Sustainability Constraint and the Equitable Intergenerational Allocation of an Exhaustible Resource

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Inadequate attention has been given to equity considerations concerning the intergenerational allocation of an exhaustible resource. Existing literature focuses primarily on intertemporal allocative efficiency and considers exclusively the welfare of the current generation. However, this efficiency-oriented approach generally leads to efficient, yet 'beggar-thy-progeny' outcomes. In this paper we propose a new approach that bluntly addresses the intergenerational equity concerns. We argue that a sustainability constraint, which specifies both the needs and obligations of each generation, has to be integrated into the discussion. We demonstrate how to impose such a constraint to discriminate a sustainable path, or paths, according to particular social objectives. We also compare the tradeoffs between the gains (levels of intergenerational equity achieved) and sacrifices (amounts of intergenerational transfers made) of various policy proposals.

1. Introduction

Is the future of the world system bound to be overgrowth, only to collapse into a dismal, depleted existence because of resource exhaustion? The Club of Rome asked this question 30 years ago. Unfortunately, today's social institutions as well as the present ways of doing things are by and large in the same, if not worse, state of dismay that had so distressed the pioneers. Nevertheless, progress that may alter this unsustainable course has been achieved over the years. The first is the establishment of solid scientific bases on several of the most serious environmental problems; it has been proven that they are all invariably due to the Earth's limited ability to assimilate the enormous byproducts (pollutants) of our daily activities (Arrow et al., 1995). The second is the increasing popularity of the concept of sustainable development as proposed in the Brundtland report (WCED, 1987), which maintains that we should be responsible not only to our own needs but also to those of future generations. These two advancements have verified the presumption that when resource exhaustibility is connected to the inaction of the current generation, the business-as-usual extraction practice will exhaust the limited environmental resource base, which

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in turn may lead to morally unacceptable outcomes at too fast a speed.[1] All these have thus reinforced the belief that the economic analysis of sustainability has to be advanced beyond mere efficiency and feasibility considerations, it has to address equity concerns as well (Howarth and Norgaard, 1992).

Ultimately, the concerns of the Club of Rome can be transformed into a problem of discriminating a development path under the combined constraints of resource exhaustibility, income feasibility and sustainability. To put it in other words, since our economic activities are inherently activities with the adverse effects of depleting the Earth's environmental resource base in an irreversible manner, it is a question of how to distribute such a finite resource base efficiently among members of different generations over time so as to achieve certain 'equitable' sustainability objectives. This has been and will continue to be the central yet perennial subject in the literature on exhaustible resources and sustainability.

However, the efficiency and equity considerations have not been treated with balance in the literature, which thrived in the aftermath of the first oil shock. In response to the suddenly eminent resource exhaustion problem, concerns have centered mainly on the issue of how to ensure resources are utilized efficiently. On the other hand, the equity aspect of the sustainability problem is largely left out of the discourse. Integrating the equity considerations is regarded as redundant, because it has been wrongly conceived that the efficiency outcomes are already optimal (Howarth and Norgaard, 1990). This is also because "it is not until very recently that there has been an economic theory of sustainability, or even any systematic application of existing theories to the issues to which it alludes (Heal, 1998, p. i)."

This major omission is largely due to a lack of consensus on the definition of sustainability. Unlike the resource exhaustibility constraint, which is essentially a physical phenomenon ; and the income feasibility constraint, which states that the agents should consume within their income range ; the constraint on sustainability depends on the definition of sustainability. Though highly pervasive, the definition of sustainable development as proposed in the Brundtland report, which states "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987, p. 43)", is by no means unequivocal. It has been widely accepted that these needs depend intrinsically on the amount of exhaustible resources they possess (Howarth, 1996). However, the academic world remains widely divided as to the exact definition of the needs of future generations and sustainability. As identified by Toman (1994), Jaeger (1995) and Tilton (1996), in one school are the concerned, which consist of ecologists, scientists and engineers, who claim sustainability means each generation should have equal access to a resource base that is essentially the same over time. Accordingly, they prescribe that drastic measures are needed and decentralized decisions, or the business-as-usual market-oriented decision-making mechanism, should be curtailed. In opposition is the school of the unconcerned, in many cases economists, who claim the efficient outcomes are the best solution. This school insists that with fine-tunings like the environmental valuation practice, the savings-investment decisions in a decentralized market economy will 'automatically' lead to a 'sustainable future'. It seems these two schools differ not only on their prescriptions but also on the undertaken analysis framework. Without a doubt, to a matter of such great importance, consensus, and not disagreement is what is urgently needed. Contrary to common belief, in this paper we argue that the seemingly contradictory arguments of the two schools can actually be addressed and explicitly compared within a clear and coherent analysis framework as long as one acknowledges the premise of our analysis, that the fulfillment of the needs of future generations ultimately depend on the amount of exhaustible resources they possess.

