# An extended OLG model for solving the Global Commons problem through intergenerational concern

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**Abstract:**

Udalov (2014) extended a collective goods problem through an Overlapping Generations Model where there is a decision regarding the type of energy use, either fossil fuel versus renewable use energy. Udalov introduced a politico-economic equilibrium contingent on the effort or commitment on renewable energy. We provide his framework but further extended it, by using an eta parameter which provides intergenerational concern among different generations, old versus youngsters. We depart from non-existent Udalov non-concern of intergenerational generations, and extend it to use a parameter – eta – which reflects this concern.

We further provide a game, in the sense of game theory, where the politico economic equilibrium is contingent on the intergenerational concern, which reflects strategic interaction among youngsters and old people. Some politico-economic results at hand. As higher intergenerational concern - eta parameter-a tribute to Stern's (2004) report, the faster the pace of recuperation of a global common good, the lower level of pollution, and politico-economic equilibria recovers the fastest (m) the investment in renewable energy.

**Key-words:** OLG model; Fossil versus renewable energy; Intergenerational concern; Pollution; Global commons. **JEL Codes:** C70; D64; D70; O13; O19.

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# 1. Introduction

This paper approaches the issue of global commons, that is a global common good that encompasses the traditional pure public definition: i) non-rivalry in consumption; ii) impossibility of exclusion; iii) impossibility of refusal or denial. National defence is a case of a pure public good. The global environment is also a pure common global good, as it is well know in traditional economics literature. Pollution does not stop at physical boundaries, as defined by national or geo-strategic and defence stances. So, our environmental approaches must tackle the issue of an environmental common good.

So, Garret Hardin (1968) has defined the famous over-exploitation of common goods, namely natural grazing land, which would be overexploited by the non-definition of property.

Coase (1960) defined the famous theorem (which led him to a Nobel prize), that the clear attribution of private property rights to either clean atmosphere or polluted one would exactly yield the same amount of external effect, that is the same level of negative externality, thus pollution. Its main caveat was the assumption of non-existence of income effects, due to the neutrality caused by quasi-linear utility preferences. Nevertheless, it remains relevant, and if we take into account income effects, one is led to assign more favourably to clean air, as the redistribution effect would come from polluters to cleaners.

Either way, the principle of paying-polluter principle, was forged by Pigou in the early 20s of the 1920's, (Pigou, 1926).

Recently, models of Integrated Assessment by Nordhaus since the early 1970s become widespread, and Nordhaus is recognized as by assigning a low discount rate, or preference for the future. Nordhaus (2019) was given the Nobel Prize in economics for his contribution to the environment, sharing it with Romer, for the growth economics of ideas.

This paper uses a standard neoclassical approach, we use the Overlapping Generations Model, first created by Allais (1947) and Samuelson (1958), and further extended by Diamond (1965).

John and Pechenino (1994) were the first to introduce the environmental assessment within an OLG model.

Udalov (2018) introduced a behavioural model of an OLG with environmental assessment.

We further extended it by a parameter of intergenerational concern, an eta, a new parameter in the utility function.

# 2. Theme and motivation

The theme of this investigation is based on how intergenerational concern can reverse the catastrophic scenario of climate change. In practice, an extension of the overlapping generations model - OLG (overlapping generations) model - proposed by Udalov (2018) was carried out. Subsequently, strategic interaction was resorted to, through Game Theory, between the young and elderly generations.

The term "ecocide (…) ecological + suicide" (Caleiro et al., 2019) acquires, every day, more importance, however, beyond this point of view directed to the "tragedy of the commons", in the development of the topic, in order to reverse the worst scenario, viable solutions are sought. The appeal to altruism plays a key role in this challenge, in order to guarantee the sustainable development of planet Earth. It is understood that Becker's notion of altruism (G. S. Becker, 1976, 1996), based on an individual's concern for the other - the direct dependence of an individual's utility function on another - is essential to solve the alterations weather.

Cooperation is the process in which groups of organisms act together for common benefit, rather than competing for their own benefit. When this does not occur voluntarily, it is essential to encourage it in order to promote environmental sustainability, preventing agents from behaving independently and only in accordance with their own interests. Since cooperation between individuals has always existed and is essential in maintaining populations, clarifying how it emerges and maintains itself, removing the (rational) selfishness that is predicted by classical economics, the discussion of this problem remains open. The challenge that is proposed is to encourage cooperation, because if the status quo is verified, our planet will be unsustainable in future generations.

## 3. Object of study and Aim or goal of research

In general, the object of study is climate change, defined by the Intergovernmental Panel for Climate Change (IPCC - International Panel for Climate Change) as the rise in temperature caused by greenhouse gas (GHG) emissions (IPCC, 2023) and its direct and indirect impacts. But, more specifically, as it is a dissertation in Economics, the socioeconomic impacts are analyzed, through the analysis of utility functions of overlapping generations and of collective social well-being.

The objective is to understand how the emergence of altruism can be the key to solving the problem. Our proposal is to introduce altruism through concern, not just contemporary between generations, but a true intertemporal intergenerational concern. In other words, we introduced a true “dynastic” concern into an OLG model ad infinitum, thus avoiding socioeconomic and environmental “myopia”.

In this way, the innovative factor of the study is precisely to introduce a parameter ($\eta$) that reflects this aspect in the utility function, and to verify the physical impacts (of the OLG model) and the socioeconomic impacts, through an evaluation of well-being.

Thus, its immediate and medium/long term consequences will be verified, and from there to assess possibilities of implementing viable environmental economic policies. Through the convergence between pure scientific research (algebraic mathematical models), theoretical research of economy and environment (simulated models), conclusions of environmental policy will be drawn.

It should be noted that this aspect of an intergenerational concern has been present in the discussion of the topic for a long time, namely with the seminal studies by Stern and Nordhaus (Nordhaus, 1977, 2018; Stern, 2007), thus proceeding to an extension of the Udalov's OLG model (Udalov, 2018, 2019).

## 3. The conventional problem: OLG and the UDALOV setting

The overlapping generations (OLG) model of Allais (1947), Samuelson (1958), and Diamond (1965) is the second basic model used in microeconomics macroeconomics. The name implies the structure, since, at any time, individuals from different generations, present simultaneously, can negotiate with each other. Each generation trades with other generations at different periods of life, and there are generations (yet to be born) whose preferences may not be accounted for in current market transactions (Allais, 1947; Diamond, 1965; Samuelson, 1958).

The model is widely applied, as it allows studying the aggregate implications of life-cycle savings by individuals. The capital stock is generated by individuals, who save during the active phase of their lives, to finance their consumption during retirement. This model is suitable for studying the determinants of the aggregate capital stock, as well as the effects of government policy (on the capital stock) and the well-being of different generations. It can also be extended to leave legacies, whether intentional or not (Blanchard & Fischer, 1989).

From an economic perspective, for there to be sustainability, intergenerational equity must be present. The distribution of rights and assets, between generations, determines whether the efficient allocation of resources sustains human well-being in the long term (Howarth & Norgaard, 1992).

There are several theoretical contributions that analyze environmental policy using an OLG model (Babu et al., 1997; Howarth & Norgaard, 1992; John et al., 1995; John & Pecchenino, 1994; Mariani et al., 2010; Ono, 2005; Ono & Maeda, 2001; Tubb, 2011; Udalov, 2014, 2018, 2019). On the one hand, there are models in which there is no environmental maintenance. Agents are unconcerned about pollution and social planners internalize externalities through taxes and transfers. Howarth and Norgaard (1992) present a model in which the externality, caused by pollution, does not affect the agents' utility. A tax is imposed on energy consumption in order to maximize the discounted sum of the lifetime utility of all generations. Babu et al. (1997) suggests the introduction of a specific tax, in order to correct the inefficiency originated by the environmental degradation, motivated by the excessive consumption of fossil fuels. Assuming that governments adopt short-term policies, ignoring the consequences on future generations, John et al. (1995) investigates the long-term effect of an environmental tax that maximizes the utility of all generations.

On the other hand, there are OLG models where the usefulness of the agents depends on the environmental quality. Under the assumption that individuals (young or old) live during two periods, working while young and consuming while old, they distribute their wages between investment in capital and environmental quality. John and Pecchenino (1994) are the pioneers in this area with the study of a potential conflict between economic growth and the maintenance of environmental quality.

Taking into account the maintenance of the environmental stock, there are models that additionally analyze the impact of environmental quality on the longevity of individuals and vice versa. Ono and Maeda (2001) analyze how aging affects the environment. Depending on risk aversion to consumption during renovation, aging can be both beneficial and harmful to the environment. Ono (2004) extends the model and investigates the impact of elderly empowerment on environmental policies. It shows that a greater longevity of society leads to environmental degradation, while a lower population growth rate contributes to an increase in environmental quality.

According to Mariani et al. (2009) agents can invest in environmental quality, depending on how long they expect to live. In turn, environmental conditions affect life expectancy. Finally, Tubb (2011) assumes that tax revenues can be spent either on environmental investments or on transfers to the elderly. An aging population increases political pressure to shift public spending in favor of transfers to retirees. However, as young people anticipate that greater longevity implies a greater return on such investment, aging may simultaneously increase the younger generation's demand for environmental investments. Thus there is a tension between the two generations regarding their preferences for government spending.

Udalov (2014, 2018, 2019), based on the OLG model suggested by John and Pecchenino (1994), presents a model with reference to political-economic voting, in terms of support for renewable energies. However, unlike John and Pecchenino (1994), where individuals invest in environmental maintenance, the decisions of individuals regarding their contributions to support renewable energies are considered. For this purpose, a Cobb-Douglas production function is used, with energy as an additional input. Being the level of energy prices, in a small open economy, considered exogenous. As young and old live in the same period, they have to decide simultaneously on their contributions to support renewable energy (Udalov, 2014, 2018, 2019).

Udadov (2018) states that, for young people, support for renewable energies has a positive effect on an individual's consumption in the following period, if the elasticity of renewable energy production is greater than the ratio of opportunity costs of renewable energies, in the sense of the loss of consumption, in the following period. Since long-term effects are discounted at their present value, the result of voting for young individuals is sensitive to changes in the discount rate, which represents the individual's intertemporal preference. A higher discount rate increases preferences for the present and has a negative effect on the level of support for renewables.

On the other hand, for the elderly, support for renewable energy negatively affects consumption and its utility in the current period. Therefore, they will not show any support for renewable energies. Through the results obtained, each generation in society has different preferences regarding the level of support for renewable energies, which will result in an intergenerational conflict between the present generations (Udalov, 2018).

# 4. An extension: the eta parameter and its newness and results

Based on the OLG model by Udalov (2018, 2019), which analyzes the optimal level of support for renewable energies by young and old, a new variable (**η** - intergenerational concern) is introduced, resulting in a new utility expression. The intergenerational concern is based on the recognition of the rights of future generations, assuming responsibility for our descendants. That is, demonstrating our care for those who follow us.

Thus, we intend to study the hypothesis that the elderly, in their current choices, will take into account the environmental quality of the following period, even assuming that they will no longer be present to enjoy this investment. Since Udalov (2014, 2018, 2019) assumes that individuals are not altruistic, which implies that the elderly do not care for the young and the young do not care about the elderly, with the inclusion of this feeling in the preferences of individuals, we intend to if there is economic and environmental sustainability (Udalov, 2014, 2018, 2019).

## 4.1. Individuals

Every period t comes a new generation and each one lives in two periods. First, when they represent the active population (young people) and then when they retire (elderly people). There are two generations alive in any period where they overlap.

