Intergenerational Transfers, Lifetime Welfare and Resource Preservation *

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Abstract. This paper studies the welfare properties of distortionary transfers in a life-cycle growth model where natural capital is private property. The main result is that, under credible pre-commitment, each newborn generation prefers positive taxes-subsidies to laissez-faire conditions when the resource share in production is sufficiently high. By increasing the degree of natural preservation, resource-saving policies raise welfare of all generations except that of the first resource owner, who suffers a deadweight loss due to taxation of the initial stock. If the first owner renounces part of his claims over initial endowments, all successive generations support resource-saving policies for purely selfish reasons.

Keywords: Distortionary Taxation, Intergenerational Transfers, Overlapping Generations, Renewable Resources, Sustainability.

JEL codes: H30, Q01, Q20.

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1. Introduction

Preserving intergenerational equity has become a worldwide political concern and achieving sustainability is increasingly considered a relevant social goal. Environmental policy is a central issue in the debate, since resources depletion and environmental degradation are major sources of intergenerational conflicts. In particular, prospects for over-exploitation of productive natural resources represent a threat for the ability of future generations to meet their own needs. Since Hotelling (1931) seminal work, economic analysis has pointed out several potential sources of the problem: over-exploitation may result from market incompleteness, excessive competition, myopic behavior, lacking motives for investment in natural preservation. Accordingly, public intervention may be called for either restoring efficiency (Toman, 1987) or settling conflicts between intertemporal efficiency and social optimality (Howarth and Norgaard, 1990).[1]

In recent times, the attribution of property rights over natural resources - as well as similar mechanisms allowing for market valuation of environmental *assets* - gained much attention in the policy debate. However, neither sustainability nor resource preservation are guaranteed when natural capital is private property. This result holds in general equilibrium models with infinitely-lived agents (Pezzey, 1992), and is furthermore valid when assuming selfish agents with finite lifetimes (Mourmouras, 1993): market valuation of resource assets can only limit the depletion rate to the extent that preserving natural capital is profitable to agents currently alive. Consequently, achieving intergenerational fairness requires a system of transfers that redistributes income among generations: examples in the recent literature on environmental economics include Mourmouras (1993), Marini and Scaramozzino (1995), Bovenberg and Heijdra (1998), Krautkraemer and Batina (1999), Gerlagh and Keyzer (2001).

The logic underlying most the above contributions is that of pursuing intergenerational fairness while preserving intertemporal efficiency, and this typically implies to consider lump-sum transfers. However, real-world policymaking is often constrained by institutional feasibility: lump-sum taxes have limited application, and policies involving intergenerational transfers likely need support of the constituency. Building on this point, we focus on the intergenerational effects of resource-saving policies enacted through distortionary measures. Specifically, we pose the following question. Consider an economy with overlapping generations where agents live for two periods and privately-owned natural capital is essential for production. Suppose that under laissez-faire the economy is placed along a path implying individual welfare be declining over time. Would selfish agents agree on a system of intergenerational transfers implying a higher degree of natural preservation?

This paper shows that, under credible pre-commitment, every newborn generation supports distortionary taxation of natural capital income for purely selfish reasons, provided a critical condition on technological parameters is satisfied. More precisely, all agents strictly prefer positive transfers in both periods of life, with respect to persistent laissez-faire conditions, if the resource-share in production is sufficiently high relative to the labor-share. The reason for this result is that higher productivity of natural capital raises the after-tax yield from resource assets: if the resource share is sufficiently high, the negative effect of second-period taxation is more than offset by the positive effect of first-period subsidies. Hence, if newborn agents are asked at birth to sign a *lifetime contract* requiring them to choose either positive or zero transfers in both periods of life, positive transfers are chosen - that is, a higher degree of natural preservation is preferred to laissez-faire - when the critical condition is satisfied.

After describing the welfare properties of lifetime contracts, we analyze the intergenerational consequences of enforcing resource-saving policies by discretionary intervention over an infinite time-horizon. The welfare time-path obtained under laissez-faire is not Pareto-comparable with that implied by permanent transfers: under resource-saving policies, resource owners at 'time zero' suffer a deadweight loss due to initial taxation of natural capital. Similarly to Gale (1973), if the first resource owner partially renounces to its claim over initial endowments, the transmission of this credit forward in time yields welfare gains for all successive generations.

Other interesting results concern with sustainability conditions: we derive explicit conditions for non-declining lifetime utility with a positive rate of technological progress, also describing interrelations and possible conflicts among alternative social goals.

2. The model

Our formal analysis draws on the Mourmouras (1993)-Krautkraemer and Batina (1999) model. Mourmouras (1993) uses the overlapping-generations setup to demonstrate that competition may lead to over-exploitation of privately-owned renewable resources, and describes a set of conservationist policies that implement the *Rawlsian path*, *i.e.* policies that keep private welfare constant, at the highest feasible level, across generations. A first major difference with respect to Mourmouras (1993) is the aim of our analysis: we study the welfare properties of distortionary transfers in order to ascertain whether, and under what institutional circumstances, selfish agents would agree on a higher rate of natural preservation with respect to laissez-faire. Second, we focus on the *existence* of situations where a distorted rate of resource use is preferred to the laissez-faire rate, without assuming a predetermined social objective: whether the distorted rate satisfies sustainability criteria - *i.e.* non-declining utility, conditions for zero-depletion, both or none of the two - it depends on parameters, and is an *ex-post* problem. Third, we study individual payoffs in a regime-contingent formulation, in order to describe the potential support for transfers in each point in time. Fourth, we include technological progress of the resource-saving type in the model, which modifies the link between sustainability and natural preservation, determining possible conflicts between alternative social objectives.[2]

In line with recent literature, we define *sustainable development* as a path implying non-decreasing welfare for future generations. The economy has an overlapping-generations structure, with each agent living for two periods and enjoying utility from consumption when young (c) and consumption when old (e). Population in period t consists of N_t young and N_{t-1} old individuals, with a constant rate n of population growth: $N_{t+1} = N_t(1+n)$. Denoting by U_t the lifetime utility of an agent born in period t, sustainability requires

$$U_{t+1}(c_{t+1}, e_{t+2}) \geq U_t(c_t, e_{t+1}), \quad \forall t \in [0, \infty). \tag{1}$$

