UNIVERSITAT
ROVIRA I VIRGILI
DEPARTAMENT D'ECONOMIA

(creip)
CENTRE DE RECERCA EN ECONOMIA INDUSTRIAL I ECONOMIA PÚBLICA

WORKING PAPERS

Col·lecció "DOCUMENTS DE TREBALL DEL DEPARTAMENT D'ECONOMIA - CREIP"

A second-best analysis of alternative instruments for the preservation of natural resources?

Maria Llop Llop

Document de treball n.5- 2016

DEPARTAMENT D'ECONOMIA – CREIP
Facultat d'Economia i Empresa

UNIVERSITAT ROVIRA I VIRGILI
DEPARTAMENT D'ECONOMIA

CREIP
CENTRE DE RECERCA EN ECONOMIA INDUSTRIAL I ECONOMIA PÚBLICA

Edita:

Departament d'Economia
www.fcee.urv.es/departaments/economia/public_html/index.html
Universitat Rovira i Virgili
Facultat d'Economia i Empresa
Av. de la Universitat, 1
43204 Reus
Tel.: +34 977 759 811
Fax: +34 977 758 907
Email: sde@urv.cat

CREIP
www.urv.cat/creip
Universitat Rovira i Virgili
Departament d'Economia
Av. de la Universitat, 1
43204 Reus
Tel.: +34 977 758 936
Email: creip@urv.cat

Adreçar comentaris al Departament d'Economia / CREIP

ISSN edició en paper: 1576 - 3382
ISSN edició electrònica: 1988 - 0820

DEPARTAMENT D'ECONOMIA – CREIP
Facultat d'Economia i Empresa

A second-best analysis of alternative instruments for the preservation of natural resources

Maria Llop
(maria.llop@urv.cat)

Department of Economics and CREIP
Universitat Rovira i Virgili
Avinguda Universitat 1, 43204 Reus, Spain

Abstract

The literature on environmental taxation provides a consistent range of knowledge about the welfare impacts of pollution regulation. In particular, an important body of research has warned that partial-equilibrium analysis is not appropriate for showing the interactions of environmental taxes with pre-existing (distortionary) taxes. However, all 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 examines the role of alternative instruments in preserving natural resources. Using a simple general-equilibrium model, the welfare effects of taxes on final goods, taxes on natural resources and extraction permits are analysed by applying a second-best approach, based on the existence of initial distortionary taxes. This analysis not only takes into account the non-use utility coming from the mere existence of natural resources, but also captures the consequences of enjoying environmental goods on labour supply decisions, through the use-value attributed to natural resources. The findings in this paper precise the standard results of the second-best literature on pollution control and offer an extension to the knowledge of the natural resources preservation policies.

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

1. Introduction

Over the last three decades, analysis of environmental taxation in economies with pre-existing taxes has attracted the interest of researchers, who have dedicated significant efforts to identifying the efficiency that must be attributed to different environmental policy instruments. In particular, the welfare effects caused by environmental taxation have received special attention, by extending the traditional (partial-equilibrium) analysis with additional economic interactions through the use of a broader (general-equilibrium) perspective. This methodological improvement in the study of environmental issues has led to extraordinary advances in the identification of the consequences of environmental regulation. As a result, the literature of environmental economics today includes a robust range of knowledge about the general-equilibrium impacts of the alternative environmental measures that regulators and policy-makers have at hand.

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 ignores pre-existing distortions can be highly imprecise. The cornerstone of this body of research is based on the idea that pre-existing taxes raise the costs of environmental interventions, and this impact is not completely offset by a possible substitution of pre-existing taxes by new environmental taxes.[1] 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

[1] See Bovenger and de Mooij (1994a, 1994b), Goulder (1995), Oates (1995), and Parry (1995), among others.

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 labour market by reducing the real wage and consequently, discouraging labour supply. Williams (2002, 2003) added an additional *benefit-side tax-interaction effect*, which captures the positive effects of environmental taxation on health and productivity that can (partially or completely) offset the costs of taxation.[2]

The literature on optimal taxation produced 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, there is no study that analyses the regulation of natural resources within this area of public economics.

As far as natural resources are concerned, some specific aspects come into play, such as the distinction between renewable and exhaustible resources,[3] the need for policy management to ensure the regeneration of renewable resources, the definition of incentives to promote an efficient use of natural resources and its extraction, and the need for a correct price policy to capture the real cost of use. Natural resources are also very heterogeneous and questions such as their particular biological laws, their specific environment, their possible use by individuals and their usefulness in the production system can differ widely. The institutional characteristics of the appropriation are also an important aspect in the analysis of natural resources. In particular, as claimed by

[2] Schwartz and Repetto (2000) represented health effects in an implicit manner 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.

