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# Beyond additive preferences: Economic behavior and the income pollution path

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## ABSTRACT

Theoretical models of the environmental Kuznets curve (EKC) almost universally assume additive preferences; we demonstrate that under non-additive preferences the sufficient condition to sign the economy's income-pollution path depends on the elasticity of substitution between consumption and environment (and not on the elasticity of marginal utility of consumption). The proposed model provides behavioral content that has been missed in the existing literature. In the model, and also departing from the previous literature, preferences change and evolve (through a variable elasticity of substitution) according to the relative scarcity of the environment.

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## 1. Introduction<sup>1</sup>

Starting with Grossman and Krueger (1995), who first empirically described the environmental Kuznets curve (EKC), a significant number of theoretical models have been proposed to explain this inverted U relationship between pollution and per capita income. According to the EKC, the emissions or the concentrations of a particular contaminant in the environment initially rise as the per capita

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income of a country or a city increases over time, reaching a maximum before finally declining even while per capita income continues growing.<sup>2</sup>

In trying to theoretically explain the occurrence of the EKC, most authors have made the simplifying assumption of additive preferences, implicitly assuming that the contribution of consumption to individual wellbeing is not affected by environmental quality.<sup>3</sup> The assumption of additive preferences helps researchers to derive simple conditions for determining the sign of the slope of the income-pollution path, within the different preference/technology contexts they believe are theoretically responsible for the EKC occurrence. At the same time, this additive preference assumption eliminates additional complexities associated with ambiguities regarding the sign of more complex partial derivatives. For some authors, however, this oversight is not trivial and has important implications. [Smith \(2012\)](#) argues, for example, that the assumption that environmental quality makes a separable contribution to wellbeing has made it necessary to impose a set of “built in” exogenously determined incentives in order to reproduce the EKC in some theoretical models. Moreover, the rather convenient and friendly assumption of additive preferences in terms of technical tractability seems to be at odds with the usual empirical observations indicating that the sign and magnitude of the effect on people’s marginal utility of consumption do depend on the level of environmental quality. For example, [Pastén and Figueroa \(2012\)](#) recall that, in the early 1960s, during the birth and initial expansion of the fish meal industry in the then rather poor city of Iquique in northern Chile, the city’s inhabitants often described the unpleasant odor that pervaded the city from new fish meal mills as the “good smell of money”. However, some years later, when the same residents of Iquique enjoyed a much higher level of income than they had in the 1960s, they began to demand environmental regulations to reduce the “unpleasant fishy odors” of the fish meal industry. This story illustrates two crucial aspects of the real world that ought to be taken into consideration when attempting to explain the income-environment relationship determining the EKC: (1) that the impact of environmental quality on people’s marginal utility of consumption is in general different from zero, and (2) that it is very plausible that this marginal impact will vary with changes in both income and/or pollution levels.

To show whether or not the EKC occurs, standard models postulate that it is necessary to determine whether the elasticity of marginal utility of consumption is greater than, equal to, or smaller than a threshold value determined by the elasticity of substitution in production between factors.<sup>4</sup> In this paper we demonstrate that, in the more general case of non-additive preferences, and contrary to what is implicitly assumed or explicitly stated in most previous works, the sufficient condition to sign the slope of the economy’s income-pollution path does not depend on the income-elasticity of the marginal utility of consumption, but does depend on the elasticity of substitution in preferences between consumption and environment (environmental quality).

It is commonly asserted and/or assumed in the literature that the elasticity of substitution in preferences is just the inverse of the elasticity of marginal utility of consumption, and therefore, nothing is gained by studying one instead of the other. However, as we demonstrate in the following section, this assertion is incorrect because, only under additive preferences, these two elasticities are the inverse of each other. In a more general setting, when the assumption of additivity does not hold, the relationship between the two elasticities is complex and depends on the different arrangements between cross partial derivatives.

[Smith \(2012\)](#) has recently pointed out the suitability of explaining the EKC as an endogenous outcome resulting from the features of the preferences and production relationships used to describe the structure of the economy. Here we make a contribution in this direction by proposing a model in which preferences are not only non-additive but are also endogenously determined by the relative scarcity of environmental quality. The behavioral content of this model provides insights into how the EKC could become a relevant theoretical framework for future policy design.

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<sup>2</sup> See [Barbier \(1997\)](#), [Dinda \(2004\)](#), and [Yandle et al. \(2004\)](#) for empirical illustrations.