The paper is organized as follows. In Section 2, we introduce a modified version of the overlapping generations (OLG) model of Olson and Knapp (1997) and trace the path of the business-as-usual resource extraction practice. Here we only consider the exhaustibility and income feasibility constraints and the sole objective is to achieve efficiency. In Section 3, the effects of the practice of environmental valuation are included by explicitly integrating the amenity value of the resource into the model.[2] We show that the environmental valuation practices, prescribed by the unconcerned group, cannot modify the 'beggar-thy-progeny' nature of the business-as-usual practice. In other words, this efficiency-oriented approach by itself is not sufficient to achieve sustainability. In Section 4, we introduce a new approach of integrating the sustainability constraint that explicitly tackles the intergenerational equity aspect of the sustainability problem. We consider the implications of this approach and compare the resultant path with those obtained under the efficiency only argument and show how the new path becomes more sustainable. Moreover, we conclude that the seemingly substantial discrepancies between the two schools lie in the treatment and selection of the sustainability constraint. We show that the sustainability concerns of the two schools can be addressed and their respective policy effects compared within one generally coherent framework, in a largely decentralized setting. Section 5 contains our concluding remarks and also highlights the possibility of applying this approach to examine the implications of other policies involving intergenerational transfers.

2. The classic framework

In this section, we review some of the fundamental conclusions of the literature on exhaustible resource allocation, which dates from the seminal paper of Hotelling (1931) and has experienced a major renaissance since the publication of *The Limits to Growth* (Meadows et al., 1972). The model we are going to examine is a modified version of that of Olson and Knapp (1997), which in itself is an OLG adaptation of that of Hotelling. Our model examines an infinite horizon economy with an exhaustible resource, an environmental firm, a production sector, and finite-lived consumers that form a sequence of overlapping generations. Time is assumed to be discrete, with $t \in T = \{0, ..., \infty\}$. There are two generations alive in each period, a young and an old generation, each consisting of a representative agent. We assume that the economy is endowed with a nonrenewable resource stock that has a finite initial value, $\psi_1 x_1 < \infty$, where x_1 denotes the initial stock level of the resource while ψ_1 is the resource price in the first period. Young agents are endowed with 1 unit of labor, to be supplied inelastically. A profit-maximizing firm hires labor and purchases an exhaustible resource input to produce a consumption good. At the beginning of each period, the resource stock x_t is owned by the old (generation $t-1$) while the old of generation 0 is endowed exclusively with the entire initial resource stock.

It is assumed that in the economy, there is an environmental firm that prepares (extracts) the exhaustible resource ready for use as production inputs. At the beginning of each period, the environmental firm acquires the property rights of the resource stock from the old at the price of ψ_t. In each period, it extracts r_t amount of the resource stock at zero extraction cost and sells it at the price of p_t^r to the consumption good producing firms. The remaining resource stock, x_{t+1}, is transferred to the young at the price of ψ_{t+1}. Hence the transition equation for the resource stock can be stated as

$$x_{t+1} = x_t - r_t, \tag{2.1}$$

which also describes the resource exhaustibility constraint that the economy is facing. Notice the business-as-usual practice of resource use closely resembles the intertemporal transition of a resource as described by (2.1).

The objective of the environmental firm is to maximize the aggregated profits over time, which is subjected to the transition equation (2.1):

$$\max \sum_{t=1}^{\infty} (p_t^r r_t + \psi_{t+1} x_{t+1} - \psi_t x_t), \tag{2.2}$$

subject to (2.1) and the non-negative conditions on r_t and x_t.

The first-order conditions for this problem can be then stated as follows:[3)]

$$p_t^r \leq \psi_{t+1} \quad \perp \quad 0 \leq r_t, \tag{2.3}$$

$$\psi_{t+1} \leq \psi_t \quad \perp \quad 0 \leq x_t, \tag{2.4}$$

Equation (2.3) is an arbitrary condition that implies that *in situ* (asset) and extractive (input) prices for the resource are the same in the equilibrium. Therefore, hereinafter, resource prices will simply be denoted by ψ_t. Equation (2.4) implies that the present value shadow price of the resource is time independent.[4] This is so because we assume in our model that the extraction cost does not depend on the remaining resource stock.[5] The conclusion we reached from equations (2.3) and (2.4) is essentially that of Hotelling (1931), although the latter utilizes a continuous-time formulation. Moreover, because of constant returns to scale in equation (2.1), for each period, the following zero profit condition holds:

$$\psi_t x_t = p_t^r r_t + \psi_{t+1} x_{t+1}. \tag{2.5}$$

The production function of the production sector is denoted to be $F(r, l)$, which is assumed to be constant returns to scale with its reduced form $y_t = f(r_t)$, where y_t is the output of the consumption good. The resource input is assumed to be important but not essential for production, with $f(0)>0$ and $\infty > f'(0) > 0$. It is assumed that f is twice continuously differentiable, strictly increasing, strictly concave, and satisfies the Inada condition $\lim_{r \to 0} f'(r) = \infty$. It is assumed that firms in this economy act competitively and their aims are to maximize their profits in each period, and their maximization problem is

$$p_t^c f(r_t) - w_t - p_t^r r_t, \tag{2.6}$$

which is subject to the production function.

Hence, firms purchase each input to the point where its price equals its marginal product so that

$$p_t^c f'(r_t) = \psi_t, \tag{2.7}$$

and

$$p_t^c f(r_t) - r_t \psi_t = w_t. \tag{2.8}$$

We assume the population is constant over time and that each generation consists of a single representative agent. For generation t, c_t^1 is the consumption when young at a price p_t^c, and c_{t+1}^2 denotes the consumption when old at a price p_{t+1}^c, respectively. Each generation has an instantaneous utility function: $U(c_t^1, c_{t+1}^2)$, subject to the income feasibility constraint that expenditures on consumption in each period are less than or equal to the available income. It is postulated that U is twice continuously differentiable, increasing in both arguments, strictly quasi-concave, and satisfies the Inada conditions for c_t^1 and c_{t+1}^2.[6] Moreover, it is assumed that each old agent in the first generation has a single period utility function $U(c_1^2)$ that is increasing in c. Old generation finances its consumption from the income earned from the sale of the resource to the environmental firm, together with its savings when young. Young generations, however, must earn an income to finance their consumption and their purchase of the resource from the environmental firm by selling their labor at the price of w_t. The life-cycle budget constraint for generation $t \geq 1$ can then be stated as

$$p_t^c c_t^1 + p_{t+1}^c c_{t+1}^2 \leq w_t, \quad (2.9)$$

which is the explicit form of the income feasibility constraint that restrains the expenditure of the agents within the range of their aggregated income.