[3] This distinction, while very common in the literature, is somewhat imprecise since both types of resources can be exhausted if the natural rules of the replenishable resources are not guaranteed (Smith, 1968).

public economics, a common property that makes resources into an unpriced commodity calls for the definition of market instruments to ensure an efficient use of resources by the economic system.

Additionally, from a consumer's point of view, most stocks of natural resources are not simply commodities used as inputs in production, since resources also contribute to the stability of ecological systems and provide environmental services to individuals. Resources thus affect private welfare not only indirectly, but also through direct channels. Specifically, the related literature has highlighted two ways in which natural resources have an effect on welfare: the use value and the non-use value.[4] The use value is associated with the recreational services that the natural resources directly used by individuals provide. The non-use value, which is hardly observable, is explained by the mere existence of natural resources and ecosystem services, and indirectly contributes to the individuals' well-being.

This welfare content is of special interest if various policy initiatives aimed at ensuring the preservation of natural resources are to be applied. As argued by Carbone and Smith (2013), non-market activities can play an important role in determining the consequences of environmental policies, given that non-market uses of nature are associated with important feedback effects on the economy.[5] By taking this idea into account, the approach in this paper is a general-equilibrium analysis of welfare effects, focusing on some of the implications of both the market and the non-market use of natural resources. In particular, in the proposed model the market's use of resources takes place through the production system. The non-market use comprises the inclusion

[4] Hausman et al. (1995).

[5] See also Phaneuf et al. (2009) for a computable general equilibrium analysis and an econometric estimation of the non-price goods and feedback effects in a non-market valuation context.

of both the use value and the non-use value of natural resources, that are beyond the rules of markets and prices.

The study of natural resources has often used dynamic models, mostly focusing on the capacity of regeneration and preservation through a long-term perspective. For instance, Heaps (1985) discussed the theory of optimal taxation for non-replenishable resources and the associated effects of the various policies on the extraction plans. Gaudet and Lasserre (1986) showed the impacts of corporate income tax on the output path of the resource extraction sector. Krautkraemer (1990) examined the effects of taxation on the depletion of non-renewable resources when ore quality is not homogeneous within a given deposit of resources. Integrating both exhaustible and renewable natural resources, Swallow (1990) presented a partial-equilibrium analysis of the trade-offs between environmental development and depletion of natural resources trough a dynamic trajectory of resources allocation. Mourmouras (1993) proposed an overlapping generations model to analyse the effects of competition on the stocks of natural resources and living standards. Farzin (1996) presented a dynamic model to analyse the effects of alternative policy instruments in the presence of two kinds of stock externalities: a resources stock externality and an environment stock externality. Using an overlapping generations model, Gerlah and Keyzer (2001) compared different policy scenarios to be applied in the case of an exhaustible resource that had amenity values.

Despite literature having mainly used dynamic approaches to study the (possible) depletion of natural resources and its intergenerational redistribution mechanisms, the static framework has proved to be extremely useful for the in-depth study of the welfare implications of environmental measures. By considering this potentiality, this paper presents a static second-best analysis of the alternative measures available to preserve natural resources. Using an optimal taxation approach, the model focuses on the welfare impacts 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 extends the environmental general-equilibrium framework to the study of natural resources. Second, it explores the welfare effects of the alternative measures available, the implementation of which would depend on the one hand, on the institutional characteristics concerning the agents' appropriation of natural resources and on the other, would also depend on those agents and activities assumed to be responsible for the negative externalities involved. Third, the analysis aims to capture some of the economy-wide implications of the non-market usages of natural resources, through the definition of the trade-off between labour 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 and services.

The paper shows that time spent on using natural goods plays an important role in the welfare effects caused by the public initiatives aimed at protecting natural resources. The institutional framework in which natural resources are used is also an important aspect to be taken into account in any definition of a resources policy. In practice, the characteristics of the institutional context to a large extent determine the type of measure applicable. By comparing alternative policies, the results illustrate that the contribution of the different (general-equilibrium) components to welfare differ depending on the policy instrument applied.

The rest of the paper is organised as follows. The next section describes a simple general-equilibrium model that captures some of the issues related to natural resources. By assuming neutrality in public revenues, the model is used to analyse the welfare effects of various interventions that can be implemented to preserve the resources provided by the ecosystems. The final section offers a conclusion.

2. The model

2.1. Assumptions

The model assumes a representative household with utility coming from two consumption goods (X and Y). The production of X requires the use of natural resources, causing therefore a negative externality, while the production of Y does not require the use of resources. Households also enjoy utility from leisure (l) and the amount of natural resources available (N). The utility function can be written as:

$$U(V(X, Y, l), N), \tag{1}$$

which is quasi-concave and continuous. This utility function assumes that resources are separable from consumption and leisure,[6] reflecting the non-use value associated with natural resources.