Each young individual is entitled to a salary (wt) for his service to companies. Those who distribute their income between current consumption (ct), current savings (st) and support for renewable energies (mt). Thus, the budget constraint for a young agent in period t is:

$$w_t = c_t + s_t + m_t \tag{1}$$

Agents face a compromise between consumption and support for renewable energies. When elderly, individuals consume the return of savings and support renewable energies. The restriction for an elderly person born in period t is:

$$c_{t+1} = (1 + r_{t+1})s_t - m_{t+1} \tag{2}$$

Individuals born in period t have definite preferences regarding consumption and environmental quality (Env) in old age and youth. The benefits, which occur in period t+1, have to be discounted at the discount rate δ. Assuming that there is no intergenerational concern, these preferences are represented by the following utility function:

$$V_t = \ln c_t^1 + \ln Env_t + \frac{1}{1+\delta}(\ln c_{t+1}^2 + \ln Env_{t+1}) \tag{3}$$

Where Envt describes the environmental quality in period t and Envt+1 defines the environmental quality in period t+1.

With the introduction of the variable corresponding to the intergenerational concern (η), the representation of the new utility function (U) will be like this[3]:

$$U_t = \ln c_t^1 + \ln Env_t + \frac{1}{1+\delta}(\ln c_{t+1}^2 + \eta \ln Env_{t+1}) \tag{4}$$

## 4.2. Firms

The company produces a homogeneous good, using capital (K), labor (L) and energy (E) in each period. The neoclassical production function is given by:

$$Y_t = K_t^{\alpha} L_t^{\beta} E_t^{1-\alpha-\beta} \tag{5}$$

Energy is produced using two imperfect substitutes, namely fossil fuels (FE) and renewable energy (RE):

[3] To consult the steps taken up to the final expression, see Appendix A.1 (Pica, 2023, p. 77).

$$E_t = FE_t^{\gamma}(\sigma m_{t-1} RE_t)^{1-\gamma} \tag{6}$$

Prior period renewable energy support increases the amount of renewable energy used in the current period, and σ indicates the effectiveness of renewable energy support.

The firm's profit in period t is:

$$\pi_t = p_t K_t^{\alpha} L_t^{\beta} E_t^{1-\alpha-\beta} - w_t L_t - r_t K_t - p_t^E E_t \tag{7}$$

Assuming that it is a small open economy, facing wages ($w_t$), interest rates ($r_t$ and energy prices ($p_t^E$), each company chooses the levels of labour ($L_t$), capital ($K_t$) and energy ($E_t$) in order to maximize their profits.

So, the first-order conditions are:

$$r_t = \alpha p_t K_t^{\alpha-1} L_t^{\beta} E_t^{1-\alpha-\beta} \tag{8}$$

$$w_t = \beta p_t K_t^{\alpha} L_t^{\beta-1} E_t^{1-\alpha-\beta} \tag{9}$$

$$p_t^E = (1-\alpha-\beta) p_t K_t^{\alpha} L_t^{\beta} E_t^{-\alpha-\beta} \tag{10}$$

These constraints state that the firm hires labour, capital, and energy until marginal outputs equal factor prices. Due to the supposed condition of perfect competition, these conditions imply the compensation of factor markets.

## 4.3. Environmental quality

The level of environmental quality is reduced by aggregate consumption, but can be increased by supporting renewable energies. This mechanism is expressed according to the following formula:

$$Env_{t+1} = Env_t - \omega c_t + \pi m_t \tag{11}$$

The term ω represents the degradation of the environment as a result of consumption in period t, while π measures the environmental improvement as a result of supporting renewable energy.

Environmental quality has an inverse relationship with the increase in the concentration of $CO_2$ in the atmosphere and, in this sense, the increase in emissions that has occurred since the

Industrial Revolution and which has been increasingly accentuated is contributing to the degradation of the environment. environment. Therefore, the environmental quality has been decreasing and from now on we are faced with three scenarios (represented in the following figure), which depend, solely and exclusively, on human action.

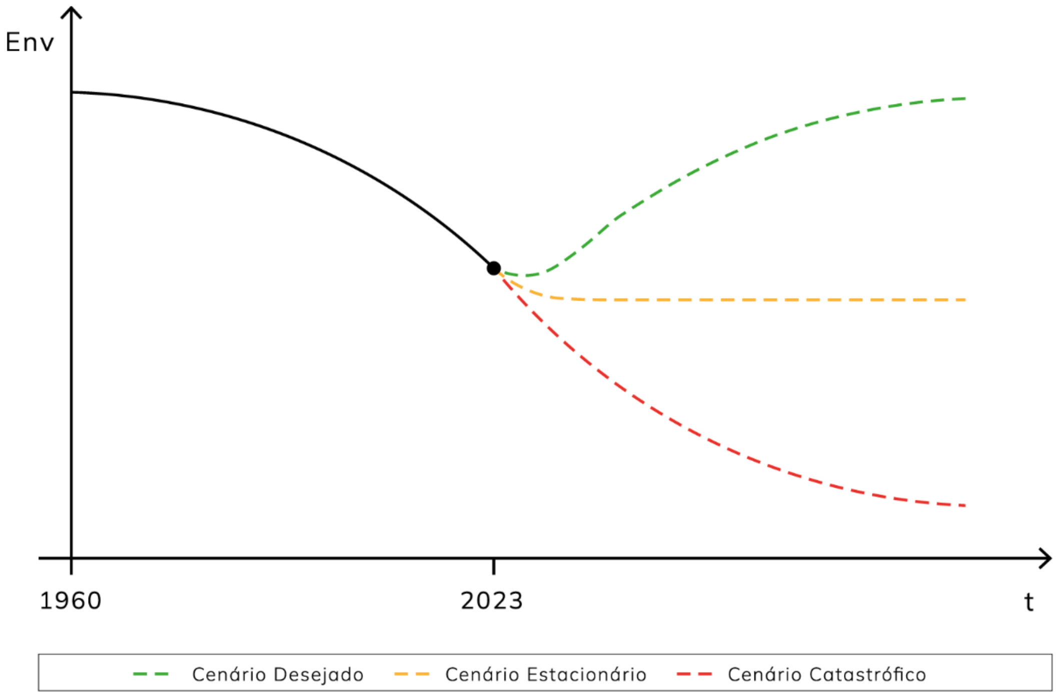


Figure 1: Evolution of environmental quality in the face of 3 scenarios

Source: Pica, 2023, fig.16

In the first scenario (Figure 1), we continue to increase $CO_2$ emissions through excessive consumption, ignoring future generations ($\pi\bar{m} < \omega\bar{c}$).. Thus, a catastrophic scenario is foreseen, represented in red dashed lines, in which the environmental quality decreases until its depletion ($Env_\infty < \ldots < Env_{t+1} < Env_t$).

Another possibility is to stagnate emissions by maintaining consumption ($\pi\bar{m} = \omega\bar{c}$), reaching a steady state, represented by the trajectory in yellow, in which the environmental quality will remain ($Env_t = Env_{t+1} = Env_\infty$).

Finally, the desired scenario, in which the population gives more value to environmental quality and supports renewable energies to the detriment of consumption ($\pi\bar{m} > \omega\bar{c}$). In this optimal scenario, displayed in green, with intergenerational concern playing a fundamental role, we can reverse the trend that has been proven and there will be an environmental improvement ($Env_\infty > \ldots > Env_{t+1} > Env_t$).

## 4.4. Youngsters

The two groups of individuals vote on the level of contributions to support renewable energy, maximizing the corresponding utility function with respect to mt. When the target individuals are young people, we only study the case in which there is intergenerational concern, as they will be in the following period and will be able to enjoy the environmental quality in that period. The U utility expression will be used. Thus, the maximization problem faced by young individuals corresponds to:

$$\max\ U_t^{young} = \ln c_t^1 + \ln Env_t + \frac{1}{1+\delta}(\ln c_{t+1}^2 + \eta \ln Env_{t+1}) \tag{12}$$

Subject to

$$c_t^1 = w_t - s_t - m_t$$

$$c_{t+1}^2 = (1 + r_{t+1})s_t - m_{t+1}$$

$$r_{t+1} = \alpha p_{t+1} K_{t+1}^{\alpha-1} L_{t+1}^{\beta} E_{t+1}^{1-\alpha-\beta}$$

$$E_{t+1} = FE_{t+1}^{\gamma}(\sigma m_t RE_{t+1})^{1-\gamma}$$

$$Env_{t+1} = Env_t - \omega c_t + \pi m_t$$

Inserting the aforementioned restrictions, the corresponding utility function of young individuals can be derived as:

$$\begin{aligned} U_t^{young} &= \ln(w_t - s_t - m_t) + \ln Env_t \\ &+ \frac{1}{1+\delta}\ln\left[\left(1 + \alpha p_{t+1} K_{t+1}^{\alpha-1} L_{t+1}^{\beta}\left(FE_{t+1}^{\gamma}(\sigma m_t RE_{t+1})^{1-\gamma}\right)^{1-\alpha-\beta}\right)\right. \\ &\left. * (w_t - c_t^1 - m_t) - m_{t+1}\right] + \frac{1}{1+\delta}\eta \ln(Env_t - \omega c_t + \pi m_t) \end{aligned} \tag{13}$$

In order to determine the optimal level of support for renewable energies by young people, the above role has to be differentiated in order of $m_t$[4]:

$$\frac{\partial U_t^{young}}{\partial m_t} = 0 \Leftrightarrow$$

$$\Leftrightarrow -\frac{1}{c_t^1} + \frac{1}{1+\delta}\left(\frac{(1-\gamma)(1-\alpha-\beta)\frac{s_t}{m_t} r_{t+1} - (1 + r_{t+1})}{c_{t+1}^2}\right) + \frac{\eta}{1+\delta} * \frac{\pi}{Env_{t+1}} = 0 \tag{14}$$

In period t, there is a negative effect $\left(-\frac{1}{c_t^1}\right)$ caused by the negative impact of $m_t$ on consumption. According to equation (11) there is an environmental improvement $\left(\frac{\eta}{1+\delta} * \frac{\pi}{Env_{t+1}}\right)$ in period t+1, as a result of support for renewable energies. However, support for renewable energies has an ambiguous effect on consumption in period t+1:

[4] See A.2 (Pica, 2023, p. 78).

$$\frac{1}{1+\delta}\left(\frac{(1-\gamma)(1-\alpha-\beta)\frac{s_t}{m_t}r_{t+1}-(1+r_{t+1})}{c_{t+1}^2}\right) \tag{15}$$

On the one hand, according to equations (2), (6) and (8), support for renewable energies increases an individual's consumption in period t+1. On the other hand, since there is a trade-off between renewable energy support and savings in period t, an increase in renewable energy support has a negative effect on consumption in period t+1 due to (1) and (2). The overall effect of mt on an individual's consumption in period t+1 is positive if the following inequality condition is met:

$$(1-\gamma)(1-\alpha-\beta) > \frac{(1+r_{t+1})m_t}{r_{t+1}s_t} \tag{16}$$

Thus, the effect of mt on an individual's consumption in period t+1 is positive, if the elasticity of RE production is greater than the ratio of opportunity costs of renewable energy, in the sense of loss of consumption, to income savings, in period t+1.