Hence, the consumers' optimization problem for an agent born at time $t \geq 1$ is max $U(c_t^1, c_{t+1}^2)$, subject to the income feasibility constraint (2.9). (2.10)

This completes our description of the model. Next we define the equilibrium of this economy.

DEFINITION 1. An *OLG competitive equilibrium* of this economy is an intertemporal resource allocation plan defined as $\{p_t^r, p_t^c, \psi_t, r_t, x_t, w_t, c_t^1, c_t^2\}$ that solves the maximization problems of the environmental firm, consumers and producers and clears all markets for $t=0, ..., \infty$.

In a competitive equilibrium as defined by Definition 1, resource outputs balance with expenditures over the infinite time horizon,[7]

$$\sum_{t=1}^{\infty} w_t + \psi_1 x_1 = \sum_{t=1}^{\infty} (p_t^c y_t + p_t^x x_t). \quad (2.11)$$

As shown in the proof Lemma 1 of Gerlagh and Keyzer (2001), as long as (2.11) holds, the resultant equilibrium is dynamically efficient.

In the following Example, we characterize the equilibrium extraction rule explicitly by specifying the utility function and production function.

EXAMPLE (PART I: BUSINESS-AS-USUAL) Suppose that each generation has a separable log utility function which is specified as

$$U(c_t^1, c_{t+1}^2) = \ln(c_t^1) + \beta \ln(c_{t+1}^2), \quad (2.12)$$

where β is the subjective discount factor. The production function is a CES one and is stated as follows

$$f(r) = [\alpha + (1-\alpha) r^{-\sigma}]^{-1/\sigma}, \quad (2.13)$$

where $0 < \alpha < 1$, and $-1 < \sigma < 0$.

The equilibrium extraction rule

Under the description of the economy and the specified utility and production function as given in the Example, the equilibrium extraction rule is given as

$$x_t = [\alpha\beta/(\beta+1)(1-\alpha) + r_t^{-\sigma}]/r_t^{-\sigma-1} \quad (2.14)$$

Moreover, since (2.11) holds, the path as defined by (2.14) is dynamically efficient.

3. Environmental valuation: its essence and limitations

Environmental valuation practice, by measuring people's preferences for the amenity values inherent in the resource, has long been regarded as being able to internalize the externalities of non-rival use of the resource amenity values, and therefore, has the potential of leading to more 'desirable' decisions. Incorporating the environmental valuation in the decision-making process is a two-tier task. The first involves the actual measuring; the methodology of which can be found in Pearce (1993) and for a good example, refer to Constanza et al. (1997).[8] The second step is about how to integrated the values obtained into the decision-making process.

The concept that individuals derive their utility not only from the consumption goods produced from the resource, but also from the amenity values inherent in the resource dates from the Krutilla (1967), and can also be found in Krautkraemer (1985, 1986). The concept of amenity values recognizes the trade-off relationship accompanying the extraction of a large number of environmental resources. Integrating such a trade-off relationship makes necessary the selection between utilizing the resource as an input in the production process and leaving it intact and consuming its amenity values. In economic models that explicitly recognize the amenity value of the resource, the utility function is a function of both the flow of the consumption goods and the flow of the resource amenities that depend upon the remaining stock of the resources.

Following Krautkraemer (1985, 1986) and Gerlagh and Keyzer (2001), the exhaustible resource we consider is assumed to yield x_t units of amenity value within each period.[9] Let p_t^x be the price of one unit of such resource amenity. Hence the total value derived from the resource in period t can then be denoted as $p_t^r r_t + p_t^x x_t$. In each period, φ_t is the given Lindahl price for one unit of the resource amenity value. Since the amenity value derived from the resource is non-rivalry in nature, it is straightforward to notice that agents living in the same period face an identical level of amenity value,

$$x_t^1 = x_t^2 = x_t, \tag{3.1}$$

and, according to the definition of Lindahl prices,

$$p_t^x = \varphi_t^1 + \varphi_t^2. \tag{3.2}$$

After the introduction of the resource amenity value, the utility function changes into $U(c_t^1, x_t, c_{t+1}^2, x_{t+1})$.[10] Moreover, as in the last section, we assume that the utility function is non-negative, differentiable, strictly concave, increasing in all its four arguments, and satisfies the Inada conditions for $c_t^1, x_t, c_{t+1}^2, x_{t+1}$.

Following the introduction of the resource amenity, the objective of the environmental firm changes into the following form, which is subject to the resource exhaustibility constraint (2.1):

$$\max \sum_{t=1}^{\infty} (p_t^r r_t + p_t^x x_t + \psi_{t+1} x_{t+1} - \psi_t x_t), \tag{3.3}$$

subject to (2.1) and the non-negative conditions on r_t and x_t.