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

$$T = L + l + E(N), \tag{2}$$

where L is labour, l is leisure and $E(N)$ represents the time spent on enjoying the services provided by the nature, which is increasing in N: $\frac{\partial E}{\partial N} > 0$. The time devoted to

[6] This representation is very common in the previous theoretical literature, which defines environmental quality as a separated argument in utility: see Bovenberg and de Mooij (1994a, 1994b), Goulder et al. (1997), Goulder et al. (1999), Parry et al. (1999) and Williams (2002, 2003), among others. Alternatively, Schwartz and Repetto (2000) and Carbone and Smith (2008) relaxed this assumption by using a non-separable utility function.

using ecosystem services responds to a notion of use-value.[7] From expression (2), the amount of natural resources directly affects the households' use of recreational services and therefore reduces the time available for work and leisure.[8]

Natural resources are also used in the production of good X.[9] The production functions of the two consumption goods take the form:

$$X = F_X(L_X, I); \tag{3}$$

$$Y = F_Y(L_Y). \tag{4}$$

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 input in the production of good X.

If the production functions are not homogenous of degree one, then production will generate profits (π) that are assumed to be an income of households. By normalising both wages and the price of natural resources to one, the profits can be expressed as follows:

$$\pi = P_X X + P_Y Y - L_X - L_Y - I, \tag{5}$$

where P_X and P_Y are the prices of X and Y, respectively.

The production and consumption of X generate a negative externality, 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

[7] Carbone and Smith (2013).

[8] The use of recreational services can be interpreted as time for sports and pleasure that is not subject to the individuals' consumption-leisure choice.

[9] This assumption captures the market usages of resources.

equivalent so that the use of one unit of I exactly reduces the amount of natural resources by one unit in the form:

$$N = \bar{N} - I, \tag{6}$$

being $I \leq \bar{N}$, so that $N \geq 0$.

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

$$(1 - \tau_L)(L + \pi) + G = P_X X + P_Y Y. \tag{7}$$

In this expression, G is a government lump-sum transfer to households. Assuming that the government is the owner of the natural resources and maintaining G constant in real terms it follows that:

$$G = \tau_L (L + \pi) + I, \tag{8}$$

where the price of natural resources is equal to unity to maintain an exogenous (fixed) value in the government revenues.

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

$$U_V V_X = \lambda P_X;$$

$$U_V V_Y = \lambda P_Y;$$

$$U_V V_l = \lambda (1 - \tau_L).$$

where the subscripts on U and V denote partial derivatives and λ is the marginal utility of income. 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): [10]

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

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

$$l(P_X, P_Y, \tau_L, \pi, N).$$

2.2. Tax on final goods

Research on measures to reduce pollution in the presence of pre-existing taxes has mainly focused on the introduction of 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 corrective tax rate τ_X per unit of consumption of X. As this new taxation is a disincentive to consumption and production of the damaging good, it would lead to a reduction in the environmental damage (i. e. in the usage of natural resources as inputs of production). This intervention is consistent with the idea that environmental responsibility is attributable to consumers and according to economic theory, taxation should be levied on those agents and activities generating the negative externality. 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 that do not enable a direct control of the use made by economic agents.

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

Note that in this situation of null control of the natural resources usages, expression (5) for the firms' profits reduces to:

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

And the new taxation changes the households' budget constraint to:

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

Taking into account both the free access to natural resources and the new tax definition, the government constraint is now equal to:

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

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 a cut in the taxation on income.

Additionally, the first-order conditions for firms' profit maximisation are given by the following expressions:[11]

$$P_X = \frac{1}{\frac{\partial F_X}{\partial L_X}} + \tau_X ;$$

$$P_Y = \frac{1}{\frac{\partial F_Y}{\partial L_Y}} . \quad (9)$$

The new first-order conditions for consumers are equal to:

$$U_V V_X = \lambda(1+\tau_X)P_X ;$$

$$U_V V_Y = \lambda P_Y ;$$

$$U_V V_l = \lambda(1-\tau_L),$$

[11] As this situation assumes that firms do not pay for natural resources, the firms' first-order conditions are limited to determining the prices of output, which are equal to the marginal costs of production.

that, together with the households time constraint (2) and households budget (7'), lead to the Marshallian demand functions for both the consumption goods (X and Y) and leisure.

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

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = \underbrace{\tau_X(1+P_X)\frac{dX}{d\tau_X} - \tau_N\frac{dN}{d\tau_X}}_{dW^P} + \underbrace{(\mu-1)\left[X + \tau_X\frac{dX}{d\tau_X}\right]}_{dW^R} - \underbrace{\mu\tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X}\right]}_{dW^C}$$

$$\underbrace{-\mu\tau_L\left[\frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_X}\right] + (\mu-1)\tau_L\left[\frac{\partial \pi}{\partial \tau_X} - \frac{\partial E}{\partial N}\frac{dN}{d\tau_X}\right]}_{dW^E}. \qquad (10)$$

On the left-hand side of 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.

