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A Second-Best Analysis of Alternative Instruments for the Preservation of Natural Resources

Maria Llop 

Department of Economics, Universitat Rovira i Virgili and CREIP, Avinguda Universitat 1, 43204 Reus, Spain; maria.llop@urv.cat; Tel.: +34-977759898

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Abstract: The literature on second-best environmental taxation provides us with a broad understanding of the welfare impacts of pollution regulation. However, most of the research undertaken to date has focused on environmental pollution, while other topics in environmental economics, such as the preservation of natural resources, have not warranted much attention in the optimal taxation literature. This paper uses a simple general-equilibrium model to analyze the welfare effects of taxes on final goods, taxes on natural resources, and extraction permits with a second-best approach based on the existence of initial distortionary taxes. This analysis not only takes into account the non-use utility of the mere existence of natural resources, but also captures the consequences of enjoying environmental goods on labor supply decisions, through the use-value attributed to natural resources. The comparison of the welfare impacts of a tax on final consumption and a tax on the use of natural resources is not conclusive. A consumption tax leads to a higher primary welfare effect than a resources tax, while taxing natural goods generates more revenue-recycling income than taxing consumption goods. In addition, as extraction permits do not generate new public revenues to reduce pre-existing distortionary taxes, this intervention entails the highest welfare costs.

Keywords: environmental regulation; natural resources; tax-interaction effects; use and non-use value

1. Introduction

In the last three decades, researchers have become increasingly interested in analyzing environmental taxation in economies with pre-existing taxes and identifying the efficiency of different environmental policy instruments. Particular attention has been paid to the effects of environmental taxation on welfare by extending the traditional (partial-equilibrium) analysis with additional economic interactions through the use of a broader (general-equilibrium) perspective.

The latest findings in this area of public economics not only suggest that policy recommendations from partial-equilibrium analysis are misleading and incorrect, but also warn that conclusions from general-equilibrium analysis that ignore pre-existing distortions can be highly imprecise. The cornerstone of this body of research is the idea that pre-existing taxes raise the cost of environmental interventions and that this impact is not completely offset by the possible substitution of pre-existing taxes with new environmental taxes. This set of contributions highlights the existence of three differentiated welfare effects when a new environmental tax is implemented: the *primary welfare effect*, which is the direct (partial-equilibrium) impact of the new taxation on the environmental externality; the *revenue-recycling effect*, which captures the benefit of replacing pre-existing distortionary taxes with the new pollution taxes; and finally, the *cost-side tax-interaction effect*, which measures the negative welfare impact of the price rises that is transmitted through the labor market by reducing the real wage and, consequently, discouraging labor supply [1–6]. Williams [7,8] added an additional *benefit-side tax-interaction effect*, which captures the positive effects of environmental taxation on health and productivity, and which can (partially or completely) offset the costs of taxation. Schwartz

and Repetto [9] implicitly represented health effects in the utility function, and treated the cost-side and benefit-side tax-interaction effects together. By contrast, Williams' contributions focused on an explicit representation of health effects in utility and proposed a distinction between the two tax-interaction effects.

The literature on optimal taxation to date has mainly focused on the analysis of environmental pollution. However, environmental economics faces other challenges that have not yet been addressed by second-best taxation research. In particular, to the best of my knowledge, no studies have analyzed the regulation of natural resources within this area of public economics.

Some specific aspects of natural resources need to be mentioned, such as the distinction between renewable and exhaustible resources, the creation of incentives to promote their efficient use and preservative extraction, and the need for a correct pricing policy to capture the real cost of use. The distinction between renewable and non-renewable resources, while very common in the literature, is somewhat imprecise, since both types of resource can be exhausted if the natural rules of replenishable resources are not guaranteed [10]. Natural resources are also highly heterogeneous and can vary widely in terms of their particular biological laws, their specific environment, their possible use by individuals and their usefulness in the production system. From an environmental economic perspective, problems related to natural resources relate to management issues coping with (the possibility of) overexploitation and depletion, on the one hand, and alleviating the (possible) negative externalities involved, on the other. Externalities linked to the exploitation of natural resources are environmental damages such as the loss of recreational areas and beauty, endangering the quality of soil to grow forests and crops, and reducing air quality. Additionally, the significance of these impacts on natural goods can be exacerbated by the institutional characteristics of the appropriation process. In particular, as is stated by public economics, a common property that turns resources into unpriced commodities requires the creation of market instruments to ensure that resources are efficiently used by the economic system.

Moreover, from a consumer's point of view, most stocks of natural resources such as fish or forests are not just commodities used as inputs in production, since these resources also contribute to the stability of ecological systems and provide environmental services to individuals. Resources therefore affect private welfare not only indirectly, but also directly. In particular, the literature has highlighted two ways in which natural resources have an effect on welfare: the use value and the non-use value [11]. The use value is associated with the recreational services that individuals enjoy by directly using natural resources. The non-use value, which is difficult to measure, is those services provided by natural resources and ecosystems, and their indirect contribution to the well-being of individuals.

This welfare component of policies is of particular interest if various initiatives have been put forward to ensure the preservation of natural resources. With this in mind, the approach adopted here is a general-equilibrium analysis of welfare effects that focuses on some of the implications of both the market and the non-market use of natural resources. In particular, in the model proposed, the production system makes natural resources available for the market. Non-market usage includes both the use value and the non-use value of natural resources beyond the rules of markets and prices.

At first, economic models of natural resources were static in nature. For instance, White [12] contains a complete review of the economic studies on renewable biological resources in the literature. In the 1970s and 1980s, studies started to use dynamic models that mostly focus on the long-term capacity for regeneration and preservation. For instance, Heaps [13] discussed the theory of optimal taxation for non-replenishable resources and the associated effects of the various policies on the extraction plans. Using an overlapping generations model, Gerlah and Keyzer [14] compared different policy scenarios to be applied in the case of an exhaustible resource with amenity values. More recently, Valente [15] studied resources' preservation and intergenerational distribution mechanisms in the context of human capital accumulation.

Although problems of (the possible) depletion and intergenerational redistribution mechanisms of natural resources are inherently dynamic, there are at least three situations in which there is

no connection between different generations, so static methods are appropriate [16]: the lengthy reproduction of natural goods (such as forests of slow-growing species), the high mobility of resources (such as migratory wildlife), and a reproductive size in one generation that has no impact on subsequent population size (such as harvestable fish). Furthermore, the static framework has proven to be extremely useful for making in-depth studies of the welfare implications of environmental measures. By considering all these potentialities, this paper presents a static analysis of the alternative measures available for preserving natural resources and the welfare impacts involved. The approach used can be regarded as complementary to dynamic analyses. Using optimal taxation, the approach focuses on the welfare consequences of taxes on final consumption goods, taxes on the intermediate uses of natural resources and, finally, non-auctioned extraction permits for natural resources.