The first-order conditions of this problem can be then stated as follows:

$$p_t^r \leq \psi_{t+1} \quad \perp \quad 0 \leq r_t, \tag{3.4}$$

$$\psi_{t+1} + p_t^x \leq \psi_t \quad \perp \quad 0 \leq x_t. \tag{3.5}$$

Because of constant returns to scale in (2.1), for every period, the following zero profit condition holds:

$$\psi_t x_t = p_t^r r_t + p_t^x x_t + \psi_{t+1} x_{t+1}. \tag{3.6}$$

Note the above equation can also be written out for the entire time horizon:[11]

$$\psi_t x_t = \sum_{\tau=t}^{\infty} (p_\tau^r r_\tau + p_\tau^x x_\tau). \tag{3.7}$$

Firms in this economy still act competitively under the motivation to maximize their profits in each period, and their maximization problem is the same as (2.6). Profit maximization implies that the resource is paid in its marginal product so that:

$$p_t^c f'(r_t) \leq p_t^r \quad \perp \quad 0 \leq r_t. \qquad (3.8)$$

It follows from the first-order conditions (3.4), (3.5) and (3.8) that if the future value of the resource amenity is sufficiently high enough relative to the maximal productivity of the extracted resource, no extraction will take place. Put it in other words, resource extraction takes place only when the maximal resource extraction productivity, $p_t^c f'(0)$, is greater than the sum of the prices of the future amenity resource values, $\sum_{\tau=t+1}^{\infty} p_\tau^x$.

Following the introduction of the resource amenity value, the life-cycle budget constraint facing the representative agent of generation t can then be stated as follows:

$$p_t^c c_t^1 + p_{t+1}^c c_{t+1}^2 + \varphi_t^1 x_t + \varphi_{t+1}^2 x_{t+1} \leq w_t, \quad (3.9)$$

which, similar to equation (2.9), is a income feasibility constraint.

The consumer optimization problem for an agent born at time $t \geq 1$ is

$$\max_{c_t^1, c_{t+1}^2, x_t, x_{t+1}} U(c_t^1, x_t, c_{t+1}^2, x_{t+1}), \quad (3.10)$$

subject to the resource exhaustibility constraint (2.1) and the revised income feasibility constraint (3.9).

DEFINITION 2. After the introduction of the resource amenity value, the *OLG competitive equilibrium* of this economy is an intertemporal resource allocation plan defined as $\{p_t^r, p_t^c, \psi_t, r_t, x_t, w_t, c_t^1, c_t^2, p_t^x, \varphi_t^1, \varphi_t^2\}$ that solves the maximization problems of the environmental firm, consumers and producers and clears all markets for $t=0, ..., \infty$. Moreover, since equation (2.10) is satisfied, the resultant equilibrium is efficient.

It is easy to verify that equation (2.10) still holds after the introduction of the resource amenity and the resultant equilibrium remains to be dynamically efficient.

EXAMPLE (PART II: BUSINESS-AS-USUAL PLUS ENVIRONMENTAL VALUATION) Following the introduction of resource amenity value, the utility function of each generation changes into one that has a separable, log utility function and a Cobb Douglas branch for the substitution between the amenity value and the consumer goods

$$U(c_t^1, x_t, c_{t+1}^2, x_{t+1}) = \ln((c_t^1)^{1-v}(x_t)^v) + \beta \ln((c_{t+1}^2)^{1-v}(x_{t+1})^v), \quad (3.11)$$

where β is the subjective discount factor. The above assumption also implies that each agent spends a constant share $0 < v < 1$ of their income on the non-rival consumption of the resource amenity, while the rest, $(1-v)$ is spent on the consumption goods. Production function remains to be unchanged and is stated as equation (2.13).

Modified equilibrium extraction rule

Following the introduction of the resource amenity value, when $r_1 > 0$ the equilibrium extraction rule is given by

$$x_t = [\alpha\beta/(\beta+1)(1-\alpha) + r_t^{-\sigma}]/r_t^{-\sigma-1}. \quad (3.12)$$

Note equation (3.12) is identical with

that of equation (2.14), which amounts to say that the introduction of resource amenity values, or the practice of environmental valuation, does not alter the resource extraction path over time. In other words, under the present setting, the resource stock level over time is independent of the prices attached to the resource amenity values. As depicted in Figure 1 and Figure 2, this extraction rule mandates an extraction pattern that depletes away the resource stock at a speed that may deemed to be unacceptably high and leaves generations in the further future to a extremely low utility level, a state of dismay that has worried the Club of Rome. Since the property rights transition mechanism as described above resembles that of the business-as-usual practice to a large extent, the business-as-usual practice, therefore, inherently it is a 'beggar-thy-progeny' practice. In addition, the practice of environmental valuation, prescribed by some to be the only needed fine-tuning to direct the course of development toward a 'sustainable' one, has no real effects on improving intergenerational equity.

4. Redefining sustainability

In the 1992 *World Development Report* (World Bank, 1992), sustainability is referred to primarily as the application of existing neoclassical principles of efficient resource and environmental management in developing countries, a view that inherently is a variation of neoclassical presentism (Toman, 1994). Therefore, the competitive efficient outcomes we reached in the previous section can be readily recognized as a path that is 'sustainable'. However, as what is shown in Figure 1, this inter-temporally efficient path may lead to 'impoverished future' outcomes that are morally unacceptable.