On the right-hand side, $\tau_N = (P_X - \tau_X)\frac{\partial F_X}{\partial N} + \frac{\partial E}{\partial N} - \frac{1}{\lambda}\frac{\partial U}{\partial N}$ is the marginal damage from the use of natural resources, or the *Pigouvian tax level*, arising from the effects on production of the damaging consumption good, consumers' use of natural resources and utility.

Also in equation (10), μ is equal to:

$$\mu = \frac{\tau_L\frac{\partial l}{\partial \tau_L}}{(1+\pi) - \tau_L\frac{\partial l}{\partial \tau_L}} + 1, \qquad (11)$$

which is defined as the *marginal cost of public funds*, showing the efficiency cost of an additional monetary unit of public revenues obtained by increasing the labour tax rate. In this expression, the quotient is the welfare loss from a marginal increase in the labour tax per monetary unit of new revenue. The numerator is the marginal rise in taxation and the denominator is the increase in government revenues form 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 the income taxation. This is a well-known partial-equilibrium definition that quantifies the marginal welfare damage associated with labour taxation.[12]

Expression (10) above shows a decomposition of the welfare effects into four different components, which have been previously suggested by the second-best literature on pollutant emissions. The first one, 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 the consumption good X from a marginal increase in taxation multiplied by the private costs of taxation, and the social cost of the externality (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 tax on consumption in relation to an indirect measure, which is the reduction in the consumption of polluting goods. The marginal benefit in expression (10), however, is defined trough a direct measure affecting the negative externality, 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 efficiency improvement of using the income from the new tax to decrease the distortionary labour 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 labour supply decisions. The element dW^C captures the *cost-side tax-interaction effect* and reflects

[12] This is a partial-equilibrium measure because it does not take into account the indirect effects of the labour taxation on the revenues obtained from the new tax.

the negative impact of the consumption tax on the labour market, by increasing final prices, reducing the real wage and discouraging labour supply (i. e. encouraging leisure). Finally, dW^B is the *benefit-side tax-interaction effect*, which expresses the impact on labour supply decisions arising from changes in benefits, changes in the amount of natural resources and changes in the time spent in using the ecosystem services. This term does not appear in most of the related contributions on pollutant emissions taxation. In contrast, as in the present model the amount of natural resources affects the labour supply decisions, any change in N will have consequences in welfare that are reflected in the component dW^B.[13]

As reported in prior literature, any change in the labour supply-leisure choice leads to a general-equilibrium impact on welfare coming from two different channels. First, as the income tax revenue is directly related to labour supply, any increase (decrease) in the labour supply generates an increase (decrease) in the taxation revenue. Changes in labour therefore require a modification in the tax rate in the opposite direction to compensate for the 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 labour) causes a welfare loss.

Additionally, if the amount of natural resources increases, there is also an increase in the use of recreational services ($E(N)$) that reduces the remaining time available for work (L) and for leisure not directly related to natural resources: l. If this reduction in the remaining time is materialised in a reduction of 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 the ecosystem services is offset by a reduction in the labour supply

[13] In a parallel way, Williams (2002, 2003) include a benefit-side tax-interaction effect by reflecting the impacts of a better environment on consumers' health and labour productivity.

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 the way that consumers reallocate the reduction of time between labour and leisure when the amount of natural resources changes.[14]

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

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

The first term on the right-hand side is equal to marginal damages divided by the sum of marginal cost of public funds and the price of X, multiplied by the quotient between marginal changes in N with respect marginal changes in the taxed good X. The second term represents the (negative) influence of the revenue-recycling effect on optimal tax. And the third term in expression (12) represents the influence of the two tax-interaction effects (cost-side and benefit-side) on optimal taxation. Specifically, it shows the positive contribution on τ_X^* of labour supply decisions due to changes in final prices, benefits, natural resources, and the negative contribution on optimal tax rate 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.

[14] Despite this result being consistent with Williams (2002, 2003), the origin of the impact of an improved environment is 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.

Note that when τ_L is equal to zero, namely in the absence of pre-existing tax distortions in the economy, then $\mu = 1$, and the optimal tax reduces to: [15]

$$\tau_X^{-} = \frac{\tau_P}{(P_X - 1)} \left[\frac{\frac{dN}{d\tau_X}}{\frac{dX}{d\tau_X}} \right], \tag{13}$$

which responds to the first-best (partial-equilibrium) optimal taxation. This is equal to the marginal external damage (i. e. the Pigouvian tax) divided by the price of the taxed good plus one, and multiplied by the relation between the marginal changes in natural resources with respect marginal changes in X (in square brackets). Note that this is a measure of the effectiveness of the taxation on the environmental externality, 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.

