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Could the environment be a normal good for you and an inferior good for me? A theory of context-dependent substitutability and needs☆

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ABSTRACT

Theoretical models often assume the environment to be a normal good, irrespective of one's income. However, a priori, nothing prohibits an environmental good from being normal for some individuals and inferior for others. We develop a conceptual framework in which private consumption and an environmental public good act as substitutes or complements for satisfying different needs. Subsequently, the environment can switch between normal and inferior depending on one's income and environment and corresponding prevalent needs. If the environment is inferior for some range of income, then the willingness to pay for environmental preservation becomes non-monotonic with respect to income. We discuss the relevance of our framework in the context of (income-adjusted) unit benefit transfers, dual-rate discounting and the Environmental Kuznets curve.

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1. Introduction

Is the environment a normal, inferior, or luxury good?[1] This question is crucial to assess the need for environmental protection and the design of prevention policies.[2] There is extensive debate on how the environment should be categorized. An environmental good is considered normal if the willingness to pay (WTP) for it increases with income (luxury if the WTP increases more than proportionally with income). Likewise, an environmental good is considered inferior if the WTP decreases with income (Flores and Carson, 1997; Ebert, 2003). Empirical evidence suggests that this WTP increases with income, often characterizing the environment as a normal good (e.g., Kristrom and Riera, 1996; Horowitz and McConnell, 2003; Jacobsen and Hanley, 2009; Martini and Tiezzi, 2014; Tyllianakis and Skuras, 2016) and in some occasions as a luxury good (e.g., Anthoff and Tol, 2012; Tyllianakis and Skuras, 2016). Only few empirical studies characterize the environment as an inferior good (e.g., Huhtala, 2010; Vo and Huynh, 2017).[3]

In theoretical models on the WTP for environmental goods, an assumption of normality is often made, either explicitly or implicitly, through the properties of the utility function. For example, a constant elasticity of substitution (CES) utility implies normality, as shown in Appendix A.3. Although some models make it possible to assume inferiority instead of normality (e.g., Kotchen, 2005), the two categories cannot coexist in the usual theoretical frameworks – the environmental good is *either* normal *or* inferior. Yet, standard theory acknowledges that some goods can become inferior at some level of income. Israel and Levinson (2014, p. 2) also recall that "no economic theory implies that goods must be normal or inferior in all ranges of income, and cannot switch back and forth. While it may seem improbable that [...] poor people choose clean environments, middle-income people prefer to trade clean environments for other goods, and rich people prefer clean environments, no economic fundamentals would be violated by such a pattern." To date, however, no *single* microeconomic theoretical framework makes it possible to encompass such a variability in preferences.

To fill this gap, we develop a conceptual framework in which the categorization of the environment as a normal or inferior good can vary with the *context*, defined with respect to both income and environmental quality. The intuition behind the possible coexistence of different categorizations for an environmental public good is that individuals value the environment for its contribution to the satisfaction of different needs, and that the prevalence of these needs changes with the context. McConnell (1997, p. 384) emphasizes that "environmental quality is a set of heterogeneous goods, only some of which may be valued more highly at higher incomes." The environment could be an inferior good when private substitutes are available to satisfy some needs. For example, Vo and Huynh (2017) claim that the existence of substitutes to groundwater protection programs (a public good) in Vietnam, such as tap water (a private good), reduces consumers' WTP for these programs with an increase of their income. On the contrary, the environment can be a normal or luxury good when it is a complement to income for the satisfaction of some other needs, recreational activities for example. When the environmental quality is exogenous, its level may be very different from one's optimal choice, by opposition with private (market) goods (see, e.g., Ebert, 2003). For those with larger difference between the given environmental quality and what they long for, "it could then be rational to allocate a large share of incremental income to the public good [i.e., the environment] when a mechanism arises for relaxing the constraint" (Amiran and Hagen, 2018). Such a pattern would depend on the marginal benefits derived from an increase of environmental quality for the satisfaction of different needs. This choice would also naturally depend on one's income.

Our contribution to the literature is twofold. Our first contribution is to clarify the theoretical link between *substitutability* and the categorization of the environment. Starting from the theoretical definition of WTP and income effects on this WTP, we derive a condition to distinguish normal and inferior goods. The literature that links substitutability to the income elasticity of WTP focuses either on the implications of a subsistence requirement on substitutability and sustainability (Baumgärtner et al., 2017b; Drupp, 2018) or on the effect of income inequality (Baumgärtner et al., 2017a) and environmental inequality (Meya, 2020) on WTP. With this objective, they derive results from the analysis of particular utility functions such as the Constant Elasticity of Substitution (CES) function (Baumgärtner et al., 2017a; Meya, 2020) or a variant of the CES function (Baumgärtner et al., 2017b). While these utility functional forms are suitable for their research purpose, they impose normality of the environment. The a priori categorization of the environment could, however, affect environmental policy design. To avoid this restriction, one needs to develop a framework that is flexible enough to encompass all categories of environmental good, i.e., a framework in which the environment can be inferior, at least in some contexts.

This is our second contribution. We develop a framework in which the categorization of environmental goods is endogenous and depends on the satisfaction of needs, making it possible for the goods to be normal or inferior. We then design utility functional forms that illustrate the flexibility of our theoretical framework. In our framework, the income elasticity of the WTP

[1] Our analysis can be generalized to other public goods.

[2] The categorization of environmental goods as normal, inferior or luxury is important to determine changes in "consumption" patterns (here, environmental values). For example, if one wants to foster donations for the environment or preservation of the environment, knowing in which way a population values it can lead to different types of policies or nudges (e.g. campaigns of information in favor of the environment, injunctive and descriptive social norms).

[3] The relatively small frequency of this finding could be explained by two facts. First, when no positive income effect on the WTP is found in an empirical study, concerns are usually raised about the construct validity of the stated preference method (Bishop and Boyle, 2017). However, "how concerned one should be about [the] lack of an income effect in individual studies is a matter of judgment [...] the good being valued could be an inferior good or simply neutral with respect to income" (Bishop and Boyle, 2017, p. 480). Second, as the income effect on the WTP varies across income ranges (Ready, 2002; Barbier et al., 2017, and most studies have been carried out in developed countries (Drupp, 2018), the possibility that some environmental goods are inferior might have been overlooked.

can be negative across some ranges of income and environmental quality and positive across other ranges, thereby endogenously categorizing the environment as a normal good in some contexts and as an inferior good in others. As far as we know, our study is the first to model such a preference variability for environmental public goods. It allows for a switch between environmental good categories in an endogenous manner,[4] offering a formalization of a pattern that has only been broadly discussed in the literature on both private and public goods (see, e.g., Mas-Colell et al., 1995; Israel and Levinson, 2014). We also extend the theoretical literature that examines how the income elasticity of the WTP varies in different ranges of income only (e.g., Barbier et al., 2017) by allowing this elasticity to vary across both income and environmental quality ranges.

Let us describe our methodology. We consider a consumer problem in which the environment is a public good, which quality (or quantity) is exogenous. First, we establish that the sign of the income elasticity of WTP, and therefore the categorization of the environment, is intricately linked to how the marginal utility of environmental quality changes with income, i.e. to the sign of the cross-derivative of the utility function. We interpret this cross-derivative in terms of *substitutability* [5] between income and the environment for practical and legibility purposes, as it is done in many other papers in the environmental economics literature, e.g. in Gollier (2012, chapter 10, p.177) and Heal (2009, p.9). This corresponds to the Edgeworth-Pareto definition of *substitutability* rather than the Hicks' one (see Samuelson, 1974), for a complete description of substitutability concepts). We find that a necessary condition for the existence of inferior environmental goods is that the marginal utility of environmental quality decreases with income, that is, income and environmental quality are substitutes. We show that using the canonical CES utility function or its derivatives implies complementarity (i.e., the marginal utility of environmental quality increases with income), which means that environmental public goods are bound to be normal goods in such frameworks.

To avoid such a priori assumptions on the category of the environmental good, we develop a theoretical framework that allows *substitutability* between income and the environment to vary across contexts, thereby permitting the environment to be considered as normal in some contexts and inferior in others within the same model. We emphasize that this *substitutability* refers to the *substitutability* between income and environmental quality within the indirect (maximized) utility function, and not the *substitutability* between goods within the utility function. We thus use the expression *indirect substitutability* whenever confusion could arise.

This framework is built upon the ideas that *(i)* individuals have different needs or desires, which can be satisfied by combining environmental and private goods, and that *(ii)* the two types of goods may interact differently for satisfying different needs. For example, the environment can be a complement to private goods for the satisfaction of some needs and a substitute for other needs. Having different interactions between goods for satisfying different needs implies that, depending on how the relative importance of the needs changes across contexts, the *indirect substitutability* can change too. The relationship between income and environmental quality could switch from substitutability to complementarity and vice-versa when the context changes. Subsequently, the categorization of the environment as a normal or inferior good may vary across ranges of income and environmental quality.

While considering that the satisfaction of every need partly relies on environmental quality, we distinguish the case in which the overall private consumption contributes to the satisfaction of all needs from the case in which different private goods specifically contribute to the satisfaction of each need. When private goods are need-specific, a hierarchy of needs can occur, with clear-cut implications in terms of *substitutability*. In both cases, we illustrate our conceptual framework with utility functional forms that exhibit *context-dependent substitutability*. Both negative and positive income effects on the WTP are allowed, depending on the context. For example, for some parameters of the functions, an environmental good is normal for very low levels of income corresponding to the satisfaction of basic needs. The environmental good becomes an inferior good for higher but still relatively low income levels and switches back to normality for higher income levels. A similar pattern occurs across the range of environmental quality.

We illustrate the interest of our results by relating our analysis to several strands of the environmental economics literature.