This analysis extends the existing literature in several ways. First, it uses the environmental general-equilibrium framework to study natural resources by defining a second-best setting in which there is an initial and distortionary tax on income. Second, it explores the welfare effects of the alternative measures available for correcting the negative impacts caused by the usage of natural resources (i.e., overexploitation and the possible negative externalities involved). Third, it aims to capture some of the economy-wide implications of the non-market usages of natural resources by defining the trade-off between labor supply decisions and the use-value of ecosystem services. In the proposed model, this trade-off is captured by a distinction between the time devoted to enjoying nature, which is directly related to the amount of natural resources available, and other types of leisure that do not depend on the use of environmental goods.

The comparison of alternative policies shows that the contribution of the different (general-equilibrium) components to welfare depends on the policy instrument applied. In particular, a tax on natural resources involves a lower primary welfare effect and a higher revenue-recycling effect than a tax on final goods. Moreover, the implementation of extraction permits leads to higher welfare costs than direct taxation on natural resources, given that, in this case, there are no new public revenues to reduce pre-existing distortionary taxes.

The rest of the paper is organized as follows. The next section describes a general-equilibrium model that is subsequently used to analyze the welfare effects of various policies that can be implemented to preserve the resources provided by ecosystems. After presenting the policy implications of the analysis, the final section draws the conclusions.

2. The Model

The model assumes a representative household with utility from two consumption goods (X and Y). The production of X requires the use of natural resources, while the production of Y does not. Households also enjoy utility from two types of leisure: l , which is not related to environmental goods, and $E(N)$, which depends on the amount of natural resources available (N). Finally, the households' utility also comes from the amount of natural resources. The utility function can be written as

$$U(V(X, Y, l, E(N)), N) \quad (1)$$

which is quasi-concave and continuous. Sub-function V combines market goods, leisure and natural resources to derive the utility from the use-based values. In addition, the utility function in (1) assumes that resources are separable from consumption and leisure, and thus reflects the non-use value associated with natural resources. This representation is very common in the previous theoretical literature, which defines environmental quality as a separate argument in utility [1,2,7,8,17–19]. An alternative approach [9,20], relaxed this assumption by using a non-separable utility function.

Consumers divide their total time endowment (T) in the following way

$$T = L + l + E(N) \quad (2)$$

where L is labour, l is leisure and $E(N)$ represents the leisure time spent enjoying the services provided by nature, which increases in N : $\frac{\partial E}{\partial N} > 0$. The time spent using ecosystem services corresponds to a notion of use-value [21]. From expression (2), the demand for leisure related to natural resources reduces the time available for work and leisure that does not depend on natural goods. $E(N)$ represents the demand for recreational services that comprise, for instance, time for sports, and leisure that is directly linked to natural goods.

Natural resources are also used in the production of good X , and this assumption captures the market usages of resources. The production functions of the two consumption goods take the form

$$X = F_X(L_X, I) \quad (3)$$

$$Y = F_Y(L_Y) \quad (4)$$

In expressions (3) and (4), L_X and L_Y represent the labour used in the production of X and Y respectively, and $L_X + L_Y = L$. In addition, I represents the amount of N used as an input in the production of good X . Production in both industries is assumed to be competitive.

If the production functions are not homogeneous to a degree of one, production will generate profits (π) that are assumed to be an income of households. By normalising wages to one, the profits can be expressed as follows

$$\pi = P_X X + P_Y Y - L_X - L_Y - P_I I \quad (5)$$

where P_X and P_Y are the prices of X and Y , respectively, and P_I is the price of natural resources used as inputs in production.

The production and consumption of good X generates a negative impact on the environment, thus affecting (i.e., reducing) the availability of natural resources. In the model, the amount of natural resources is equal to the difference between an initial given stock (\bar{N}) minus the quantity of resources used by the production system (I), the units of which are equivalent, so that the use of one unit of I reduces the amount of natural resources by exactly one unit in the form

$$N = \bar{N} - I \quad (6)$$

where $I \leq \bar{N}$, so that $N \geq 0$. As \bar{N} is fixed, expression (6) illustrates a broad set of resource-setting situations such as a non-renewable natural good, a long reproductive framework that converts current resources into invariable stock in the short–medium term, high resource mobility, and pre-reproductive mortality in a current population that does not affect subsequent population size. In all these cases, expression (6) encompasses two possible scenarios: an initial stock that is not enough to satisfy all needs, which leads to a depletion problem and, alternatively, a stock big enough to satisfy all needs, which leads to a natural resource management problem.

In the initial situation, there is only one (pre-existing) tax in the economy, which taxes all households' income (labor earnings and profits) at a proportional tax rate τ_L . The household budget constraint is, therefore, equal to

$$(1 - \tau_L)(L + \pi) + G = P_X X + P_Y Y \quad (7)$$

In this expression, G is a government lump-sum transfer to households and is equal to

$$G = \tau_L(L + \pi) \quad (8)$$

which is held constant in real terms.

Households maximize the utility function (1) subject to the time constraint (2) and budget constraint (7), and the income tax rate, the government transfers, the price of final goods and damages on natural resources are taken as given. This yields the first-order conditions for consumers

$$\begin{aligned}U_V V_X &= \lambda P_X \\U_V V_Y &= \lambda P_Y \\U_V V_l &= \lambda(1 - \tau_L)\left(1 + \frac{dE}{dl}\right) \\U_V V_E E_N &= \lambda(1 - \tau_L)\left(1 + \frac{dE}{dE}\right)\end{aligned}$$

where the subscripts on U , V and E denote partial derivatives, λ is the Lagrange multiplier or the marginal utility of income, and the terms $\frac{dE}{dl}$ and $\frac{dE}{dE}$ measure the degree of substitutability between the two categories of leisure. These terms are obtained by totally differentiating the consumers' time restriction, and using the expressions $\frac{dE}{dl} = -\left(1 + \frac{dE}{dl}\right)$ and $\frac{dE}{dE} = -\left(1 + \frac{dE}{dE}\right)$. The corresponding (Marshallian) uncompensated demand functions for the consumption goods and leisure are obtained from these consumers' first-order conditions, together with the households' time restriction (2) and the households' budget constraint (7)

$$X(P_X, P_Y, \tau_L, \pi, N); Y(P_X, P_Y, \tau_L, \pi, N); l(P_X, P_Y, \tau_L, \pi, N); E(P_X, P_Y, \tau_L, \pi, N)$$

Note that as the public lump-sum transfer to consumers G is assumed to be constant in real terms, it is not included as an argument in the demand functions for consumption and leisure.

The equilibrium of the model requires that demand (for goods and labor) must be equal to supply, and government revenues equal to government transfers.

3. Tax on Final Goods

Research into measures to reduce pollution when taxes are already in place has mainly focused on introducing new taxation on the final (polluting) goods. The general-equilibrium model presented above provides the means to measure the welfare effects of a tax on consumption goods, which is implemented to preserve the stock of natural resources.