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 to taxation is higher (lower) than the contribution of the two tax-interaction effects jointly (the cost-side and the benefit-side).

2.3. Tax on natural resources

The depletion of some types of natural resources, such as timber, petroleum 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 tax τ_r per unit of natural resources used in production. Implicitly, taxing the resources directly means that the public agent can control the access and usage made by firms. This intervention is

[15] Jacobs and de Mooij (2015) demonstrated that the optimal second-best taxation should not be determined by marginal environmental damages corrected (i. e. divided) by the marginal cost of public funds, which it is assumed to be always equal to unity in the optimal tax rate. These authors showed that the effective value of the marginal cost of public funds can be either smaller or larger than one depending on the ability of the tax system to redistribute income.

therefore consistent with a situation in which market instruments for resources are available and can be used in order to promote an efficient use. More specifically, the idea that the environmental responsibility falls on production, together with the government's ability to control access to use of natural resources, would justify the implementation of this kind of measure.

Under this situation, the taxation on natural resources modifies firms' profits in the following way:

$$\pi = P_X X + P_Y Y - L_X - L_Y - P_I(1+\tau_I)I. \qquad (5'')$$

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:

$$G = \tau_L(L+\pi) + (1+\tau_I)I.$$

(8'')

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

$$P_X = \frac{1}{\frac{\partial F_X}{\partial L_X}};$$

$$P_Y = \frac{1}{\frac{\partial F_Y}{\partial L_Y}};$$

$$P_I = \frac{P_X}{(1-\tau_I)}\frac{\partial F_X}{\partial I}. \qquad (9')$$

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

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

$$\frac{1}{\lambda}\frac{dU}{d\tau_I} = \underbrace{-\tau_P \frac{dN}{d\tau_I}}_{dW^P} + \underbrace{(\mu - 1)\left[I + (1+\tau_I)\frac{dI}{d\tau_I}\right]}_{dW^R} \underbrace{- \mu\tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_I} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_I}\right]}_{dW^C} -$$

$$\underbrace{-\mu\tau_L\left[\frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_I} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_I}\right] + (\mu-1)\tau_L\left[\frac{d\pi}{d\tau_I} - \frac{\partial \varepsilon}{\partial N}\frac{dN}{d\tau_I}\right]}_{dW^B}, \qquad (14)$$

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

Parallel to 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, arising from the social costs of the externality.[16]

The second component, dW^R, is the *revenue-recycling effect* and shows the efficiency gain of using the new tax revenue to reduce the labour 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 production system (I) because the new tax is levied on the use of natural resource. Note that the revenue-recycling effect is greater than it was in expression (10), as this intervention necessarily implies the existence of a price mechanism for natural resources, which it is assumed to be directly controlled by the public agent.

Also 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 the negative impact

[16] Note that as taxation is levied on production, the (partial-equilibrium) private costs are null under this intervention.

on labour supply decisions of the increase in final prices that reduces the real wages and subsequently discourages labour supply. The latter shows the effects on the labour 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 significant differences in two ways. First, it is important to note the different role played by the private costs associated with the 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 a final taxation on consumption. Second, the revenue-recycling effects of the two interventions differ. Specifically, a market mechanism allowing the definition of a tax on I implies a higher revenue-recycling income, in contrast to a situation of taxing final consumption.

The comparison of expressions (10) and (14) therefore provides an ambiguous result which will depend on what effect dominates the other. A tax on natural resources causes a lower primary welfare effect (a higher welfare loss) and a higher revenue-recycling effect, in comparison with a tax on final goods, that causes 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:

$$\tau_I^* = \frac{-\tau_F}{(\mu-1)} + \left[\frac{I}{\frac{dN}{d\tau_I}} - 1\right] - \frac{1}{(\mu-1)}\left|\mu\tau_L\left(\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_I} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_I} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_I} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_I}\right) + \tau_L\left(\frac{d\pi}{d\tau_I} - \frac{\partial b}{\partial N}\frac{dN}{d\tau_I}\right)\right|\frac{1}{\frac{dN}{d\tau_I}} \quad (15)$$

The first term on the right-hand side shows the (negative) contribution of the social costs on optimal tax.[17] The second term captures the (negative) influence of the revenue-recycling effect. Finally, the rest of terms represent the influence of the two tax-interaction effects (the cost-side and the benefit-side, respectively) on optimal taxation.

In a first-best world (i. e. when τ_L is equal to zero), the optimal tax on the use of natural resources is simplified to:

$$\tau_I^* = \frac{-\tau_P}{(\mu-1)} + \left[\frac{I}{\frac{dN}{d\tau_I}} - 1\right], \tag{16}$$

being equal to the Pigouvian tax rate divided by the marginal cost of public funds minus one, plus an additional term showing the contribution of the revenue recycling effect to optimal tax rate.