<sup>3</sup> The most prominent examples in the literature are [López \(1994\)](#), [Jones and Manuelli \(1995\)](#), [Stokey \(1998\)](#), [Andreoni and Levinson \(2001\)](#), [Lieb \(2002\)](#), [Copeland and Taylor \(2003\)](#), and [Johansson and Kriström \(2007\)](#).

<sup>4</sup> [Figueroa and Pastén \(2013\)](#) show that (under additive preferences) all the theoretical models justifying the occurrence of the EKC – based either on preferences or technology – share a common origin and can be framed in terms of the comparison between these two elasticities.

The remainder of this paper is arranged as follows: Section 2 presents the model; Section 3 illustrates the main results; and Section 4 presents the conclusions.

## 2. A non-additive preference model explaining the EKC occurrence

In this section we develop a static general equilibrium model in which the government maximizes a bivariate social utility function  $U(c, q)$  which depends on both consumption  $c$  and environmental quality  $q$ . This utility function is increasing and concave in both arguments, and it is twice continuously differentiable with respect to  $c$  and  $q$ .<sup>5</sup>

Our model has two features that are important to keep in mind: (1) environment is treated as a flow rather than as a stock, and for simplicity we assume that there is a linear relationship between the two<sup>6</sup> and (2) we assume that growth is exogenous in our model, which differs from recent literature that has incorporated endogenous sources of growth (see, for example, López and Yoon, 2014).

Due to the absence of dynamics, and following the literature, consumption  $c$  is assumed to be equal to income  $y$ , and hence both variables are used interchangeably throughout the paper. For simplicity, intra- and inter-generational aspects are disregarded here. Technological progress is assumed to be exogenous, similar to López (1994) and Stokey (1998). In addition, we follow the standard assumption that pollution levels are optimal and determined by an efficient price system. Although it is quite extreme, this assumption is justifiable because it provides a benchmark against which more relevant policy alternatives can be contrasted (see López and Mitra, 2000).

The production function  $f(\cdot)$  is kept simple to isolate preferences from technology; it is given by  $y = f(k, p)$ , where  $k$  is a broad definition of capital including both physical and human capital, and  $p$  is the flow of pollution such that  $p = 1 - q$ . The production function complies with the usual assumptions (increasing and concave in factors, Inada conditions, etc.). In this model, following Tahvonon and Kuuluvainen (1993) and López (1994), pollution plays a role as a factor of production.

The consumer maximization problem is given by:

$$\max_q U(f(k, 1 - q), q) \quad (1)$$

Optimal environmental quality  $q^*$  is given by the following first order conditions, where subscripts denote partial differentiation:

$$Z = -U_c(f(k, 1 - q^*), q^*)f_p(k, 1 - q^*) + U_q(f(k, 1 - q^*), q^*) = 0 \quad (2)$$

It is straightforward to see that expression (2) implies equality between marginal benefits  $-U_q$  and marginal cost  $-U_c f_p$  of environmental quality  $q$ . We assume that the second order condition  $Z_q < 0$  is satisfied. Defining  $\rho$  as the elasticity of substitution in production between factors (i.e., between pollution and capital) such that  $\rho = (f_k f_p / f_p k f)$  and partially differentiating  $Z$  with respect to  $q$  and  $k$ , we obtain Proposition 1.

**Proposition 1.** Under additive preferences, condition  $-\frac{U_{ccc}}{U_c} \leq (\geq) \frac{1}{\rho}$  is sufficient to have  $\frac{dq}{dk} \geq (\leq) 0$ .

For a formal proof of this proposition see López (1994). Proposition 1 shows that the sign of the slope of the income–pollution path depends on whether the value of the elasticity of marginal utility of consumption ( $-(U_{ccc}/U_c)$ ), is smaller than, equal to, or greater than a threshold value given by the inverse of the elasticity of substitution in production between factors,  $1/\rho$ . Note that Proposition 1 is a local condition showing under what circumstances, for a given level of income, pollution increases (or decreases) as income grows. However if the elasticity of marginal utility of consumption  $a = -(U_{ccc}/U_c)$  increases for a range of income (a global condition) such that there is only one unique point where  $a$  crosses the threshold value  $1/\rho$  from below, an EKC emerges (see Figure 1 in López (1994), p. 172).<sup>7</sup> The

<sup>5</sup> One drawback of this setting is that we are assuming there is only one final consumption good, thereby neglecting the output composition effect. López and Yoon (2014) propose a model with two final goods that allows the study of scale, composition and technique effects of economic growth.