First, our framework offers interesting perspectives when it comes to benefit transfers of environmental values, the most commonly applied non-market valuation technique (Johnston et al., 2015).[6] One way of transferring environmental values from a study site to a policy site is to adjust WTP values for income. The recent literature reports that the income elasticity of WTP might not be constant depending on the income level of a population (Barbier et al., 2017). This means that a value transfer considering constant income elasticities of WTP might be distorted, potentially resulting in incorrect policy recommendations. However, Barbier et al.'s theoretical model and empirical findings suggest that, although non-constant, the income elasticity of WTP is less than one, thereby categorizing the environmental good as normal. The contingency that the environmental good is categorized differently in the study site and the policy site, as we propose in our framework, is one additional dimension that benefit transfer analysts might wish to consider. By allowing for the potential existence of inferior environmental goods at one of the sites, the misestimation of the WTP at the policy site would not only result in a misestimation of the magnitude of the value adjustment but also its direction. By direction of the value adjustment, we mean that, if the environmental good is inferior

[4] There are frameworks in which the sign of the income effects on WTP could change over time due to an exogenous change of some parameters over time (see, e.g., Gollier, 2019), who uses a CES utility function with a substitutability parameter varying exogenously over time). This could explain a change of categorization of the environment for one individual but not the coexistence of several categories of goods for different individuals.

[5] By the term *substitutability*, we always refer to the cross-derivative of the utility function, unless stated otherwise. Throughout the study, we use the term *substitutability* with italicized letters when referring to the terminology, thereby encompassing both substitutability and complementarity in the Edgeworth-Pareto sense.

[6] We refer the reader to Johnston et al. (2015, 2021) for an overview of the broad literature on environmental value transfers.

in the policy site, the resulting estimated WTP value should be smaller than in the study site whereas it would be larger under the (incorrect) assumption that the environmental good is normal in the policy site. The consideration of the categorization of goods in benefit transfers might be all the more important in very low-income contexts where *(i)* inferior environmental goods are more likely and *(ii)* funding to conduct primary environmental valuation studies might be low, leading to a higher demand for benefit transfer (Iovanna and Griffiths, 2006; Johnston and Thomassin, 2010) and particularly (income-adjusted) unit value transfers that are more convenient to implement than other methods (Rolfe et al., 2015; Newbold et al., 2018). We discuss the potential implications of our results in this context from a theoretical perspective and provide some avenues for research for the practical implementation of our framework.

Second, from a dynamic perspective, we also discuss how our framework could affect dual-rate discounting. By developing the expressions of the consumption and environmental discount rates, we show that the last term, namely the so-called substitution effect, depends on the *substitutability* between goods. This means that using our framework could change the *substitutability* between consumption and environmental quality, potentially affecting how consumption and environmental quality are traded off between the present and the future.

Finally, our framework can also be connected to the environmental Kuznets curve (EKC) literature. Part of this literature relates the EKC to environmental preferences. Interestingly, EKC has been sometimes argued to emerge from a change of the relationship between consumption and environmental quality, switching from strongly substitutable to strongly complementary (Kijima et al., 2010, p. 1192). This requires the sign of the cross-derivative of the utility function to vary, which is possible in our framework but not in the other theoretical frameworks, unless one imposes an exogenous change in parameters values.

The remainder of the paper is organized as follows. Section 2 identifies the link between the income effect on the WTP and the *substitutability* between income and environmental quality, thereby drawing implications for the categorization of environmental public goods. Section 3 introduces our concept of context-dependent *substitutability* based on needs. Section 4 discusses the results in the light of several strands of the environmental economics literature and provides avenues for future research. The Appendix gathers the proofs and mathematical details.

2. ***Substitutability*** and the categorization of environmental goods

We first establish the links between *substitutability* and the categorization of the environment in the standard framework, without referring to needs.

Consider a consumer whose utility U is increasing at a decreasing rate with private consumption c and the level (quality or quantity) E of an environmental public good. For now, we consider a single consumption good; this assumption will be relaxed in Section 3.2.

Notations. The set of strictly positive real numbers is denoted by $\mathbb{R}^*_+ =]0, +\infty)$. Subscripts are used to denote function derivatives, for example, for the utility function we write $U_i \equiv \frac{\partial U}{\partial i}$ and $U_{ij} \equiv \frac{\partial^2 U}{\partial i \partial j}$ for $i, j \in \{c, E\}$.

Assumption 1. The utility function $U\colon \mathbb{R}_+^{*2} \longmapsto \mathbb{R}$ is continuous and twice differentiable, strictly increasing, and concave in each of its arguments, i.e., $U_i > 0$ and $U_{ii} \leq 0$ for $i \in \{c, E\}$.

Assuming decreasing marginal utility, we depart from the ordinal utility framework. We do not assume cardinality even so, but only concavity, which is an interesting compromise between ordinality and cardinality (Mandler, 2006).[7] We show in Appendix A.5 that the assumption of concavity, which is less restrictive than cardinality, is sufficient to make our results robust to all increasing concave transformations of utility.

Most environmental goods are non-market goods, and environmental quality is a public rather than a private good. Essentially, it cannot be chosen by the consumer and is considered exogenous to the problem of utility maximization (Ebert, 2003). The objective of the consumer is to maximize own utility $U(c, E)$ by choosing consumption c, subject to a budget constraint depending on the given price p and income Y and the given environmental quality E. As Y and E are both exogenous to the consumer, we define the context of consumption choices as follows.

Definition 1 (Context). The context is defined as the endowment of the consumer in terms of both income and environmental quality, that is, $(Y, E) \in \mathbb{R}_+^{*2}$.

Given context (Y, E) and price p, the following optimization problem defines the indirect (maximized) utility

$$V(Y, E, p) = \max_c \quad U(c, E) \quad s.\,t. \quad pc \leq Y \text{ and } E \text{ fixed}. \tag{1}$$

Denoting the demand function derived from this problem by $c^*(Y, E, p)$, indirect utility can be expressed as

$$V(Y, E, p) = U(c^*(Y, E, p), E). \tag{2}$$

[7] While ordinality and cardinality have often been opposed in the literature (e.g. Samuelson, 1974), they are only two extremes of the utility measurement spectrum (Mandler, 2006). Of particular interest for our framework, Mandler states that “the psychology consisting of all concave utility representations of a given preference relation is larger than any cardinal psychology it intersects, but smaller than any ordinal psychology it intersects. Concavity thus presupposes an intermediate standard of measurement and does not deserve its strongly nonordinalist reputation.”.

In the simple case of an aggregate consumption good, whenever $U_c > 0$, we have $c^* = Y/p$ at the optimum, and thus $V(Y, E, p) = U(Y/p, E)$.

When dealing with a public good, one can determine the value attributed to this non-market good by measuring the WTP of an individual for the increased supply of this good. In utility terms, the willingness to pay for a one-unit improvement of environmental quality, or equivalently the marginal willingness to pay (MWTP), is equal to the marginal rate of substitution between income and environmental quality:

$$MWTP(Y, E, p) = \frac{V_E}{V_Y}. \tag{3}$$

This marginal WTP corresponds to the Lindahl price.[8]

2.1. Categorization of environmental public goods

There has been a debate about whether the income elasticity of demand or the income elasticity of the WTP for environmental services is the best indicator to categorize an environmental good as normal or luxury. While the former elasticity informs about the categorization of private goods (Mas-Colell et al., 1995, chapter 2), we follow Ebert (2003, p.436), who considers that the latter provides decisive information about the categorization of environmental *public* goods.

Formally, the income elasticity of the WTP can be written as follows,

$$\varepsilon^{WTP} = \frac{\frac{\partial WTP}{WTP}}{\frac{\partial Y}{Y}} = \frac{\partial WTP}{\partial Y}\frac{Y}{WTP}, \tag{4}$$

which has the same sign as the income effect $\frac{\partial WTP}{\partial Y}$ since $Y > 0$ and $WTP > 0$.

Based on Ebert (2003, p.447), an environmental good can be considered inferior if the WTP for increasing the environmental good decreases with income ($\varepsilon^{WTP} < 0$) and normal if the WTP for increasing the environmental good increases with income ($\varepsilon^{WTP} > 0$). The good is considered a luxury if the WTP for increasing the environmental good increases more than proportionally with income ($\varepsilon^{WTP} > 1$).

Typically, the empirical literature finds $0 < \varepsilon^{WTP} < 1$ (Kristrom and Riera, 1996; Flores and Carson, 1997; Jacobsen and Hanley, 2009; Wang et al., 2013). This means that the environment is considered a normal good. Luxury environmental goods are also found to a smaller extent in the literature e.g. Anthoff and Tol (2012) for climate change prevention in the medium-term and Tyllianakis and Skuras (2016) for the restoration of the good ecological status of water bodies. The inferior category of environmental goods was underrepresented in the literature a few years ago, and rarely interpreted (e.g., McFadden and Leonard, 1993; McFadden, 1994; Horowitz and McConnell, 2003) but empirical evidence on inferiority has recently grown (e.g., Huhtala, 2010; Vo and Huynh, 2017) and attracted attention regarding why it might be underrepresented (e.g. Drupp, 2018.

2.2. Categorization of environmental goods and *substitutability*

Let us now focus on the sign of the income effect on the WTP (or equivalently the sign of the income elasticity of WTP):

$$\frac{\partial WTP}{\partial Y} = \frac{\partial\left(\frac{V_E}{V_Y}\right)}{\partial Y} = \frac{V_{YE}V_Y - V_{YY}V_E}{V_Y^2}. \tag{5}$$

Our assumptions on the utility function (Assumption 1) imply $V_Y > 0$, $V_E > 0$, and $V_{YY} \leq 0$. The cross-derivative V_{YE} captures how the marginal utility of income changes when environmental quality increases and vice versa. This is the only element in Eq. (5) whose sign is not determined by our assumptions.