Consider a tax rate τ_X per unit of consumption of X . As this new taxation is a disincentive to consuming and producing harmful goods, environmental damage will be reduced (i.e., fewer natural resources will be used as inputs of production). This intervention is consistent with the idea that environmental responsibility is attributable to consumers and, accordingly, taxation should be levied on the agents assumed to generate the negative impact on the environment. From a practical point of view, this measure is applicable when the use of natural resources cannot be directly taxed because the use of resources is completely free. In other words, the tax on consumption could be implemented in the absence of prices or other market instruments for natural resources, which do not allow economic agents to directly control its use.

Note that in this situation of taxation, in conjunction with the null control of natural resource usages, expression (5) for firms' profits reduces to

$$\pi = (P_X - \tau_X)X + P_Y Y - L_X - L_Y \quad (5a)$$

Taking into account the new tax definition, the (fixed) government constraint is now equal to

$$G = \tau_L(L + \pi) + \tau_X X \quad (8a)$$

where τ_X is the revenue-neutral tax imposed on X , with revenues used to finance reductions in τ_L . In other words, as the level of government spending G is given, revenues from the final consumption tax are used to compensate for a cut in the taxation on income. In a static model with only one final good, a tax swap that raises taxation on that good and lowers income tax would have no effect. To avoid this isomorphism, the model considers another final (non-taxed) good Y .

Firms choose the input quantities according to their profit maximization behavior. Specifically, the first-order conditions for firms' profit maximization are given by

$$\begin{aligned} P_X &= \frac{1}{\frac{\partial F_X}{\partial L_X}} + \tau_X \\ P_Y &= \frac{1}{\frac{\partial F_Y}{\partial L_Y}} \end{aligned} \quad (9)$$

The first-order conditions for consumers in conjunction with the household time constraint (2) and household budget (7) lead to the Marshallian demand functions for both the consumption goods (X and Y) and the two leisure demands (l and E).

The welfare general-equilibrium impact of the tax on X corresponds to (Appendix A contains the full derivation)

$$\begin{aligned} \frac{1}{\lambda} \frac{dU}{d\tau_X} &= \\ \underbrace{\tau_X \frac{dX}{d\tau_X} - \tau_P \frac{dN}{d\tau_X}}_{\text{Primary welfare effect}} &+ \underbrace{(\mu - 1) \left[X + \tau_X \frac{dX}{d\tau_X} \right]}_{\text{Revenue - recycling effect}} \\ &+ \underbrace{\left[\frac{dE}{dl} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right] - (\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right]}_{\text{Cost - side tax - interaction effect}} \\ &+ \underbrace{\left[\frac{dE}{dl} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_X} \right] - \mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_X} \right]}_{\text{Benefit - side tax - interaction effect}} \\ &+ \underbrace{\left[\frac{dl}{dE} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \left[\frac{dN}{d\tau_X} \right] + \left(\mu - 1 + \frac{\partial E}{\partial \pi} \right) \tau_L \frac{d\pi}{d\tau_X}}_{dW^B} \end{aligned} \quad (10)$$

In this expression, λ is the marginal utility of income and $\frac{dU}{d\tau_X}$ quantifies the impact on welfare of a unitary increase in the new tax. This quantifies the monetized welfare effect of the tax change.

In addition, $\tau_P = (P_X - \tau_X) \frac{\partial F_X}{\partial l} + \left(\frac{\partial E}{\partial N} - 1 \right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$ is the marginal damage of the use of natural resources, which arises from the effects on production of the harmful consumption good, consumers' use of natural resources, and utility. Following Pigou [22], this term has been defined in the literature as the *Pigouvian tax level*, which establishes a (first-best) tax equal to marginal damages for the correction of pollution externalities. More recently, Gahvari [23] provided a clarification of the concept of Pigouvian tax.

In the natural resources context used in this paper, the Pigouvian tax should be broadly interpreted as a prescription to correct those environmental damages associated with the use of natural goods.

In Equation (10), μ is equal to

$$\mu = \frac{\left[\tau_L - (1 - \tau_L) \frac{dE}{dl} \right] \frac{\partial l}{\partial \tau_L}}{(L + \pi) - \tau_L \left(\frac{\partial l}{\partial \tau_L} + \frac{\partial E}{\partial \tau_L} \right)} + 1 \quad (11)$$

which is defined as the *marginal cost of public funds*, and shows the efficiency cost of an additional monetary unit of public revenues obtained by increasing the labor tax rate. In this expression, the quotient is the welfare loss from a marginal increase in the labor tax per monetary unit of new revenue. The numerator is the marginal rise in taxation and the denominator is the increase in government revenues from a marginal increase in τ_L . Then, the cost to consumers is equal to the deadweight loss (the quotient) plus the additional income (one) of a marginal increase in income taxation. This is a well-known partial-equilibrium definition because it does not take into account

the indirect effects of labor taxation on the revenues obtained from the new tax, and quantifies the marginal welfare damage associated with labor taxation.

Expression (10) above shows a decomposition of the welfare effects into four different components [7,8] in a second-best context of pollutant emissions. The first of these, dW^P , is the *primary welfare effect* containing the partial-equilibrium impact of implementing τ_X . This impact is the difference between the reduction in consumption good X after a marginal increase in taxation multiplied by the private costs of taxation, and the damage to natural goods (the Pigouvian tax multiplied by the marginal change in natural resources), which is the marginal social benefit. Typically, the literature has defined the marginal social benefits on pollution of a consumption tax in relation to an indirect measure, that is, the reduction in the consumption of polluting goods. The marginal benefit in expression (10), however, is defined by means of a direct measure affecting the negative environmental impacts, which is the marginal change in the amount of natural resources.

The second component in expression (10), dW^R , is the well-known *revenue-recycling effect* or the improvement in efficiency of using the income from the new tax to decrease the distortionary labor tax. This (positive) effect is equal to the marginal revenue from the new tax (in square brackets) multiplied by the welfare loss due to income taxation: $(\mu - 1)$.

The last two components in (10) show the impact of the new taxation on labor supply decisions. Unlike previous contributions, these two elements extend the labor-consumption choice to include leisure related to recreational resources. In particular, the element dW^C captures the *cost-side tax-interaction effect* and reflects the negative impact that the consumption tax has on the labor market by increasing final prices, reducing the real wage and discouraging labor supply from two different channels (the encouragement of leisure not related to nature, typically reflected in the literature, and the encouragement of leisure related to natural goods). Finally, dW^B is the *benefit-side tax-interaction effect*, which expresses the impact on labor supply decisions arising from changes in benefits and changes in the amount of natural resources. In this model, therefore, the impacts of a consumption tax on labor supply decisions come from two different sources: the effects on leisure that depends on natural goods (E) and the effects on other types of leisure (l). Given that labour supply decisions are affected by the amount of recreational resources, any change in N will have consequences on welfare, which will be reflected in the component dW^B .