<sup>6</sup> For dynamics models of the EKC see Chavas (2004), Chimeli and Braden (2005), Kelly (2003), López and Yoon (2014), and Hartman and Kwon (2005).

<sup>7</sup>  $\lim_{c \rightarrow \infty} a(c) > 1/\rho$  guarantees that function  $a(c)$  crosses the threshold value  $1/\rho$  at least once.

elasticity of marginal utility of consumption  $a = -(U_{cc}c/U_c)$  is also known as the coefficient of relative risk aversion (RRA) in the economics of risk and uncertainty.<sup>8</sup>

The intuition behind [Proposition 1](#) is as follows: economic growth increases willingness to pay for the environment. If the value of the environment is totally internalized through the market or other institutional arrangements, the price that firms have to pay for pollution increases. As a result, at some point, profit-maximizing polluting firms are willing to substitute pollution for more conventional factors as long as the elasticity of substitution in production between pollution and capital is positive ([López, 1994](#)).

This intuition rests heavily on the assumption that the value the consumer attaches to the environment grows as income grows. This value is given by the marginal rate of substitution between environment and income (consumption)  $v(c, q) = U_q/U_c$ .

Under additive preferences, this growing valuation of the environment is due exclusively to the fact that people become satiated by consumption, and thus attach more importance to the other good (environment). As an anonymous reviewer pointed out to us, decreasing marginal utility does not necessarily imply satiation. In our setting, satiation in consumption occurs if the limit value of the marginal utility of consumption tends to zero rather than to a positive value. If this is the case, the elasticity of marginal utility of consumption is greater than one (this point was made by [Lieb, 2002](#)). Thus, the marginal utility (which is the denominator of  $v(c, q) = U_q/U_c$ ) decreases rapidly while the numerator remains constant (because under additive preferences  $U_{qc} = 0$ ).

In summary, in additive preference models, the sole and exclusive reason for the EKC is a built-in tendency toward satiation in consumption. This is obviously a technical implication resulting from the assumed additive structure of preferences and therefore it is not an explanation of how consumers' attitude toward the environment changes at different levels of income.

Satiation is not a popular concept among economists; nevertheless, as we have shown above, satiation is implicit in each model of the EKC with additive preferences (i.e., in almost all models of the EKC). However, in a more general setting, in which preferences are non-additive, the assumption of satiation is not even necessary for the EKC to occur. Consider, for example, the attitudinal characterization of the individual toward the environment given by the plausible case of  $U_{qc} > 0$ . As income grows, willingness to pay  $v(\cdot)$  now grows not only because the marginal utility of consumption  $U_c$  decreases, but also because the marginal utility of the environment  $U_q$  increases as income grows, which renders satiation unnecessary.

**Proposition 2.** *In the general case, with non-additive preferences, the condition  $-\frac{U_{cc}c}{U_c} + \frac{U_{qc}c}{U_q} \leq (\geq) \frac{1}{\rho}$  is sufficient to have  $\frac{dp}{dk} \geq (\leq) 0$ .*

**Proof.** See [Appendix A](#).

According to [Proposition 2](#), the sign of the slope of the income–pollution path  $dp/dk$  depends on whether the value of the elasticity of marginal utility of consumption  $-(U_{cc}c/U_c)$  plus the elasticity of marginal utility of the environment  $U_{qc}c/U_q$  is smaller than, equal to or greater than the threshold value  $1/\rho$ . Similar to [Proposition 1](#), the condition in [Proposition 2](#) is a local condition. If the sum of both elasticities increases for a range of income (a global condition) such that there is only one unique point where this sum crosses the threshold value  $1/\rho$  from below, an EKC emerges.

Therefore in order to analyze the occurrence of the EKC we have to impose restrictions on the signs of  $-(U_{cc}c/U_c)$  and on  $U_{qc}c/U_q$  and also restrictions on how both parameters evolve as income grows. It is possible to impose the strong restriction that  $U_{qc} = 0$ , in which case we are back to [Proposition 1](#); however at this point it would seem evident that this restriction is too strong a requirement to theoretically justify the EKC occurrence.