2.4. Extraction permits

Another instrument available to protect natural resources consists of the implementation of non-auctioned extraction permits that convert resources into non-free commodities, given that the regulator quantitatively limits their use.[18] 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.

Implementing a permits policy does not affect the initial optimisation problem and demand functions of consumers. In addition, despite the use of natural resources is quantitatively limited, firms do not pay for the use of natural inputs. This means that

---

[17] 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.

[18] In a parallel way, Goulder et al. (1997), Parry (1997), Goulder et al. (1999) and Parry et al. (1999) analysed the emission permits (or quotas) in the context of a second-best general-equilibrium analysis of pollutant emissions.

under this situation the benefits respond to expression (5'). The new government constraint is limited to show revenues coming from the income tax:

$$G = \tau_L (L + \pi). \tag{17}$$

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 labour taxation.[19]

According to Goulder et al. (1999), the permits policy can be represented as a virtual tax on resources, which discourages production because firms indirectly support the burden of the intervention.[20] Let us assume that τ_i^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:

$$\frac{1}{\lambda}\frac{dU}{d\tau_i^V} = \underbrace{-\tau_N \frac{dN}{d\tau_i^V}}_{dW^P} \underbrace{- \mu\tau_L \left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_i^V} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_i^V}\right]}_{dW^C} -$$

$$\underbrace{-\mu\tau_L \left[\frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_i^V} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_i^V}\right] + (\mu - 1)\tau_L \left[\frac{d\pi}{d\tau_i^V} - \frac{\partial c}{\partial N}\frac{dN}{d\tau_i^V}\right]}_{dW^B}. \tag{18}$$

This expression shows the *primary welfare effect* (dW^P), which is the same as if the taxation was applied on natural resources (expression (14)). In addition, as the policy raises the price of consumption goods relative to leisure, there is a reduction in the real wage and a discouragement in the labour 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 the extraction permits on labour supply decisions

[19] If extraction permits were auctioned, they would give rise to public revenues, and the policy effects would be the same as when a tax on natural resources is applied.

[20] The virtual tax is based on the idea that firms indirectly receive the corresponding revenues of the taxation, in the form of the economic rents caused by the fact that the reduction in the amount of resources implies a reduction in output.

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 (18)) is based on the revenue recycling effect, which disappears under the permits policy.[21] Given that there are no new public revenues to reduce pre-existing distortionary taxes, the implementation of extraction permits involves higher welfare costs compared to a direct taxation on natural resources.

The corresponding expression for a first-world situation and for the optimal taxation system is given by:

$$0 = -\tau_p \frac{dn}{d\tau_j^P}, \tag{19}$$

where the welfare effects of the extraction permits are null and there is not pre-existing distortionary taxes in the economy ($\tau_L = 0$).

3. Conclusions

Previous environmental research on measures to reduce pollution has argued that there is a positive impact of substituting environmental taxes by pre-existing taxes that can (completely or partially) offset the negative impact of the new taxation on the labour market decisions. Additionally, Williams (2002, 2003) 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 form the benefits of a cleaner environment take.

[21] This result is consistent with Goulder et al. (1997), Parry (1997), Goulder et al. (1999) and Parry et al. (1999), who analysed alternative abatement measures to mitigate carbon emissions.

In a similar way, the model in this paper extends the literature of the second-best environmental taxation to natural resources. Specifically, it focuses on the study of various measures for preserving the stock of natural resources by taking into account both the market uses and non-market uses of environmental goods. In the model, the market uses are reflected through the natural inputs used by firms. And the non-market aspects of the ecosystem services capture both the use and the non-use economic implications of environmental goods. The use value of resources is modelled as time that households dedicate to enjoy natural goods. The non-use value is captured by the utility associated to the existence of natural resources.

The conventional results of the prior literature can be reinterpreted by considering the influence on the labour-supply decisions of the (non-priced) services related to natural resources. By taking into account the use value of natural goods, the correction of the negative externality affecting natural resources implies a positive effect on welfare that reduces the cost of implementing environmental instruments. In other words, if time spent by individuals for enjoying nature is taken into account, the negative impacts of environmental measures are counterbalanced.

In addition, the welfare impact of environmental regulations can depend on the type of measure applied, which at the same time conditions the agents supporting the burden of taxation. Taxes on final consumption generate a higher first-best impact and a lower revenue recycling effect in contrast with a direct taxation on natural resources. And finally, given that a permits policy limiting the amount of resources that can be used does not generate taxation revenues, the highest cost in terms of welfare is associated to this intervention.

The paper opens up new areas for future research. As described by Carbone and Smith (2013), individuals combine market goods and services with non-market environmental goods to compound the use of recreational services. A further step, 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 taking place in individuals' use of natural resources.