By deriving Eq. (2) with respect to income Y and environmental quality E, we can study the components of the cross-derivative of indirect utility:

$$V_{YE} = c^*_{YE}U_c + c^*_Y[c^*_E U_{cc} + U_{cE}]. \tag{6}$$

The cross-derivative of the indirect utility is related to the derivatives and cross-derivative of the utility function as well as to the response of the demand function c^* to changes in the context (Y, E). As we consider an environmental public good, E is provided in a fixed quantity for free and does not affect the budget. Consumption is not affected by a change in environmental quality, and we have $c^* = Y/p$, and thus $c^*_Y = 1/p$, $c^*_E = 0$, and $c^*_{YE} = 0$. Therefore, Eq. (6) is reduced to $V_{YE} = U_{cE}/p$.[9]

The sign of the cross-derivative of a utility function gives information on the *substitutability* between goods. This is a common interpretation in the environmental economics literature (see e.g. Heal, 2009, p.8 and Gollier (2012, chapter 10 p.177).

[8] Given the level of environmental quality E, the Lindahl price is the WTP for an additional unit or a unitary improvement in environmental quality.

[9] Eq. (6) makes it possible to study the more general case in which an environmental change affects the overall consumption. This could be the case when the environment affects income (e.g., through labor productivity), consumption good price (e.g., through production costs), or is framed as an environmental market-like good (e.g., through taxation or fees). In Appendix A.1, we study the interplay between indirect and between-good *substitutabilities*, as described in Eq. (6), when the elasticities are not nil.

Goods are considered substitutes (complements) if environmental quality decreases (increases) the marginal utility of consumption i.e. $U_{cE} < 0$ ($U_{cE} > 0$). Although this interpretation relies on a cardinal view of utility (Samuelson, 1974), we use it for practical and legibility purposes as typically done in the literature.

By extension, *substitutability* between income and the environment can be defined with respect to the indirect (maximized) utility as follows.

Definition 2 (Indirect *substitutability*). The sign of the cross-partial derivative V_{YE} of indirect utility can be interpreted as the substitutability between income Y and environmental quality E. The income and environmental quality are substitutes when $V_{YE} < 0$, independent when $V_{YE} = 0$, and complements when $V_{YE} > 0$.

Thus, the sign of the cross-derivative V_{YE} of indirect utility exclusively depends on the sign of the cross-derivative U_{cE} of the utility function, leading to Proposition 1.

Proposition 1 (Indirect *substitutability* with a public good). Whenever the environment is a public good, and there is a single consumption good, the income and environmental quality are complements (substitutes) if and only if consumption and environmental quality are complements (substitutes). Formally,

$$\forall \quad Y, E > 0 \begin{Bmatrix} V_{YE} > 0 \Leftrightarrow U_{cE}(c^*, E) > 0 \\ V_{YE} < 0 \Leftrightarrow U_{cE}(c^*, E) < 0 \\ V_{YE} = 0 \Leftrightarrow U_{cE}(c^*, E) = 0. \end{Bmatrix} \tag{7}$$

Therefore, indirect *substitutability* only relies on the *substitutability* between goods when environmental quality is a public good.[10]

Now, we can discuss the link between the income effect on the WTP and indirect *substitutability*, and thus between the categorization of public goods and indirect *substitutability*. From Eq. (5), as $V_Y > 0$, $V_E > 0$, and $V_{YY} \leq 0$, a positive income effect on the WTP would occur either if income and environmental quality are substitutes or complements, whereas a negative income effect on the WTP would occur only if income and environmental quality are substitutes. This result is formalized in Proposition 2 (proof in Appendix A.2).

Proposition 2 (Inferior public goods and indirect *substitutability*). *A necessary condition for a negative income effect on the WTP, that is, for an environmental public good to be inferior, is that income and environmental quality are substitutes. This condition is necessary and sufficient if marginal utility of income is constant.*

Table 1 summarizes the three possible cases and single impossible case emerging from Proposition 2.

While indirect complementarity imposes positive income effect on the WTP, indirect substitutability can lead to both negative and positive income effects. When would a negative effect occur? When would an environmental public good be inferior? According to Eq. (5), it occurs when $\frac{V_{EY}}{V_E} < \frac{V_{YY}}{V_Y} \leq 0$, that is, when an additional unit of income reduces relatively more the marginal utility of the environment than the marginal utility of income. In this case, one values an environmental improvement less, which leads to a negative income effect (Case **(2)**). For example, if private consumption and the quality of the environment are sufficiently substitutes (i.e., if V_{EY} is sufficiently negative), then an increase in income may reduce the WTP for the environment. Conversely, if an additional unit of income decreases one's marginal utility of income relatively more than it decreases the marginal utility of the environment (formally, when $\frac{V_{YY}}{V_Y} < \frac{V_{EY}}{V_E} \leq 0$), then one would value income less when compared to an improvement in environmental quality, leading to a positive income effect (Case **(1)**). The same effect occurs in the complementarity case (Case **(3)**) in which an additional unit of income increases the marginal utility of the environment (with $\frac{V_{YY}}{V_Y} \leq 0 < \frac{V_{EY}}{V_E}$). In that case, the environment is never an inferior good.

The empirical literature on demand analysis has long acknowledged the possibility that the category of a good may change with income (Lewbel and Houthakker, 2018). Likewise, relating to the WTP, Israel and Levinson (2014) argue that environmental goods should not be restricted to one category across all income ranges. The theoretical models studying environmental goods do not allow the categorization of the environment to vary with the context. The most commonly used utility functions, such as the CES function (Flores and Carson, 1997; Ebert, 2003; Baumgärtner et al., 2017a), usually imply indirect complementarity and thus normality (Case **(3)** in Table 1 only).[11] To the best of our knowledge, there is no theoretical framework that makes it possible for an environmental good to switch among Cases **(1)**–**(3)** in Table 1 with the change in context.

We propose a theoretical framework that is flexible enough to allow for the categorization of public goods to vary across the context (i.e., with the income and environmental quality), and even to cover the case discussed in the introduction in which a good would switch from normal to inferior and to normal again when income increases.

[10] We relax the assumption of a single consumption good in Section 3.2, which results in a link between indirect *substitutability* and the *substitutability* between goods that is more subtle.

[11] We provide an analysis of several utility functional forms in Appendix A.3. Extended CES utility functions, such as those with a subsistence requirement (Baumgärtner et al., 2017b), are also analyzed.

Table 1
Link between indirect *substitutability* and income effects.

	Positive income effect (normality/luxury)	Negative income effect (inferiority)
Indirect substitutability	**Case (1): possible**	**Case (2): possible**
Indirect complementarity	**Case (3): possible**	Case (4): not possible

3. Context-dependent *substitutability* and needs

We consider that utility is derived from the satisfaction of different needs, or wants.[12]

The satisfaction of every need is partially dependent on environmental quality. However, the way the environment interacts with private goods for the satisfaction of needs may differ. We show that if the environment is a substitute for private goods for the satisfaction of some needs and a complement for the satisfaction of other needs, then the categorization of an environmental public good can vary across the context. The environment may be an inferior good for some income and environmental quality levels, while it will be a normal good in other contexts.

We distinguish the case in which the overall private consumption contributes to the satisfaction of all needs (Section 3.3.1) from the case in which different private goods specifically contribute to the satisfaction of different needs (Section 3.2). The single-good case allows us to link our framework to the literature and emphasize our contribution. From an empirical perspective, this case is also relevant when considering aggregate income or consumption data, that is, when no information on good-specific expenditures is available. The case of need-specific consumption goods is more realistic but requires richer data on expenditures and their purpose.

3.1. Need satisfaction with a single consumption good and the environment

We assume that the consumer derives utility from consumption and environmental quality through the satisfaction of two needs, A and B. For the sake of simplicity, we consider only two needs, but the framework can be extended to accommodate more than two needs. The satisfaction of both the needs depends on the consumption of a private aggregate good c as well as on environmental quality E. We start by considering a single (aggregate) consumption good to match the literature and conceptual framework described in the previous section and Appendix A.3 but relax this assumption in the next subsection.

Within Need A and Need B, the interaction between consumption c and environmental quality E can be different. For instance, private and environmental goods can be complements for the satisfaction of Need A, while they would act as substitutes for the satisfaction of Need B. Need satisfaction is represented by specific functions $A(c, E)$ and $B(c, E)$, encompassing the interaction between goods for each need. We assume these functions to be increasing and concave in each of their arguments, i.e, $A_c > 0$, $B_c > 0$, $A_E > 0$, $B_E > 0$, $A_{cc} \leq 0$, $B_{cc} \leq 0$, $A_{EE} \leq 0$, and $B_{EE} \leq 0$. For the sake of simplicity, we assume there are no interactions between the needs, and that need satisfaction is measured in the same unit as utility. Utility can thus be expressed as $U(c, E) = A(c, E) + B(c, E)$. This specification provides clearer results.

For an environmental public good, the indirect utility function (Eq. (2)) is given by $V(Y, E, p) = U(Y/p, E) = A(Y/p, E) + B(Y/p, E)$. The associated indirect *substitutability* is given by

$$V_{YE} = \frac{1}{p}U_{cE} = \frac{1}{p}(A_{cE}(Y/p, E) + B_{cE}(Y/p, E)). \tag{8}$$

Thus, indirect *substitutability* depends on the between-good *substitutability* for satisfying both the needs. If the environment and the private good interact in a different way for satisfying the two needs and the magnitude of the two effects varies across the context, then the sign of V_{YE} may differ from one context to another, thereby making indirect *substitutability* context-dependent.