Younger individuals will vote for a level of $m_t$ that balances negative and positive effects so that $\frac{\partial U_t^{young}}{\partial m_t} = 0$. Since long-term effects, which occur in the future, are discounted at their present value, the result of voting for young individuals is sensitive to changes in the discount rate δ, which represents the individual's intertemporal preference. A higher δ increases preferences for the present and has a negative effect on the level of support for renewables (Udalov, 2018).

Deriving utility as a function of environmental quality[5]:

$$\frac{\partial U_t^{young}}{\partial Env_t} = 0 \Leftrightarrow \frac{1}{Env_t} + \frac{\eta}{(1+\delta)Env_{t+1}} = 0 \tag{17}$$

Intergenerational concern, in period t, has a positive effect on environmental quality in t+1. From expression (17) one can derive the marginal rate of substitution between present and future environmental quality $TMS_{Env_{t+1};Env_t}$. TMS measures the rate at which an individual is willing to give up one good for another, keeping his level of satisfaction constant[6].

$$TMS_{Env_{t+1};Env_t} = \frac{\eta}{(1+\delta)} \tag{18}$$

In this case, TMS corresponds to the rate at which a young person gives up environmental quality in the present in exchange for environmental quality in the future. From expression (18) we

[5] See A.2 (Pica, 2023, p. 78).
[6] See A.2 (Pica, 2023, p. 79).

conclude that the greater the intergenerational concern and the lower the discount rate, the more importance the individual will give to environmental quality in the following period.

Regarding optimal consumption[7]:

$$\frac{\partial U_t^{young}}{\partial c_t^1} = 0 \Leftrightarrow \frac{1}{c_t^1} - \frac{1}{1+\delta}\left(\frac{1+r_{t+1}}{c_{t+1}^2} + \frac{\eta\omega}{Env_{t+1}}\right) = 0 \tag{19}$$

Consumption has a positive effect on young people's utility and a negative relationship with generational concern and environmental quality in the following period.

Introducing the expression relative to optimal environmental quality, in a steady state situation, we can analyze how consumption by environmental quality evolves, through the ratio between $\bar{c}$ an $\overline{Env}$:[8]

$$\frac{\bar{c}}{\overline{Env}} = \left(\frac{\bar{r}-\delta}{1+\delta}\right)\frac{\omega}{\eta} \tag{20}$$

$(c_t^1 = c_{t+1}^2 = \bar{c}\,;\ Env_t = Env_{t+1} = \overline{Env}\,;\ r_{t+1} = \bar{r})$

Bearing in mind that it makes no sense for an individual's consumption to show negative values, a reference constant ($\mu^1$) is added, representing the value of consumption, for young people. Thus, the greater the value of the constant, the greater the base importance that consumption represents in the utility of this generation.

$$\left[\frac{\bar{c}}{\overline{Env}}\right]^{young} = \left(\frac{\bar{r}-\delta}{1+\delta}\right)\frac{\omega}{\eta} + \mu^1 \tag{21}$$

For a better evaluation, deterministic simulations were used, parameterizing the variables r,δ,η,ω and $\mu^1$ (0.5%≤r̅≤10%, 0.5%≤δ≤10.5%, 0, 1≤η≤20, 0.1≤ω≤20 and $\mu^1$=1 or 10), through Excel. The following figures (17 to 26) contain surfaces that illustrate, on three axes, the size of the temporal trade-off between the intertemporal discount rate (δ), that is, how time is evaluated in the utility function of each generation; the interest rate (r), which evaluates time as the opportunity cost of market resources; and consumption, by environmental quality (c̅/(Env)̅ ), which assesses how young people value consumption to the detriment of the environmental stock, over time.

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[7] See A.2 (Pica, 2023, p. 78).

[8] See A.2 (Pica, 2023, p. 79).

First, we will analyze the case in which young people give less importance to consumption ($\mu^1$=1).

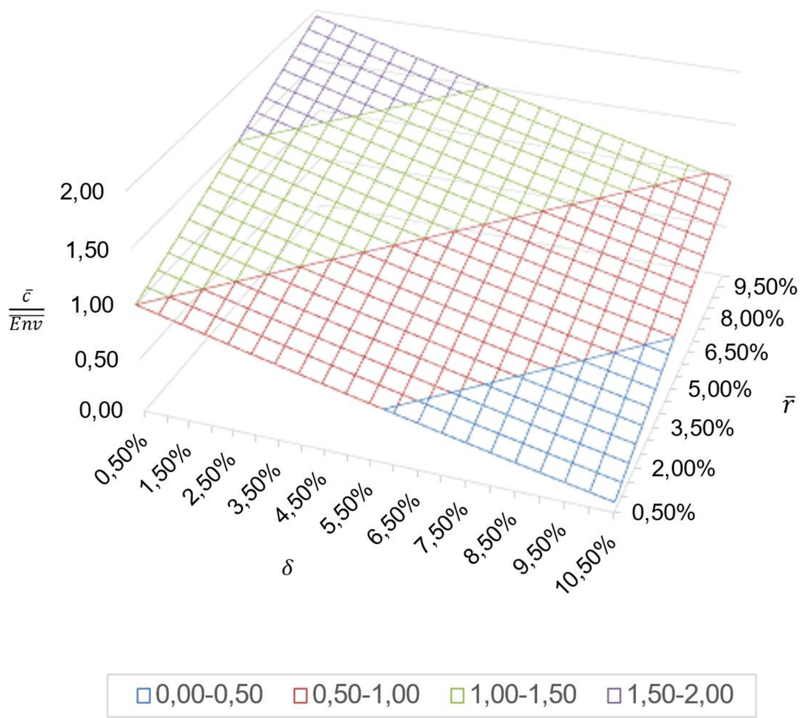


Figure 2: Evolution of consumption by environmental quality (η=0.1, ω=1 and $\mu^1$=1)

Source: Pica, 2023

Figure 2 shows a rather low intergenerational concern value and reasonable environmental degradation (η=0.1 and ω=1). To guarantee the steady state balance of young people, assuming a low level of consumption, due to environmental quality (values between 0 and 1), there must be a low interest rate and a high discount rate. On the contrary, if the interest rate is high and the intertemporal discount rate is low, then the surface has higher levels of consumption, due to environmental quality (values between 1 and 2).

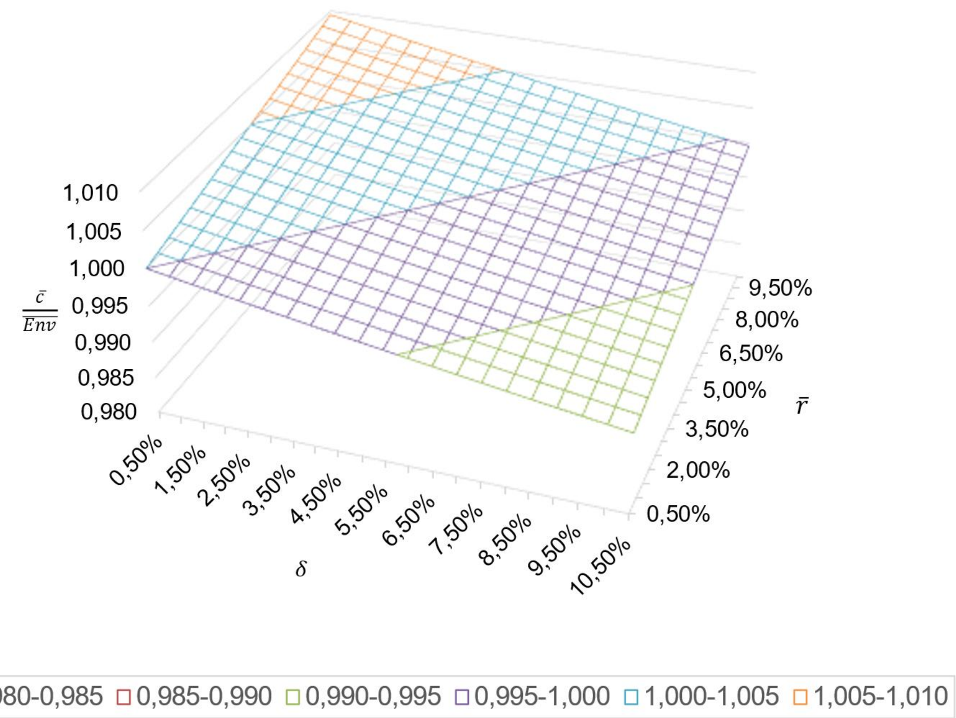


Figure 3: Evolution of consumption by environmental quality (η=1, ω=0.1 and $\mu^1$=1)

Source: Pica, 2023

In the following case (Figure 3) the scenario for η and ω is reversed (η=0.1 and ω=1). Thus, it appears that with values of intergenerational concern greater than those of environmental degradation, there is a slight break in the consumption interval, around one unit. However, the environmental degradation presenting such low values (0.1), which means that the consumption presents a low degradation, allows to have a surface with smaller variations. Consumption, by environmental stock, thus varies between values from 0.98 to 1.01, resulting in a very flat surface around 1. Once again, consumption has a direct proportional relationship with the interest rate, while with the intertemporal discount rate it is inversely proportional.

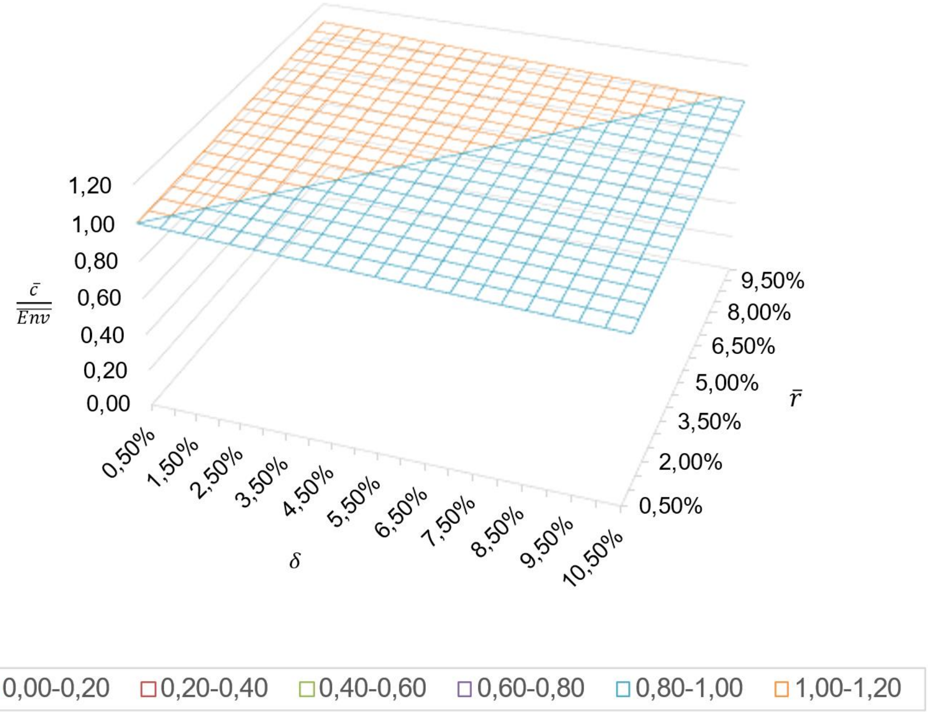


Figure 4: Evolution of consumption by environmental quality (η=1, ω=1 and $\mu^1$=1)

Source: Pica, 2023.