Furthermore, the insights on the importance of the type of policy chosen makes interesting the study of the influence attributable to the institutional characteristics of the resources appropriation process. From a practical point of view, the ability to choose interventions to protect natural resources is very limited, and depends on the existence or absence of market instruments. This suggests the significant role played by the institutional context, which should be taken into account in the study of environmental goods.

Acknowledgements

The author gratefully acknowledges the financial support of the Spanish Ministry of Culture (grant ECO2013-41917-P) and the regional Government of Catalonia (grant SGR2014-299 and "Xarxa de Referència d'R+D+I en Economia Aplicada"). Useful comments and suggestions by Antonio Manresa have substantially improved an earlier draft.

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:

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = (1+\tau_X)P_X\frac{dX}{d\tau_X} + P_Y\frac{dY}{d\tau_X} + (1-\tau_L)\frac{dl}{d\tau_X} + \frac{1}{\lambda}\frac{\partial U}{\partial N}\frac{dN}{d\tau_X}. \qquad \text{(A.1)}$$

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:

$$\frac{dL_X}{d\tau_X} = (P_X - \tau_X)\left[\frac{dX}{d\tau_X} + \frac{\partial F_X}{\partial l}\frac{dN}{d\tau_X}\right], \tag{A.2}$$

and a parallel approach for good Y yields:

$$\frac{dL_Y}{d\tau_X} = P_Y\frac{dY}{d\tau_X}. \tag{A.3}$$

By totally differentiating the consumers' time constraint (2) with respect to τ_X, using $\frac{dT}{d\tau_X} = 0$, substituting the result into (A.2) and (A.3), and then subtracting from (A.1) yields:

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = \tau_X(1 + P_X)\frac{dX}{d\tau_X} - \tau_P\frac{dN}{d\tau_X} - \tau_L\frac{dl}{d\tau_X}. \tag{A.4}$$

Taking the total derivative of the government budget constraint (8′), using $\frac{dG}{d\tau_X} = 0$, substituting into $\frac{dl}{d\tau_X} = \frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \tau_L}\frac{d\tau_L}{d\tau_X} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_X}$, and rearranging terms gives:

$$\frac{d\tau_L}{d\tau_X} = -\frac{X + \tau_X\frac{dX}{d\tau_X} - \tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{d\pi}{d\tau_X}\left(\frac{\partial l}{\partial \pi} - 1\right) + \frac{\partial l}{\partial N}\frac{dN}{d\tau_X} + \frac{\partial E}{\partial N}\frac{dN}{d\tau_X}\right]}{L + \pi - \tau_L\frac{\partial l}{\partial \tau_L}}. \tag{A5}$$

Finally, substituting the expression (A.5) into the preceding expression for $\frac{dl}{d\tau_X}$, subsequently substituting the result into the expression (A.4), and finally grouping terms gives equation (10).

Appendix B. 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:

$$\frac{1}{\lambda}\frac{dU}{d\tau_I} = P_X\frac{dX}{d\tau_I} + P_Y\frac{dY}{d\tau_I} + (1-\tau_L)\frac{dl}{d\tau_I} + \frac{1}{\lambda}\frac{\partial U}{\partial N}\frac{dN}{d\tau_I}. \quad \text{(B.1)}$$

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

$$\frac{dL_X}{d\tau_I} = P_X\left[\frac{dX}{d\tau_I} + \frac{\partial F_X}{\partial N}\frac{dN}{d\tau_I}\right], \quad \text{(B.2)}$$

and a similar approach for good Y yields:

$$\frac{dL_Y}{d\tau_I} = P_Y\frac{dY}{d\tau_I}. \quad \text{(B.3)}$$

By totally differentiating the household time constraint (2) with respect to τ_I, using $\frac{dT}{d\tau_I} = 0$, substituting the result into (B.2) and (B.3) and then subtracting from (B.1) gives:

$$\frac{1}{\lambda}\frac{dU}{d\tau_I} = -\tau_P\frac{dN}{d\tau_I} - \tau_L\frac{dl}{d\tau_I}. \quad \text{(B.4)}$$

Taking the total derivative of the public budget constraint (8''), using $\frac{dG}{d\tau_I} = 0$, substituting into $\frac{dl}{d\tau_I} = \frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_I} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_I} + \frac{\partial l}{\partial \tau_L}\frac{d\tau_L}{d\tau_I} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_I} + \frac{\partial l}{\partial N}\frac{dN}{d\tau_I}$, and then arranging terms, it follows that:

$$\frac{d\tau_L}{d\tau_I} = -\frac{I + (1+\tau_I)\frac{dI}{d\tau_I} - \tau_L\left[\frac{\partial L}{\partial P_X}\frac{dP_X}{d\tau_I} + \frac{\partial L}{\partial P_Y}\frac{dP_Y}{d\tau_I} + \frac{d\pi}{d\tau_I}\left(\frac{\partial L}{\partial \pi} - 1\right) + \frac{\partial L}{\partial N}\frac{dN}{d\tau_I} + \frac{\partial E}{\partial N}\frac{dN}{d\tau_I}\right]}{L + \pi - \tau_L\frac{\partial L}{\partial \tau_L}}. \quad \text{(B.5)}$$

Inserting (B.5) into the preceding expression for $\frac{dl}{d\tau_I}$ and substituting the resulting expression into (B.4), yields equation (14).