We can illustrate this idea with the example of water quality (McConnell, 1997, p. 391), which is considered a public good in the literature (e.g. Grant and Langpap, 2019, p. 5337). Consider a basic need (e.g., drinking clean water) and an ancillary need (e.g., enjoying recreational activities). On the one hand, water quality and private consumption (e.g. bottled water or filtration system) can reasonably be perceived as substitutes to satisfy the basic need. On the other hand, environmental quality and private consumption can be complements for recreational activities, as activities in lakes or rivers expose individuals to water pollutants, which reduces the marginal utility of these activities. If an increase of income generates a larger consumption of

[12] This approach echoes some of the classical aspects of both empirical and theoretical analyses of consumer choices. In Engel's work, expenditures for private goods are classified according to the wants they serve, and the idea of a hierarchy in these wants is used to interpret the observed consumption patterns; however, without using a theoretical model (Chai and Moneta, 2010). Engel's curves are key to describing consumption patterns and categorizing inferior goods. According to Chai and Moneta (2010), "the desirability of developing a theoretical explanation for the shape of Engel curves based on a rich behavioral foundation has been duly noted in the literature, but this issue has not been properly investigated since Engel's time." Our analysis provides a basis to establish a theoretical framework to study preferences for public goods based on need satisfaction. In the consumer theory of Lancaster (1966), utility is not derived from goods directly, but from their characteristics through different activities combining the goods in different ways. Lipsey and Rosenbluth (1971) show that even if all characteristics are valuable, a good may be inferior if it shares sufficient characteristics with a "superior" good. A similar pattern occurs in our framework for environmental goods if activities are interpreted as actions aimed at satisfying needs.

both bottled water and recreational activities, an increase of private consumption reduces the marginal benefit derived from water quality for the basic need and increases the marginal benefit derived from water quality for the ancillary need. For individuals who depend on the environment for the satisfaction of basic needs, the substitution effect may dominate, whereas the complementarity effect may dominate for wealthier individuals with more recreational activities. In other words, depending on the context (high or low income; high or low water quality), an increase in water quality can be perceived as a complement or a substitute to income, depending on the prevalent need. Therefore, in this example, low income individuals would rather perceive water quality and income as substitutes, resulting in either normality or inferiority of the quality of water (Cases (1) or (2) in Table 1). Conversely, high income individuals would experience complementarity between income and water quality, resulting in normality of the quality of water (Case (3) in Table 1).

To illustrate the flexibility of our framework, we provide an example of utility function with context-dependent *substitutability* (CDS).

3.1.1. An example of a utility function with CDS

Consider a utility function with the following putative form.[13] For any $(c, E) \in \mathbb{R}_+^{*2}$,

$$U(c, E) = c^\gamma E^\omega - \frac{\theta}{c^\alpha E^\beta}, \tag{9}$$

where $\theta > 0$ and $0 < \gamma, \omega, \alpha, \beta < 1$ are given parameters. For simplicity, we call it the CDS utility function.

This function would correspond to the need-satisfaction functions $A(c, E) = c^\gamma E^\omega$ and $B(c, E) = -\frac{\theta}{c^\alpha E^\beta}$. We have $A_{cE} = \gamma\omega c^{\gamma-1}E^{\omega-1} > 0$, meaning that the private good complements the environmental quality in satisfying Need A, whereas $B_{cE} = -\theta\alpha\beta c^{-\alpha-1}E^{-\beta-1} < 0$, meaning that the private good acts as a substitute for environmental quality in satisfying Need B.

Fig. 1 shows the indifference curves associated with the CDS utility function for a specific combination of parameter values. The properties of function U are consistent with preferences satisfying completeness, continuity, transitivity, and non-satiation. The preferences represented by U are not homothetic. The cross-partial derivative of the CDS utility function is

$$U_{cE} = A_{cE} + B_{cE} = \gamma\omega c^{\gamma-1}E^{\omega-1} - \theta\alpha\beta c^{-\alpha-1}E^{-\beta-1}. \tag{10}$$

As the first term in the sum is positive and the second term is negative, its sign depends on the context, that is, on environmental quality and income levels. This allows us to derive the indirect *substitutability*, which, for demand $c^*(Y, E, p) = Y/p$, depends on the context (values of Y and E) as follows,

$$\begin{cases} V_{YE} < 0 & \Leftrightarrow \quad Y < K/E^{\frac{\omega+\beta}{\gamma+\alpha}} \\ V_{YE} = 0 & \Leftrightarrow \quad Y = K/E^{\frac{\omega+\beta}{\gamma+\alpha}} \\ V_{YE} > 0 & \Leftrightarrow \quad Y > K/E^{\frac{\omega+\beta}{\gamma+\alpha}} \end{cases}$$

where $K = p\left(\theta\frac{\alpha}{\gamma}\frac{\beta}{\omega}\right)^{\frac{1}{\gamma+\alpha}}$ is a constant.

Fig. 2 illustrates the indirect *substitutability* of the CDS utility function. For relatively low values of environmental quality and/or income levels, income and environmental quality are substitutes (the gray area). For higher values, income and environmental quality are complements (the white area). This pattern is particular to the CDS utility function. We do not claim that this should be universal. The frontier between the areas covering substitutability and complementarity depends on the price p of the private good. As p increases, the purchasing power decreases, which increases the size of the domain wherein income and the environment substitute one for the other in the provision of utility.

3.1.2. CDS preferences exhibiting inferiority of the environment

We derive the conditions under which a negative income elasticity of the WTP occurs with the CDS specification, in line with condition (5).

Proposition 3 (Negative income elasticity of the WTP under CDS preferences). There are contexts in which the income effects on the WTP is negative (and therefore $\varepsilon^{WTP} < 0$) *for the CDS utility* (9) if and only if we jointly have $\gamma + \alpha > 1$ *and* $\frac{\gamma\beta}{\omega\alpha} > \frac{(\gamma+\alpha+1)^2}{(\gamma+\alpha-1)^2}$.

The proof of Proposition 3 is in Appendix A.4. This condition is satisfied for the following set of parameters (among others): $\alpha = \beta = \gamma = 0.99$ and $\omega = 0.01$; in the case of these parameters, the range of contexts for which the environment is an inferior good is large. Fig. 3 illustrates this case.

The black curves with black labels in Fig. 3 indicate the levels of income elasticity. The light green area illustrates the contexts for which the environment is an inferior good (negative income elasticity of the WTP). The two dark green areas indicate contexts for which the environment is a normal good (positive income elasticity of the WTP). The white curve indicates the frontier between the substitutability and complementarity domains (i.e., $V(Y, E) > 0$ above the curve and $V(Y, E) < 0$ below

[13] Other possible functions are $U(c, E) = c^\gamma E^\omega + \theta \ln(c^\alpha + E^\beta)$ and $U(c, E) = cE - e^{\theta-c-E}$.

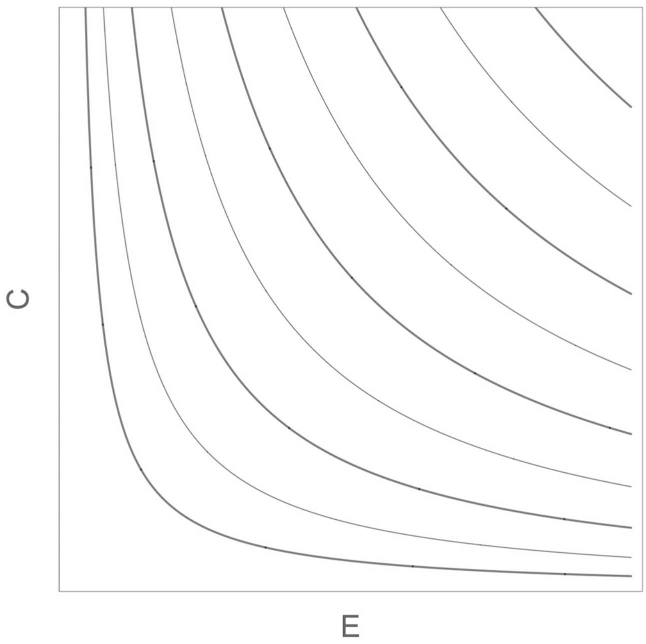

Fig. 1. Indifference curves of the CDS utility function ($\alpha = \beta = \gamma = \omega = 0.5$ and $\theta = 100$).

it). The income elasticity of the WTP can be negative only when income and environmental quality are substitutes (Proposition 2). Thus, the CDS utility function allows for a categorization of environmental goods that depends on the context.[14]

3.1.3. Heterogeneity of contexts

In the case of the parameters of the CDS utility function used in Fig. 3, different preferences toward the environment (WTP) coexist.

We can interpret this heterogeneity with the example of water quality. Consider different regions that differ in terms of the quality of water and/or income, that is, different contexts. For simplicity, we consider that the contexts denoted by **(1)** and **(2)** have a similar, lower water quality and differ only with respect to their income. Contexts **(3)**–**(5)** share a similar, higher water quality and also differ only with respect to their income.

In the higher water quality case, for individuals with an extremely low-income level, as in context **(3)**, the satisfaction of basic needs (drinking safe water) might heavily rely on the water quality. Because of the low level of income in this context, an increase in income may not allow the individual to cover her needs of clean water by purchasing bottled water. Instead, because private consumption and water quality are substitutes, she might be willing to "pay" more for water quality. In this case, water quality is a normal good.[15] In context **(4)**, private consumption and water quality are also substitutes. With a similar water quality, but a higher income, private consumption of bottled water may cover most of the basic need, and an individual will have a low dependence on water quality. As income increases, the individual would exhibit a lower WTP for water quality. The quality of water is inferior in that context. In context **(5)**, corresponding to a high income, ancillary needs may prevail and income may act as a complement to water quality. Recreational activities may require both a good water quality and income. As higher income allows for more private consumption of recreation, the WTP for water quality increases with additional income (normal good).

The magnitude of the income bracket for which there is a negative income effect on the WTP varies with environmental quality. In Fig. 3, in regions characterized by lower environmental quality (contexts **(1)** and **(2)**), inferiority of the environment occurs for a larger range of income levels than in regions that have a better environmental quality (contexts **(3)**–**(5)**). The lower the environmental quality, the larger will be the income bracket for which there is a negative income effect on the WTP. As

[14] With the CES or extended CES utility function, the whole graph would be dark green. The income and environmental quality would be complements in all contexts, and the environmental good would be a normal good.

[15] It may seem unrealistic that very low-income individuals would be willing to pay monetarily for a better water quality. However, in tribal economies, the extremely low income of native people and their high willingness to protect the environment (see UN Environment Article) leads to a consideration of the WTP beyond its proper *monetary* definition. The non-monetary WTP can take various forms, such as spending time protecting the environment or engaging in benevolent communication in favor of environmental protection.