Sustainability, as proposed in the Brundtland report, is unambiguous on the conceptual connection between the needs of future generations and the obligations of the present. It is now widely accepted that the present generation should be responsible for future generations, and must take their welfare into consideration before optimizing that of its own. What lacks consensus is the exact definition of the needs of the future and the obligations of the present to their progeny. It is on this issue, not on the former, that the two schools remain divided. Howarth (1996 ; 1998 ; 2000) suggests that these concerns to the progeny can generally be transformed into levels of intergenerational transfers. It is therefore possible to address this issue within one coherent framework, in which the needs and obligations of each generation are clearly defined according to the claims of different schools. As noted by Howarth and Norgaard (1990 ; 1992 ; 1995), whether efficient allocation of resources sustains human welfare across generations depends on how the rights and assets are allocated among generations.

According to this view, the search for the sustainable path should be a twofold practice: the equity concern comes first, and second is the efficiency concern. Although the endowed resource being consumed without waste (the efficiency concern) is important, it is not as eminent as that of the former. This is because decisions on how to efficiently dispose an income can only be made after the exact amount and the nature of that income have been learnt.

Therefore, any resource allocation process that addresses equity considerations actually should come into two steps. The first centers on the sustainable concerns and defines the rights of each generation to the resource entitlement and its obligations to future generations; while the second, aims at finding ways that lead to "no wastes" allocation effects, both in the production and in the allocative process. The latter, as what is done in the previous section, involves subjecting the agents' objective function to a budget feasibility constraint that states what has been given is fully consumed and nothing is to be left over. The sustainability concern is addressed in the same fashion by further modifying the budget constraint to reflect the needs and obligations explicitly, that is, by adding a sustainability constraint. In other words, in the case that both the needs and obligations can be explicitly expressed as intergenerational transfers, what is needed is to rewrite the agents' budget constraint so that its disposable incomes reflect both its needs and obligations. Hence, it is easy to see that the business-as-usual practice we examine in the last section is unsustainable since it is asymmetric: the efficiency concern is addressed, while the sustainability concerns is largely missed. However, ironically, to neoclassical presentists, it is still 'sustainable' since according to their underlying value judgments, which focuses exclusively on the welfare of the present and is essentially indifferent to those of the future generations, the needs of the future are not important and the present has no moral obligations to provide for the future. As argued by Howard and Norgaard (1992), "incorporating environmental values *per se* in decision-making will not bring about sustainability unless each generation is committed to transferring to the next sufficient natural resource ... to make development sustainable (p. 473)," merely putting a higher price tag while pretending to not understand the fundamental fact that the needs of the future depends on the amount of resource they receive will never lead an economy to a sustainable path that is in accordance to the Brundtland definition of sustainability.

The rationale behind this argument is provided by Toman (1994), who acknowledges that there are actually infinitely many intergenerational social allocation plans that represent different sets of intergenerational welfare weights, without the 'dictatorship' of the current generation, that are consistent with the Pareto principle. The point is that not all the plans are sustainable since by sustainability one does not simply imply 'no waste'. Only those that pass an additional criterion on distributive justice (no matter how it is defined), the sustainability constraint, should it be classified as sustainable.

Unfortunately, due to the ambiguity concerning the concept of sustainability, there does not exist a solid and universal concept of distributive justice that commands unanimous intellectual support (Toman, 1994) and the criteria used in the literature have been rather arbitrary. Depending on the underlying value judgments, the treatment ranges from the ones that care only for the current generation and its immediate descendants, to those that put a overwhelming emphasis on the further future generations. We assume that these concerns can be addressed through the intergenerational redistribution of incomes. That is, each generation is taxed according to its extraction of the resource, and the pooled tax is then distributed among future generations to compensate their lose from the decrease of the resource stock. In other words, we propose that it is necessary to impose an intergenerational tax regime to tackle the equity concerns. To ensure that such a mechanism is established, an allocation agency is introduced into the economy. In period t, it collects extractive taxes, $\tau_t r_t$, at the tax rate of τ_t, on the basis of resource extraction r_t from the income of the young generation. It then distributes its income to later generations. From the allocation agency, the agent of generation t receives an income claim of the amount H_t^1 when young, and H_{t+1}^2, when old. The budget constraint of the allocation agency can be stated as follows:

$$\sum_{t=1}^{\infty} \tau_t r_t = \sum_{t=1}^{\infty} (H_t^1 + H_t^2). \tag{4.1}$$

The value of total assets held by the allocation agency in period t, F_t, is the sum to be allocated to the subsequent generations at the ending of the same period

$$F_t = H_{t+1}^2 + \sum_{\tau=t,\cdots,\infty} (H_{\tau+1}^1 + H_{\tau+2}^2). \tag{4.2}$$

Following the introduction of the intergenerational transfer mechanism, the budget constraint (3.10) changes into

$$\begin{aligned} & p_t^c c_t^1 + p_{t+1}^c c_{t+1}^2 + \varphi_t^1 x_t + \varphi_{t+1}^2 x_{t+1} \\ & \quad \leq (w_t - \tau_t r_t) + H_t^1 + H_{t+1}^2. \end{aligned} \tag{4.3}$$

Notice that the first term of the right-hand side of equation 4.3 describes the obligations of the generation, while the last two terms depict the additional income claims it is entitled to, which, adjusted by the left-hand side that states its consumption preferences, reflects its needs. Unlike (3.10), (4.3) is a budget constraint that combines both the income feasibility constraint and the sustainability constraint that explicitly considers the needs and obligations, which are largely consistent with the definition of sustainable development as provided by the Brundtland report. Accordingly, the consumers' problem now changes into optimizing (3.11), subject to the resource exhaustibility constraint (2.1) and the combined constraint of (4.3), a constraint that combines both the income feasibility constraint and the sustainability constraint. Without a doubt, the needs and obligations as stated here are perceptions of those of the present and vary according to the underlying value judgments. In addition, the business-as-usual practice we discussed in the previous section can be readily expressed as a policy rule that entitles no transfers to the future generations, that is, $H^1_t = H^2_{t+1} = 0$; and mandates the present to no obligations, that is, $\tau_t = 0$.