References

Bovenberg, A. and de Mooij, R. A. (1994a). Environmental levies and distortionary taxation, *American Economic Review*, 84, 1085-1089.

Bovenberg, A. and de Mooij, R. A. (1994b). Environmental taxes and labor-market distortions, *European Journal of Political Economics*, 10, 655-683.

Carbone, J. C. and Smith, V. K. (2008). Evaluating policy interventions with general equilibrium externalities, *Journal of Public Economics*, 92, 1254-1274.

Carbone, J. C. and Smith, V. K. (2013). Valuing nature in a general equilibrium, *Journal of Environmental Economics and Management*, 66, 72-89.

Farzin, Y. H. (1996). Optimal pricing of environmental and natural resources use with stock externalities, *Journal of Public Economics*, 62, 31-57.

Gaudet, G. and Lasserre, P. (1986). Capital income taxation, depletion allowances, and nonrenewable resource extraction, *Journal of Public Economics*, 29, 241-253.

Gerlagh, R. and Keyzer, M. (2001). Sustainability and the intergenerational distribution of natural resource entitlements, *Journal of Public Economics*, 79, 315-341.

Goulder, L. H. (1995). Environmental taxation and the double dividend: A reader's guide, *International Tax and Public Finance*, 2, 157-183.

Goulder, L. H.; Parry, I. W. H. and Burtraw, D. (1997). Revenue-raising versus other approaches to environmental protection: The critical significance of preexisting tax distortions, *Rand Journal of Economics*, 28, 708-731.

Goulder, L. H.; Parry, I. W. H.; Williams, R. C. and Burtraw, D. (1999). The cost-effectiveness of alternative instruments for environmental protection in a second-best setting, *Journal of Public Economics*, 72, 329-360.

Hausman, J. A.; Leonard, G. K. and McFadden, D. (1995). A utility-consistent, combined discrete choice and count data model. Assessing recreational use losses due to natural resource damage, *Journal of Public Economics*, 56, 1-30.

Heaps, T. (1985). The taxation of nonreplenishable natural resources revisited, *Journal of Environmental Economics and Management*, 12, 14-27.

Jacobs, B. and de Mooij, R. A. (2015). Pigou meets Mirrlees: On the irrelevance of tax distortions for the second-best Pigouvian tax, *Journal of Environmental Economics and Management*, 71, 90-108.

Krautkraemer, J. A. (1990). Taxation, ore quality selection and the depletion of a heterogeneous deposit of a non-renewable resource, *Journal of Environmental Economics and Management*, 18, 120-135.

Mourmouras, A. (1993). Conservationist government policies and intergenerational equity in an overlapping generations model with renewable resources, *Journal of Public Economics*, 51, 249-268.

Oates, W. E. (1995). Green taxes: Can we protect the environment and improve the tax system at the same time?, *Southern Economic Journal*, 61, 914-922.

Parry, I. W. H. (1995). Pollution taxes and revenue recycling, *Journal of Environmental Economics and Management*, 29, 64-77.

Parry, I. W. H. (1997). Environmental taxes and quotas in the presence of distorting taxes in factor markets, *Resource and Energy Economics*, 19, 203-220.

Parry, I. W. H.; Williams, R. C. and Goulder, L. H. (1999). When can carbon abatement policies increase welfare? The fundamental role of distorted factor markets, *Journal of Environmental Economics and Management*, 37, 52-84.

Phaneuf, D. J.; Carbone, J. C. and Herriges, J. A. (2009). Non-price equilibria for non-marketed goods, *Journal of Environmental Economics and Management*, 57, 45-64.

Schwartz, J. and Repetto, R. (2000). Nonseparable utility and the double dividend debate: Reconsidering the tax-interaction effect, *Environmental and Resource Economics*, 15, 149-157.

Smith, V. L. (1968). Economics of production from natural resources, *American Economic Review*, 58, 409-431.

Swallow, S. K. (1990). Depletion of the environmental basis for renewable resources: The economics of interdependent renewable and non-renewable resources, *Journal of Environmental Economics and Management*, 19, 281-296.

Williams, R. C. (2002). Environmental tax-interactions when pollution affects health or productivity, *Journal of Environmental Economics and Management*, 44, 261-270.

Williams, R. C. (2003). Health effects and optimal environmental taxes, *Journal of Public Economics*, 87, 323-335.