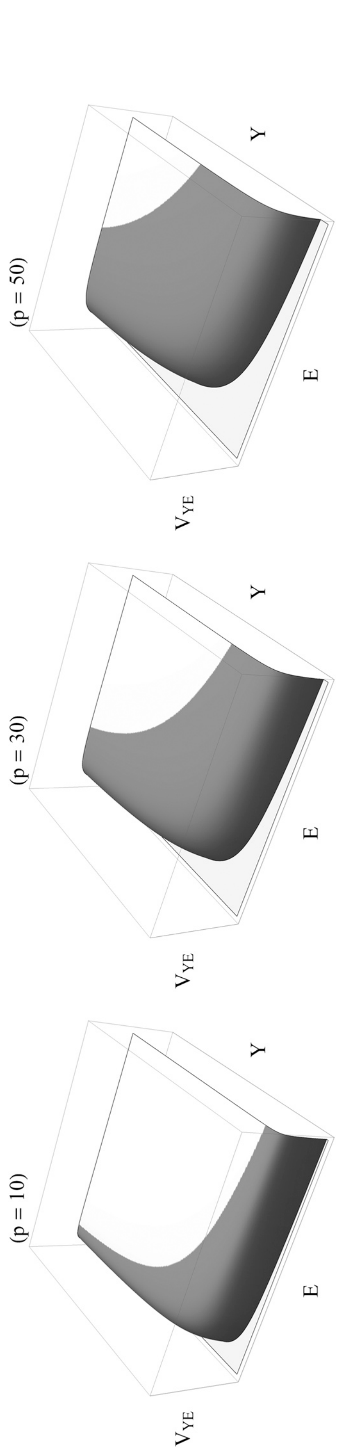

Fig. 2. *Substitutability* for a CDS utility function with parameters $\alpha = \beta = \gamma = \omega = 0.5$ and $\theta = 100$, for different prices p. Y and E are substitutes in the gray area and complements in the white area.

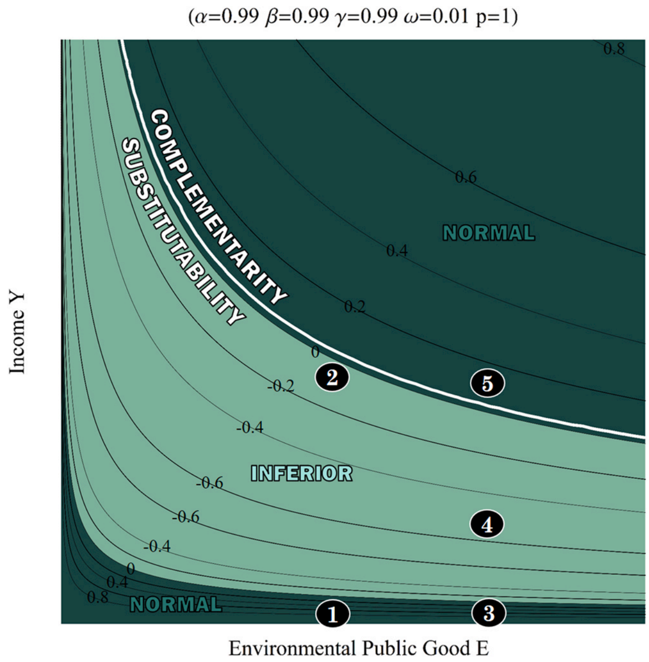

Fig. 3. Income elasticity of the WTP under CDS preferences.

environmental quality worsens, richer individuals are more likely to exhibit a negative income effect. With such preferences, countries with poor environmental conditions may enter a vicious circle, when the environmental degradation resulting from growth and increasing income induces an overall diminishing WTP for environmental preservation. Certainly, these interpretations are specific to some parameters of the CDS utility functional form. Altogether, such a utility function could represent situations in which a negative income effect on the WTP would occur more in low-income countries, and would have a higher likelihood of occurrence when environmental quality is low.

In line with our illustration in Fig. 3, Israel and Levinson (2004) offer an empirical analysis (in connection with the theoretical EKC literature) in which they relate income to environmental preferences, using the World Values Survey. They use a proxy to the marginal WTP for the environment, and show that households with higher relative incomes are more likely to support higher prices for the environment, that households with medium and low relative incomes are less likely to support such price increase, but "for some reason," households in the lowest category of incomes are more likely to support a higher relative price for the environment (Israel and Levinson, 2014, p. 10–11). Our framework could provide a "reason" for such a pattern to occur, as illustrated in our plot of the WTP as a function of income in the following subsection.

3.1.4. Benefit transfers

Our results can shed light on the literature related to (income-adjusted) unit value transfers, which is often used in practice despite the higher accuracy of other (more complex) methods such as benefit function transfers and given the lower level of expertize needed (Johnston et al., 2015, chapter 1, p. 10–11). Let's discuss the implications of our framework from a theoretical perspective. When the environment is an inferior good for some range of income, the WTP is non-monotonic and decreases for that range.[16] Figs. 4 and 5 represent the marginal WTP as a function of income for the two levels of environmental quality discussed previously.[17] On both figures, the pattern is similar. The WTP first increases with income, then decreases, and, finally, rises again as income increases.[18]

[16] While our framework deals with individual WTP or a representative agent's WTP, benefit transfers relate to average WTPs. One could think that, by averaging environmental preferences, assuming normality of the environmental good could be reasonable, i.e. inferiority would be irrelevant in this context. However, it is not clear. As an example, Barbier et al. (2017) find an income elasticity of 0.6–0.7 in higher income countries and of 0.1–0.2 in lower income countries. However, the lower-income countries that are considered in that paper are those around the Baltic sea. Performing the same kind of evaluation in even lower-income countries such as African or South American countries might lead to negative income elasticities of WTP, especially given the very-close-to-zero elasticities found in Barbier et al.'s paper in relatively low-income countries in Europe but relatively high-income countries compared to the rest of the world.

[17] The axes in Fig. 4 and Fig. 5 have the same scale and ensure that the marginal WTP can directly be compared across the two figures. Compared to Fig. 3, we extended the range of income to discuss further interesting cases.

[18] Israel and Levinson (2004, Figs. 5(C) and 5(D), p. 25) plot the relationship between income and the priority accorded to environmental issues, and they show

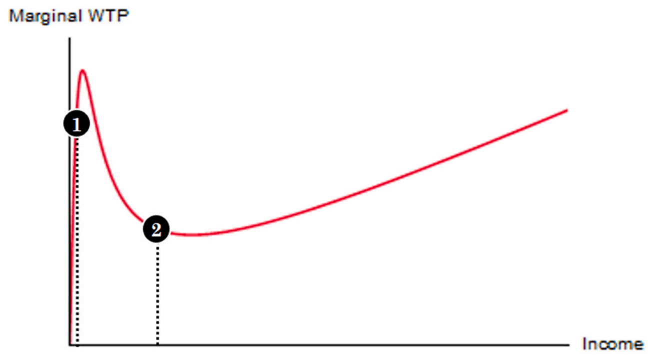

Fig. 4. Marginal WTP as a function of income – lower environmental quality.

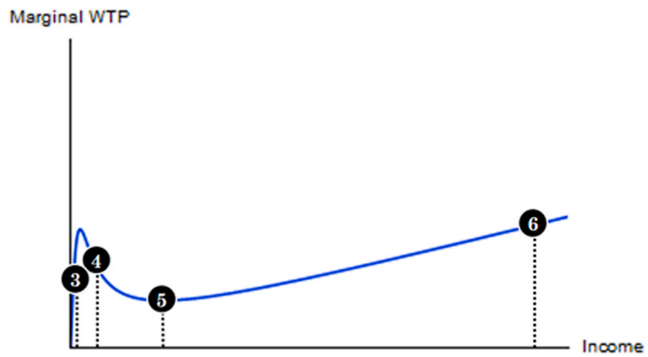

Fig. 5. Marginal WTP as a function of income – higher environmental quality.

Consider unit benefit transfers among different contexts tagged in Fig. 3.[19] Applying a unit income elasticity, with the underlying assumption of normality, would lead to estimating a higher WTP in richer contexts and a lower WTP in poorer contexts when compared to the study site. For example, the WTP in context **(2)** would be estimated higher than in the poorer context **(1)**. Fig. 4 illustrates that the opposite occurs when CDS preferences, that exhibit inferiority across a range of income, are taken into account. A similar misestimation, or what we could call a misestimation in the *direction* of the value adjustment, would occur between contexts **(4)** and **(5)** in Fig. 5 if the environmental good is assumed normal in all contexts. This is due to the fact that, within a range of income wherein the environment is perceived as an inferior good, poorer individuals value the environment *more* than richer individuals do.

This kind of misestimation would occur mainly when the two sites are characterized by contexts positioned on different sides of an income-effect border (light green/dark green in Fig. 3), even when the two sites are relatively similar in terms of income and environmental quality. When the difference in income of the two sites is large and covers mainly incomes for which the environment is a normal good, a standard unit value transfer may not lead to an incorrect *direction* of the value adjustment but would still result in an error in the *magnitude* of the value adjustment, as found in the literature. This is illustrated by the overall positive income effect between context **(4)** and the richer context **(6)** in Fig. 5.

Therefore, with actual non-monotonic WTP profiles, using unit value transfer could result in a misestimation of the direction and/or the magnitude of the value adjustment. In certain cases, the direction may be right, and the magnitude distorted (e.g., between contexts **(4)** and **(6)**). In other cases, both the direction and magnitude may be distorted (e.g., between contexts **(1)** and **(2)**). The misestimation may be even stronger if the two sites are different in both income and environmental quality (e.g., between contexts **(1)** and **(5)**).

Overall, the categorization of environmental goods is an additional aspect that benefit transfer experts might be willing to take into account.[20] Although empirical evidence only rarely finds that environmental goods are inferior, our hypothesis is that

(*footnote continued*)
a sharp increase for low income levels, then a downward trend followed by a rebound for higher income levels. Of course, this is not a proof that the patterns in our results for the CDS function with particular parameters is backed-up by empirical data, but our model offers ways to accommodate (and possibly interpret) such patterns if encountered in the data.