Any change in the consumption-leisure choice leads to a general-equilibrium impact on welfare. There are two reasons for this. First, as income tax revenue is directly related to labor supply, any increase (decrease) in the labor supply generates an increase (decrease) in taxation revenue. Changes in labor therefore require the tax rate to be modified in the opposite direction to compensate for income tax revenues. Second, as the private cost of leisure (wage net of taxation) is lower than its social cost (pre-tax wage), any rise in leisure (i.e., fall in labor) causes a loss in welfare. The cost-side tax-interaction effect reflects the sum of these two components of the environmental tax, and the benefit-side tax-interaction effect reflects a similar sum due to the increase in natural resources. Note that if $N = 0$, then the results are equivalent to those reported in the literature: dW^C is limited to showing the impacts of τ_X on l and dW^B is limited to showing the impacts of τ_X on profits.

If the amount of natural resources increases, there is a corresponding increase in the demand for recreational services (E), which reduces the time available for work (L) and for leisure not directly related to natural resources (l). If the reduction in the remaining time materialises in a reduction in leisure, there is a positive impact on welfare that could offset the cost-side tax-interaction effect. However, if the extra time devoted to using ecosystem services is offset by a reduction in the labor supply while leisure remains at its initial level, there is a negative welfare effect that reinforces the cost-side tax-interaction effect. Consequently, the sign of the benefit-side tax-interaction effect is ambiguous, and will depend on how consumers reallocate the reduction in time between labor and leisure when the amount of natural resources changes. Although this result is consistent with [7,8], the impact of an improved environment is originated in the opposite direction. Williams' conclusion

is based on a reduction (increase) in time spent sick due to a cleaner environment, while the present conclusion is based on an increase (reduction) in time spent using recreational services.

The optimal tax rate is calculated by setting the marginal change in welfare equal to zero, and then solving for τ_X

$$\begin{aligned} \tau_X^* = & \frac{\tau_P}{\mu} \left[\frac{dN}{d\tau_X} \right] - \frac{(\mu-1)X}{\mu} \left[\frac{dX}{d\tau_X} \right] \\ & + \frac{1}{\mu} \left[\left[\mu\tau_L - \frac{dE}{dl}(1-\tau_L) \right] \left(\frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right) + (\mu-1)\tau_L \left(\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right) \right] \left[\frac{dX}{d\tau_X} \right] \\ & + \frac{1}{\mu} \left[\left[\mu\tau_L - \frac{dE}{dl}(1-\tau_L) \right] \left(\frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_X} \right) + \mu\tau_L \left(\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_X} \right) \right] \left[\frac{dX}{d\tau_X} \right] \\ & - \frac{1}{\mu} \left[\left[\frac{dl}{dE}(1-\tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \frac{dN}{d\tau_X} + (\mu-1 + \frac{\partial E}{\partial \pi}) \tau_L \frac{d\pi}{d\tau_X} \right] \left[\frac{dX}{d\tau_X} \right] \end{aligned} \quad (12)$$

The first term is equal to marginal damages divided by the marginal cost of public funds and multiplied by the quotient between marginal changes in N with respect to marginal changes in the taxed good X . The second term represents the (negative) influence of the revenue-recycling effect on optimal tax. The other terms in expression (12) represent the influence of the two tax-interaction effects (cost-side and benefit-side) on optimal taxation. Specifically, they show the positive contribution of labor supply decisions due to changes in final prices, benefits, natural resources and the negative contribution of changes in the demand for ecosystem services. The sign of this term can be either positive or negative, depending on the magnitude of all these effects individually.

Note that when τ_L is equal to zero, namely in the absence of pre-existing tax distortions in the economy, together with the assumption of a null substitution between the two demands for leisure (that is, $\frac{dl}{dE} = \frac{dl}{dE} = 0$), then $\mu = 1$, and the optimal tax reduces to

$$\tau_X^* = \tau_P \left[\frac{dN}{d\tau_X} \right] \left[\frac{dX}{d\tau_X} \right] \quad (13)$$

which corresponds to first-best (partial-equilibrium) optimal taxation. This is equal to the marginal environmental damage (i.e., the Pigouvian tax) multiplied by the relation between the marginal changes in natural resources with respect to marginal changes in X (in square brackets). Note that this is a measure of the effectiveness of the taxation, as it establishes a relationship between the final objective of the intervention, which is the control of N , and the intermediate (instrumental) objective, which is the taxed consumption good X . Jacobs and de Mooij [24] demonstrated that optimal second-best taxation should not be determined by marginal environmental damages corrected (i.e., divided) by the marginal cost of public funds, which is assumed to be always equal to unity in the optimal tax rate. They showed that whether the effective value of the marginal cost of public funds is smaller or larger than one depends on the ability of the tax system to redistribute income.

By comparing expressions (12) and (13), the second-best optimal tax rate will be lower (higher) than the optimal tax in a first-world setting if the contribution of the revenue-recycling effect on taxation is higher (lower) than the joint contribution of the two tax-interaction effects (the cost-side and the benefit-side).

4. Tax on Natural Resources

The overexploitation and depletion of some types of natural resources, such as timber, fish or minerals, is directly related to their use as inputs within the production system. In this section, let us assume that the government levies a revenue-neutral ad-valorem tax τ_I on the natural resources used in production. Implicitly, taxing the resources directly means that the public agent can control firms' access and usage. This intervention is therefore consistent with a situation in which market instruments for resources are available and can be used in order to encourage their efficient use. More specifically,

the idea that environmental responsibility falls on production, together with the government’s ability to control access to the use of natural resources, would justify the implementation of this kind of measure.

In this situation, the taxation on natural resources modifies firms’ profits in the following way

$$\pi = P_X X + P_Y Y - L_X - L_Y - P_I(1 + \tau_I)I \tag{5b}$$

As this policy levies taxation on production, the consumers’ budget constraint coincides with expression (7) for the initial situation. In addition, the government budget constraint defines the fixed transfer to households as

$$G = \tau_L(L + \pi) + (1 + \tau_I)I \tag{8b}$$

which contains the new revenues coming from the taxation of natural resources.

As firms do pay for the consumption of natural resources, the new first-order conditions for profit maximization determine both the price of consumption goods (X and Y) and the price of I, which are equal to the marginal costs of production

$$\begin{aligned} P_X &= \frac{1}{\frac{\partial F_X}{\partial L_X}} \\ P_Y &= \frac{1}{\frac{\partial F_Y}{\partial L_Y}} \\ P_I &= \frac{P_X}{(1 + \tau_I)} \frac{\partial F_X}{\partial I} \end{aligned} \tag{9a}$$

The initial first-order conditions for consumers, together with the households’ time restriction (2) and budget restriction (7), lead to the Marshallian demand functions for both consumption goods and leisure goods.

