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Environmental taxation and international trade in a tax-distorted economy

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Abstract

International environmental agreements have met with the reluctance of some national authorities to accept general commitments aimed at reducing greenhouse gas emissions. While acknowledging the crucial significance of the climate change process, politicians and regulators in some countries have argued that pollution measures would have a negative impact on their domestic welfare. This paper uses a standard general equilibrium model of perfect competition to examine the welfare effects of taxing a polluting exported good through an explicit representation of the trade relations of the economy in the presence of pre-existing taxes. The equivalent autarky model is used to contrast the welfare impacts with the open economy situation. The results extend the scope of the literature on second-best environmental taxation by identifying the complexity of the components affecting welfare in open economies. This demonstrates the potential importance for the general equilibrium welfare effects of environmental policies when applied to exporting countries.

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1. Introduction

According to United Nations, the fight against climate change requires a worldwide strategy, including a global commitment with the engagement of the industrialised countries.[2] This global approach is needed to address a generalised problem, having both causes and consequences beyond the administrative borders of individual countries. However, the history of the climate international agreements has revealed the reluctance of some countries to accept measures that could harm their domestic industry, especially in the case of export-oriented economies. In particular, the Kyoto Protocol showed an evident gap between the science of climate change, which predicts rapid and inevitable increases in global temperatures, and the policy responses to mitigate the anthropogenic phenomenon of climate change. Until today, such policy measures have defined insufficient responses to reach an appreciable mitigation of impacts (Helm, 2008).

Indeed, obtaining a significant decrease in greenhouse emissions requires a structural transformation of the economic systems, adapting both the production and consumption processes to obtain energy from clean sources, and abandoning energy from fossil fuels. The required transformation of the energy system is not a trivial issue from the socioeconomic and technological points of view, at least in the short and medium term.

A common evidence materialised in international agreements is that countries' willingness to reduce emissions is inversely related to a country's openness to trade and propensity to export (Hoel, 2001). In addition, trade becomes an important issue when different environmental measures are applied at a national level, as climate interventions potentially reduce competitiveness and internal activity (Simmons *et al.*, 2009; Harrison, 2015). As environmental measures generate an increase in effective

[2] United Nations (2019).

prices for exported goods, international agreements are viewed as damaging for the competitiveness of domestic industries while benefiting the competitiveness of foreign industries, especially if the competing countries have weak environmental standards (Flannery, 2016). According to this point of view, international environmental commitments would generate a decline in exports and a subsequent negative knock-on effect on the domestic activity (Levinson and Taylor, 2008).

Over the last 40 years, the debate about trade and environment has been accompanied by an extensive literature, which has evolved in various research areas while making use of various methodological frameworks.[3] In particular, Antweiler *et al.* (2001) and Copeland and Taylor (2003) analysed the impacts of free trade on the environment by deriving, both theoretically and empirically, three different impacts of trade on the environment: the scale effect, the technique effect and the composition effect.[4] The relationship between environmental regulation, competitiveness, economic growth and the comparative advantage of countries and firms has also been studied by using both empirical and analytical approaches.[5] Within this body of literature, the interactions and potential conflicts between free trade and ecological policies have been analysed.[6]

Another set of contributions has analysed the welfare costs associated with environmental regulation, using a general equilibrium perspective that takes into account the initial tax distortions of a closed economy. In all these studies, pre-existing

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[3] See Williams (2001) for a survey of the trade-environment debate.

[4] Other papers analysing the relationship between trade and pollution are, for instance, Perroni and Wigle (1994), Copeland and Taylor (2005), Chen and Wooland (2013), and Lapan and Sikdar (2017).

[5] Among others, Jaffe *et al.* (1995), Xu (2000), and Althammer and Hille (2016) have provided empirical analyses; Pethig (1976), Copeland (1994), Sartzetakis and Constantatos (1995), and Lahiri and Symeonidis (2017) have proposed theoretical evaluations.