[19] Context **(6)** in Fig. 5 is not in the range of income depicted in Fig. 3.

[20] Indeed, the literature on benefit transfers is broad and already analyzes several aspects of the method that influence the accuracy of the environmental value transfers. Examples are the consideration of temporal dimensions, cultural differences and income inequality differences between sites (Johnston et al.,

i) related research has not spanned all the contexts that can be studied (most studies were done in rather developed countries) and/or *ii)* findings related to inferior goods are often not interpreted. We discuss the potential selection bias further in Section 4.

3.2. Need satisfaction with need-specific consumption goods and the environment

Assuming a single aggregate consumption good as in Section 3.3.1 amounts to assuming that the consumer will purchase the same bundle of commodities irrespective of the given income or environmental quality levels. If the interplay between private goods and the environment depends on the context, then the type of goods purchased may also depend on the context. In fact, if goods are purchased to satisfy different needs that have relative importance, then income would more likely be devoted to the purchase of goods that contribute to the satisfaction of the currently more urgent need. From this viewpoint, the assumption of a single composite consumption good is restrictive.

In this section, we relax this assumption and consider the case in which different private goods contribute to various needs differently. For simplicity, we consider two private goods, each contributing to the satisfaction of one (and only one) of the needs. This is a simplified case in which each private good has a single characteristic, as discussed in Lancaster (1966, p. 136–137).[21] The environment, however, is assumed to have two characteristics and contribute to both the needs.

The private consumption associated with Need A is denoted by $c_A \in \mathbb{R}^+$, and the private consumption associated with Need B is denoted by $c_B \in \mathbb{R}^+$. The corresponding prices, denoted by p_A and p_B, are given, finite, and positive (i.e., $0 < p_A < \infty$ and $0 < p_B < \infty$). Environmental quality E contributes to the satisfaction of the two needs, possibly, in different ways. The need-satisfaction functions are, respectively, denoted by $A(c_A, E)$ and $B(c_B, E)$ and are assumed to be continuous and twice differentiable. We assume that the need-satisfaction functions satisfy the following assumptions: $A_{c_A} > 0$, $A_{c_A c_A} \leq 0$, $A_E > 0$, $A_{EE} \leq 0$, $B_{c_B} > 0$, $B_{c_B c_B} < 0$, $B_E > 0$, $B_{EE} \leq 0$. Utility is denoted by $U(c_A, c_B, E)$. For the sake of simplicity, we assume the separability of needs and that need satisfaction is measured in the same unit as utility. This ensures that $U(c_A, c_B, E) = A(c_A, E) + B(c_B, E)$. Given the properties of A and B, the utility function $U(c_A, c_B, E)$ has the following properties:

- $U_{c_A}(c_A, c_B, E) > 0$ and $U_{c_A c_A}(c_A, c_B, E) \leq 0$;
- $U_{c_B}(c_A, c_B, E) > 0$ and $U_{c_B c_B}(c_A, c_B, E) < 0$;
- $U_E(c_A, c_B, E) > 0$; $U_{EE}(c_A, c_B, E) \leq 0$.

Our framework aims to capture consumer decisions in a given context. The objective of the consumer is to maximize own utility, which depends on the satisfaction of the two needs, by choosing the optimal consumption levels c_A and c_B, given the budget Y, prices p_A and p_B, and environmental quality E.

$$\begin{aligned} V(Y, E, p_A, p_B) &= \max c_A, c_B \quad U(c_A, c_B, E) \\ & \qquad s.\ t \begin{Bmatrix} p_A c_A + p_B c_B \leq Y, \\ c_A, c_B \geq 0, \\ \text{given } Y, E, p_A, p_B. \end{Bmatrix} \end{aligned} \tag{11}$$

V is the indirect utility function, namely the optimal level of utility obtained in a context (Y, E) and given prices (p_A, p_B).

Denoting the demand functions for the two private goods (which are implicitly defined by the optimization problem (11)) by $c_A{}^*\ (Y, E, p_A, p_B)$ and $c_B{}^*\ (Y, E, p_A, p_B)$, the indirect utility can be written as

$$V(Y, E, p_A, p_B) = A(c_A{}^*(Y, E, p_A, p_B), E) + B(c_B{}^*(Y, E, p_A, p_B), E). \tag{12}$$

The cross-partial derivative of this expression gives us indirect *substitutability*:

$$\begin{aligned} V_{YE} = &\left(A_{c_A c_A} \frac{\partial c^*{}_A}{\partial E} + A_{c_A E} \right) \frac{\partial c^*{}_A}{\partial Y} + A_{c_A} \frac{\partial c_A^{*2}}{\partial Y \partial E} + \left(B_{c_B c_B} \frac{\partial c^*{}_B}{\partial E} + B_{c_B E} \right) \frac{\partial c^*{}_B}{\partial Y} \\ &+ B_{c_B} \frac{\partial c_B^{*2}}{\partial Y \partial E}. \end{aligned} \tag{13}$$

This expression depends on the *substitutability* between private goods and the environment for both need satisfactions (i.e., $A_{c_A E}$ and $B_{c_B E}$), in interaction with the response of demands to changes in the context, particularly, with income Y. The term $\frac{\partial c^*{}_A}{\partial Y}$ (resp. $\frac{\partial c^*{}_B}{\partial Y}$) is proportional to the share of marginal income allocated to the satisfaction of Need A (resp. B), with the condition that marginal income is fully used, that is, $p_A \frac{\partial c^*{}_A}{\partial Y} + p_B \frac{\partial c^*{}_B}{\partial Y} = 1$ (from the budget constraint). If marginal income is mainly allocated to the satisfaction of one of the needs, then the *substitutability* of the associated private good with the environment for

(*footnote continued*)
2018, p. 185–86).

[21] The specific goods can be thought of aggregate goods for each need, for example, a composite food basket, on the one hand, and the rest of the economic goods, on the other hand, if one considers the first need to be food consumption, as opposed to another ancillary need. The problem could also be set in terms of need-specific expenditure by suppressing prices.

the satisfaction of that need would influence indirect *substitutability* more than the *substitutability* of the other private good with the environment for the satisfaction of the other need. The extreme case in which marginal income is allocated to a single good (e.g., $\frac{\partial c^*_B}{\partial Y} = 1/p_B$ and $\frac{\partial c^*_A}{\partial Y} = 0$) provides an intuitive discussion of Eq. (13) and makes it possible to establish a direct link between indirect *substitutability* and between-good *substitutability* for that need. Such behavior prevails when there is a (partial) need hierarchy, a particular case we examine now.

3.2.1. A case with need hierarchy

Consider a hierarchical behavior in the satisfaction of needs, with Need B being of primary importance with respect to Need A. This would be the case if Need B corresponds to *basic* needs and Need A to *ancillary* needs. A hierarchy of needs is often related to quasi-lexicographic preferences in the literature, as presented in the transposition of Maslow's theory of motivation (Maslow, 1943) in a utility maximization framework (e.g., Seeley, 1992). However, imposing such restrictions on the optimization problem is unnecessary. Appendix B provides simple properties that utility can satisfy and that induce (endogenous) hierarchical behavior. A hierarchy simply emerges as a corner solution of a utility maximization problem when the utility function satisfies such properties. This allows us to avoid imposing *exogenous* thresholds for satiation (or for behavioral change, as in Baumgärtner et al. (2017b). Appendix B describes the way the *endogenous* thresholds for behavioral changes are derived in our framework. We refer to such thresholds below.

Let us describe a stylized hierarchical behavior in our framework. For some range of (low) income, the marginal income is exclusively allocated to the satisfaction of the basic need B. For a higher range of income, marginal income is allocated to the satisfaction of both the needs. For the remaining range of income, marginal income is exclusively allocated to the satisfaction of the ancillary need A. The threshold below which marginal income is only allocated to Need B, with $c^*_B = \frac{Y}{p_B}$ and $c^*_A = 0$, is denoted by $\underline{Y}(E, p_A, p_B)$. The threshold above which additional income is only allocated to Need A, with $c^*_B = \bar{c}_B$ and $c^*_A = \frac{Y - \bar{c}_B p_B}{p_A}$, where $\bar{c}_B$ is the maximum private consumption devoted to the satisfaction of Need B, is denoted by $\overline{Y}(E, p_A, p_B) \geq \underline{Y}(E, p_A, p_B)$. Subsequently, the indirect utility function can be written as follows (dropping the arguments of the endogenous thresholds $\underline{Y}$ and $\overline{Y}$):

$$V(Y, E, p_A, p_B) = \begin{cases} U\left(0, \frac{Y}{p_B}, E\right) = B\left(\frac{Y}{p_B}, E\right) & \text{if } Y \leq \underline{Y} \\ U(c_A^*(Y, E, p_A, p_B), c_B^*(Y, E, p_A, p_B), E) & \text{if } \underline{Y} < Y \leq \overline{Y} \\ U\left(\frac{Y - \bar{c}_B p_B}{p_A}, \bar{c}_B, E\right) = A\left(\frac{Y - \bar{c}_B p_B}{p_A}, E\right) & \text{if } \overline{Y} < Y \\ \qquad + B(\bar{c}_B, E) & \end{cases}$$

This leads to the following result for indirect *substitutability* [22].

$$V_{YE} = \begin{cases} \frac{B_{c_B E}}{p_B} & \text{if } Y < \underline{Y} \\ \text{Eq.}(13) & \text{if } \underline{Y} < Y < \overline{Y} \\ \frac{A_{c_A E}}{p_A} & \text{if } \overline{Y} < Y \end{cases}$$

In this case of (partial) hierarchy, indirect *substitutability* in the two extreme cases, which correspond to the allocation of marginal income for purchasing a single good, relies on the *substitutability* between goods for the satisfaction of the relevant need only. Consequently, in a given environmental context E, two individuals with different income levels Y may exhibit different preferences for the environment because they allocate marginal income to the satisfaction of different needs. The thresholds $\underline{Y}$ and $\overline{Y}$ depend on environmental quality E (and on prices p_A and p_B). Essentially, the income threshold at which behavior changes varies with a change in environmental quality. We discuss this effect with an example.[23]

3.2.2. An example of a utility function with need hierarchy and CDS for two goods

To illustrate the previous results, we provide an example of a utility function based on the two needs, for which there is a hierarchy with a *prevalence* [24] of the basic need B for low-income levels and a *strong non-satiety* [25] of the ancillary need A.