The welfare effects of taxation on natural resources can now be expressed as (see Appendix A for the full derivation)

$$\begin{aligned} &\frac{1}{\lambda} \frac{dU}{d\tau_I} = \\ &\underbrace{-\tau_P \frac{dN}{d\tau_I}}_{dW^P} \text{ Primary welfare effect} \\ &+ \underbrace{(\mu - 1) \left[I + (1 + \tau_I) \frac{dI}{d\tau_I} \right]}_{dW^R} \text{ Revenue - recycling effect} \\ &+ \underbrace{\left[\frac{dE}{d\tau_I} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right] - (\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right]}_{dW^C} \text{ Cost - side tax - interaction effect} \\ &+ \underbrace{\left[\frac{dE}{d\tau_I} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_I} \right] - \mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_I} \right]}_{dW^B} \text{ Benefit - side tax - interaction effect} \\ &+ \underbrace{\left[\frac{dI}{d\tau_I} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \frac{dN}{d\tau_I} + \left(\mu - 1 + \frac{\partial E}{\partial N} \right) \tau_L \frac{d\pi}{d\tau_I}}_{dW^B} \end{aligned} \tag{14}$$

where the Pigouvian tax level is given by $\tau_P = P_X \frac{\partial F_X}{\partial I} + \left(\frac{\partial E}{\partial N} - 1 \right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$ and reflects the marginal damage from the usage of resources, which is due to the production of X, utility and the use of recreational services.

In parallel with expression (10), expression (14) divides the welfare effects into four components. The first, dW^P , is the primary welfare effect containing the partial-equilibrium impact of the tax on natural resources, which arises from environmental damages due to natural resources usage. Note that, as taxation is levied on production, the (partial-equilibrium) private costs of consumption are null under this intervention.

The second component, dW^R , is the *revenue-recycling effect* and shows the efficiency gain of using the new tax revenue to reduce the labor tax. This effect is equal to the welfare loss of income taxation $(\mu - 1)$ multiplied by the revenues obtained from the new tax (in square brackets). The tax revenues are now defined in terms of the inputs used by the production system (I) because the tax is levied on the use of natural resources.

In expression (14), dW^C and dW^B are, respectively, the *cost-side tax-interaction effect* and the *benefit-side tax-interaction effect*. The former shows how the increase in final prices reduces real wages and thus has a negative impact on labor supply decisions and diminishes labor supply. The latter shows the effects on the labor market of changes in benefits, changes in the amount of natural resources and changes in the use of recreational services by consumers.

The comparison of the welfare impacts of an (indirect) intervention affecting final consumption and a (direct) measure affecting the use of natural resources shows two types of significant difference (see Table 1 for details). First, it is important to note the different roles played by the private costs associated with each policy, which disappear in the event of a tax implemented on production. Consequently, taxing the inputs used by the production system exacerbates the partial-equilibrium welfare losses in relation to implementing taxation on consumption. Second, the revenue-recycling effects of the two interventions differ. Specifically, a market mechanism that defines a tax on I implies a higher revenue-recycling income than a tax on final consumption, because the assumption of resources owned by the government implies a higher tax base.

The comparison of expressions (10) and (14) therefore provides an ambiguous result that depends on which of the two effects dominates. A tax on natural resources has a lower primary welfare effect (a higher welfare loss) and a higher revenue-recycling effect than a tax on final goods, which has a higher primary effect (a higher welfare gain) and a lower revenue-recycling effect.

By setting expression (14) equal to zero and solving for τ_I , the optimal tax on natural resources is equal to

$$\begin{aligned} \tau_I^* = & \frac{-\tau_P}{(\mu-1)} + \left[\frac{I}{\frac{dN}{d\tau_I}} - 1 \right] + \frac{1}{(\mu-1)} \left[\left[\frac{dE}{dI} (1 - \tau_L) - \mu\tau_L \right] \left(\frac{\partial I}{\partial P_X} \frac{dP_X}{d\tau_I} + \right. \right. \\ & \left. \left. \frac{\partial I}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right) \frac{1}{\frac{dN}{d\tau_I}} - \tau_L \left(\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right) \frac{1}{\frac{dN}{d\tau_I}} + \frac{1}{(\mu-1)} \left[(1 - \tau_L) \frac{dE}{dI} - \right. \right. \\ & \left. \left. \mu\tau_L \right] \left(\frac{\partial I}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial I}{\partial N} \frac{dN}{d\tau_I} \right) \frac{1}{\frac{dN}{d\tau_I}} - \frac{1}{(\mu-1)} \left[\mu\tau_L \left(\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_I} \right) + (1 - \tau_L) \frac{dI}{dE} + \right. \right. \\ & \left. \left. \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] + \tau_L \left(\mu - 1 + \frac{\partial E}{\partial N} \right) \frac{d\pi}{d\tau_I} \right] \frac{1}{\frac{dN}{d\tau_I}} \end{aligned} \quad (15)$$

The first term on the right-hand side shows the (negative) contribution of social costs to optimal tax. The negative sign of this term is explained by the fact that, through expression (6), any change in I causes an equal and inverse change in N .

The second term captures the (negative) influence of the revenue-recycling effect. Finally, the remaining terms represent the influence of the two tax-interaction effects (the cost-side and the benefit-side, respectively) on optimal taxation.

Table 1. Welfare components.

	<i>Tax on Final Goods</i>	<i>Tax on Natural Resources</i>	<i>Extraction Permits</i>
<i>Pigouvian tax level</i> (τ_P)	$(P_X - \tau_X) \frac{\partial F_X}{\partial I} + \left(\frac{\partial E}{\partial N} - 1\right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$	$P_X \frac{\partial F_X}{\partial I} + \left(\frac{\partial E}{\partial N} - 1\right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$	$P_X \frac{\partial F_X}{\partial I} + \left(\frac{\partial E}{\partial N} - 1\right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$
<i>Primary effect</i> (dW^P)	$\tau_X \frac{dX}{d\tau_X} - \tau_P \frac{dN}{d\tau_X}$	$-\tau_P \frac{dN}{d\tau_I}$	$-\tau_P \frac{dN}{d\tau_I^V}$
<i>Revenue-recycling effect</i> (dW^R)	$(\mu - 1) \left[X + \tau_X \frac{dX}{d\tau_X} \right]$	$(\mu - 1) \left[I + (1 + \tau_I) \frac{dI}{d\tau_I} \right]$	0
<i>Cost-side tax-interaction effect</i> (dW^C)	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial I}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right]$ $-(\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_X} \right]$	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial I}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right]$ $-(\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_I} \right]$	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial P_X} \frac{dP_X}{d\tau_I^V} + \frac{\partial I}{\partial P_Y} \frac{dP_Y}{d\tau_I^V} \right]$ $-(\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_I^V} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_I^V} \right]$
<i>Benefit-side tax-interaction effect</i> (dW^B)	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial I}{\partial N} \frac{dN}{d\tau_X} \right] -$ $\mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_X} \right] +$ $\left[\frac{dI}{dE} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \left[\frac{dN}{d\tau_X} \right] + \left(\mu - 1 + \frac{\partial E}{\partial \pi} \right) \tau_L \frac{d\pi}{d\tau_X}$	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial I}{\partial N} \frac{dN}{d\tau_I} \right] -$ $\mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_I} \right] +$ $\left[\frac{dI}{dE} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \left[\frac{dN}{d\tau_I} \right] + \left(\mu - 1 + \frac{\partial E}{\partial \pi} \right) \tau_L \frac{d\pi}{d\tau_I}$	$\left[\frac{dE}{dI} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial I}{\partial \pi} \frac{d\pi}{d\tau_I^V} + \frac{\partial I}{\partial N} \frac{dN}{d\tau_I^V} \right] -$ $\mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_I^V} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_I^V} \right] +$ $\left[\frac{dI}{dE} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \left[\frac{dN}{d\tau_I^V} \right] + \left(\mu - 1 + \frac{\partial E}{\partial \pi} \right) \tau_L \frac{d\pi}{d\tau_I^V}$