As mentioned above, in the context of uncertainty, the term  $a = -(U_{cc}c/U_c)$  is known as the coefficient of relative risk aversion (RRA). Most people agree that the sign of this coefficient is positive; there

<sup>8</sup> For policy analysis, [Pastén and Figueroa \(2012\)](#) emphasize the pollutant's harmfulness and how "green" the society is (given by the income level at which the marginal utility of consumption tends asymptotically to zero) as determinants of the elasticity of marginal utility of consumption, among others, leading to a higher turning point and therefore implying that societies become "green" at high levels of income.

is less agreement however about the sign of its slope, although several authors agree that RRA increases with income (see Arrow, 1971). The term  $U_{qc}c/U_q$ , on the other hand, even though it is less studied, also has a counterpart in the economics of risk and uncertainty where the parameter  $\gamma = -(U_{qc}c/U_q)$  is known as the coefficient of relative correlation aversion, or RCA (Gollier, 2010). The RCA depends on the sign of  $U_{qc}$ , which is subject to debate. Gollier assumes that  $\gamma$  is positive, implying that  $U_{qc} < 0$ ; however,  $U_{qc} > 0$  is an assumption with which most economists would agree (Lieb, 2002).

Eeckhoudt and Schlesinger (2006) identify higher order cross derivatives as indications of a preference for combining relatively good outcomes with bad ones which, in the context of risk and uncertainty, is interpreted as the desire to disaggregate harm from unavoidable risks and losses. In the certainty environment in which our paper is developed, we can use Eeckhoudt and Schlesinger's (2006) concepts, and characterize high income as a good outcome and high pollution as a bad outcome.

**Definition 1** (based on Eeckhoudt et al., 2007). Let  $\varphi$  and  $\delta$  be arbitrary positive constants. An individual is correlation averse if the sequence  $[(c - \varphi, q); (c, q - \delta)]$  is preferred to the sequence  $[(c - \varphi, q - \delta); (c, q)]$  such that  $c - \varphi > 0$  and  $q - \delta > 0$ .

Someone who is correlation averse prefers less environmental quality (more pollution) in the period (or state) with the higher level of income, because correlation-aversion implies that a higher level of income mitigates the pain of a reduction in environmental quality. On the other hand, for a correlation loving individual, the ordering of the above preferences is reversed, because he/she enjoys money (consumption) less if he/she lives in a dirty environment.

**Proposition 3.** The condition  $U_{qc} < 0$  is equivalent to correlation aversion.

For a proof of this proposition see Eeckhoudt et al. (2007).

There is no conclusive empirical evidence supporting the assumption of correlation aversion or correlation loving. Intuitively it could be expected that correlation aversion occurs at low levels of income (such that people are willing to mix good with bad at low levels of income), but that this preference ordering reverses at high income levels (indeed, this is the case in our example in Section 3). According to Proposition 2, for a given coefficient of relative risk aversion, a decreasing coefficient of relative correlation aversion is sufficient for an EKC to emerge. This shows the importance of correlation aversion, and particularly a decreasing coefficient of relative correlation aversion (i.e., shifting from correlation aversion to correlation loving as income grows) as a new concept introduced in the analysis of the EKC. This concept is totally neglected under the assumption of additive preferences.

Even though there are some empirical studies that attempt to determine if people are correlation averters or correlation lovers in risk and uncertainty contexts (see Andersen et al., 2011 for a source), there is no conclusive evidence yet on whether individuals should be expected to be correlation averters or correlation lovers between consumption and environment. Therefore, there are no solid theoretical or normative grounds to impose correlation aversion, and thus, as Proposition 2 indicates, conditions for an EKC to occur are complex. This explains why the assumption of zero cross partial derivative,  $U_{cq} = 0$ , has been so universally imposed in theoretical EKC papers. We would like to go beyond the assumption of additive preferences, and at the same time impose weaker conditions for preferences than those presented in Proposition 2. Fortunately we are able to show in Proposition 4 that under homothetic preferences,<sup>9</sup> no restriction on the preferences-cross partial derivative is necessary, and a simpler sign condition for the slope of the elasticity of substitution in preferences explains the EKC occurrence. Interestingly, this elasticity can also be intuitively associated with the relative scarcity between environmental quality and consumption.

If we assume that the marginal rate of substitution between consumption and environmental quality  $v(x)$  is a function only of the consumption to environment ratio  $c/q$  (homothetic preferences), it is possible to write the marginal rate of substitution between environment and consumption,  $v(x)$ , as:

$$v(x) \equiv \frac{U_q}{U_c} \tag{3}$$

<sup>9</sup> Homothetic preferences are defined here as preferences where the MRS  $v(\cdot)$  depends solely on the ratio  $c/q$ .

where  $x = c/q$ , and the elasticity of substitution in preferences between consumption and environmental quality is given by  $\varepsilon(x) = v/v'x$ . We state the following proposition:

**Proposition 4.** *If preferences are homothetic, condition  $\varepsilon(x) \geq (\leq) \rho$  is sufficient to have  $\frac{dp}{dk} \geq (\leq) 0$ .*