On the surface of Figure 4, intergenerational concern and environmental degradation caused by consumption represent a trade-off between the two. In this case, they assume the same value (η=1 and ω=1) and show some stability on the simulated surface. Young people's surface area of environmental consumption varies around 1 (values between 0.8 and 1.2), but this increase in environmental degradation, relative to Figure 18, requires greater trade-offs between discount rates and interest rate, ceteris paribus, showing higher values. However, compared to Figure 17, consumption has lower values, because it increases intergenerational concern.

Simulations with η=2, ω=1 and $\mu^1$=1 and with η=1, ω=2 and $\mu^1$=1 can be found in Appendix[9]. These balance surfaces and their analysis are similar to the previous ones and, thus, complement and prove the analysis carried out.

[9] See A.2 (Pica, 2023, pp. 79 and 80).

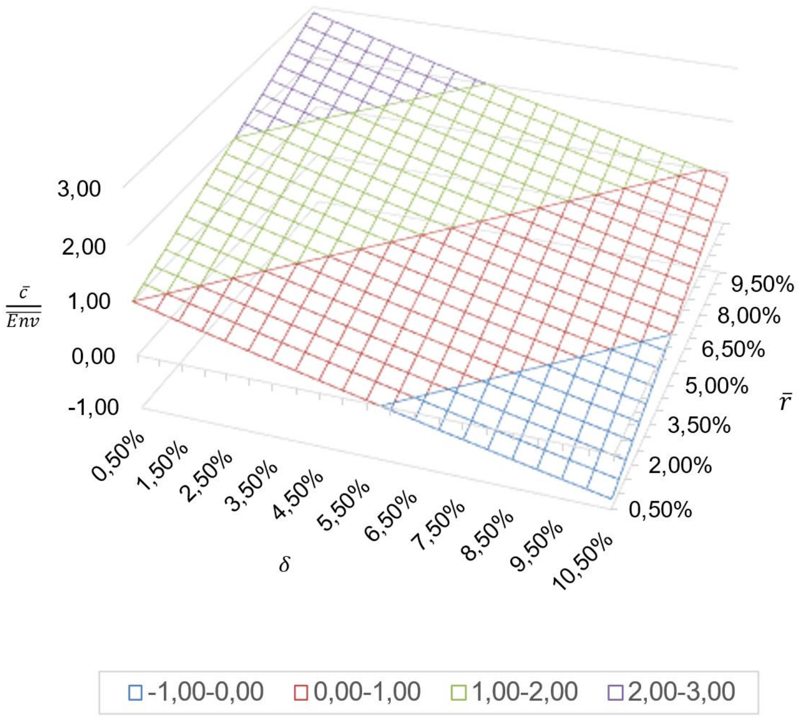


Figure 5: Evolution of consumption by environmental quality (η=1, ω=20 and $\mu^1$=1)

Source: Pica, 2023

In the case of Figure 5, the degradation is so accentuated (η=1 and ω=20) that the balance of consumption, by environmental quality, reaches negative values (the surface area in blue). Since we restrict ourselves to positive environmental consumption, its interpretation may be limited to the positive factor, or, eventually, to negative externalities and economic ills. For simplicity, we will truncate it to the positive ortant. In Appendix are parameterized simulations (with $\mu^1$=10) so that the consumption is limited to the positive ortant [10].

It should be noted that, as in the previous figures, the steady state balance of young people revolves around the value of the constant that reflects the importance of consumption ( $\mu^1$). However, as environmental degradation assumes such a high value, the trade-offs between discount and interest rates are very high. In such a way that the environmental consumption of young people fluctuates up to 3 units.

[10] See A.2 (Pica, 2023, p. 84).

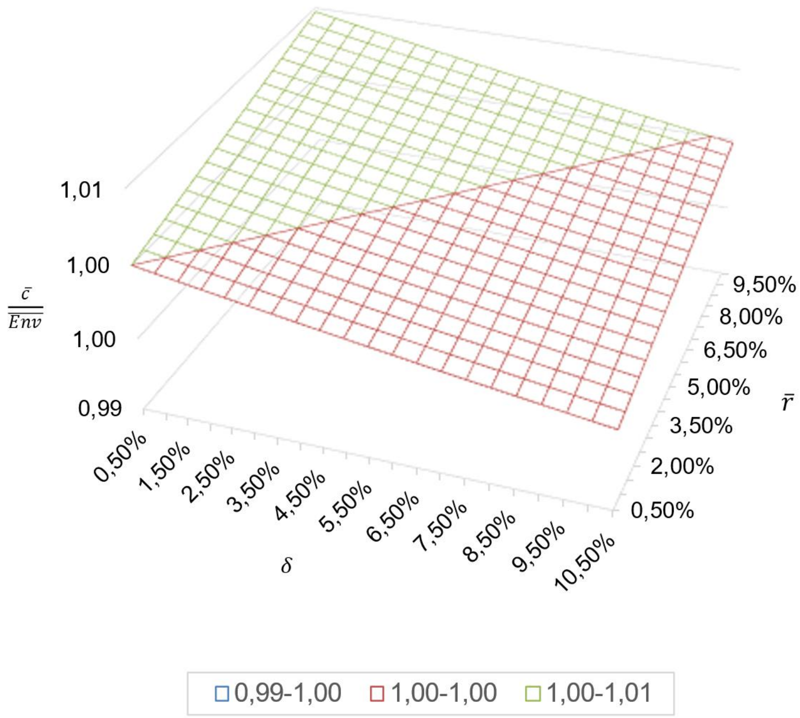


Figure 6: Evolution of consumption by environmental quality (η=20, ω=1 and $\mu^1$=1)

Source: Pica, 2023.

Figure 6 shows that a very substantial increase in intergenerational concern (η=20 and ω=1), the central theme of this dissertation, results in an equilibrium surface of environmental consumption oscillating, again, around unity, but in a very stable. The consumption surface, by environmental quality, for young people shows values between 0.99 and 1.01.

The two previous graphs (Figures 20 and 21) calculate and demonstrate that the consumption equilibrium surface, by environmental stock, is very sensitive to environmental degradation, and, at the same time, that an increase in intergenerational concern, in the face of environmental degradation, translates into a stabilization of consumption.

Subsequently, similar simulations are used, however, the importance of consumption in young people's utility is increased ( $\mu^1$=10). With this parameterization, the balance surfaces start to oscillate, slightly or strongly, around the 10 consumption units, according to environmental quality. These demonstrations and respective analyzes can be found in Appendix[11] .

## 4.5. Elderly

Since pensioners are not present in the following period, we are faced with two scenarios. In the first, the elderly do not want to leave a legacy of environmental quality after they die, consuming as much as possible and ignoring the next generations (without intergenerational concern). In the second, they are concerned with future generations and are interested in the quality of the future environment, even if they are not present to enjoy it (with intergenerational concern). Therefore, we will analyze these two possibilities.

[11] See A.2 (Pica, 2023, pp. 81, 82, 83 and 84)

## 4.5.1 Elderly - No Intergenerational Concern (η=0)

With regard to the elderly, they cannot enjoy, in terms of their well-being, possible benefits from the positive effect of consumption, in period t+1. And, as there is no intergenerational concern, they also do not benefit from improvements in environmental quality in the following period. Thus, its maximization problem, in period t, is obtained by the utility V:

$$\max \ V_t^{old} = \ln c_t^2 + \ln Env_t \tag{22}$$
$$s.a.$$
$$c_t^2 = (1 + r_t)s_{t-1} - m_t$$

Inserting the above constraint in the objective function, the pensioners' utility function is as follows:

$$V_t^{old} = \ln\big((1 + r_t)s_{t-1} - m_t\big) + \ln Env_t \tag{23}$$

To estimate the optimal level of renewable energy support for seniors[12]:

$$\frac{\partial V_t^{old}}{\partial m_t} = 0 \Leftrightarrow -\frac{1}{c_t^2} < 0 \tag{24}$$

As we can see, support for renewable energies negatively affects the consumption and utility of the elderly, in period t. These would be against supporting renewable energies and would vote for a minimum level of mt, resulting in an intergenerational conflict.

## 4.5.1 Elderly - With Intergenerational Concern (η>0)

In this case it is assumed that there is dynastic concern. The non-use of the effect of consumption in t+1 remains, however, the elderly will be able to improve their well-being by increasing the environmental quality in the following period. Then, the maximization problem, in period t, passes to:

$$\max \ U_t^{old} = \ln c_t^2 + \ln Env_t + \frac{\eta}{1+\delta} \ln Env_{t+1} \tag{25}$$

Subject to

$$c_t^2 = (1 + r_t)s_{t-1} - m_t$$
$$Env_{t+1} = Env_t - \omega c_t + \pi m_t$$

[12] See A.3 (Pica, 2023, p. 85).

Entering restrictions:

$$U_t^{old} = \ln[(1+r_t)s_{t-1} - m_t] + \ln Env_t + \frac{\eta}{1+\delta}\ln(Env_t - \omega c_t + \pi m_t) \qquad (26)$$

To estimate the optimal level of retiree support for renewable energy:[13]

$$\frac{\partial U_t^{old}}{\partial m_t} = 0 \Leftrightarrow -\frac{1}{c_t^2} + \frac{\pi\eta}{Env_{t+1}(1+\delta)} = 0 \qquad (27)$$

Support for renewable energies negatively affects consumption, however with the introduction of the intergenerational concern factor, it is confirmed that m positively affects the utility of the elderly in period t.

With regard to optimal environmental quality, it is concluded that the degree of satisfaction of the elderly person increases, and intergenerational concern has a positive effect on environmental quality in period t+1.

$$\frac{\partial U_t^{old}}{\partial Env_t} = 0 \Leftrightarrow \frac{1}{Env_t} + \frac{\eta}{Env_{t+1}(1+\delta)} = 0 \qquad (28)$$

The expression is identical to that of young people, and therefore $TMS_{Env_{t+1};Env_t}$ has the same interpretation.[14]

In order to estimate the optimal level of consumption by the elderly, their utility function has to be differentiated with respect to $c_t^2$:[15]

$$\frac{\partial U_t^{old}}{\partial c_t^2} = 0 \Leftrightarrow \frac{1}{c_t^2} - \frac{\omega\eta}{Env_{t+1}(1+\delta)} = 0 \qquad (29)$$

Consumption has a positive effect on the utility of the elderly, but has a negative relationship with environmental quality in the following period.

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[13] See A.4 (Pica, 2023, p. 86).
[14] See A.2 (Pica, 2023, p. 79).
[15] See A.4 (Pica, 2023, p. 86).

Introducing the expression relative to optimal environmental quality, in a steady state situation, we obtain the condition of consumption by environmental quality $\left(\frac{\bar{c}}{\overline{Env}}\right)$:[16]

$$\frac{\bar{c}}{\overline{Env}} = -\frac{1}{\omega} \tag{30}$$

For the results to always have positive values, a constant representative of the reference value for consumption by the elderly ($\mu^2$) is added.

$$\left[\frac{\bar{c}}{\overline{Env}}\right]^{old} = -\frac{1}{\omega} + \mu^2 \tag{31}$$

Figure 7 shows the behaviour of consumption by environmental stock $\left(\frac{\bar{c}}{\overline{Env}}\right)$in the face of changes in environmental degradation caused by consumption by the elderly (0.1≤ω≤20), according to four scenarios ($\mu^2$=10; $\mu^2$=20; $\mu^2$=30; $\mu^2$=40).