5. Extraction Permits

Another instrument that can be used to protect natural resources consists of implementing non-auctioned extraction permits that convert resources into non-free commodities because the regulator quantitatively limits their use. This situation implicitly assumes that the government is able to control access to the resources and accordingly defines an acceptable quantity that can be used by agents. Parallel studies by Goulder et al. [17], Goulder et al. [18] and Parry et al. [19] analysed emission permits (or quotas) in the context of a second-best general-equilibrium analysis of pollutant emissions.

Implementing a permits policy does not affect the initial optimization problem or the demand functions of consumers. Moreover, although the use of natural resources is quantitatively limited, firms do not pay for the use of natural inputs. This means that under this situation the benefits will be those in expression (5). The new government constraint is limited to showing revenues generated by income tax (expression (8)). Unlike the preceding measures, therefore, this intervention does not generate new public revenues. Consequently, the non-auctioned extraction permits do not allow for a reduction in the pre-existing labor taxation. Freely allocated permits are chosen with the explicit purpose of identifying the welfare impacts when the revenue-recycling effect is null. If extraction permits were auctioned, they would give rise to public revenues, and the policy effects would be the same as if a tax on natural resources were applied.

According to Goulder et al. [18], the permits policy can be represented as a virtual tax on resources, which discourages production because firms indirectly support the burden of the intervention. The virtual tax is based on the idea that firms indirectly receive the corresponding revenues from taxation in the form of economic rents due to the fact that reducing the amount of resources implies a reduction in output. Let us assume that τ_l^V is the virtual tax corresponding to the desired level of extraction permits to be implemented. The impact on welfare can then be expressed as

$$\begin{aligned}
 \frac{1}{\lambda} \frac{dU}{d\tau_l^V} = & \\
 & \underbrace{-\tau_P \frac{dN}{d\tau_l^V}}_{\text{Primary welfare effect}} \\
 & + \underbrace{\left[\frac{dW^P}{dl} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_l^V} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_l^V} \right] - (\mu - 1) \tau_L \left[\frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_l^V} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_l^V} \right]}_{\text{Cost - side tax - interaction effect}} \\
 & + \underbrace{\left[\frac{dE}{dl} (1 - \tau_L) - \mu \tau_L \right] \left[\frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_l^V} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_l^V} \right] - \mu \tau_L \left[\frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_l^V} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_l^V} \right]}_{\text{Benefit - side tax - interaction effect}} \\
 & + \underbrace{\left[\frac{dl}{dE} (1 - \tau_L) + \tau_L \left(\frac{\partial E}{\partial N} - 1 \right) \right] \frac{dN}{d\tau_l^V} + \left(\mu - 1 + \frac{\partial E}{\partial N} \right) \tau_L \frac{d\pi}{d\tau_l^V}}_{dW^B}
 \end{aligned} \tag{16}$$

where $\tau_P = P_X \frac{\partial F_X}{\partial l} + \left(\frac{\partial E}{\partial N} - 1 \right) - \frac{1}{\lambda} \frac{\partial U}{\partial N}$ is the *Pigouvian tax level*. This expression shows the *primary welfare effect* (dW^P), which is the same as if the taxation was applied to natural resources (expression (14)). In addition, as the policy raises the price of consumption goods relative to leisure, there is a reduction in real wages and a fall in the labor supply. These (negative) effects are captured by a *cost-side tax-interaction effect* (dW^C). Moreover, the *benefit-side tax-interaction effect* (dW^B) shows the impacts of extraction permits on labor supply decisions arising specifically from changes in profits and changes in the amount of natural resources.

The only difference in terms of welfare between directly taxing resources and implementing extraction permits (expressions (14) and (16)) lies with the revenue recycling effect, which disappears under the permits policy (see Table 1). Given that no new public revenues reduce pre-existing distortionary taxes, the implementation of extraction permits leads to higher welfare costs than direct taxation on natural resources, and this result is consistent with [17–19].

6. Policy Implications and Empirical Evaluation

The theoretical framework proposed in this paper could draw some implications for real-world policy making. To date, the empirical analysis of environmental fiscal reforms has mainly focused on pollutant emissions and its consequences at both socioeconomic and environmental levels. Nonetheless, the progressive degradation of some natural resources, in direct consonance with the worldwide increase in the demand for natural goods and energy-related goods, has positioned the preservation of resources at the forefront of environmental worries.

Taxes to preserve natural resources are implemented to discourage behavior that is potentially damaging for environmental goods and this provides incentives for ecosystems' preservation. This knowledge is important not only for areas such as environmental policy and environmental fiscal reforms but also for analytical purposes. Following the ambiguity of the model results to discriminate among the various instruments analyzed, taxes to preserve resources differ in their general-equilibrium impacts on welfare and this poses an undoubted interest in the specific effects that could be at stake in real economies. That is, the use of applied models to test some of the theoretical results related to natural resources, such as the ones analyzed in this paper, is necessary in order to provide insights regarding the way the different policy instruments work in real life.

However, the gap between theoretical analyses and the empirical world can only be covered if adequate and updated data are available to precisely reflect the characteristics of the economy. Hence good quality data are essential for implementing the outcomes provided in this paper and these (indispensable) data encompass not only economic variables but also environmental variables that should be accessible to researchers.