Denoting by R_t the stock of natural resources available in the economy, we also define *no-depletion paths* as those paths satisfying

$$R_{t+1} \geq R_t, \quad \forall t \in [0, \infty). \tag{2}$$

Prospects for sustainability and natural preservation depend on the intergenerational distribution of entitlements, which affects the time-path of resource use, and in turn, the production frontier and consumption possibilities of yet to born generations. In this regard, we assume a grandfathering process *à la* Krautkraemer and Batina (1999): at the beginning of period t, the whole stock of natural resources in the economy R_t is held by old agents. Part of R is used as *natural capital* in production (X), while the remaining stock constitutes *resource assets* (A):

$$R_t = A_t + X_t. \tag{3}$$

Old agents sell resource assets A_t to young agents at unit price q_t, and receive a gross marginal rent p_t for each unit of natural capital X_t supplied to the firm producing the consumption good. Prices and marginal rents are expressed in terms of the consumption good, and *per-young* quantities of resource assets and natural capital are denoted by $a_t = A_t/N_t$ and $x_t = X_t/N_t$, respectively. While natural capital goes destroyed in the production process, resource assets sold to newborn generations are brought forward in time: $q_t a_t$ can thus be interpreted as the investment of each young agent in natural preservation. Assuming that between t and $t+1$ the natural resource grows at constant regeneration rate ε, the natural stock available at the beginning of period $t+1$ equals

$$R_{t+1} = (1+\varepsilon)(R_t - X_t) = (1+\varepsilon) A_t. \tag{4}$$

Only young agents work, supplying inelastically one unit of labor services. The consumption good is produced by means of natural capital and labor, and we allow for a positive rate δ of *resource-augmenting* technological progress:

$$Y_t = (m_t X_t)^{\alpha} (N_t)^{1-\alpha}, \tag{5}$$

$$m_t = m_{t-1}(1+\delta), \tag{6}$$

where Y_t is aggregate output, N_t equals total labor units provided by currently young, and m_t is a process enhancing the productivity of natural capital X_t at rate $\delta > 0$.[3] Denoting by w the wage rate, profit maximization implies

$$p_t = \alpha y_t x_t^{-1} = \alpha m_t^{\alpha} x_t^{\alpha-1}, \tag{7}$$

$$w_t = (1-\alpha) y_t = (1-\alpha) m_t^{\alpha} x_t^{\alpha}, \tag{8}$$

where $y = Y/N$ is output per worker.

Intergenerational transfers take the following form: the investment in preservation of young agents is subsidized by taxing the income from natural capital of old agents, and fiscal authorities keep balanced budget in each period. Formally,

$$c_t = w_t - q_t (1 - d_t) a_t, \tag{9}$$

$$e_{t+1} = [p_{t+1} (1 - \tau_{t+1}) x_{t+1} + q_{t+1} a_{t+1}] (1 + n), \tag{10}$$

$$p_t \tau_t X_t = q_t A_t d_t, \tag{11}$$

$$y_t = c_t + e_t (1 + n)^{-1}. \tag{12}$$

Equations (9) and (10) represent budget constraints faced by each individual born in period t, where d is the subsidy rate on investments in preservation, and τ is the tax rate on natural capital income.[4] Equation (11) is the government budget constraint, and equation (12) is the aggregate resource constraint of the economy. Agents are homogeneous and have logarithmic preferences: lifetime utility is $U_t = \log c_t + \beta \log e_{t+1}$, where $\beta \in (0, 1)$ is the individual discount factor. Equilibrium in the resource market requires

$$q_t = p_t (1 - \tau_t) \tag{13}$$

in each period.[5] The consumer problem consists of choosing c_t and e_{t+1} in order to maximize lifetime utility subject to (9)-(10): first order conditions read

$$\frac{e_{t+1}}{\beta c_t} = \frac{q_{t+1} (1 + \varepsilon)}{q_t (1 - d_t)}. \tag{14}$$

The temporary equilibrium of the economy is characterized by the following relations (see Appendix): the *natural capital-resource asset ratio* (z) equals

$$z_t = \frac{x_t}{a_t} = \frac{\alpha (1 + \beta)}{\beta (1 - \alpha)} (1 - \tau_t) (1 - d_t), \tag{15}$$

and the dynamics of the economy are described by

$$\theta^R_{t+1} = \frac{1 + \varepsilon}{1 + z_t}, \tag{16}$$

$$\theta^x_{t+1} = \frac{z_{t+1} (1 + \varepsilon)}{z_t (1 + z_{t+1}) (1 + n)}, \tag{17}$$

$$\theta^y_{t+1} = \left[\frac{z_{t+1} (1 + \rho)}{z_t (1 + z_{t+1})} \right]^\alpha, \tag{18}$$

where $\theta^v_{t+1} = (v_{t+1}/v_t)$ for the generic variable v_t. Note that in equation (18) we have defined the *augmentation rate* ρ as

$$1 + \rho = \frac{(1 + \varepsilon)(1 + \delta)}{(1 + n)}. \tag{19}$$

Our analysis proceeds as follows: first, we derive conditions for sustainability and no-depletion in a *laissez-faire economy*; second, we describe how resource-saving policies - *i.e.* fiscal measures implying a higher degree of resource preservation with respect to laissez-faire - can be implemented through intergenerational transfers.

2.1. The laissez-faire economy

Setting tax-subsidy rates equal to zero, it follows from (15) that the natural capital-resource asset ratio is constant over time:

$$z_t = \frac{\alpha (1 + \beta)}{\beta (1 - \alpha)} = \tilde{z} \text{ for all } t. \tag{20}$$

The laissez-faire economy exhibits the knife-edge property: setting $z_{t+1} = z_t = \tilde{z}$ in equation (18), the growth rate of output per worker is constant over time, and it can be positive, negative, or equal to zero, depending on parameters. With respect to Mourmouras (1993) and Krautkraemer and Batina (1999), the presence of technological progress crucially modifies the link between resources depletion and sustainability (all proofs are in Appendix):

PROPOSITION 1. *A necessary and sufficient condition for no-depletion in the laissez-faire economy is*

$$\tilde{z} \leq \varepsilon. \tag{21}$$

PROPOSITION 2. *A necessary and sufficient condition for sustainability in the laissez-faire economy is*

$$\tilde{z} \leq \rho, \tag{22}$$

or equivalently

$$1 + \gamma \leq \left(\frac{1 - \alpha}{\alpha}\right) \left[\frac{(1 + \delta)(1 + \varepsilon)}{(1 + n)} - 1\right] - 1, \tag{23}$$

where $\gamma = \beta^{-1} - 1$ *is the individual pure rate of time preference.*

Expression (23) is conceptually analogous to the long-run sustainability condition holding in economies with infinitely-lived agents: in the standard capital-resource model, optimal consumption per capita is asymptotically non-decreasing if the social discount rate does not exceed the sum of the rates of technical progress and natural regeneration (Valente, 2005). Similarly, (23) shows that sustainability obtains provided the joint effect of δ and ε is not offset by the impatience to consume out (γ).