DEFINITION 3. An *OLG competitive equilibrium* of this economy under the consideration of the sustainability constraint is an intertemporal resource allocation plan defined as $\{p^T_t, p^X_t, p^C_t, \varphi^1_t, \varphi^2_t, \psi_t, r_t, x_t, w_t, c^1_t, c^2_t, \tau_t, H^1_t, H^2_t\}$ that solves the maximization problems of the environmental firm, consumers and producers and clears all markets for $t = 0, \ldots, \infty$. The resultant equilibrium is efficient since equation (2.10) still holds.

In what follows, we demonstrate how the allocative effects can be modified when each generation provide a strictly positive amount of intergenerational transfers to its progeny. Notice with the addition of an additional criterion on intergenerational equity, the discussion is advanced beyond mere efficiency concerns. In Cai (2002), four alternative sustainability policy scenarios have been identified while their respective policy implications thoroughly examined. Table 1 outlines the obligations, expressed as τ_t, and the needs, H^1_t and H^2_t of each generation under the four policy scenarios.

In Example (Part III), we demonstrate how this approach of integrating the sustainability constraint is applied in the decision-making process. We choose the Polluter Pays Principle (PPP) as our criterion, which acknowledges that each generation should be guaranteed to an identical ability to consume the amenity values, and at the same time, it is also mandated that it must assume the responsibility for addressing the long-term adverse effects of which they are a primary cause.[14)]

EXAMPLE (PART III : PPP) In order to fulfill the polluter pays principle, the allocation agency entitles each generation to come to an income claim of $H^1_t = \varphi^1_t(x_1 - x_t)$ when young, and, $H^2_{t+1} = \varphi^2_{t+1}(x_1 - x_{t+1})$ when old. The resulting extractive tax

Table 1. Sustainability policy scenarios

	Business-as-usual practice	Equal resource entitlement policy[12)]	Polluter pays policy	Strong sustainability policy[13)]
H^1_t	0	$\varphi^1_t x_1$	$\varphi^1_t(x_1 - x_t)$	φ^1_t
H^1_t	0	$\varphi^2_t x_1$	$\varphi^2_t(x_1 - x_t)$	φ^2_t
$\tau_t r_t$	0	$\psi_1 r_t$	$\psi_{t+1} r_t$	0

rate therefore is $\tau_t = \sum_{\tau=t+1}^{\infty} p_\tau^x = \psi_{t+1}$, which implies this policy mandates that the current generation should compensate for the decrease of the amenity value as a result of the permanent loss of the resource stock, which members of the future generations would otherwise be able to consume continuously as a source of resource amenity.

The life-cycle budget constraint for generation $t \geq 1$ now addresses the sustainability considerations and is stated as follows

$$p_t^c c_t^1 + p_{t+1}^c c_{t+1}^2 + \varphi_t^1 x_t + \varphi_{t+1}^2 x_{t+1} \leq w_t - \psi_{t+1} r_t + \varphi_t^1 (x_1 - x_t) + \varphi_{t+1}^2 (x_1 - x_{t+1}). \quad (4.4)$$

Under the polluter pays policy, the optimal consumption when young, c_t^1, is

$$c_t^1 = \frac{\left[f(r_t) - f'(r_t) r_t - \frac{f'(r_t) r_t}{p_t^c}\right](1-v)}{(1+v+\beta+v\beta) - \frac{v x_1}{x_t} - \frac{\beta v x_1}{x_{t+1}}}, \quad (4.5)$$

while the life-cycle saving of each agent, s_t, is

$$s_t = p_t^c \left[f(r_t) - f'(r_t) r_t - \frac{f'(r_t) r_t}{p_t^c}\right] \left\{1 + \frac{v x_1 - x_t}{x_t \left[(1+v+\beta+v\beta) - \frac{v x_1}{x_t} - \frac{\beta v x_1}{x_t - r_t}\right]}\right\} = p_t^c f'(r_t)(x_t - r_t) - F_{t+1}. \quad (4.6)$$

From (4.1) and (4.2), it is straightforward to see that over time, the condition under which this scenario remains viable is $F_t = \psi_t (x_1 - x_{t+1})$. Hence, (4.6) can be restated as (4.6′), which implicitly defines the equilibrium extraction rule

$$s_t = p_t^c \left[f(r_t) - \left(1 + \frac{1}{p_t^c}\right) f'(r_t) r_t\right] \left\{1 + \frac{v x_1 - x_t}{x_t \left[(\beta+1) - \frac{v x_1}{x_t} - \frac{\beta v x_1}{x_t - r_t}\right]}\right\} = p_t^c f'(r_t)(2x_t - 2r_t - x_1). \quad (4.6')$$

In what follows, the results of a numerical simulation is presented to allow the effects of the implementation of the sustainability constraint be examined explicitly.