Moreover, the empirical applications require the specification of some particular issues such as the broad concepts of consumption taxation and natural resources taxation. The former involves various fiscal instruments linked to the use of natural resources by individuals, such as taxes on water consumption and taxes on activities related to recreational services (for instance, camping, hiking, and fishing). The latter involves taxation linked to the extraction and use of natural resources in the production system by firms, and comprises taxation on mineral extraction, taxes on timber or deforestation, taxes on land use or taxes on the production of resource-intensive goods, among others. Specific examples are the retail sales tax on recreational services applied in the Washington State, that includes charges for skydiving, ballooning, paragliding, day trips for sightseeing purposes, fishing, play golf, horseback riding, guided hunting, or shooting sports. In the European Union, some countries apply tourist taxes designed to preserve environmental goods, conserve resources and offset the possible negative impacts of tourism. This is the case of the occupancy taxes that are applied in some of Europe's most popular destinations such as the city of Paris and many of the Spanish regions.

The implementation of the model also requires the definition of the conceptual logic describing the different channels through which environmental goods interact with the economy. In particular, the distinction between the use and non-use value connected with natural resources at the empirical level requires precise and complete data on leisure demand, households' preferences structures and flows of environmental inputs of production. For the rest of variables involved in the model, which describe the production technology and government budget structure, data availability is also paramount to encompass empirical research.

From a methodological perspective, the transition from the theoretical model to an application for actual economies would be perfectly possible given that operational tools are available nowadays. This makes it is possible to adapt the complexity of the analytical concepts to the diversity and particular characteristics of real economies. In this vein, for example, Carbone and Smith [20] proposed an analytical and numerical model to evaluate the externalities due to reductions in air quality. In addition, computational tools may provide results for individual regions (economies) or by groups of them. Depending on model specification and the nature and quality of databases, empirical models can estimate different economy-wide interrelations in which the geographic dimension could affect the results when natural resource policies are evaluated.

7. Conclusions

Previous research on measures to reduce environmental pollution has argued that substituting pre-existing taxes for environmental taxes has a positive impact that can (completely or partially) offset the negative impact of new taxation on labor market decisions. In addition, [7,8] has highlighted the existence of a new welfare effect, the benefit-side tax-interaction effect, which can magnify or reduce the benefits of the new taxation depending on what forms the benefits of a cleaner environment take.

In a similar way, the model in this paper expands on the literature on the second-best environmental taxation of natural resources. In particular, it focuses on various measures for preserving the stock of natural resources by taking into account the market and non-market uses of environmental goods. In the model, market uses are reflected by the natural inputs used by firms, and the non-market uses of ecosystem services capture the economic implications of both the use and non-use value of recreational resources. The use value is modeled as the leisure that is directly connected with natural ecosystems. The non-use value is captured by the utility associated with the existence of natural resources.

The conventional results of previous studies can be reinterpreted by considering the influence on labor-supply decisions of the (non-priced) services related to natural resources. By taking into account the use value of natural goods, correcting the environmental damages that affect natural resources has a positive effect on welfare and reduces the cost of implementing environmental instruments. In other words, if time spent by individuals on enjoying nature is taken into account, the negative impacts of environmental measures are counterbalanced.

Moreover, the welfare impact of environmental regulations can depend on the type of measure applied. Taxes on final consumption generate a higher first-best impact and a lower revenue recycling effect than direct taxation on natural resources. Finally, the highest cost in terms of welfare is associated with a permits policy because it does not generate taxation revenues.

Real-world applications of the policy measures analyzed in this paper are required if these theoretical results are to be tested in practice. In relation to empirical assessments, the use of a single-country perspective could limit the representation of the (geographic) interconnected impacts, whereas a multi-country perspective allows to capture the transmission mechanisms and the interrelations affecting natural resources. Despite the evaluations by [25–27], among others, clarifying some aspects of natural resources policies at the empirical level, further efforts should be made to gain knowledge about the empirical consequences of natural resources management.

In addition, the present paper opens up new areas for future research. As reported by Carbone and Smith [21], individuals combine market goods and services with non-market environmental goods to compound the use of recreational services. Further research, beyond the scope of this paper, would consist of addressing these relationships in a general-equilibrium framework by capturing the links between the market (priced) and non-market (non-priced) components that are involved in individuals' use of natural resources.

The (static) representative household model used in this paper does not reflect the intergenerational mechanisms nor the individual patterns inherent to the natural resource issues. Hence, future research should explore the utilization of overlapping generation models and heterogeneous agents to improve the explanatory ability in relation to natural goods' preservation and its individual dimension. In addition, the closed-economy perspective could be replaced by an open-economy model able to capture the potential benefits of terms of trade and foreign investment. This would open up the option of analyzing financial linkages with the rest of the world and the consequent impacts on environmental resources. Research on natural resources needs to also pay attention to the spatial dimension, since environmental affectation is transmitted over space. In this respect, issues such as environmental interactions occurring in space, spatial patterns of resource usages, the impact of economic activities on some specific (spatially-allocated) natural goods, and environmental interregional spillovers have to be taken into account explicitly when measures to preserve natural resources are analyzed.

Furthermore, given the present paper's insights into the important effects of the different types of policy, it would also be interesting to study the influence of the institutional characteristics of the

resources' appropriation process on their preservation and on private welfare. From a practical point of view, the ability to choose interventions to protect natural resources is very limited and depends on both the existence and the absence of market instruments. This suggests that institutions play a significant role, and this should explicitly be taken into account in the future research of environmental goods.

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Appendix A

Derivation of Equation (10)

Totally differentiating the utility function (1) with respect to τ_X , substituting in the first-order conditions of consumers and dividing by λ yields

$$\frac{1}{\lambda} \frac{dU}{d\tau_X} = P_X \frac{dX}{d\tau_X} + P_Y \frac{dY}{d\tau_X} + (1 - \tau_L) \left(1 + \frac{dE}{dl} \right) \frac{dl}{d\tau_X} + (1 - \tau_L) \left(1 + \frac{dl}{dE} \right) \frac{dN}{d\tau_X} + \frac{1}{\lambda} \frac{\partial U}{\partial N} \frac{dN}{d\tau_X} \quad (\text{A1})$$

Taking the total derivative of the production function (3) with respect to τ_X , substituting in Equation (9) for the price of X and solving subsequently for $\frac{dL_X}{d\tau_X}$ gives the following expression

$$\frac{dL_X}{d\tau_X} = (P_X - \tau_X) \left[\frac{dX}{d\tau_X} + \frac{\partial F_X}{\partial I} \frac{dN}{d\tau_X} \right] \quad (\text{A2})$$

and a parallel approach for good Y yields

$$\frac{dL_Y}{d\tau_X} = P_Y \frac{dY}{d\tau_X} \quad (\text{A3})$$

Totally differentiating the consumers' time constraint (2) with respect to τ_X , using $\frac{dT}{d\tau_X} = 0$, substituting the result into (A2) and (A3), and then subtracting from (A1) yields

$$\frac{1}{\lambda} \frac{dU}{d\tau_X} = \tau_X \frac{dX}{d\tau_X} - \tau_P \frac{dN}{d\tau_X} + \left[(1 - \tau_L) \frac{dE}{dl} - \tau_L \right] \frac{dl}{d\tau_X} + \left[(1 - \tau_L) \frac{dl}{dE} - \tau_L \right] \frac{dN}{d\tau_X} \quad (\text{A4})$$