Whether sustainability conditions are more restrictive than conditions for no-depletion depends on the rates of technological progress and population growth: assuming ε and n strictly positive,

LEMMA 3. *If $\delta < n$, the laissez-faire economy may exhibit no-depletion together with unsustainability; if $\delta > n$, the economy may exhibit resource depletion together with sustainability; if $\delta = n$, the economy displays either (i) unsustainability with positive depletion, or (ii) sustainability with no-depletion.*

Lemma 3 can be verified by means of Figure 1, which describes the interrelations, and possible conflicts, between resource preservation and sustainability: in particular, it shows that *no-depletion per se does not guarantee sustained utility.* By (21) and (22), the sustainability threshold $z^{sus} = \rho$ increases with δ, while the no-depletion locus $z^{ndp} = \varepsilon$ is horizontal in the $(\delta,\, z)$ plane: consequently, different combinations of parameters may determine sustainability, no-depletion, both, or none of the two. Moreover, it follows from (21) and (22) that

COROLLARY 4. *If $\tilde{z} = \varepsilon$ and $\delta = n$, then*

$$U_{t+1} = U_t \text{ and } R_{t+1} = R_t, \quad \forall t \in [0, \infty) . \tag{24}$$

The situation described by (24) satisfies most used notions of sustainable development: future generations do not experience declining utility (standard definition), each generation enjoys the same welfare level (Rawlsian intergenerational equity), and natural capital as such is preserved over time (strong sustainability). This very special case is represented by point S in Figure 1.

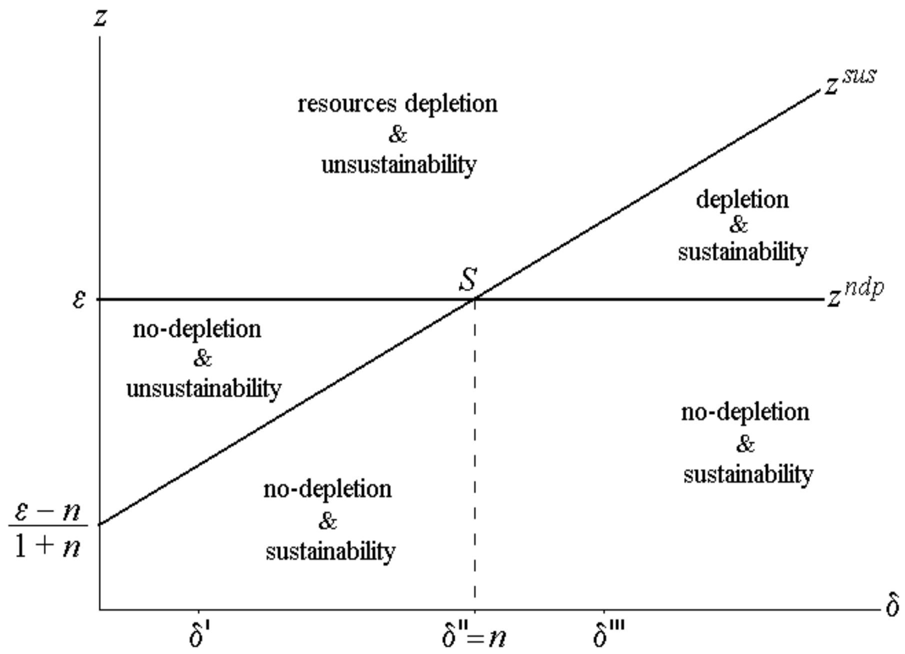

Figure 1. The knife-edge model: sustainability and no-depletion conditions for given values of n, ε, and α. By (21) and (22), in the laissez-faire economy no-depletion obtains for a couple of values $(\tilde{z}, \delta)$ below the locus z^{ndp}, while sustainability obtains for a couple of values $(\tilde{z}, \delta)$ below the locus z^{sus}.

2.2. The economy with transfers

Propositions 1 and 2 suggest that if the economy is unsustainable under laissez-faire, a *ceteris paribus* reduction in z_t due to intergenerational transfers will bring the economy towards the sustainability threshold. Balanced budget policies with positive taxes affect the gap $(z_t - \tilde{z})$ unambiguously: from (15) and (20), the natural capital-resource asset ratio at time t equals

$$z_t = \tilde{z}\,(1 - \tau_t)\,(1 - d_t)\,. \tag{25}$$

Assume that the policymaker aims at achieving a pre-determined level z': substituting (25) in the government budget constraint (11), the target level $z_t = z'$ is obtained by setting $d_t = d'$ and $\tau_t = \tau'$, where

$$d' = \frac{\tilde{z} - z'}{1 + \tilde{z}} \text{ and } \tau' = \frac{\tilde{z} - z'}{\tilde{z}\,(1 + z')}. \tag{26}$$

Expressions (26) allow to derive the critical levels of τ_t and d_t needed to obtain the desired depletion rate. For example, by Proposition 1 the resource stock is constant over time if $z_t = \varepsilon$ for each t: setting $z' = \varepsilon$ in (26) we obtain the critical rates to obtain zero depletion of the natural stock. By the same reasoning,

LEMMA 5. *Setting* $d_t = \frac{\tilde{z}-\rho}{1+\tilde{z}}$ *and* $\tau_t = \frac{\tilde{z}-\rho}{\tilde{z}(1+\rho)}$ *for each* $t \in [0, \infty)$ *implies* $z_t = \rho$ *and* $U_{t+1} = U_t$ *for each* $t \in [0, \infty)$.

More generally, any fiscal intervention that keeps z_t below the laissez-faire level $\tilde{z}$ constitutes a *resource-saving policy*: lowering the natural capital-resource assets ratio is associated to lower rates of resource use in production (or equivalently, to a higher degree of preservation). By (26), positive tax-subsidy rates ($\tau' > 0$, $d' > 0$) are always associated to resource-saving policies ($z' < \tilde{z}$).