**Proof.** See Appendix B.

Proposition 4 is the basis for the analysis of the underlying factors explaining the presence of an EKC. It states that the shape of the income–pollution relationship depends on the differences in two parameters: the elasticity of substitution in preferences between consumption and environment,  $\varepsilon(x)$ , and the elasticity of substitution in production between factors,  $\rho$ . According to this proposition, if the elasticity of substitution in preferences is constant such that  $\varepsilon(x) = \bar{\varepsilon}$ , pollution grows monotonically with income if  $\bar{\varepsilon} > \bar{\rho}$  and decreases monotonically if  $\bar{\varepsilon} < \bar{\rho}$ . Consequently, the EKC cannot occur with a constant elasticity of substitution in preferences, but if  $\varepsilon$  is a decreasing function of  $x$ , then the EKC emerges. At the point where  $\varepsilon(x) = \rho$ , a turning point occurs at which the EKC changes from a positive slope to a negative slope.

Thus, with constant elasticity of substitution (as in a CES utility function) only monotonic (increasing or decreasing) relationships are encountered. If the elasticity of substitution  $\varepsilon$  decreases as the relative scarcity of the environment given by  $x$  increases, pollution first increases and then decreases with income, describing the EKC. Therefore, it is the relative scarcity of the environment that determines tastes and preferences regarding the environment, and thus this set of preferences corresponds to a type of endogenous preferences. Preferences determine the choice between consumption and the environment but there is also a feedback effect from the state of the environment to preferences (through the elasticity of substitution). This, in fact, constitutes a basic mutually causal link between the relative scarcity of welfare determinants, people's preferences, and their resulting behavior. This is very much in line with the fundamental behavioral postulates of economic theory, and therefore provides attitudinal and behavioral bases for the EKC occurrence that are more appealing than previous more ad hoc theoretical explanations.

Defining the elasticity of marginal utility of consumption (or the coefficient of relative risk aversion) as  $a = -(U_{cc}/U_c)$  and the coefficient of relative correlation aversion (or the negative of the elasticity of the marginal utility of the environment) as  $\gamma = -(U_{qc}/U_q)$ , we have the following proposition:

**Proposition 5.**

$$\frac{1}{\varepsilon} = a - \gamma \quad (4)$$

**Proof.** See Appendix C.

According to (4) the inverse of the elasticity of substitution in preferences is linked by an identity to the concept of elasticity of marginal utility of consumption  $a$ , and to the coefficient of correlation aversion  $\gamma$ , in such a way that if the value of one of these parameters is fixed, a relationship between the other two emerges. The best-known example is  $\gamma = 0$ , such that  $1/\varepsilon = a$ , which corresponds to the particular case of additive preferences with a resulting elasticity of marginal utility of consumption equal to the inverse of the elasticity of substitution between consumption and environment. It is clear, however, that this relationship is a very restricted particular case. Another case is that in which consumption and environment are perfect substitutes (i.e.,  $\varepsilon \rightarrow \infty$ ); here  $a = \gamma$ , so a given change in income has the same impact on the marginal utility of consumption  $U_c$  as on the marginal utility of the environment  $U_q$ , leaving the marginal rate of substitution  $v(\cdot)$  unaffected by economic growth. Thus the consumers' marginal willingness to pay for the environment does not change as the economy grows, so there is no restraint on firms polluting and consequently pollution increases monotonically as income grows.

The social value (willingness to pay) of the environment grows as income grows if  $1/\varepsilon$  is positive, which is the case if either  $\gamma < 0$  (the individual is correlation loving) or  $a > \gamma$  for  $\gamma > 0$  (the individual is correlation averse). If the elasticity of substitution between goods  $\varepsilon$  is lower than the elasticity of substitution between factors  $\rho$ , sustainable economic growth emerges with the value of

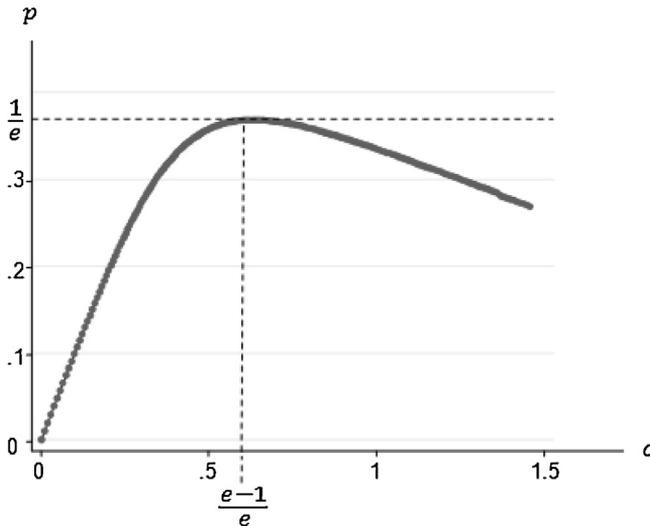


Fig. 1. The environmental Kuznets curve.

the environment growing enough to induce substitution of pollution for more conventional factors of production.