[22] The derivatives at the threshold levels $\underline{Y}$ and $\overline{Y}$ may not be well-defined. We discuss these cases in Appendix B.1.

[23] Proposition 5 in Appendix B provides a general result on the links between such thresholds and on the *substitutability* between private goods and the environment for the satisfaction of both the needs.

[24] Roughly speaking, this means that income is allocated only to the basic Need B for low-income levels. Refer to Appendix B for the formal definitions of this property.

[25] Roughly speaking, this means that marginal income is allocated only to the ancillary need A for high-income levels. This does not mean that the basic need B is fulfilled, nor requires *absolute satiety* of Need B. Refer to Appendix B for the formal definition of these properties.

For any $(c_A, c_B, E) \in \mathbb{R}_+^{*3}$, consider the utility function

$$U(c_A, c_B, E) = c_A E^{\omega} - \frac{\theta}{c_B^{\alpha} E^{\beta}} \tag{14}$$

with $0 < \omega, \alpha, \beta < 1$, and $\theta > 0$.

Here, Need A is such that, for any $(c_A, E) \in \mathbb{R}_+^{*2}$, $A(c_A, E) = c_A E^{\omega}$, and Need B is such that, for any $(c_B, E) \in \mathbb{R}_+^{*2}$, $B(c_B, E) = -\frac{\theta}{c_B^{\alpha} E^{\beta}}$. The cross-derivatives of the need-satisfaction functions are $A_{c_A E} = \omega E^{\omega-1} > 0$ and $B_{c_B E} = -\theta\alpha\beta c_B^{-\alpha-1} E^{-\beta-1} < 0$. Therefore, in this example, there is complementarity between goods for the satisfaction of Need A and substitutability between goods for the satisfaction of Need B.

For a given environmental quality E, the marginal utility derived from the consumption of good c_A is constant and equal to E^{ω}. Regarding Need B, the marginal utility derived from the consumption of good c_B is $B_{c_B} = \frac{\alpha\theta}{c_B^{\alpha+1} E^{\beta}}$, which varies continuously and monotonically from $+\infty$ when the consumption of c_B is nil to 0 when the consumption is infinite. Hence, there is a consumption threshold $\hat{c}_B$ under which marginal income has a higher marginal utility when it is allocated to Need B and above which the marginal income should be allocated to Need A only. This case of pure hierarchy[26] is described and resolved in Appendix B. We denote the corresponding income threshold by $\bar{Y}(E, p_A, p_B)$. This threshold is such that $U_{c_A}(0, \frac{\bar{Y}}{p_B}, E)/p_A = U_{c_B}(0, \frac{\bar{Y}}{p_B}, E)/p_B$. Given that $U_{c_A}(0, \frac{Y}{p_B}, E) = E^{\omega}$ and $U_{c_B}(0, \frac{Y}{p_B}, E) = \alpha\theta E^{-\beta}\left(\frac{p_B}{Y}\right)^{\alpha+1}$, its expression is as follows:

$$\bar{Y}(E, p_A, p_B) = p_B\left(\frac{p_A}{p_B}\frac{\alpha\theta}{E^{\omega+\beta}}\right)^{\frac{1}{\alpha+1}}. \tag{15}$$

Fig. 6 illustrates this case of a pure hierarchy for $p_A = p_B = 1$ to ease the visual interpretation.

Depending on the context (Y, E), additional income is either allocated to the satisfaction of the basic need B (increase in c_B) for low income, or the ancillary need A (increase in c_A) for a sufficiently large income. As a consequence, income and environmental quality are substitutes for low income and complements for high income. The income threshold $\bar{Y}(E, p_A, p_B)$ at which behavior changes is decreasing with environmental quality (see Proposition 5 in Appendix B). The intuition for this pattern is as follows. As the environmental quality increases, the marginal utility of consumption for the satisfaction of Need B decreases due to substitutability, whereas the marginal utility of consumption for the satisfaction of Need A increases due to complementarity. Expenditures for the satisfaction of Need A start at a lower income level when there is an improvement in environmental quality.

4. Discussion

The novelty of our framework lies in the conceptual link between needs satisfaction, *substitutability* and the categorization of environmental goods. In our framework, private consumption and environmental quality may act as substitutes or complements depending on one's needs. The prevalence of a specific need in a given context of income and environmental quality leads an individual to perceive income and the environment as either substitutes or complements. This indirect *substitutability* affects individual preferences regarding the environment, that is, whether the individual is willing to pay more, or less, for environmental improvements as income rises.

This framework allows us to contribute to several strands of literature. First, concerning the theoretical literature related to the income elasticity of WTP (e.g. Flores and Carson, 1997; Ebert, 2003; Barbier et al., 2017; Baumgärtner et al., 2017a, 2017b; Meya, 2020), we offered a framework that endogenizes the categorization of environmental goods. Indeed, the common frameworks only allow environmental goods to be *either* normal *or* inferior, with no flexibility. In particular, our framework allows us to address the lack of consideration of inferior environmental goods in the current theoretical models, as discussed in Appendix A.3. Second, we enriched this literature by considering an additional contextual dimension, environmental quality, which, beside income (see e.g. Barbier et al., 2017), influences the income elasticity of the WTP. How the WTP for the environment increases with income may indeed be affected by the quality of the environment as well. Last but not least, we provided utility functional forms that illustrate our framework. The CDS utility functional form we scrutinized is one of many examples. The interpretation of the underlying preferences should not be considered universal, but rather as an illustration of the flexibility of our framework. Our aim was to show that such a model with CDS allows for a variation in the category of environmental goods depending on the income and environmental context of individuals.

In this section, we discuss the links of our approach with *i)* environmental effects on the WTP[27], *ii)* (income-adjusted) unit value transfers, *iii)* dual-rate discounting and *iv)* the EKC. For each of these literatures, we provide potential avenues for future research.

[26] 'Pure' in the sense that there is a complete switch in behavior regarding the allocation of marginal income to the two needs, contrary to the case of the partial hierarchy described before, wherein marginal income was allocated to both goods for a range of income. When there is a pure hierarchy, the two previously defined thresholds, $\underline{Y}$ and $\bar{Y}$, merge.

[27] The environmental effect refers to the effect of a change of the environmental status quo on the WTP.

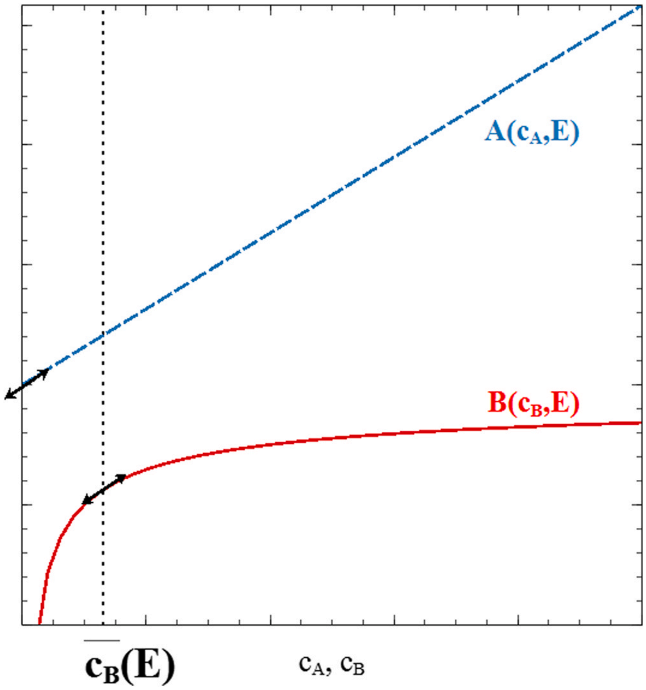

Fig. 6. Utility from needs satisfaction in the case of pure hierarchy.

4.1. Environmental effects on WTP

Our framework offers insights on the environmental effect on the WTP. Similar to the study on the income effect, our framework relates the environmental effect on the WTP with *substitutability* between income and the environment, which is in line with Amiran and Hagen (2010). We can express the environmental elasticity of the WTP[28] as $\varepsilon^E = \frac{\partial WTP}{WTP} / \frac{\partial E}{E}$ where the environmental effect is

$$\frac{\partial WTP}{\partial E} = \frac{\partial \left(\frac{V_E}{V_Y} \right)}{\partial E} dE = \frac{V_{EE} V_Y - V_{YE} V_E}{V_Y^2} dE. \tag{16}$$

Would two individuals with the same income but different environmental qualities be willing to pay the same for environmental improvements? Intuitively, one might think that their contribution might not be the same and that the WTP would decrease as environmental quality improves. Nonetheless, a positive environmental effect can occur when income and environmental quality are sufficiently substitutes. This would mean that individuals are willing to pay more as environmental quality improves. Our framework makes it possible to study such cases in which some individuals may be less willing to pay for environmental preservation as environmental quality increases, while others may be more willing to pay for it, depending on the context.