3. Resource-saving transfers and lifetime welfare

We now compare the effects of laissez-faire and transfers on individual payoffs in each period: in this regime-contingent formulation, individual payoffs represent the potential political support for resource-saving measures, as if agents were asked to choose between laissez-faire and positive transfers in each period. Assuming that each newborn agent takes the history of previous regimes as given, we show that positive transfers in both periods of life may yield higher private payoffs with respect to *life-persistent* laissez-faire (zero taxes and subsidies in both periods) if a precise condition on technological parameters is fulfilled. The payoff associated to persistent transfers is however dominated by a third option: as intuitive, agents would be made better-off by experiencing positive transfers in the first period of life, and laissez-faire in the second, because such regime shift allows to avoid taxation. This implies that resource-saving policies would be supported if the government had access to a commitment device which we call *lifetime contract*.

3.1. Regime-contingent payoffs

Denote by η_t the outcome of an unspecified political process: η_t is a flag indicating whether laissez-faire or resource-saving transfers are implemented in period t:

$$\eta_t = \begin{cases} 0 \Leftrightarrow \ z_t = \tilde{z} & (\textit{laissez-faire}) \\ 1 \Leftrightarrow \ z_t = z' < \tilde{z} & \text{(res-saving transfers)} \end{cases} \tag{27}$$

The individual payoff V_t of each agent born in $t \geq 0$ depends on the two outcomes realized during her lifetime (η_t and η_{t+1}) as well as on the whole history of previous outcomes $H_t = \{\eta_0, \eta_1, ..., \eta_{t-1}\}$:

$$V_t\left(\eta_t, \eta_{t+1}, H_t\right) = U_t\left[c_t\left(\eta_t, H_t\right), e_{t+1}\left(\eta_t, \eta_{t+1}, H_t\right)\right]. \tag{28}$$

Assuming that agents cannot modify previous outcomes, H_t is taken as given and the individual payoff of every agent born in $T \geq 0$ can be written as (see Appendix)

$$V_T\left(\eta_T, \eta_{T+1}, H_T\right) = \Omega_T\left(H_T\right) + \log\left(\frac{z_T}{1+z_T}\right)^{\alpha}\left[\frac{\left(1+\rho\right)z_{T+1}}{\left(1+z_T\right)\left(1+z_{T+1}\right)}\right]^{\alpha\beta}, \tag{29}$$

where Ω_T is taken as given at T. Suppressing argument H for simplicity, we set $V_T\left(\eta_T, \eta_{T+1}, H_T\right) = V_T\left(\eta_T, \eta_{T+1}\right)$ and compute payoffs $V_T\left(0,0\right)$, $V_T\left(0,1\right)$, $V_T\left(1,0\right)$, $V_T\left(1,1\right)$ on the basis of (29). We will refer to $V_T\left(0,0\right)$ and $V_T\left(1,1\right)$ as to payoffs yielded by *life-persistent regimes* ($\eta_t = \eta_{t+1}$). In the Appendix, we show that for any value of $z' < \tilde{z}$,

$$V_T\left(0,0\right) > V_T\left(0,1\right) \tag{30}$$

$$V_T\left(1,0\right) > V_T\left(1,1\right) \tag{31}$$

in each period $T \geq 0$. On the one hand, this result is intuitive: inequalities (30) and (31) imply that if agents could modify η_{T+1} while taking η_T as given, they would have an incentive to avoid taxation in the second period of life. On the other hand, (30) and (31) do not rule out situations where selfish agents would prefer persistent transfers to persistent laissez-faire: $V_T\left(1,1\right)$ and $V_T\left(0,0\right)$ cannot be ranked a priori, so it is possible to have the interesting case

$$V_T\left(1,0\right) > V_T\left(1,1\right) > V_T\left(0,0\right) > V_T\left(0,1\right). \tag{32}$$

The explicit condition to obtain (32) is derived below:

PROPOSITION 6. *Individual payoffs are ranked as in (32) if and only if*

$$\left(\alpha\frac{1+\beta}{\beta+\alpha}\right)^{1+\beta}\left(\beta\frac{1-\alpha}{\beta+\alpha}\right)^{\beta}<\left(\frac{z'}{1+z'}\right)^{1+\beta}\left(1+z'\right)^{-\beta}. \quad (33)$$

Condition (33) is necessary and sufficient to have $V_T(1,1) > V_T(0,0)$, that is, private agents strictly prefer life-persistent transfers to persistent laissez-faire. For a given discount factor β, inequality (33) defines the set of all possible combinations of α and z' implying $V_T(1,1) > V_T(0,0)$. This set can be characterized by defining the policy index

$$\mu = (1-\tau)(1-d) \equiv z'/\tilde{z}. \quad (34)$$

Index μ is fixed by fiscal authorities, as it results from the level of tax-subsidy rates, and $\mu < 1$ means that fiscal authorities enact resource-saving policies (this is equivalent to assume that fiscal authorities set $z' = \mu\tilde{z}$, where the natural capital-resource asset ratio equals the desired fraction μ of the laissez-faire level $\tilde{z}$). As shown in the Appendix, the welfare gap $\Phi = V(0,0) - V(1,1)$ can be rewritten as

$$\Phi = \log\left(\frac{1}{\mu}\right)^{\alpha+\alpha\beta}\left[\frac{\beta(1-\alpha)+\mu\alpha(1+\beta)}{\beta(1-\alpha)+\alpha(1+\beta)}\right]^{\alpha+2\alpha\beta}, \quad (35)$$

where μ is a choice variable independent of α. From (35), the sign of $\partial\Phi/\partial\alpha$ is ambiguous because the derivative of the term in square brackets is negative for $\mu < 1$. Fixing μ and β, it can be easily verified with numerical substitutions that the gap function $\Phi(\alpha;\bar{\mu},\bar{\beta})$ has an inverted-U shape with respect to α: imposing $\Phi = 0$ determines two values of the resource share, α_1 and α_2, with $\Phi > 0$ when $\alpha \in (\alpha_1, \alpha_2)$. Consequently, we have $V(1,1) > V(0,0)$ for relatively high and relatively low values of α: as shown in Figure 2.*a*, if the resource-share is either below α_1, or above α_2, the gap function Φ assumes negative values.