### 3. Example of a specific utility function

In Fig. 1, after switching the two variables shown on its axes, the striking similarity of the EKC with the textbook case of the backward bending labor supply (BLS) curve is immediately evident. Hanoch (1965) is one of the few authors who have tried to explain the backward bending labor supply (see Barzel and McDonald, 1973; Lin, 2003 for others models explaining the BLS). His contribution was to show that: (1) the assumption of non-homothetic preferences is not necessary for a BLS to occur and, (2) the BLS can emerge even under homothetic preferences. Hanoch's use of a simple functional form for preferences to illustrate his point was convincing; however, he missed a crucial point in explaining why the curve bends backwards: his specific utility function implicitly assumes an elasticity of substitution between labor earnings and leisure that decreases with an increase in the earnings/leisure ratio. As described below, our contribution here is to show that the characteristic backward bend exhibited by the EKC is due precisely to the crucial point missed by Hanoch in his model of the BLS: a utility function exhibiting an elasticity of substitution between consumption and environment that decreases with the consumption/environment ratio.<sup>10</sup> This is so because from a theoretical point of view the BLS and the EKC share some similarities, the main one being that both empirical phenomena are modeled as a two goods case: one of the goods is income (or consumption) and the other is a freely endowed good (leisure and environment, respectively). Nonetheless there are some important differences. Firstly, while leisure is a freely tradable good, environment is not. Secondly, while the BLS focuses on the relationship between the quantity of a bad and its price, the EKC focuses on the relationship between the quantity of a bad and income. Thirdly, the BLS describes individual preferences, while in the EKC the focus is on social preferences. Finally, and most importantly from the perspective of this paper, the BLS is a partial equilibrium model while the EKC has to be modeled in a general equilibrium setting. Keeping in mind these differences and consequently adapting the

<sup>10</sup> In Hanoch's BLS model the ratio of the two variables involved is (labor) earnings/leisure instead of consumption (or income)/environment as in our EKC model.

model, we show that implicit in Hanoch’s model is an elasticity of substitution that decreases with the ratio of income to the endowed good (leisure), and hence the value attached to one hour of work by a poor person who has a large amount of leisure available is quite different from the value attached to that hour of work by a rich person with no spare leisure. In the same way, in our model explaining the EKC occurrence, society values the environment much more when it is materially rich (in income) and short on environment than when it is materially poor (in income) and has plenty of environment available.

Using the same notation as above, the Hanoch (1965) utility function can be written as:

$$U(c, q) = qe^{[-e^{(-c/q)}]} = qe^{[-e^{(-x)}]} \tag{5}$$

Using a logarithmic transformation of (5) this becomes:

$$U^*(c, q) = \ln(q) - e^{[-c/q]} = \ln(q) - e^{[-x]} \tag{5'}$$

The marginal rate of substitution as defined in Eq. (3) is given by

$$v(x) = e^{(c/q)} - \frac{c}{q} = e^x - x > 0 \tag{6}$$

$v(x)$  in (6) is a function only of the consumption/environment ratio. The elasticity of substitution is therefore given by:

$$\varepsilon(x) = \frac{1}{x} \frac{e^x - x}{e^x - 1} \tag{7}$$

which is positive and decreasing for  $x \geq 0$ . This implies the following:

$$\begin{aligned} &\text{if } x < 1, \text{ then } \varepsilon(x) > 1; \text{ and} \\ &\text{if } x > 1, \text{ then } \varepsilon(x) < 1 \end{aligned} \tag{8}$$