Taking the total derivative of the government budget constraint (8a), using $\frac{dG}{d\tau_X} = 0$ and operating

$$\frac{dl}{d\tau_X} = \frac{-\tau_L \frac{dE}{d\tau_X} + L \frac{d\tau_L}{d\tau_X} + \tau_L \frac{d\pi}{d\tau_X} + \pi \frac{d\tau_L}{d\tau_X} + X + \tau_X \frac{dX}{d\tau_X}}{\tau_L} \quad (\text{A5})$$

then substituting this expression into $\frac{dl}{d\tau_X} = \frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \tau_L} \frac{d\tau_L}{d\tau_X} + \frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_X}$, using $\frac{dE}{d\tau_X} = \frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_X} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_X} + \frac{\partial E}{\partial \tau_L} \frac{d\tau_L}{d\tau_X} + \frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_X} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_X}$, and rearranging terms gives

$$\frac{d\tau_L}{d\tau_X} = - \frac{X + \tau_X \frac{dX}{d\tau_X} - \tau_L \left[\left(\frac{\partial l}{\partial P_X} + \frac{\partial E}{\partial P_X} \right) \frac{dP_X}{d\tau_X} + \left(\frac{\partial l}{\partial P_Y} + \frac{\partial E}{\partial P_Y} \right) \frac{dP_Y}{d\tau_X} + \left(\frac{\partial l}{\partial \pi} + \frac{\partial E}{\partial \pi} \right) \frac{d\pi}{d\tau_X} + \left(\frac{\partial l}{\partial N} + \frac{\partial E}{\partial N} \right) \frac{dN}{d\tau_X} - \frac{d\pi}{d\tau_X} \right]}{L + \pi - \tau_L \left(\frac{\partial l}{\partial \tau_L} + \frac{\partial E}{\partial \tau_L} \right)} \quad (\text{A6})$$

Finally, substituting (A6) into the preceding expression for $\frac{dl}{d\tau_X}$, subsequently substituting the result into the expression (A4), and finally grouping terms gives Equation (10).

Derivation of Equation (14)

Taking the total derivative of the utility function (1) with respect to τ_I , substituting in the first-order conditions of consumers and dividing by λ yields

$$\frac{1}{\lambda} \frac{dU}{d\tau_I} = P_X \frac{dX}{d\tau_I} + P_Y \frac{dY}{d\tau_I} + (1 - \tau_L) \left(1 + \frac{dE}{dl}\right) \frac{dl}{d\tau_I} + (1 - \tau_L) \left(1 + \frac{dl}{dE}\right) \frac{dN}{d\tau_I} + \frac{1}{\lambda} \frac{\partial U}{\partial N} \frac{dN}{d\tau_I} \quad (A7)$$

Totally differentiating the production function (3) with respect to τ_I , substituting into Equation (9a) for the price of X, and then solving for $\frac{dL_X}{d\tau_I}$

$$\frac{dL_X}{d\tau_I} = P_X \left[\frac{dX}{d\tau_I} + \frac{\partial F_X}{\partial I} \frac{dN}{d\tau_I} \right] \quad (A8)$$

and a similar approach for good Y yields

$$\frac{dL_Y}{d\tau_I} = P_Y \frac{dY}{d\tau_I} \quad (A9)$$

Taking the total derivative of the household time constraint (2) with respect to τ_I , using $\frac{dT}{d\tau_I} = 0$, substituting the result into (A8) and (A9) and then subtracting from (A7) gives

$$\frac{1}{\lambda} \frac{dU}{d\tau_I} = -\tau_P \frac{dN}{d\tau_I} + \left[(1 - \tau_L) \frac{dE}{dl} - \tau_L \right] \frac{dl}{d\tau_I} + \left[(1 - \tau_L) \frac{dl}{dE} - \tau_L \right] \frac{dN}{d\tau_I} \quad (A10)$$

Totally differentiating the public budget constraint (8b), using $\frac{dG}{d\tau_I} = 0$ and rearranging terms

$$\frac{dl}{d\tau_I} = \frac{-\tau_L \frac{dE}{d\tau_I} + L \frac{d\tau_L}{d\tau_I} + \tau_L \frac{d\pi}{d\tau_I} + \pi \frac{d\tau_L}{d\tau_I} + I + (1 + \tau_I) \frac{dl}{d\tau_I}}{\tau_L} \quad (A11)$$

Substituting this expression into $\frac{dl}{d\tau_I} = \frac{\partial l}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial l}{\partial P_Y} \frac{dP_Y}{d\tau_I} + \frac{\partial l}{\partial \tau_L} \frac{d\tau_L}{d\tau_I} + \frac{\partial l}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial l}{\partial N} \frac{dN}{d\tau_I}$, using $\frac{dE}{d\tau_I} = \frac{\partial E}{\partial P_X} \frac{dP_X}{d\tau_I} + \frac{\partial E}{\partial P_Y} \frac{dP_Y}{d\tau_I} + \frac{\partial E}{\partial \tau_L} \frac{d\tau_L}{d\tau_I} + \frac{\partial E}{\partial \pi} \frac{d\pi}{d\tau_I} + \frac{\partial E}{\partial N} \frac{dN}{d\tau_I}$, and then operating terms yields

$$\frac{dl}{d\tau_I} = \frac{I + (1 + \tau_I) \frac{dl}{d\tau_I} - \tau_L \left[\left(\frac{\partial l}{\partial P_X} + \frac{\partial E}{\partial P_X} \right) \frac{dP_X}{d\tau_I} + \left(\frac{\partial l}{\partial P_Y} + \frac{\partial E}{\partial P_Y} \right) \frac{dP_Y}{d\tau_I} + \left(\frac{\partial l}{\partial \tau_L} + \frac{\partial E}{\partial \tau_L} \right) \frac{d\tau_L}{d\tau_I} + \left(\frac{\partial l}{\partial \pi} + \frac{\partial E}{\partial \pi} \right) \frac{d\pi}{d\tau_I} + \left(\frac{\partial l}{\partial N} + \frac{\partial E}{\partial N} \right) \frac{dN}{d\tau_I} - \frac{d\pi}{d\tau_I} \right]}{L + \pi - \tau_L \left(\frac{\partial l}{\partial \tau_L} + \frac{\partial E}{\partial \tau_L} \right)} \quad (A12)$$

Inserting (A12) into the preceding expression for $\frac{dl}{d\tau_I}$ and substituting the result into (A11), yields Equation (14).

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