Numerical examples suggest that α_1 is very close to zero: it is difficult that the resource share lies within the interval $(0, \alpha_1)$, whereas having $\alpha_2 < \alpha < 1$ appears plausible; condition (33) can thus be restated, with good approximation, by saying that $V(1,1) > V(0,0)$ provided the resource share is sufficiently high ($\alpha > \alpha_2$). The economic interpretation of this result is that if natural capital is highly productive, the positive effect of first-period subsidies more than compensates the loss due to second-period taxation: the higher is α, the higher is the after-tax yield received by the old when selling resource assets to the newborn.

Critical levels α_1 and α_2 are affected by the policy target μ: Figure 2.b shows that the lower is μ, the lower is α_1 and the higher is α_2. This result can be interpreted as follows. As explained in section 2.2, the lower is z', the higher is the *degree of natural preservation* implied by resource-saving transfers. However, from the agents point of view, the lower is z' the higher is the private cost of transfers: hence, if fiscal authorities set z' relatively close to the laissez-faire value $\tilde{z}$ (*i.e.* $\mu \to 1$) the private cost of transfers is relatively small, and condition (33) is likely to be met; conversely, if the policymaker is more inclined towards natural preservation ($\mu \to 0$), persistent transfers are more demanding and condition (33) is more restrictive. Being α_1 close to zero, this result can be reasserted as follows: the higher is the degree of preservation associated to positive transfers, the higher is the lower bound (α_2) for the resource share to have $V(1,1) > V(0,0)$.

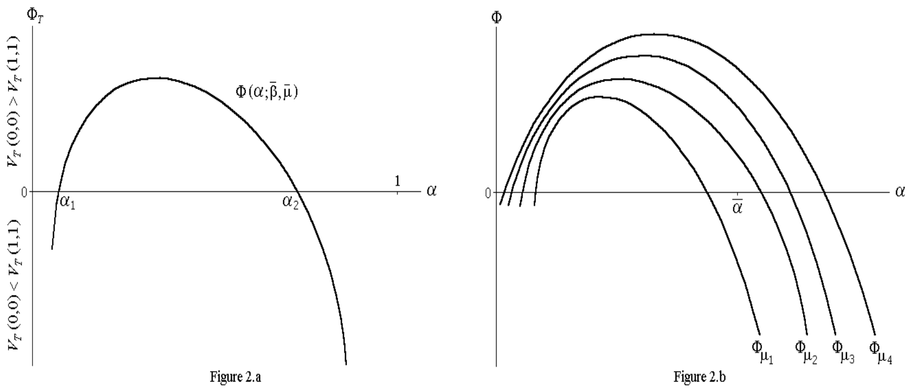

Figure 2. *Graph* (a): fixing β and μ, the gap $\Phi = V(0,0) - V(1,1)$ is drawn as a function of α. Condition (33) defines two intervals, $(0, \alpha_1)$ and $(\alpha_2, 1)$, over which the value of α is compatible with $V(1,1) > V(0,0)$. *Graph* (b): fixing β, the gap function $\Phi = V(0,0) - V(1,1)$ is drawn as a parametric function for different values of $\mu = \mu_1, ..., \mu_4$, with $\mu_1 > \mu_2 > \mu_3 > \mu_4$.

3.2. Lifetime contracts and discretionary policies

It follows from Proposition 6 that if agents are asked at birth to sign a *lifetime contract* requiring them to choose between persistent transfers and persistent laissez-faire, every agent born at $t \geq 0$ chooses resource-saving transfers. With respect to this result, three main points should be emphasized. First, lifetime contracts embody a notion of credible pre-commitment: if the technological condition is fulfilled, agents prefer positive transfers provided that no regime switch is allowed during the life-cycle. Second, private agents would not enforce such contracts by themselves as no compensation is received by resource owners at $t = 0$: this is the 'first father problem' discussed below. Third, whether a sustainable path would be supported by means of lifetime contracts it depends on the whole set of parameters. Suppose that the laissez-faire economy is unsustainable, and that a lifetime contract asks newborn agents to choose between $\tilde{z} > \rho$ and $z' = \rho$. If the technological condition is satisfied in this case, then lifetime contracts support a constant utility path. However, as shown in Figure 2.b, the lower is $\mu = z'/\tilde{z}$ the more restrictive is the technological condition: hence, the range of values of α compatible with $V(1,1) > V(0,0)$ is limited if $\tilde{z}$ is very high relative to ρ, whereas conditions for an 'agreement on sustainability' are less restrictive if $\tilde{z}$ is relatively close to ρ.[6]

Our results have interesting implications when considering discretionary policies over an infinite time-horizon. Assume that fiscal authorities may choose the sequence of intertemporal allocations from period zero onward. The individual first-best payoff $V(1,0)$ cannot be assigned to every generation, because implementing it in each t is not possible: if $V_t = V_t(1,0)$ then $V_{t+1} = V_{t+1}(1,0)$ is unfeasible. Hence, from a social-planning perspective, the relevant inequality in ranking (32) is the central one, $V(1,1) > V(0,0)$, which refers to life-persistent regimes. This in turn suggests to investigate the welfare effects of implementing the two *sequences* of lifetime contracts

$$\{\tau_t = 0, d_t = 0\}_{t=0}^{\infty} \text{ or } \{\tau_t = \tau', d_t = d'\}_{t=0}^{\infty}$$

through discretionary measures; we refer to these sequences as to *permanent laissez-faire* and *permanent transfers*, respectively.

Having assumed grandfathering, the resource stock at time zero is entirely held by those old at time zero. In this scenario, a typical *first* *father problem* arises with respect to resource-saving policies: suppose that inequality (33) is fulfilled, and assume that fiscal authorities implement permanent transfers, that is, $z_t = z' < \tilde{z}$ for $t = 0, ..., \infty$. While every agent born at, or after time zero gains from this policy, initial subsidies must be financed by those old at $t = 0$. Hence, welfare improvements due to permanent transfers pertain to all agents, with the exception of the first generation of 'fathers'.

