}$) and a tilde to indicate threshold values (e.g., $\tilde{E}$). Subscripts of d and c refer to dirty and clean technologies, respectively.

APPENDIX B: BENCHMARK MODEL WITH PUBLIC ABATEMENT

We here present the benchmark model with public instead of private abatement. Since agents do not have to decide on environmental maintenance, the utility function can be simplified to

$$U_t = \ln(c_t) + \pi_t \ln(d_{t+1}) \tag{B.1}$$

Like Mariani et al. (2010), we assume that longevity can take two values, $\bar{\pi}$ or $\underline{\pi}$ depending on the state of the environment. Since the agents have to pay a share τ of their wage in taxes to finance abatement, their first period budget constraint is given by

$$(1-\tau)w_t = c_t + s_t \tag{B.2}$$

The second period budget constraint is still given by

$$d_{t+1} = \frac{s_t(1+r_{t+1})}{\pi_t} \tag{B.3}$$

Final output Y_t is produced by perfectly competitive firms using capital K_t and labor L_t according to the production function

$$Y_t = AK_t^{\alpha}L_t^{1-\alpha} \tag{B.4}$$

or, in per capita terms

$$y_t = Ak_t^{\alpha} \tag{B.5}$$

The capital stock evolves according to

$$k_{t+1} = (1-\delta)k_t + s_t \tag{B.6}$$

where $\delta \in [0,1]$ denotes the depreciation rate. Environmental quality is assumed to deteriorate with production Y_t and to improve with public abatement M_t:

$$E_{t+1} = (1-\eta)E_t + \sigma M_t - pY_t \tag{B.7}$$

where η denotes the natural rate of deterioration of the environment, and $\sigma, p > 0$ are given parameters. The government is assumed to run a balanced budget, thus using all the tax revenue for abatement:

$$M_t = \tau w_t \tag{B.8}$$

B.1 | Optimal choices

In this economy, agents divide their wage between consumption and savings to maximize their lifetime utility which yields

$$s_t = \frac{\pi_t}{1+\pi_t}(1-\tau)w_t \tag{B.9}$$

$$c_t = \frac{1}{1+\pi_t}(1-\tau)w_t \tag{B.10}$$

Factor prices are derived from the optimization problem of profit-maximizing firms, yielding

$$w_t = A(1-\alpha)k_t^{\alpha} \tag{B.11}$$

$$1 + r_t = A\alpha k_t^{\alpha-1} \tag{B.12}$$

Plugging the factor prices (B.11)–(B.12) into the dynamic equations for capital and environmental quality yield

$$k_{t+1} = (1-\delta)k_t + \frac{\pi_t}{1+\pi_t}(1-\tau)A(1-\alpha)k_t^{\alpha} \tag{B.13}$$

$$E_{t+1} = (1-\eta)E_t + \sigma\tau A(1-\alpha)k_t^{\alpha} - pAk_t^{\alpha} \tag{B.14}$$

B.2 | Steady state

The steady states of the dynamic system can be derived by setting $k_{t+1} = k_t = k$ and $E_{t+1} = E_t = E$ in Equations (B.13) and (B.14). The steady state value(s) of physical capital are given by

$$k^* = \left(\frac{\pi(1-\tau)A(1-\alpha)}{(1+\pi)\delta} \right)^{\frac{1}{1-\alpha}} \tag{B.15}$$

with π equal to $\bar{\pi}$ and/or $\underline{\pi}$. The steady state(s) of environmental quality can be calculated by plugging optimal choices and k^* into Equation (B.14) and is (are) given by

$$E^* = \frac{[\sigma\tau A(1-\alpha) - p]}{\eta} \left(\frac{\pi(1-\tau(1-\alpha))}{(1+\pi)\delta} \right)^{\frac{\alpha}{1-\alpha}} \tag{B.16}$$

$$= \tilde{c} \cdot \left(\frac{\pi}{1+\pi} \right)^{\frac{\alpha}{1-\alpha}} \tag{B.17}$$

where $\tilde{c}$ is a constant that only depends on parameter values. Multiplicity of steady states occurs if $E(\underline{\pi}) < \tilde{E} < E(\bar{\pi})$.

APPENDIX C: METHODOLOGY

To obtain as many relevant contributions as possible, we carried out a literature review in July 2020 using the abstract and citation database Scopus and the database search engine Web of Science. Additionally, we used the web search engine Google Scholar for backward and forward reference searching. We checked for new references twice in January and October 2021. To limit the number of search results, we limited the subject area in Scopus to relevant fields, which yielded a total of 639 references. We further excluded specific keywords from other research fields, leading to a total of 419 references. Table C.1 provides an overview of search terms and number of results. We

TABLE C.1 Search strategy.

Source	Search terms	Results
Scopus	ALL((“Overlapping generations” OR “OLG”) AND (“Environment*” OR “Pollution”) AND (“life expectancy” OR “mortality” OR “Longevity” OR “lifetime” OR “survival”)) AND (LIMIT-TO(SUBJAREA, “ECON”) OR LIMIT-TO(SUBJAREA, “ENVI”) OR LIMIT-TO(SUBJAREA, “SOCI”)OR LIMIT-TO(SUBJAREA, “BUSI”) OR LIMIT-TO(SUBJAREA, “MULT”) OR LIMIT-TO(SUBJAREA, “MATH”) OR LIMIT-TO(SUBJAREA, “EART”) OR LIMIT-TO(SUBJAREA, “PSYC”) OR LIMIT-TO(SUBJAREA, “ARTS”) ORLIMIT-TO(SUBJAREA, “ENER”) OR LIMIT-TO(SUBJAREA, “DECI”) OR LIMIT-TO(SUBJAREA, “Undefined”)) AND PUBYEAR > 2004	419
Web of Science	ALL FIELDS: ((“Overlapping generations” OR “OLG”)) AND ALL FIELDS: ((“Environment” OR ”Pollution”)) AND ALL FIELDS: ((“life expectancy” OR “longevity” OR “mortality” OR “lifetime” OR “survival”))	33
Google Scholar	Backward & forward reference searching	5

selected the final list of references according to predefined criteria: The papers included had to present an OLG model with life expectancy endogenously depending on pollution or environmental quality. In total, we found 22 studies that met our search criteria. We then performed backward and forward reference searching, yielding another four working papers (two of which have been published since) and one book chapter.