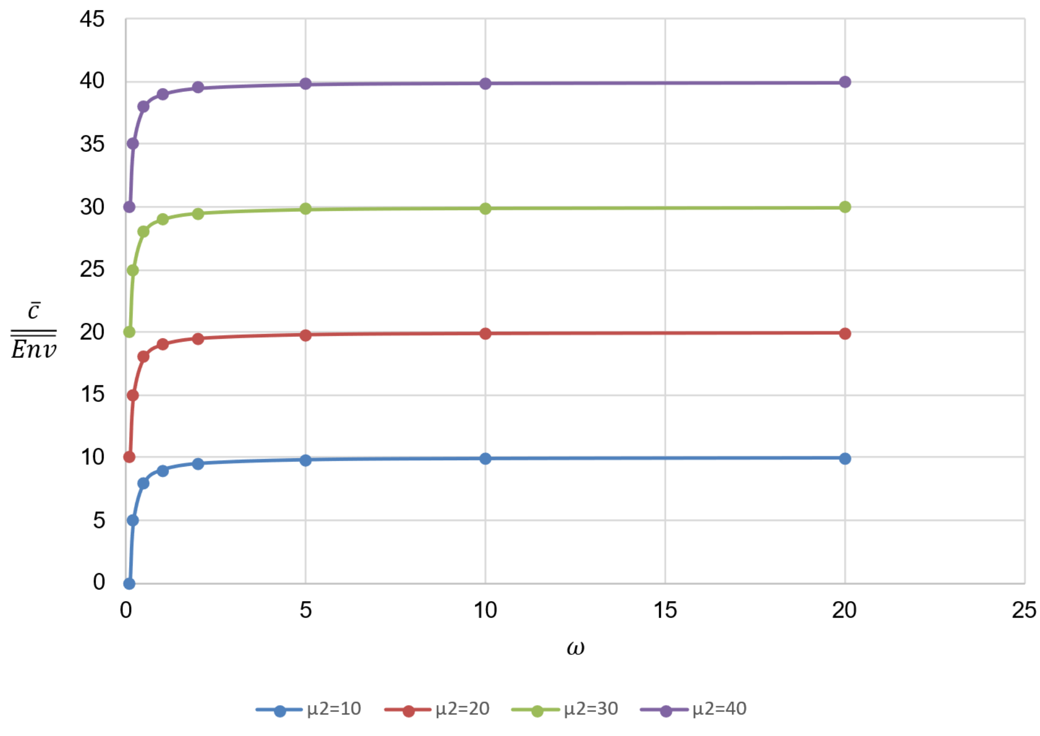


Figure 7: Evolution of consumption by environmental quality (0.1≤ω≤20)

Source: Pica, 2023.

[16]See A.4 (Pica, 2023, p. 87).

Consumption by the elderly, per unit of environmental quality, tends to converge to the assumed mean steady state parameter. For example, if $\mu^2$=10, the consumption values converge to 10, if $\mu^2$=20, the consumption values converge to 20 and so on. The function represents a family of parametric rectangular hyperbolas in $\mu^2$. As environmental degradation increases, consumption, by environmental quality, also increases.

## 5. Strategic Interaction – Nash Equilibrium – Deterministic Solutions

This chapter resorts to the strategic interaction between the young and elderly generations. Based on Game Theory, the optimal correspondence of young people intersected with that of the elderly results in a Nash equilibrium surface (NE), which once reached, no one has incentives to deviate, considering a situation of pure strategies (Nash, 1950a, 1950b).

Equating the two expressions, as a function of η (intergenerational concern), we get:[17]

$$\left[\frac{\bar{c}}{\overline{Env}}\right]^{young} = \left[\frac{\bar{c}}{\overline{Env}}\right]^{old} \Leftrightarrow \eta = (-\omega + \mu^*)\frac{\omega(\bar{r} - \delta)}{(1 + \delta)} \tag{32}$$

with $\mu^2 - \mu^1 = \mu^*$.

The following figures (8 to 19) contain surfaces contingent on the model parameters $\bar{r}$, δ and ω (0.5%≤$\bar{r}$≤10%,0.5%≤δ≤10.5%,0.1≤ω ≤20 and $\mu^*$=1 or $\mu^*$=10 or $\mu^*$=20), respectively, real interest rate, intertemporal discount rate and the parameter of environmental degradation by consumption. These surfaces in question illustrate, in three axes, the size of the temporal trade-off between, the intertemporal discount rate (δ), that is, how time is evaluated in the utility function of each generation; the market capitalization rate (r), which evaluates time as the opportunity cost of market resources; and intergenerational concern (η), which assesses how each generation cares about the others over time. The black line limits the Nash equilibrium frontier. The EN is the vector subspace generated between the two lines up to infinity. In this case, the parameters limit the surface of EN in a triangle. Therefore, if $\bar{r}$ and δ grow, the surface of EN follows the lines.

Initially, we present the case in which the young generation gives more importance to consumption than the elderly generation, that is, when the parameter differential

$\mu^2 - \mu^1 = \mu^* < 0$. In our simulated case we consider $\mu^*$=-10.

[17] See A.5 (Pica, 2023, p. 87).

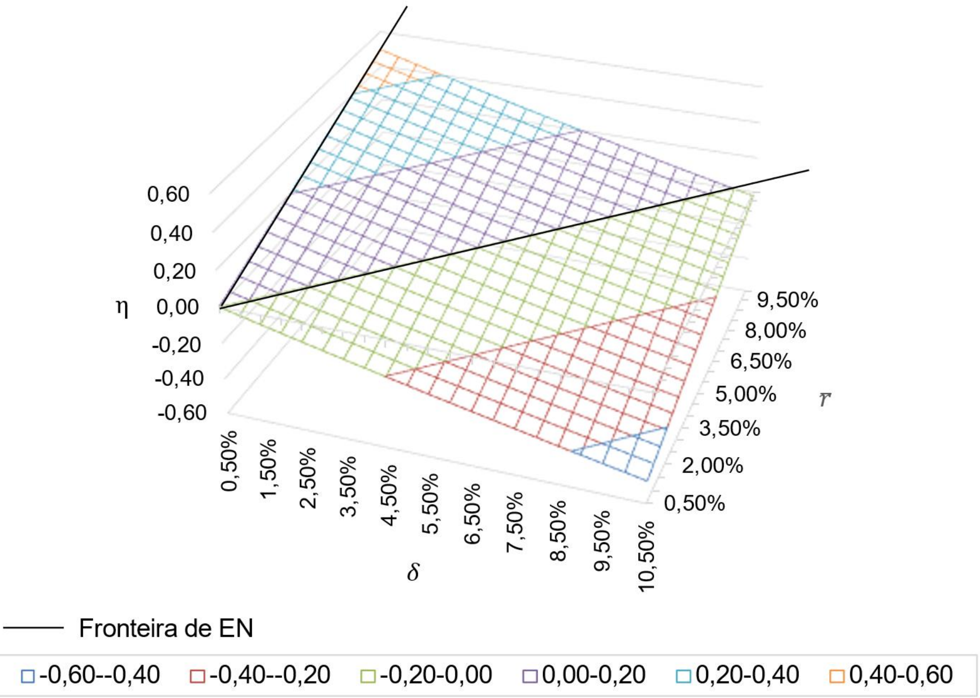


Figure 8: Intergenerational Concern NE Surface (ω=0.5 and μ*=-10). Source: Pica, 2023.

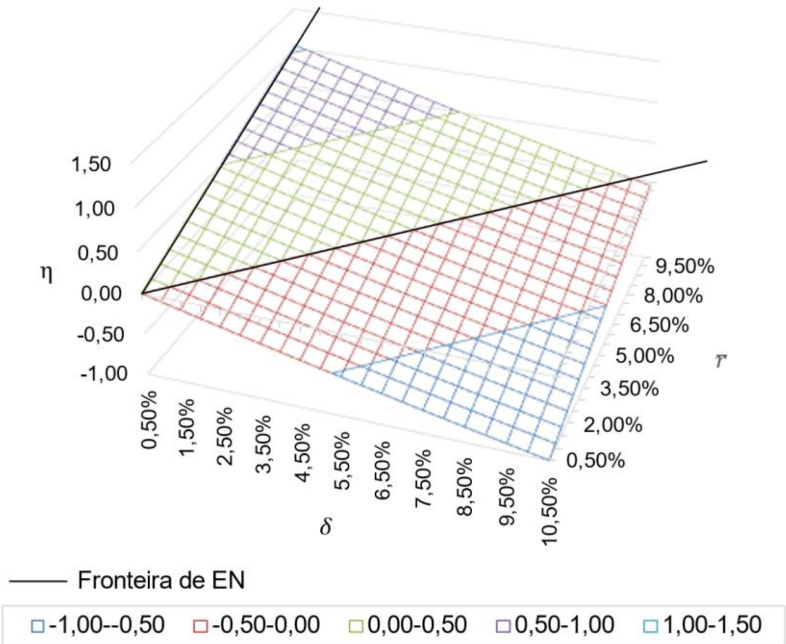


Figure 9: Surface of NE of Intergenerational Concern (ω=1 and μ*=-10). Source: Pica, 2023.

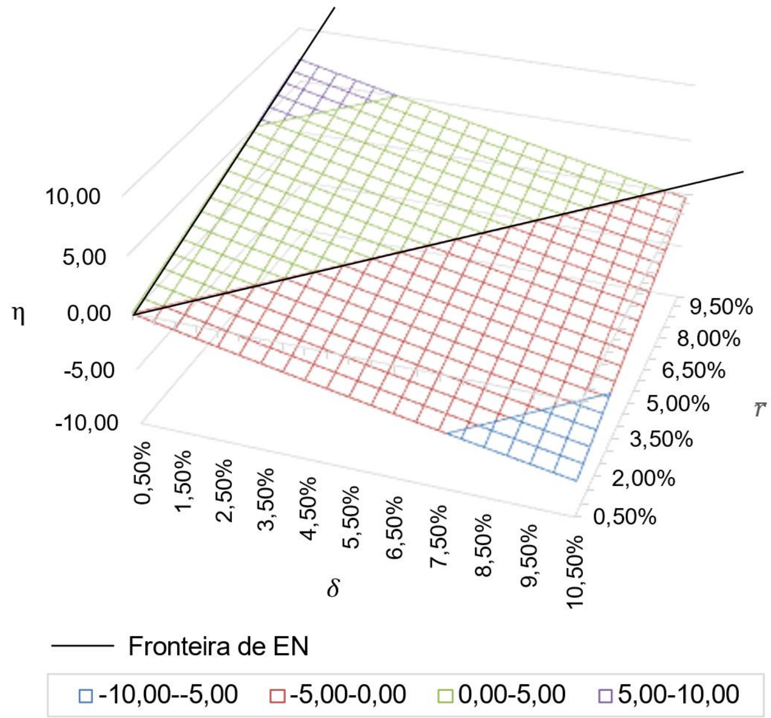


Figure 10: Surface of NE of Intergenerational Concern (ω=5 and μ* = -10). Source: Pica, 2023.