ASSUMPTION 1. The parameters in the utility function and the production function are specified as follows: $v = 0.1$, is the constant share of the expenditures on the resource amenity relative to the consumption good; $\sigma = -0.67$ is the elasticity of substitution; $\alpha = 0.3$, is the distributional parameter denoting relative factor shares; $\beta = 0.9$, is the subjective discount factor, moreover, since $\beta < 1$, we are discussing the 'Samuelson case' (Gale, 1973), in which a consumer values consumption more when young than when old; $\hat{\psi}_1 = \psi_1 / p_1^c = 0.1$ is the relative stock price of the resource in the first period, with $p_1^c = 1$; and finally, $x_1 = 10{,}000$ is the initial stock level of the resource at the beginning of the first period.

Figure 1, Figure 2 compares the resource stock level and the agents' utility level over time under the business-as-usual practice and the polluter pays policy, respectively. It is ready to observe that the polluter pays policy leads the economy to a more stable life-cycle utility level, and higher resource stock levels over time as

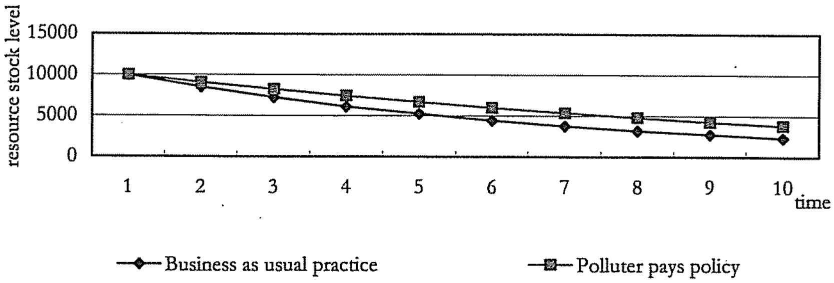

Figure 1. Short-run resource stock level

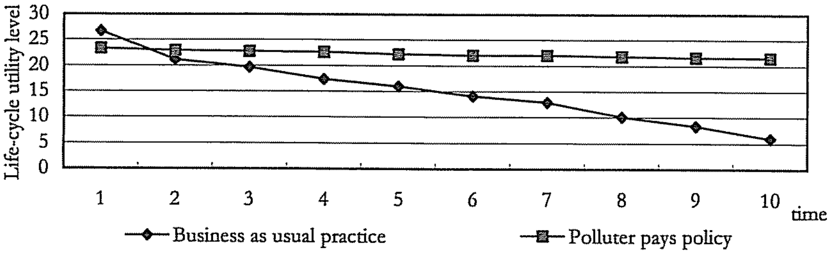

Figure 2. Short-run life-cycle utility level

Table 2. The long-run stock levels and life-cycle utility levels

	Business-as-usual practice	Polluter pays policy
x^*	0.0952	909.274
U	1.27834	17.4093

compared with the business-as-usual practice. As shown in Table 1, which examines the steady states of the three scenarios we have been discussing. It is easy to observe that in the very long-run,[15] this decreasing trend may lead the utility level to extremely low values, indeed a "dismal and depleted" existence that had worried the Club of Rome. It is in this meaning that the business-as-usual is inherently a 'beggar-thy-progeny' practice. Environmental valuation, therefore, by itself is not enough to shift the course of economic development toward a more sustainable one. Changes in the social institution, such as the establishment of an intergenerational allocation agency, are needed to turn our present way of doing things into a more sustainable direction.

5. Concluding remark

It has been argued in this paper that the search for a sustainable path over time involves addressing not only the income feasibility constraint and ensuring that no products (resource) is wasted, but also the consideration of the sustainability constraint that explicitly defines the needs and obligations of each generation. Sustainability constraint, no matter how it is defined, requires that it is the welfare of each generation, and not the welfare of the present, should be examined and maximized. This is so because considering the welfare of the present only may lead to outcomes that are achieved at the sacrifice of future generations. It has also been pointed out that this approach of applying the combined constraints can be applied to address the sustainability discourse more effectively since it provides a coherent framework within which the views and stands of different groups can be directly outlined and bluntly compared.

Undeniably, the activities of *homo sapiens* always accompany irrevocable destruction of their surrounding environment, such as the depletion of the exhaustible resources. Their activities also affect the future states of the human society. With the rapid advancement of the modern technology and numerous powerful social institutions, what is agreed upon can be implemented in a sweeping manner. We are forced more than ever to consider extremely carefully before any decision is to be made, since the resultant impact may be incredibly profound. We cannot take the advantage of our predecessors, but for sure, we can prosper at the price of an 'impoverished future'. It is not difficult for us to borrow from our progeny to finance a stimulus package today without worrying about how the debts will be repaid. Moreover, we should not simply say since the aggregated benefits are greater than the aggregated losses, and no waste occurs, we are making the right decisions. Decisions made this way will in general, as what is shown in this paper, accrue the benefits to the current, and the losses to the future. If we are to acknowledge sustainability among generations, we will need a drastic paradigm change. We need to design a new paradigm in which the current are always responsible for their decisions, both to themselves and to those yet to come; and the one that can ensure a win-win outcome between people living today, and those living further in the future. The approach of integrating the sustainability constraint as proposed in this paper is a starting point. It should be incorporated into all decision-making process that deals with event that spans over a number of centuries and affects the welfare levels of many generations.