4.2. (Income-adjusted) unit benefit transfers literature

Benefit transfers constitute a promising tool to address the increasing demand for environmental valuation (Richardson et al., 2015). In particular, there is a growing interest in *international* value transfer since many countries – and particularly less developed countries (Drupp, 2018) – do not have primary valuation studies on hand (Johnston et al., 2018). Although there is generally greater accuracy with benefit function transfers compared to (adjusted) unit value transfers (Johnston et al., 2021), the recent literature on international benefit transfers (see Johnston et al., 2018, for a full review) essentially reports that income-adjusted unit value transfer may perform better than function transfer (e.g. Czajkowski and Ščasný, 2010; Bateman et al., 2011; Lindhjem and Navrud, 2015; Andreopoulos and Damigos, 2017; Czajkowski et al., 2017; Artell et al., 2019).[29] Our theoretical model could be relevant in this international benefit transfer framework for two reasons. The first reason has been mentioned above, that is the potential outperformance of income-adjusted unit value transfers, which is the only transfer method, among

[28] As far as we know, few studies estimate the environmental elasticity of the WTP (e.g., Rollins and Lyke, 1998).
[29] Which does not mean that adjusting for income is enough to generate lower transfer errors (Johnston and Thomassin, 2010).

the many methods proposed in this literature, our framework can be connected with. The second reason is the current publication selection bias toward relatively developed countries in the environmental valuation literature (Drupp, 2018). Indeed, when browsing the literature on environmental valuation, one can observe that most studies were conducted in relatively high-income countries. For example, in their meta-analysis on the WTP for biodiversity, Jacobsen and Hanley (2009) mainly identify studies from developed countries. While 112 studies of their sample have been conducted in Europe, North America, and Australia, only 33 studies have been conducted in developing countries, including Africa, Asia, and South America. The meta-analyses of Schläpfer (2006) and Horowitz and McConnell (2003) mostly refer to studies in developed countries. Kristrom and Riera (1996) find a positive income effect on the WTP based on European datasets. By broadening the origins of the studies on environmental valuation (i.e., by broadening the studied ranges of income as well as the environmental quality levels), negative income effects might emerge more often than is currently observed.[30] We could reasonably expect an increasing demand for environmental valuation in developing countries in the future. Since less developed countries often have less financial resources to conduct primary valuations, we could also expect a greater use of (international) benefit transfers in these countries. While the categorization of environmental goods as normal seems valid in relatively high-income contexts, inferiority could arise from contexts depicting a conflict between development and environmental preservation. Therefore, the consideration of the whole span of categories of environmental goods as we propose would be relevant if (income-adjusted) unit value transfers are used in the context of lower income countries.

Until here, we have only discussed the theoretical implications of our framework on benefit transfers. It would be interesting to consider the practical implications of our CDS utility function: how feasible it is and if applicable, whether it improves the accuracy and validity of benefit transfers. One approach would be to derive an explicit benefit transfer function (following Loomis, 1992) and drawing on microeconomics e.g. Smith et al., 2002; Baumgärtner et al., 2017a) that could be tested empirically in a multi-country convergent validity analysis (see e.g. Czajkowski et al., 2017; Meya et al., 2019). Another approach would be to derive restrictions one should impose to (meta-)regression benefit transfer that is otherwise based on best statistical fit (see e.g. Moeltner, 2019; Newbold et al., 2018).[31]

4.3. Dynamic frameworks: intertemporal WTP and dual-rate discounting

Our framework could also be used in a dynamic context. Given the evolution of income and environmental quality, how the environmental WTP varies over time and how it is affected by changes in income and environmental quality can be assessed through the following equation, where the dots refer to derivatives with respect to time:

$$\frac{\dot{WTP}}{WTP} = \frac{\frac{dWTP}{WTP}}{\frac{dY}{Y}}\frac{\dot{Y}}{Y} + \frac{\frac{dWTP}{WTP}}{\frac{dE}{E}}\frac{\dot{E}}{E} \tag{17}$$

in which $\frac{\dot{WTP}}{WTP}$ is the growth rate of the WTP, $\frac{\dot{Y}}{Y}$ is the income growth rate, and $\frac{\dot{E}}{E}$ is the environmental growth rate (Horowitz, 2002). Moreover, in a dynamic version of our framework, *substitutability* could change over time, potentially leading to different categorizations of the environment over time for a single (or representative) individual or after averaging WTPs across different individuals. A time-varying *substitutability* would not only affect income effects on WTP as in Eq. (17) but also how WTPs are valued in the future, via the discount rates. In this regard, our framework can be connected with the literature on dual-rate discounting (e.g. Yang, 2003; Tol, 2004; Guesnerie, 2004; Weikard and Zhu, 2005; Hoel and Sterner, 2007; Sterner and Persson, 2008; Kögel, 2009; Gollier, 2010; Traeger, 2011; Echazu et al., 2012; Venmans and Groom, 2021). The expressions of the consumption and environmental discount rates are respectively as follows:

$$r^c = \delta + g_c\eta_{c,c} + g_E\eta_{c,E}, \tag{18}$$

$$r^E = \delta + g_E\eta_{E,E} + g_c\eta_{E,c}. \tag{19}$$

with $g_c = \frac{\dot{c}}{c}$ and $g_E = \frac{\dot{E}}{E}$ the consumption and environmental growth rates respectively. Both discount rates are the sum of three terms. The first term δ is the rate of pure preference for the present. The second term corresponds to the so-called *growth effect*. It depends on the elasticity of marginal utility for consumption $\eta_{c,c} \equiv -\frac{\frac{\partial u_c}{u_c}}{\frac{\partial c}{c}} = -c\frac{u_{cc}}{u_c}$ for the economic discount rate r^c, and on that for environmental quality $\eta_{E,E} \equiv -\frac{\frac{\partial u_E}{u_E}}{\frac{\partial E}{E}} = -E\frac{u_{EE}}{u_E}$, for the environmental discount rate r^E. The third term is the so-called *substitution effect*. It depends on the cross elasticities of marginal utility $\eta_{c,E} \equiv -\frac{\frac{\partial u_c}{u_c}}{\frac{\partial E}{E}} = -E\frac{u_{cE}}{u_c}$ and $\eta_{E,c} \equiv -\frac{\frac{\partial u_E}{u_E}}{\frac{\partial c}{c}} = -c\frac{u_{cE}}{u_E}$. Therefore, the two discount rates depend on the *substitutability* between the two goods through $\eta_{c,E}$ for r^c and $\eta_{E,c}$ for r^E. We can show that the

[30] In their meta-analysis, Horowitz and McConnell (2003, footnote 2) report that about 5% of the studies find such an effect in their sample but they do not interpret it.

[31] We owe these suggestions to an anonymous referee.

substitution effect has opposite impacts on the two discount rates whether consumption and environmental quality are substitutes or complements. The connection between our framework and dual-rate discounting is all the more interesting when an environmental (or economic) shock occurs. In such a case, the individual could change her perception of the two goods, for example by considering the two goods as complements initially and as substitutes once the shock has occurred. An avenue for research would be to analyze how preferences change the growth path in classical natural resources models considering environmental quality as a contributor to well-being. This way, we could determine optimal growth rates and study the evolution of discount rates over time and particularly exogenous shocks on goods' quantities. It could also be interesting to study an EKC trajectory and derive the evolution of the discount rates along this path.

4.4. Environmental Kuznets curve

While our purpose is not to provide an exhaustive review of the EKC literature (see Dasgupta et al., 2002 and Kijima et al., 2010 for reviews) or to establish strong connections with it (which would require the addition of a pollution model to our analysis), it is worth discussing the theoretical papers that relate EKC to preferences. McConnell (1997) studies a model offering a direct connection between our analysis and the EKC. He examines the role of the income elasticity of demand for environmental quality on the EKC, without imposing a condition on the substitutability of income and environmental quality. While an EKC can be due to a change in the sign of the income elasticity of demand for environmental quality, he emphasizes that this cannot happen with additively separable preferences, as the income elasticity is always positive in this case.[32] Lieb (2002) highlights, however, that the relationship between the income elasticity of demand for environmental quality and the EKC is ambiguous. Interestingly, he relates the EKC pattern to satiation, a potentially strong driver of change in the sign of the income elasticity of the WTP in our framework (see Appendix B.1). In a model close to that of McConnell (1997) and generalizing that of Stokey (1998), with consumption-related pollution, abatement, and a representative consumer, satiation in consumption is sufficient to generate an EKC, but a 'tendency to satiation' (i.e., that the environment is a normal good) is necessary. In particular, utility of consumption has to be bounded from above in Stokey's model. When discussing a model *à la* McConnell (1997), Kijima et al. (2010) point out that an EKC can be due to a change of the relationship between consumption and environmental quality, switching from strongly substitutable to strongly complementary (Kijima et al., 2010, p. 1192). It is of course not possible to represent such preferences when the sign of the cross-derivative of the utility function is the same everywhere.[33]. Our framework makes such a change possible and provides an interpretation for such a pattern, with the satisfaction of different needs changing across income and environmental contexts. Kijima et al. (2010) also refer to DiVita (2004) who proposed a model in which an EKC is explained by the marginal disutility of pollution alone, without conditions on the production-side of the economy. In this setting, the marginal disutility from pollution depends on the level of income, and an EKC emerges if this relationship exhibits a U-shape. Altogether, our framework could be used in EKC-related models to study such patterns.

Overall, our paper provides a general theoretical framework as well as particular utility functions that allow researchers to include all possible categories of environmental goods in their models without changing exogenous parameters. Beyond theory and given the reasonable expectation that future environmental valuation studies might be increasingly performed in less developed countries, accounting for the whole range of categories of environmental goods might prevent the potential (good-category-related) misestimation of environmental values and help improve corresponding policy recommendations.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.reseneeco.2022.101316.

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[32] López (1994) proposes a model in which there is an EKC when the substitutability between conventional production factors and pollution in production is high, and marginal utility declines sufficiently sharply with consumption. As he assumes additively separable preferences, the result depends on income only (on the elasticity of the marginal utility of consumption) and not on the pollution level. Many authors assume additive-separability of preferences (e.g. Selden and Song, 1995; Stokey, 1998).

[33] Of course, one could always represent preferences through a set of ad hoc utility functions each defined on a subset of the goods-map and parameterized to allow for such a switch. One could also assume an exogenous change in parameters' values over time, as in Gollier (2019). Our framework offers some rational for such a switch, which occurs endogenously.

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