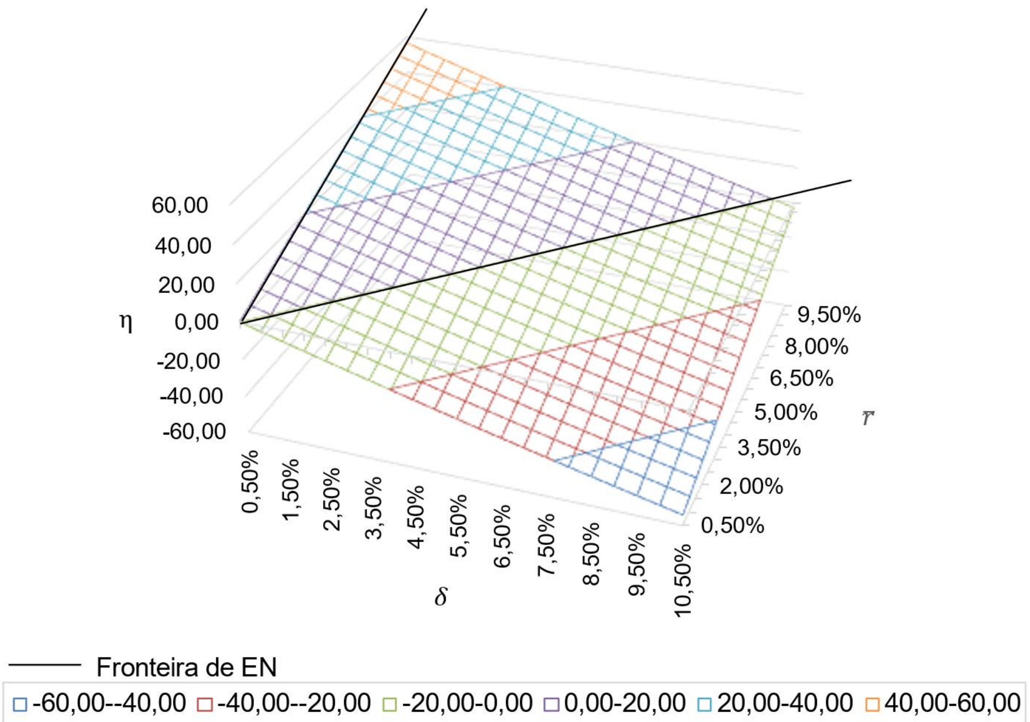


Figure 11: Surface of NE of Intergenerational Concern (ω=20 and μ* = -10). Source: Pica, 2023.

In the previous charts (Figures 8 to 11) the intergenerational concern of NE grows proportionally with the interest rate. Regarding the first two figures, when environmental degradation, caused by consumption, assumes low values (0.5≤ω≤1) a sustainable Nash equilibrium is reached, with the intergenerational concern also taking low values (up to 1.5). As the degradation values increase (5≤ω≤20), a much higher degree of intergenerational concern is required from the model, reaching up to 60 units, as can be seen in previous simulations. It should also be noted that the surface of NE of intergenerational concern increases, proportionally, with low values of the discount rate and high values of the interest rate.

In the next case, both generations assign the same importance to consumption ($\mu^2 - \mu^1 = \mu^* = 0$).

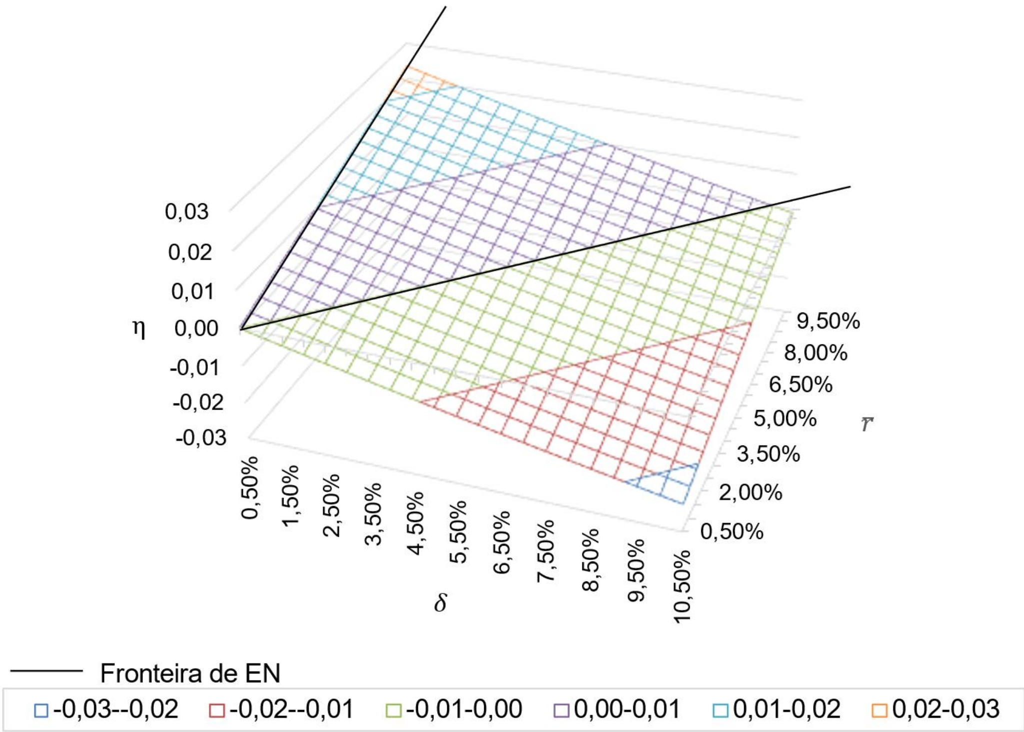


Figure 12: Surface of the Intergenerational Concern (ω=0.5 and μ^*=0)

Source: Pica, 2023

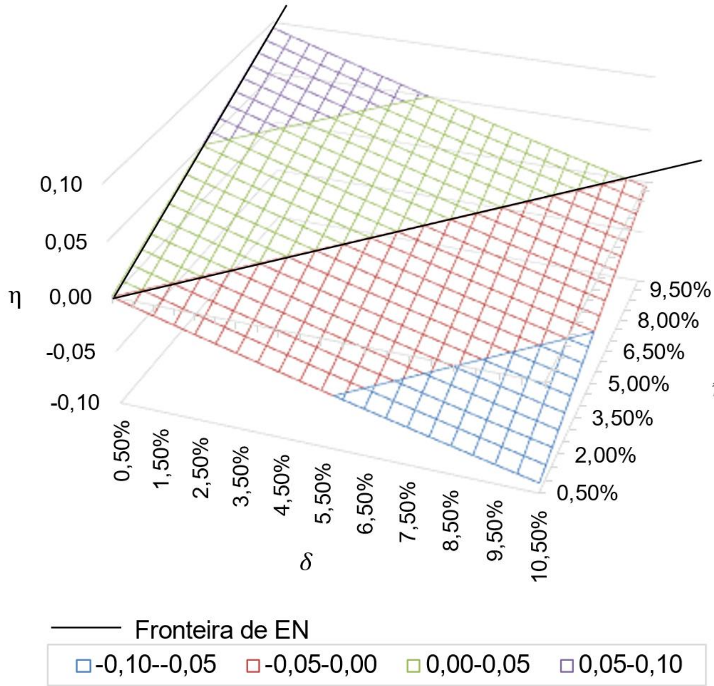


Figure 13: Surface of NE of Intergenerational Concern (ω=1 and μ*=0). Source: Pica, 2023.

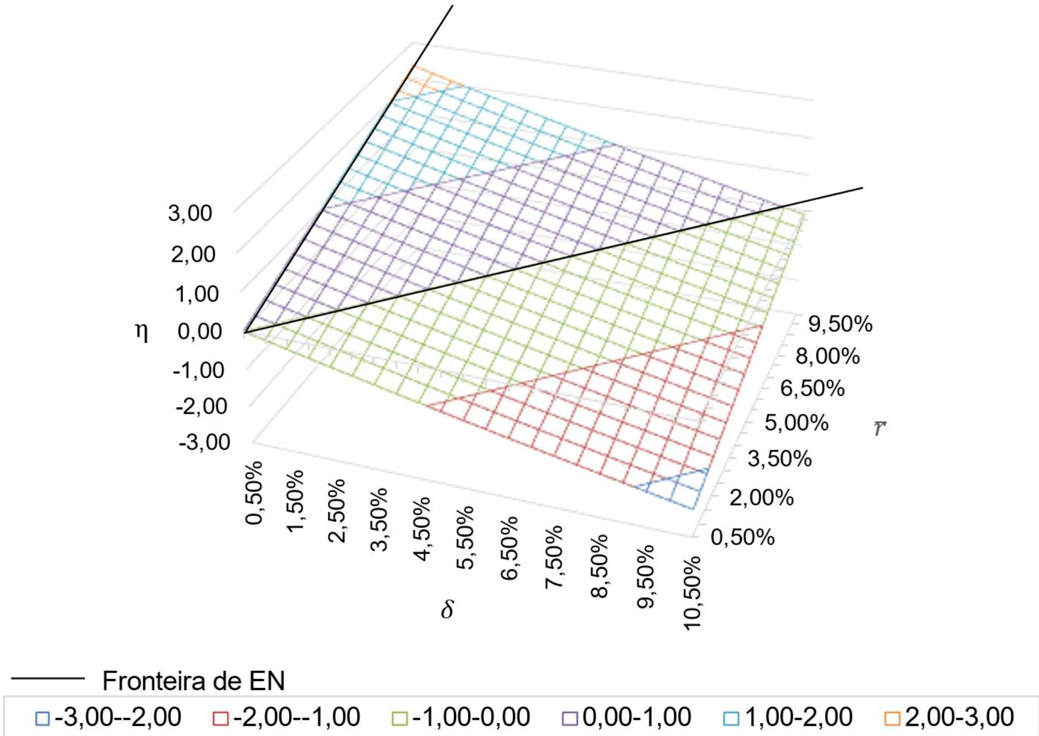


Figure 14: Surface of NE of Intergenerational Concern (ω=5 and μ*=0) Source: Pica, 2023.

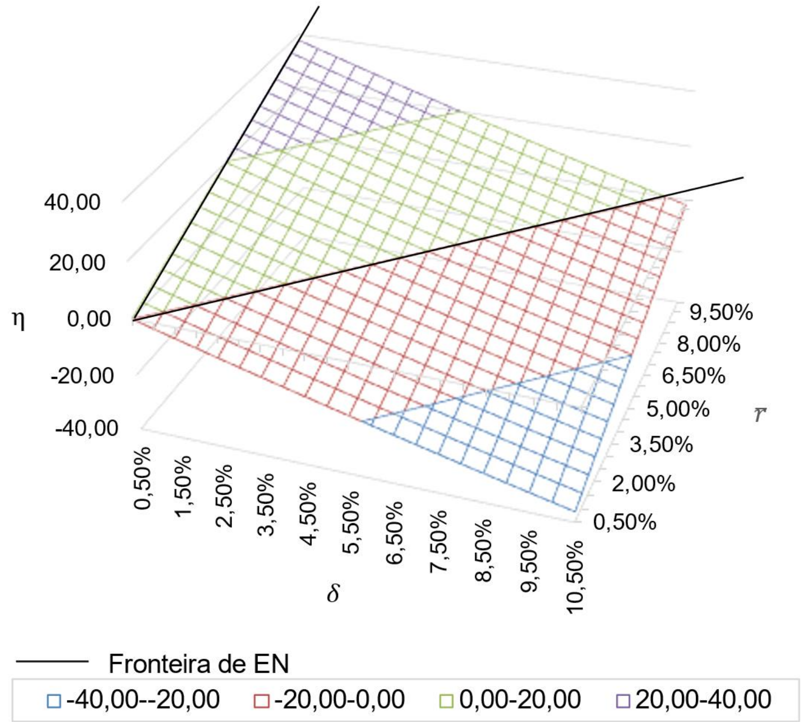


Figure 15: Surface of NE of Intergenerational Concern (ω=20 and μ*=0).Source: Pica, 2023.