Turing back to the exhaustible resource, it should be noted that the academic also remains to be divided on how 'exhaustible' the exhaustible resource in consideration actually is and whether the constant elasticity of substitution in the production function is appropriate. This paper does not devote any space to examine these two issues in depth. Therefore, the most natural way to satisfactorily continue the discussion initiated this paper would be to extent the framework to consider the two problems as mentioned above.

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Notes

1) In the wake of the possible disastrous outcomes of sever environmental problems such as deforestation, stratospheric ozone depletion and global warming, both the public and the governments has accepted this view, that it is necessary to preserve vital environmental resources for future generations. The public's perception of the Earth has undertaken a drastic transformation in the twenties century. Until the 1970s, the Earth we live in is generally viewed as renewable, with virgin soil in abundance to be conquered and cultivated. It was not until after the sharp rise in world oil prices in 1973 did the public really assumes the idea that part of the Earth is actually exhaustible in nature. Due to the persistent efforts of concerned ecologists in preaching the public about the importance of conserving, protecting and restoring the health and integrity of the Earth's ecosystem, the concept that inherently, human activities leads to the pollution of the environment, and the Earth's ability to absorb the pollutants is finite is now pervasive. At the Earth Summit in Rio de Janeiro in 1992, governments from the world committed themselves to global efforts to free our descendants from the danger of living on planet whose ecosystems and resources can no longer provide for their needs.

2) This endeavor extends the model to one that is similar to that of Gerlagh and Keyzer (2001).

3) The complementary sign, "$\perp$-sign", represents the complementary conditions: the left-hand side is a strictly equality if the right-hand side is a strict inequality, and vice versa.

4) The time index in ψ_t, which can actually be dropped and the present value shadow price can be simply denoted as ψ, is retained in the following analysis, however, for comparison purposes.

5) Refer to Sweeney (1993).

6) That is, $\lim_{c_t^1 \to 0} U_1(c_t^1, c_{t+1}^2) = \infty$ for any $c_{t+1}^2 > 0$ and $\lim_{c_{t+1}^2 \to 0} U_2(c_t^1, c_{t+1}^2) = \infty$ for any $c_t^1 > 0$.

7) As in Gerlagh and Keyzer (2001), hereinafter we assume the initial value of the stock is finite, $\psi_1 x_1 < \infty$ and $\lim_{t\to\infty} \psi_t k_t = 0$. Following the proof of Lemma 2 in Gerlagh and Keyzer (2001), it is easy to see that the total value of the consumption goods produced over time is finite, $\sum_{t=1}^{\infty} p_t^c y_t < \infty$. According to the firm's zero profit condition, it is clear to see that over time,

$$\sum_{t=1}^{\infty} p_t^c y_t = \sum_{t=1}^{\infty} (w_t + p_t^r r_t),$$

so the aggregated wage that agents get over time is also finite, $\sum_{t=1}^{\infty} w_t < \infty$ Notice the above equation can be written out as

$$\psi_t x_t = \sum_{\tau = t, \cdots, \infty} (p_\tau^r r_\tau + p_\tau^x x_\tau),$$

which implies for the entire time horizon,

$$\psi_1 x_1 = \sum_{t=1}^{\infty} (p_t^r r_t + p_t^x x_t).$$

Therefore, $\sum_{t=1}^{\infty}(p_t^c y_t + p_t^x x_t) < \infty$, and (2.10) is established.

8) Following Krutilla (1967) and Krutilla and Fisher (1975), Krautkraemer (1985) claims that "the natural world generates a variety of amenity services including the scientific, recreational, and aesthetic value of preserved natural environments," and hence assumes that "the flow of resource amenities will depend upon the remaining stock of natural environment."

9) Costanza et al. (1997) calculated that the entire ecosystem services are at least three times more important to us than our own addition to our well-being as measured by gross domestic product. As noted by Norgaard and Bode (1998), such a number provides new and critically important benchmarks for environmental discourse with respect to where we are and the relative importance of things.

10) Following Krautkraemer (1985) and Gerlagh and Keyzer (2001), the life-cycle utility of the agents is assumed to be a function of both the flow of consumption and the flow of resource amenities. Krautkraemer (1985) claims that "if the development of preserved environments is irreversible, then there is a functional relationship between the flow of resource amenities and the remaining resource stock. This relationship will be subsumed within the utility function so that utility will be described as a function of the flow of consumption and the remaining resource stock."

11) Following Gerlagh and Keyzer (2001), throughout this paper, we assume that $\lim_{t\to\infty} \psi_t x_t = 0$.

12) The equal resource entitlement policy entitles each generation to an income claim to one unit of the resource amenity.

13) The strong sustainability policy scenario entitles each generation to enjoy a resource base that is essentially the same as that of the first generation (Howarth 1997), that is, $x_t = x_1$.

14) The PPP originally proposed is OECD (1975) is defined as a principle that requires those using up the environmental resources should bear the costs of avoiding or of containing the damage to within acceptable limits according to "national environmental standards". Hence the accompanying polices varies according to the "environmental standards" adopted. Here for exposition purpose, we assume that such an environmental standard mandates that each generation should have access to an identical stock level of the resources, and any reduction should hence be compensated.

15) By "very long run", we mean the steady states. Gerlagh and Keyzer (2001) prove that the economy as described above converges to steady states. In the steady states, the resource stock remains to be unchanged and resource extraction is zero over time. Since extraction is zero in the steady states, the output of the economy changes into $y_t = f(0)$. And since no extraction takes place, the extraction tax is zero and the wage income of the consumer becomes $w_t = f(0)$.

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