On the one hand, the first father problem implies that, considering the time-path of private welfare over all generations, permanent laissez-faire and permanent transfers cannot be Pareto-ranked. On the other hand, resource-saving policies recall the logic of Gale-type intergenerational transfers: considering a two-generations pure exchange economy, Gale (1973) showed that the first generation can raise future welfare by renouncing part of its claim over the endowment to the benefit of the second generation, which in turn transmits a claim to its successor, and so on. In our setting, with fundamental differences duly taken into account,[7] permanent resource-saving transfers work in a similar way: the initial tax $\tau_0 p_0 X_0$ amounts at the share of claims over natural capital not received by the first owner, and subsidies to the newborn bring the associated credit forward in time. Clearly, enacting permanent transfers involves a paternalistic action at time zero, as no generation would selfishly make the initial gift: readapting Gale's (1973) argument to our model, resource-saving transfers begin after the economy

> "has been running along for some time in the [no-transfers] equilibrium but at time $t = 0$ some of the old people realize that if they are willing to give up ever so little of their second-period consumption the economy in the future will move up toward [higher welfare for future generations]. (...) If this altruistic scenario sounds too unrealistic, one can instead imagine a central authority which levies an income tax on the old people in period zero and then sells this income back to the young." (*ibid.*, p.29).

Alternatively, one can imagine the same process in a privatization scenario, where natural resources previously owned by the State are sold at lower-than-efficiency price to young generations in period zero, and permanent transfers are then implemented. In this case, the initial selling price (determined by the government) is equivalent to a proportional subsidy at time zero, implying a deadweight loss for the public owner.[8] Even here, taxing natural capital incomes of all successive generations would find justification in the argument of lifetime contracts.

It should be emphasized that the potential support for distortionary transfers in our model is driven by purely selfish motives. In this regard, our analysis is close to the view that intergenerational exchange need not be linked to parental altruism, as recently argued by Boldrin and Rustichini (2000) and Rangel (2003). The general questions asked by these authors is: why should present generations invest in assets that are valuable only to future ones? Boldrin and Rustichini (2000) and Rangel (2003) use game-theoretical arguments to show that positive transfers may arise as voting equilibria when intergenerational altruism is absent.[9] In particular, Boldrin and Rustichini (2000) show that pay-as-you-go social security can be voted into existence by the majority, because the reduction in current saving implied by taxation raises future returns on capital, thus compensating the negative effect of pension financing. Recalling Proposition 6, our main result hinges on a similar interest-rate effect, which is however reversed due to the father-to-son scheme we have assumed.

4. Conclusions

This paper analyzed the welfare properties of distortionary transfers in a growth model with overlapping generations and privately-owned natural capital. In this framework, Mourmouras (1993) and Krautkraemer and Batina (1999) have shown that unsustainability and resources depletion are likely an outcome of excessive competition. We have shown that implementing father-to-son transfers through proportional taxes and subsidies brings a higher degree of resource preservation with respect to laissez-faire. The main result is that if individuals are credibly pre-committed, all *newborn* agents prefer positive transfer to laissez-faire conditions provided the resource-share in production is sufficiently high relative to the labor-share. This result hinges on the assumption that private agents earn income from selling resource assets in the second period of life: when natural capital productivity is sufficiently high, private gains from first-period subsidies more than compensate the loss due to second-period taxation. Hence, if the critical condition on parameters is satisfied, resource-saving transfers are suitable to protect the welfare of future generations, and are supported by newborn agents for purely selfish reasons. Implementing resource-saving policies through discretionary intervention implies a welfare time-path not Pareto-comparable with that obtained under laissez-faire, because resource owners at time zero suffer a deadweight loss due to taxation of the initial stock. Similarly to Gale (1973), if the first resource owner partially renounces to its claim over initial endowments, the transmission of this credit forward in time yields welfare gains for all successive generations.

Appendix

The consumer problem. By (3), (13) and (4), the second-period individual constraint (10) can be rewritten as $e_{t+1} = q_{t+1} (1+\varepsilon) a_t$,which can be substituted in (9) to obtain

$$c_t = w_t - \frac{q_t (1-d_t) e_{t+1}}{q_{t+1} (1+\varepsilon)}. \tag{A1}$$

The individual problem consists of choosing c_t and e_{t+1} in order to maximize lifetime utility subject to (A1): first order conditions for an interior solution imply (14). Substituting equilibrium prices (8)-(7) and condition (14) in individual budget constraints (9) and (10), equilibrium consumption levels are

$$c_t = \frac{w_t}{1+\beta} = \frac{1}{1+\beta} (1-\alpha) y_t, \tag{A2}$$

$$e_{t+1} = \frac{1+n}{1+\beta} (\alpha+\beta) y_{t+1}. \tag{A3}$$

Deriving equation (15). Substituting $e_{t+1} = q_{t+1} (1+\varepsilon) a_t$ in (A3) gives

$$a_t = \frac{(1+n)(\alpha+\beta)}{q_{t+1} (1+\beta)(1+\varepsilon)} y_{t+1}. \tag{A4}$$

From (7) and (13), $q_{t+1} = \alpha m_{t+1}^{\alpha} x_{t+1}^{\alpha-1} (1-\tau_{t+1})$ can be substituted in (A4) to obtain

$$a_t = \frac{(1+n)(\alpha+\beta)}{\alpha (1+\beta)(1+\varepsilon)(1-\tau_{t+1})} x_{t+1}. \tag{A5}$$

Now consider the system

$$\frac{q_{t+1}}{q_t} = \frac{e_{t+1}\left(1-d_t^y\right)}{\beta c_t\left(1+d_{t+1}^o\right)\left(1+\varepsilon\right)}, \tag{A6}$$

$$\frac{q_{t+1}}{q_t} = \frac{p_{t+1}}{p_t}\left(\frac{1-\tau_{t+1}}{1-\tau_t}\right), \tag{A7}$$

where (A6) is the optimality condition (14), and (A7) is implied by no-arbitrage condition (13). Substituting (A2)-(A3) in (A6), and (7) in (A7) respectively gives

$$\frac{q_{t+1}}{q_t} = \frac{(1+n)(\alpha+\beta)(1-d_t)}{\beta(1-\alpha)(1+\varepsilon)}\left(\frac{y_{t+1}}{y_t}\right), \tag{A8}$$

$$\frac{q_{t+1}}{q_t} = \frac{x_t}{x_{t+1}}\left(\frac{1-\tau_{t+1}}{1-\tau_t}\right)\frac{y_{t+1}}{y_t}, \tag{A9}$$

implying

$$\frac{x_{t+1}}{x_t} = \frac{\beta(1-\alpha)(1+\varepsilon)(1-\tau_{t+1})}{(1+n)(\alpha+\beta)(1-d_t)(1-\tau_t)}. \tag{A10}$$

Substituting (A10) in (A5) gives eq.(15) in the text.