The previous graphs (Figures 12 to 15) lack an analysis similar to the previous one, in the sense that the NE surfaces of intergenerational concern increase, proportionally, with high interest rate values. However, with the difference that the impact on intergenerational concern is lower in all domains of parameterization. That is, it's like downloading the entire simulation, with $\mu^*=0$, compared to $\mu^*=-10$. The value attributed to consumption, both for young people and for the elderly, is identical, so it appears that there is already some agreement between them. That is, the exogenous consumption parameters of both generations cancel each other out because they coincide ($\mu^1=\mu^2$). That is, there is a double coincidence of wills and Nash's equilibrium surface is soon more easily reached. Thus, the increase of $\mu^*$, compared to the previous case, and the variations of environmental degradation of 0.5, 1, 5 and 20, cause the balance of the parameter of interest (intergenerational concern) to oscillate between maximum values of 0.03, 0.1, 3 and 40, respectively, as can be seen in the previous figures.

Finally, we present the case in which the elderly give more importance to consumption than the young ($\mu^2 - \mu^1 = \mu^* > 0$). In the simulated case, $\mu^*=10$ is considered.

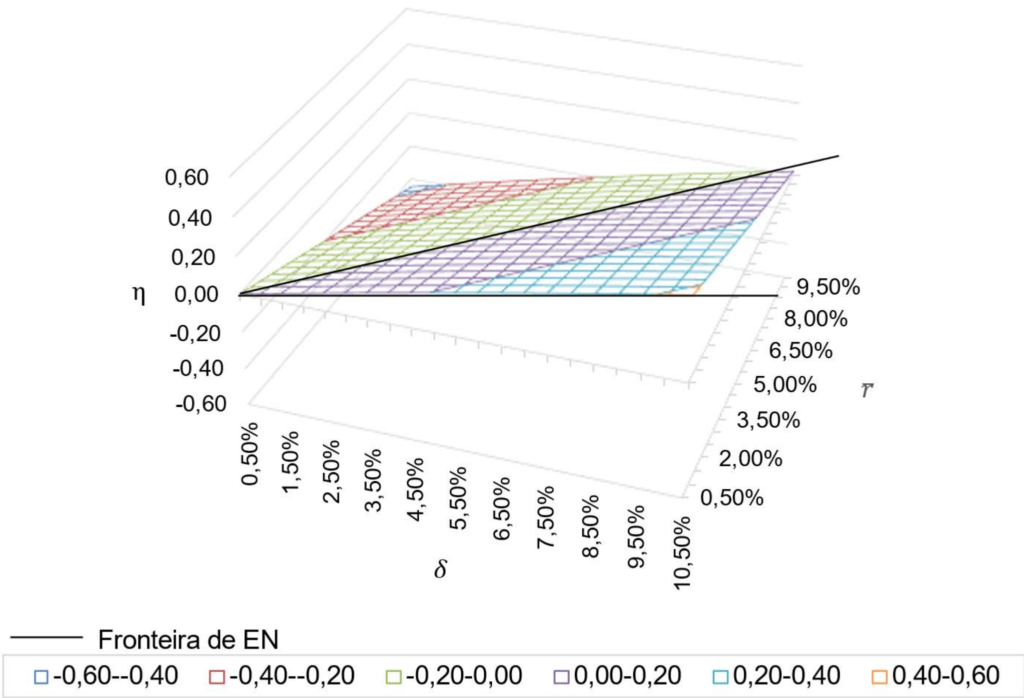


Figure 16: Surface of NE of Intergenerational Concern (ω=0.5 and μ*=10)

Source: Pica, 2023

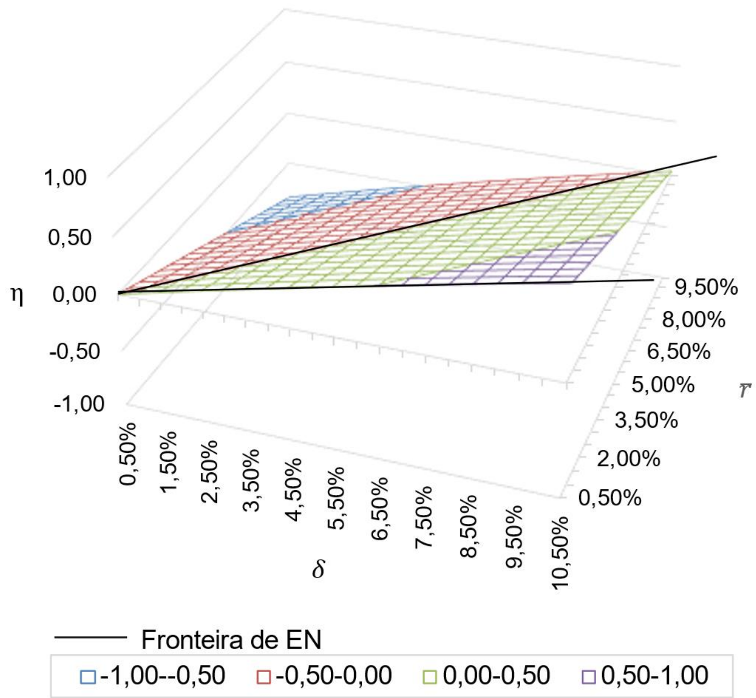


Figure 17: Surface of NE of Intergenerational Concern (ω=1 and μ*=10)
Source: Pica, 2023.

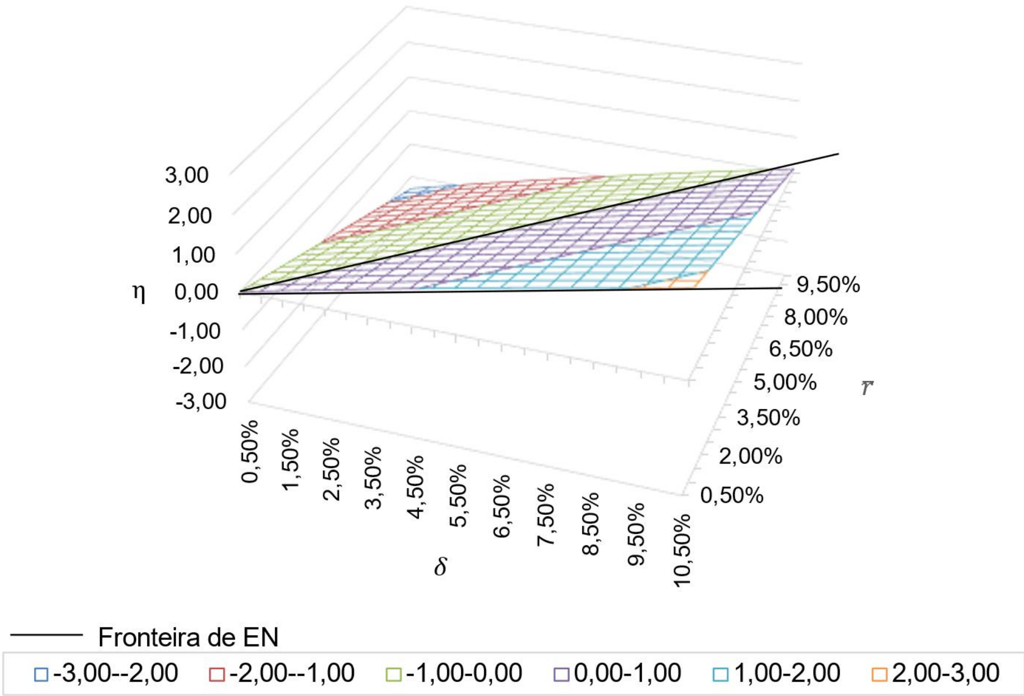


Figure 18: Surface of NE of Intergenerational Concern (ω=5 and μ^*=10)

Source: Pica, 2023.

In Figures 16 to 18 we see that, unlike the previous EN surfaces (Figures 8 to 15), these present a surface with a slope directly proportional to high values of the intertemporal discount rate, and to lower values of the interest rate. With μ^*=10, the values of the intergenerational concern for balance are 0.6, 1 and 3, depending on the increase in the level of environmental degradation (0.5, 1 and 5, respectively).

A result different from the previous ones is related to the parameterization of the surface reached in Figure 19 (ω=20). In which the environmental degradation exceeds the consumption parameter, and the EN surface gains a profile exactly equal to the simulations with μ*=-10 or μ*=0. Thus, a considerably high level of intergenerational concern is required for sustainable development to exist.

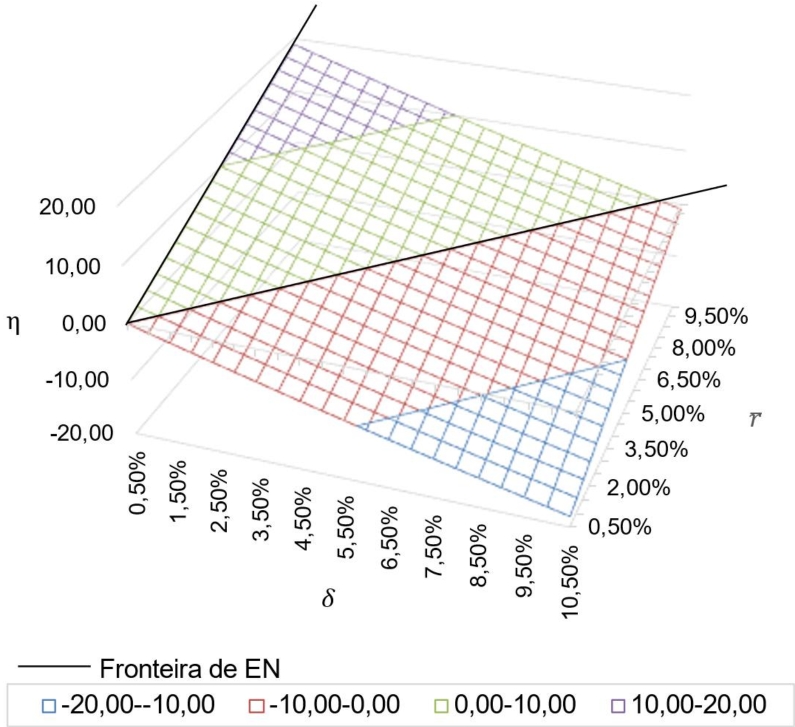


Figure 19: Intergenerational Concern NE Surface (ω=20 and μ*=10)

Source: Pica, 2023

Whenever environmental degradation, caused by consumption, increases, intergenerational concern will also have to increase to balance the level of environmental stock in the following period.

# 6. Discussion of Results

Ex ante, Udalov (2018), based on the OLG model, suggested by John and Pecchenino (1994), presents a model with reference to political-economic voting, at the level of support for renewable energies (m). As young and old live in the same period, they have to decide at the same time on their contributions to support renewable energy. The author presents a table referring to the effects and preferential level of support for renewable energies.

Table 1: Summary of effects and preferred level of support for renewable energies without intergenerational concern

| | Elderly | Youngsters |
|---|---|---|
| Effect on $c_t$ | < 0 | < 0 |
| Effect on $Env_{t+1}$ | n.a. | > 0 |
| Effect on $c_{t+1}$ | n.a. | > 0 se $\left((1-\gamma)(1-\alpha-\beta) > \frac{(1+r_{t+1})m_t}{r_{t+1}s_t}\right)$ |
| Voting in $m_t$ | = 0 | $m_t^{young} \geq m_t^{old}$ |

Fonte: (Udalov, 2018). Adapted by Pica, 2023. n.a.= non aplicable.