In order to shed light on the condition in (8) here we employ a very simple CES production function in which  $\rho$  is the elasticity of substitution between capital  $k$  and pollution  $p$ :

$$c = [k^{(\rho-1)/\rho} + p^{(\rho-1)/\rho}]^{\rho/(\rho-1)}$$

Then, by imposing the equilibrium condition that the marginal rate of substitution  $v(x)$  equals the marginal product of pollution  $f_p$ , we obtain:

$$v(x) = \pi = \left(\frac{c}{p}\right)^{1/\rho} \tag{9}$$

where  $\pi$  corresponds to the equilibrium relative price of pollution in terms of consumption. If the marginal damage is fully internalized by society, the EKC income–pollution relationship can be derived in a straightforward manner from (9):

$$p = (v(x))^{-\rho} c = (e^x - x)^{-\rho} c$$

Assuming for simplicity that  $\rho = 1$  we obtain:

$$p = \frac{1}{e^x - x} c = \frac{1}{e^x - x} xq = \frac{1}{e^x - x} x(1 - p) \tag{10}$$

Eq. (10) implies that the EKC is given by:

$$p = xe^{-x}; \quad c = (e^x - x)xe^{-x} \tag{11}$$

Finally, the slope of the income–pollution path is given by:

$$\frac{dp}{dc} > 0 \quad \text{for } x < 1, \quad c < \frac{e - 1}{e} \tag{12}$$

$$\frac{dp}{dc} < 0 \quad \text{for } x > 1 \quad c > \frac{e - 1}{e} \tag{12'}$$

As Fig. 1 illustrates, at the EKC's turning point consumption is  $c = (e - 1)/e$  ( $x = 1$ ) and pollution is  $p = 1/e$ , which corresponds to the maximum amount of pollution attained, or about 37% of the initial endowment of pristine environment, attained when income per capita is  $(e - 1)/e \sim 0.63$ .

Finally, for the particular utility function used here, it is interesting to reveal what determines the parameters corresponding to the elasticity of marginal utility of consumption (or coefficient of relative risk aversion)  $a$  and to the coefficient of relative correlation aversion  $\gamma$ . Remember that according to Eq. (4) and the definition of  $a$  and  $\gamma$ :

$$\frac{1}{\varepsilon} = a - \gamma \quad (13)$$

Therefore,  $a$  and  $\gamma$  are given by the expressions in Eqs. (14) and (15):

$$a = -\frac{U_{cc}c}{U_c} = x \quad (14)$$

$$\gamma = -\frac{U_{qc}c}{q} = \frac{x[1-x]}{[e^x-x]} \quad (15)$$

Note that  $a \geq \gamma$  for  $x \geq 0$ .

And, according to (13) and using (7), it is evident that the difference between both coefficients is equal to the inverse of the elasticity of substitution  $\varepsilon$ :

$$a - \gamma = \frac{x(e^x - 1)}{(e^x - x)} = \frac{1}{\varepsilon(x)} \quad (16)$$

Additionally, note also that

$$\text{for } x < 1, \text{ or } c < \frac{e-1}{e}, \quad \gamma > 0 \quad (17)$$

$$\text{for } x > 1 \text{ or } c > \frac{e-1}{e}, \quad \gamma < 0 \quad (17')$$

Eqs. (17) and (17') imply that consumers exhibiting the type of preferences proposed by Hanoch (1965) shift from correlation aversion to correlation loving as income grows: they are correlation averters at low levels of income (below the turning point of the EKC) and correlation lovers at high levels of income (above the turning point of the EKC).

#### 4. Conclusions

To provide behavioral content for the usual theoretical explanations of the EKC occurrence, we have proposed a model with three significant improvements in comparison to the models generally used in the literature. First, in our model preferences are endogenously determined by the relative scarcity between consumption (or income) and environmental quality (or pollution), which has a direct behavioral interpretation rooted in the very foundations of economic thinking. Second, our model represents a significant generalization of previous models, which use additive preferences. Such models are quite restrictive, implicitly assuming that the contribution of consumption to individual wellbeing is not affected by environmental quality. This assumption is generally used to provide technical tractability but enjoys neither theoretical nor empirical support.

Third, lifting the assumption of additive preferences eliminates the need for satiation in consumption for the EKC to occur. This is because the conceptually and theoretically unjustified straightjacket of the equivalence of the elasticity of substitution in preferences between consumption and environmental quality and the inverse of the elasticity of marginal utility is no longer artificially imposed on the analysis. In this context, the concept of coefficient of correlation aversion borrowed from the economics of risk and uncertainty emerges, which is neglected in the case of additive preferences.