Deriving equations (16)-(18). Equations (16) and (17) are obtained by substituting (15) in equations (3) and (4). By (5) and (6), $y = m^\alpha x^\alpha$ so that $\theta^y = \left[(1+\delta)\,\theta^x\right]^\alpha$, which implies (18) by virtue of (17).

Proof of Proposition 1. It follows immediately from (16) that no-depletion, *i.e.* $\theta^R \geq 1$, obtains if and only if inequality (21) is satisfied.

Proof of Proposition 2. Under laissez-faire $z_{t+1} = z_t = \tilde{z}$, which implies that U_t is proportional to y_t (see equation (36) derived below). Hence, satisfying the sustainability condition (1) in the laissez-faire economy requires $\theta^y \geq 1$. Setting $z_{t+1} = z_t = \tilde{z}$ in (18) it follows that $\theta^y \geq 1$ if and only if (22) is satisfied. Substituting (15) and $\gamma = \beta^{-1} - 1$ in (22) yields (23).

Proof of Lemma 3. Looking at Figure 1, Lemma 3 is proved as follows: if $n > 0$, the vertical intercept of the locus z^{sus} is strictly below the horizontal locus z^{ndp}. Therefore, it is possible to have a couple of values $\delta = \delta'$ and $\tilde{z} = z'$ such that $0 < \delta' < n$ and $z^{sus} < z' < z^{ndp}$ (no-depletion and unsustainability). Viceversa, for high enough δ''' it is possible to have $\delta = \delta'''$ and $\tilde{z} = z'''$ such that $n < \delta'''$ and $z^{ndp} < z''' < z^{sus}$ (depletion and sustainability). Finally, critical values of z for sustainability and no-depletion coincide ($z^{ndp} = z^{sus}$) along the vertical line $\delta = \delta'' = n$, so that we have either depletion and unsustainability ($\tilde{z} > z^{ndp} = z^{sus}$), or no-depletion and sustainability ($\tilde{z} \leq z^{ndp} = z^{sus}$). Corollary 4 is also verified by means of Figure 1, and it follows immediately from Propositions 1 and 2.

Deriving tax-subsidy rates in (26). Setting $z_t = z'$, $\tau_t = \tau'$ and $d_t = d'$ in equations (25) and (11) gives

$$z' = \tilde{z}\left(1-\tau'\right)\left(1-d'\right), \tag{A11}$$

$$\tau' z' = \left(1-\tau'\right) d', \tag{A12}$$

respectively. Substituting (A12) in (A11) gives $\tau' = \frac{d'}{\tilde{z}(1-d')}$, which can be substituted back in (A11) to obtain $d' = \frac{\tilde{z}-z'}{1+\tilde{z}}$, which is the subsidy rate level in (26). The tax rate level in (26) then follows from $\tau' = \frac{d'}{\tilde{z}(1-d')}$ as obtained above.

Proof of Lemma 5. It follows from (A2)-(A3) that

$$U_t = \log\left(\frac{1-\alpha}{1+\beta}\right) + \beta \log\left(1+n\right)\frac{\alpha+\beta}{1+\beta} + \log y_t + \beta \log y_{t+1}. \tag{A13}$$

By (18), $\beta \log y_{t+1} = \beta \log y_t + \alpha\beta \log \frac{z_{t+1}(1+\rho)}{z_t(1+z_{t+1})}$, and (A13) can be rewritten as

$$U_t = \log\left(\frac{1-\alpha}{1+\beta}\right) + \beta \log \frac{(1+n)(\alpha+\beta)}{1+\beta} + \alpha\beta \log \frac{z_{t+1}(1+\rho)}{z_t(1+z_{t+1})} + (1+\beta)\log y_t. \tag{A14}$$

Hence, $U_{t+1} - U_t = \log\left[\frac{z_{t+2}(1+\rho)}{z_{t+1}(1+z_{t+2})}\right]^{\alpha\beta}\left[\frac{z_{t+1}(1+\rho)}{z_t(1+z_{t+1})}\right]^{\alpha}$, implying that any path with constant lifetime utility requires

$$\frac{z_{t+2}}{1+z_{t+2}} = \frac{z_{t+1}}{(1+\rho)}\left[\frac{z_t\left(1+z_{t+1}\right)}{z_{t+1}\left(1+\rho\right)}\right]^{\frac{1}{\beta}} \quad \text{for each } t \in [0,\infty). \tag{A15}$$

The dynamic rule (A15) can be satisfied by different sequences of z_t. If the policymaker keeps z_t constant over time, rule (A15) is however satisfied if and only if $z_t = \rho$ for each $t \in [0,\infty)$, which proves Lemma 5.

Deriving expression (29). Given the initial endowment $R_0 \equiv r_0 N_0$, solving (16) and (17) backward yields

$$x_t = r_0\left(\frac{1+\varepsilon}{1+n}\right)^t \cdot \frac{z_t}{1+z_t}\prod_{j=0}^{t-1}\frac{1}{1+z_j}. \tag{A16}$$

Substituting (A16) in $y_t = m_t^\alpha x_t^\alpha$ gives

$$y_t = \left(\frac{z_t}{1+z_t}\phi_t\right)^\alpha, \tag{A17}$$

where

$$\phi_t = \frac{r_0 m_0 (1+\rho)^t}{\prod_{j=0}^{t-1}(1+z_j)} \tag{A18}$$

is a function of H_t and is therefore taken as given by the agent born in period t. Expression (A18) implies that $\phi_{t+1} = \phi_t (1+\rho)(1+z_t)^{-1}$, thus

$$y_{t+1} = \left[\frac{(1+\rho) z_{t+1}}{(1+z_t)(1+z_{t+1})}\phi_t\right]^\alpha. \tag{A19}$$

Substituting (A17) and (A19) in (A13) yields

$$U_t = \log\left(\frac{1-\alpha}{1+\beta}\right)\left(\frac{z_t}{1+z_t}\phi_t\right)^\alpha + \beta\log\frac{(1+n)(\alpha+\beta)}{1+\beta}\left[\frac{(1+\rho) z_{t+1}}{(1+z_t)(1+z_{t+1})}\phi_t\right]^\alpha.$$

Setting $\Omega_t = \log\left(\frac{1-\alpha}{1+\beta}\right)\phi_t^\alpha\left[\frac{(1+n)(\alpha+\beta)}{1+\beta}\phi_t^\alpha\right]^\beta$ yields expression (29) in the text.