As can be seen in Table 1, for young people, support for renewable energies has a positive effect on consumption in the following period, if the elasticity of renewable energy production is greater than their opportunity cost ratio, i.e. , in the sense of the loss of consumption, in the following period. Since the long-term effects are discounted at their current value, the result of voting for young individuals is sensitive to changes in the discount rate, as this represents the individual's intertemporal preference. A higher discount rate increases preferences for the present and has a negative effect on the level of support for renewables (Udalov, 2018).

On the other hand, for the elderly, support for renewable energy negatively affects consumption and its utility in the current period, as there is no intergenerational concern. Therefore, they will not show any support for renewable energies. Through the results obtained, each generation in society has different preferences regarding the level of support for renewable energies, which will result in an intergenerational conflict between the present generations (Udalov, 2018).

Ex post, with the introduction of the new variable (intergenerational concern), the environmental quality in the following period is included in the utility function of the elderly. That said, the choices / preferences will change, compared to the model proposed by Udalov.

Through the $TMS_{Env_{t+1};Env_t}$ rate at which an individual gives up environmental quality in the present in exchange for environmental quality in the future -, both for young people and for elderly, it is clear that the greater the intergenerational concern and the lower the intertemporal discount rate, the more importance (an individual) will give to environmental quality in the following period.

Subsequently, deterministic simulations of balance surfaces were used, in Excel, to analyze the evolution of consumption, by environmental quality, for the two generations.

With regard to young people, it should be noted that to guarantee the steady state balance, assuming a low level of consumption, due to environmental stock, there must be a high discount rate and a low interest rate. The surfaces of the graphs demonstrate that the consumption equilibrium surface, due to environmental quality, is very sensitive to environmental degradation, and, at the same time, that an increase in intergenerational concern, in the face of environmental degradation, translates into a stabilization of consumption. It can also be concluded that with the increase in the importance of consumption in the utility of young people, we can see that consumption values, due to environmental quality, increase.

As for the elderly, consumption, per unit of environmental quality, tends to converge to the average steady state parameter assumed. For example, if $\mu^2=10$ , the consumption values converge to 10, if $\mu^2=20$ , the consumption values converge to 20 and so on. The function represents a family of parametric rectangular hyperbolas in $\mu^2$. As environmental degradation increases, consumption, due to environmental degradation, also increases.

In a situation of strategic interaction, based on Game Theory, in which the preferences of both generations are included, several Nash equilibrium surfaces related to intergenerational concern were simulated. In a first case, in which young people give greater importance to consumption than the elderly, it was found that the intergenerational concern about NE grows proportionally with the interest rate, and when degradation assumes low values, a NE is obtained sustainable with intergenerational concern taking low values. As degradation increases, a much higher level of intergenerational concern is required from the model, in balance.

When both generations equally value consumption, the exogenous consumption parameters of both generations coincide. That is, there is a double coincidence of wills and the Nash equilibrium surface is more easily reached.

In the case where the elderly value consumption more than the young, we find that, unlike the other EN surfaces, this surface has a slope directly proportional to the intertemporal discount rate and low interest rate values. However, when environmental degradation exceeds the consumption parameter, the EN surface starts to follow the interest rate. This requires a considerably high level of intergenerational concern. Whenever environmental degradation, caused by consumption, increases, intergenerational concern will also have to increase, to balance the level of environmental stock in the following period.

It should also be noted that the case in which the NE surface, relative to intergenerational concern, reaches higher values is when young people attach greater importance to consumption than the elderly.

To support the contributions of intergenerational concern, Table 2 presents its effects on environmental quality and consumption for the following period, as well as support for renewable energies in the same period.

Table 2: Summary of the effects of intergenerational concern in steady state.

| | Elderly | Youngsters |
|---|---|---|
| Effect on $Env_{t+1}$ | > 0 | > 0 |
| Effect on $c_{t+1}$ | n.a. | < 0 |
| Effect on $m_t$ | > 0 | > 0 |

Source: Pica, 2023. n.a.= non aplicable.

As can be seen in the table above, intergenerational concern has a positive effect on energy support and environmental quality for both generations. Regarding consumption, in the following period (only for young people, as the elderly will not be able to enjoy consumption in the following period, due to the fact that they are no longer present), intergenerational concern has a negative effect. This means that the increase in intergenerational concern causes a drop in consumption, increases support for renewable energies and, consequently, will lead to improvements in environmental quality.

That said, a table similar to Table 1 will be presented, but with the intergenerational concern already included for analysis.

Table 3: Summary of effects and preferred level of support for renewable energy with intergenerational concern

| | Elderly | Youngsters |
|---|---|---|
| Effect on $c_t$ | < 0 | < 0 |
| Effect on $Env_{t+1}$ | > 0 | > 0 |
| Effect on $c_{t+1}$ | n.a. | > 0 se $\left((1-\gamma)(1-\alpha-\beta) > \frac{(1+r_{t+1})m_t}{r_{t+1}s_t}\right)$ |
| $m_t$ | ≥ 0 | ≥0 |

Source: Pica, 2023. n.a.= non applicable.

As can be seen in Table 3, the introduction of the new parameter means that the positive effect of supporting renewable energies is also considered by the elderly. Therefore, the contribution in support of renewable energies is no longer null for the elderly. In this way, the scenario of intergenerational conflict suggested by Udalov is reversed, as the contributions of both the elderly and young people can be positive, increasing the possibility of achieving environmental sustainability, due to the simple fact that intergenerational concern is present in the preferences of individuals.

## 8. Conclusion

With the introduction of a new variable (intergenerational concern), we present a new utility function that translates into new preferences for the elderly, compared to the model proposed by Udalov (2018). Using deterministic simulations, we can analyze the evolution of consumption, by environmental quality, in a steady state situation, for young and old generations. It is important to point out that the Nash surface simulations, although deterministic, are contingent on reasonable parameters of reality (thus, they will be calibrated), in which we make changes in the intertemporal discount rate, interest rate, environmental degradation, and intergenerational concern.

We conclude that, for society as a whole, according to the TMS between present and future environmental quality, a low intertemporal discount rate translates into a decrease in consumption, ceteris paribus, reinforcing the position of several authors. Namely Udalov, where a higher discount rate increases preferences for the present and has a negative effect on the level of support for renewables (Udalov, 2018); Stern who defends a policy with a very low discount rate (Stern, 2007); Geoffrey Heal, who also points out the fundamental role of proper choice (Heal, 2017); as well as Brekke and Johansson-Stenman, who advise choosing a social discount rate (considerably) lower than the average return on productive expenditure, ie investment (Brekke & Johansson-Stenman, 2008).

The simulated graphs for young people demonstrate that the consumption equilibrium surface, by environmental quality, is very sensitive to the degree of degradation, and that an increase in intergenerational concern, in the face of environmental degradation, translates into a stabilization of consumption. This result would be expected, however, it contributes to demonstrate the robustness of the model. It is also inferred that with the increasing importance of consumption in the utility of young people, the values of consumption by environmental quality increase.

With regard to the elderly, intergenerational concern made them attach importance to environmental quality in the following period, even though they were not present to enjoy it.

That is, with the introduction of the variable of interest, there is a greater probability of leaving an environmental legacy for future generations, depending on the trade-offs between the level of consumption and intergenerational concern. Through the simulations that demonstrate the evolution of consumption, by environmental quality, it was verified that it tends to converge to the degree of importance given to consumption by generation. Environmental degradation has a direct proportional relationship with consumption.

Later, using Game Theory, we present situations of strategic interaction between both generations. The optimal correspondence of young people intersected with that of the elderly gives rise to a Nash equilibrium surface, which once reached, no one has incentives to deviate (Nash, 1950a, 1950b).

The NE surface, related to intergenerational concern, reaches higher values when young people give greater importance to consumption than the elderly. In this case, it was verified that the intergenerational concern for NE increases proportionally with the interest rate, and when degradation assumes low values, a sustainable NE is reached with the intergenerational concern also taking low values, in a situation of equilibrium.

When both generations equally value consumption, it appears that there is already some agreement between them, that is, the exogenous parameters of consumption, of both generations, cancel each other out because they coincide. That is, there is a double coincidence of wills and the Nash equilibrium surface is more easily reached.

In the case in which the elderly value consumption more than the young, it appears that, unlike the other EN surfaces, this has a slope directly proportional to the intertemporal discount rate, and inversely proportional to the interest rate. However, when environmental degradation exceeds the consumption parameter, the EN surface has a positive relationship with the interest rate. In this way, a considerably high level of intergenerational concern is required for sustainable development to exist. Whenever environmental degradation caused by consumption increases, intergenerational concern will also have to increase, to balance the level of environmental stock in the following period. This is a valid and interesting result, not only because it confirms the importance of the immediate degradation of consumption, but also because it highlights the fact that intergenerational concern is the balance bridge for situations of extreme degradation.

With the application of this new scenario, the intergenerational conflict suggested by Udalov was avoided, as the contributions, whether from the elderly or the young, could be positive, increasing the possibility of achieving environmental sustainability. However, the fact that society as a whole is concerned about future environmental quality could increase the percentage of individuals' compliance, reducing concerns, as they think that everyone acts in agreement, referring us to free-riding. Thus, in order to combat this unwanted phenomenon, we would have to lower the desertion premium, as we have demonstrated, resorting to evolutionary Game Theory, in order to commit society to cooperating among all. Not only to benefit those present, but also to leave an environmental legacy for others, who will have the same rights as those present to enjoy our planet. That said, intergenerational concern would be fundamental to ensure environmental sustainability, which is called into question by the degradation caused by consumerism.

If the causes of climate change are anthropogenic, then it will have to be human society to reverse this undesirable situation, according to the diagnoses presented in Hardin (1968), which refer to the problem of over-exploitation of resources. However, the solution will have to take global proportions.

The Coase Theorem (1960), which refers to internalizing externalities, the Pigou tax (1920) and the polluter pays principle are viable solutions. However, short, medium and long term solutions inevitably involve a greater intergenerational concern, in a context of OLG models. That is, the dynastic concern is crucial and can be the solving factor of the global/holistic problem.

This research is, therefore, a way of empowering future generations, as its knowledge and dissemination allows young people to consciously decide their own future and also that of humanity, considering climate change, its anthropogenic causes, as well as like the economy.

## 9. Limitations of Analysis and Further extensions

This research has some limitations that can be considered as an opportunity for future research. First, a linear deterministic model was simulated and, in a future situation, it is intended to approach this topic with stochastic shocks. On the other hand, we restrict ourselves to simulations contingent on the model values in the positive ortant and compute the surface / Nash equilibrium correspondence. In the future, it is considered relevant to calculate the adjustment trajectory for the steady state.

Another limitation is related to the fact that we assume the same intergenerational concern, a variable of interest, both for young people and for the elderly. It will be a valid and interesting extension to extend to different parameters of intergenerational concern for both generations. For example, intergenerational concern could be modelled as a learning parameter throughout the game, that is, with evolutionary Game Theory. The agents would learn to play better and better, with changes in the variable of interest, leading to the reversal of ecocide.

Moreover, there is another hidden dimension in the wave of climate change, referring to the principles of subsidiarity, permanence, and precaution. That is, the fact that climate change is also associated with a biodiversity crisis, which is beyond the scope of this dissertation, but which is a point that we are aware that should be addressed later, making reference to The Economics Biodiversity: the Dasgupta Review (2021).

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