Our model offers a preference driven explanation of the EKC occurrence; this explanation is the consequence of an elasticity of substitution in preferences between income and environmental quality that decreases when the relative scarcity of the environment increases (i.e., as the ratio of consumption

to environmental quality increases). As a result, the social valuation of the environment given by the willingness to pay for a marginal improvement in environmental quality increases as income grows, because environmental quality becomes scarcer relative to consumption. This explanation of the EKC occurrence driven by people's behavior arising from and justified by the most basic and accepted notions of economic scarcity should be more appealing to economists and social scientists than previous explanations supported by unsatisfactorily justified technicalities with behavioral implications that are refuted empirically.

## Appendix A.

### Proof of Proposition 2

The slope of the income pollution path is given by:

$$\frac{dp}{dk} = -\frac{dq}{dk} = \frac{Z_K}{Z_q} = \frac{U_{qc}f_k - U_{cc}f_kf_p - U_{cf}f_{pk}}{Z_q} \quad (\text{A1})$$

where  $Z_q < 0$  if the second order condition is fulfilled.

Note that (A1) can be expressed as:

$$\frac{dp}{dk} = \frac{Z_k}{Z_q} = \frac{1}{Z_q} \frac{U_{cf}f_k}{c} \left( -\frac{U_{cc}c}{U_c} + \frac{U_{qc}c}{f_p U_c} - \frac{1}{\rho} \right) \quad (\text{A2})$$

where  $\rho = (f_k f_p / f_p k f)$  is the elasticity of substitution in production between capital and pollution and the first order condition assures that  $f_p U_c = U_q$ ; then the sign of  $dp/dk$  depends on the sign of the term inside brackets in (A2). It is possible to show that  $(U_{qc}c/U_q) - (U_{cc}c/U_c) \leq (\geq) (1/\rho)$  is sufficient to have  $(dp/dk) \geq (\leq) 0$

## Appendix B.

### Proof of Proposition 4

$$v(x) = \frac{U_q}{U_c}, \quad x = \frac{c}{q} \quad (\text{B1})$$

If  $v(x)$  is positive and differentiable, and preferences exhibit a diminishing marginal rate of substitution between consumption and environment, then the following expression holds along an indifference curve:

$$\frac{d^2c}{dq^2} = v'(x) \left[ v(x) \frac{1}{q} + \frac{c}{q^2} \right] > 0. \quad (\text{B2})$$

Condition (B2) allows us to express the first order condition in terms of the equality of the marginal rate of substitution between consumption and pollution  $v(x)$  and the marginal rate of transformation between income (consumption) and pollution  $f_p(k, p)$ , such that:

$$v(x) = f_p(k, p) \quad (\text{B3})$$

The slope for the consumption path and for the pollution path can be found by differentiating (B3) and the production function  $c = f(k, p)$  in  $c$  and  $p$  with respect to  $k$ .

$$\frac{\partial c}{\partial k} = \frac{f_p + (f_k/f_{pk})(v'(c/q^2) - f_{pp})}{\Delta} \quad (\text{B4})$$

The expression above is positive as long as  $f_{pk} > 0$  (i.e., if pollution and the conventional factor of production  $k$  are complements) and where:

$$\Delta = \frac{1}{f_{pk}} \left[ v'(x) \left( v(x) \frac{1}{q} + \frac{c}{q^2} \right) - f_{pp} \right] > 0. \quad (\text{B5})$$

Similarly:

$$\frac{\partial q}{\partial k} = \frac{1}{\Delta} \left[ \frac{f_k}{f_{pk}} v'(x) \frac{1}{q} - 1 \right]. \quad (\text{B6})$$

This expression can be further simplified to:

$$\frac{\partial p}{\partial k} = \frac{1}{\Delta} \left[ 1 - \frac{\bar{\rho}}{\varepsilon(x)} \right] \quad (\text{B7})$$

where  $\bar{\rho} = (f_k f_p / f_{pk} f)$  is the elasticity of substitution between capital and pollution in the production function,  $\varepsilon(x)$  is the elasticity of substitution between consumption and environmental quality defined as  $\varepsilon(x) = v/v'x$ , and we have used the fact that  $q = 1 - p$ . Proposition 4 follows from (B7).

## Appendix C.

### Proof of Proposition 5

$$v_x \frac{1}{q} = \frac{U_{qc} U_c - U_{cc} U_q}{(U_c)^2} \quad (\text{C1})$$

Dividing both sides of (C1) by  $v = U_q / U_c$ , rearranging, and multiplying by  $c$  we obtain:

$$\frac{v'x}{v} = -\frac{U_{cc} c}{U_c} + \frac{U_{qc} c}{U_q}$$

Thus  $1/\varepsilon = a - \gamma$  as in Proposition 5.

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