Deriving expressions (30) and (31). It follows from (29) that

$$\begin{aligned}
V(0,0) &= \Omega + \log\left(\frac{\tilde{z}}{1+\tilde{z}}\right)^\alpha\left(\frac{1}{1+\tilde{z}}\right)^{\alpha\beta}\left[\frac{(1+\rho)\tilde{z}}{1+\tilde{z}}\right]^{\alpha\beta}, && \text{(A20)}\\
V(0,1) &= \Omega + \log\left(\frac{\tilde{z}}{1+\tilde{z}}\right)^\alpha\left(\frac{1}{1+\tilde{z}}\right)^{\alpha\beta}\left[\frac{(1+\rho) z'}{1+z'}\right]^{\alpha\beta}, && \text{(A21)}\\
V(1,0) &= \Omega + \log\left(\frac{z'}{1+z'}\right)^\alpha\left(\frac{1}{1+z'}\right)^{\alpha\beta}\left[\frac{(1+\rho)\tilde{z}}{1+\tilde{z}}\right]^{\alpha\beta}, && \text{(A22)}\\
V(1,1) &= \Omega + \log\left(\frac{z'}{1+z'}\right)^\alpha\left(\frac{1}{1+z'}\right)^{\alpha\beta}\left[\frac{(1+\rho) z'}{1+z'}\right]^{\alpha\beta}. && \text{(A23)}
\end{aligned}$$

Expressions (30) and (31) in the text are proved as follows: $\tilde{z} > z'$ implies

$$\frac{z'}{\tilde{z}}\left(\frac{1+\tilde{z}}{1+z'}\right) < 1. \tag{A24}$$

Hence, from (A20)-(A21) we have $V(0,0) > V(0,1)$, because $\left[\frac{\tilde{z}(1+z')}{z'(1+\tilde{z})}\right]^\alpha > 1$; from (A22)-(A23) we have $V(1,0) > V(1,1)$, because $\left[\frac{\tilde{z}(1+z')}{z'(1+\tilde{z})}\right]^{\alpha\beta} > 1$.

Proof of Proposition 6. By (A20) and (A23), $V(0,0) < V(1,1)$ if and only if

$$\left(\frac{\tilde{z}}{1+\tilde{z}}\right)^{\alpha(1+\beta)}\left(\frac{1}{1+\tilde{z}}\right)^{\alpha\beta} < \left(\frac{z'}{1+z'}\right)^{\alpha(1+\beta)}\left(\frac{1}{1+z'}\right)^{\alpha\beta}.$$

Substituting $1 + \tilde{z} = \frac{\beta+\alpha}{\beta(1-\alpha)}$, this inequality reduces to (33). It follows from (30) and (31) that if (33) is satisfied the only possible payoff ranking is (32).

Deriving expression (35). From (A20) and (A23), the gap $\Phi = V(0,0) - V(1,1)$ equals

$$\Phi = \log \left(\frac{\tilde{z}}{z'}\right)^{\alpha+\alpha\beta} \left(\frac{1+z'}{1+\tilde{z}}\right)^{\alpha+2\alpha\beta}.$$

Substituting $z' = \mu\tilde{z}$ and eq.(15) in the above expression yields equation (35) in the text.

Notes

[1] Bromley (1990) forcefully argues that environmental policy should not be restricted to efficiency targets. In line with this view is the idea that sustainable development is a matter of intergenerational equity and, once the social objective incorporates fairness concerns, efficiency *per se* does not guarantee socially optimal outcomes (Howarth, 1991; Howarth and Norgaard, 1990).

[2] All the above differences also apply with respect to Kraukraemer and Batina (1999), who consider a non-constant rate of natural regeneration in a Mourmouras (1993) setting.

[3] A positive rate of resource-augmenting technical progress may thought of as resulting from the development of new resource-saving techniques that become available over time.

[4] The population growth rate appears in (10) because e is individual consumption of the old, whereas x and a represent *per young* quantities: aggregate consumption at time $t+1$ equals $e_{t+1}N_t = p_{t+1}(1-\tau_{t+1})X_{t+1} + q_{t+1}A_{t+1}$.

[5] Equation (13) is a standard no-arbitrage condition requiring that resource owners are indifferent at the margin between alternative uses of the natural stock R: net marginal rents from natural capital must equal net marginal returns from resource asset sales.

[6] This point can be clarified by means of Figure 2.b: assume that $\rho = \mu_2\tilde{z}$, the laissez-faire rate is $\tilde{z} > \mu_1\tilde{z} > \mu_2\tilde{z}$, and the resource share equals $\alpha = \bar{\alpha}$. In this case, newborn agents would agree on 'light' resource-saving policies $z' = \mu_1\tilde{z}$, but would not agree on the 'more demanding' sustainable policy $z' = \mu_2\tilde{z} = \rho$, because the resource share $\bar{\alpha}$ is too low. Assume instead $\rho = \mu_1\tilde{z}$ and $\alpha = \bar{\alpha}$: in this case, newborn agents would agree on the sustainable program $z' = \mu_1\tilde{z} = \rho$.

[7] In Gale (1973), the government leans back after taxing the first generation, and intergenerational exchange (equivalent to lump-sum transfers) arises on voluntary basis given the absence of capital. In our model, welfare gains hinge on the productive

role of natural capital, so that improvements (i) occur only if the technological condition is satisfied, and (ii) derive from transfers that distort the rate of resource use in production.

[8] Unless sterilized by means of alternative fiscal instruments, the public welfare loss would again fall on the currently old in some form, depending on the regime experienced before period zero. In this regard, relaxing the balanced-budget hypothesis suggests a role for public debt: bond issuance at time zero allows to finance initial subsidies, and the government may smooth service repayments over time according to a calibrated fiscal rule. Whether similar rules for intergenerational *fiscal* fairness are compatible with natural preservation and political support is an interesting topic that might deserve further research.

[9] Rangel (2003) shows that positive expenditures in goods that only benefit the elderly (such as social security) are necessary to achieve an equilibrium with efficient investment in goods that benefit future generations (such as clean environment and education).

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