[6] For example, Krutilla (1991) proposed the need for modifying the structure of environmental taxes when the economy trades with the external markets; Barrett (1994) examined the government incentives to define environmental standards for industries competing in the world market; Burguet and Sempere (2003) analytically analysed how trade liberalization affects environmental policies in a bilateral context of imperfect competition; and Limao (2005) presented a model to analyse whether linking cooperation in trade policy to environmental policy generates more cooperation in both policies.

taxes are a crucial starting point that places this literature in a second-best setting. Within this field, the pioneering papers pointed out the existence of two welfare effects caused by environmental taxation:[7] the *primary welfare effect*, or the partial equilibrium impact of the new taxation on reducing the polluting good, and the *revenue-recycling effect*, or the benefit of replacing pre-existing distortionary taxes with the pollution taxation. The results of these contributions pointed out that environmental regulation could generate increases in welfare if pre-existing distorting taxes were replaced by the new environmental taxes.[8]

Subsequently, an extensive set of papers suggested the existence of an additional (negative) welfare effect: the *tax-interaction effect*, reflecting a loss of welfare due to the increase in real prices generated by the emission taxation, which reduces the real wage and subsequently diminishes the labour supply and aggravates the distortions inherent to the pre-existing tax system.[9] These papers demonstrated that the efficiency costs of environmental interventions are higher in a world with initial tax distortions in factor markets than in a situation where those distortions do not exist. The latest finding in this literature was proposed by Williams (2002, 2003), who defined an additional *benefit-side tax-interaction effect* to be added to the welfare impact measurement. This new component captures the positive contribution of environmental taxation on consumers' health and labour productivity that can (partially or completely) offset the costs of environmental taxation.[10]

[7] See for example Terkla (1984) and Oates (1993).
[8] This positive impact on welfare has been defined as the *double dividend hypothesis*.
[9] Among others, the papers by Bovenberg and de Mooij (1994a, 1994b), Goulder (1995), Parry (1995), and Parry *et al*. (1999) first proposed the tax-interaction effect.
[10] Alternatively, Schwartz and Repetto (2000) analysed in depth how the previous results of the literature would change if environmental quality did impact on consumers' labour-leisure decision through the introduction of environmental quality as a non-separable argument in the utility function of consumers.

Later, Bento and Jacobsen (2007) extended the double dividend analysis by incorporating a fixed-factor in the production of the dirty good, which involves the generation of Ricardian rents in the economy. In this context, the introduction of an environmental tax with revenues used to reduce pre-existing labour taxes can generate a double dividend situation. In addition, Liu (2013) proposed the introduction of a *tax evasion effect* to the welfare measurement when an environmental tax reform is applied. This additional component captures the change in real costs supported evading taxes and allows to enhance welfare.

Broadly speaking, the welfare consequences of environmental taxes in open economies have been explored through the use of two differential general equilibrium approaches. The first one adopts the assumption of small open economy, focusing on the implications of the interplay between trade policies and environmental regulations within a specific economy. Examples in this field are Bovenberg and van der Ploeg (1994), who explored the effects on public finance, unemployment and domestic capital stock of increased concern for environment; Bovenberg and van der Ploeg (1998), who studied the effects on wage formation, employment and environmental quality of environmental tax reforms; Neary (2006), who reviewed and extended three approaches to environmental and trade policies (competitive general equilibrium, oligopoly and monopolistic competition); or Gulati and Roy (2008), who analysed the role of the national treatment principle in the environmental regulation of an open economy.

The second approach uses a (broader) perspective of large open economies, taking a global look to the trade-environment interaction. Turunen-Red and Woodland (2004), for instance, analysed the feasibility of Pareto-improving multilateral reforms of environmental and trade policies in a model of international trade. By using an empirical perspective, Fisher and Fox (2007, 2012) looked at the relationship between trade and environmental taxation in the context of pre-existing distortionary taxes, through the use of the computable general equilibrium (CGE) framework. By incorporating tax and trade distortions, the main conclusions of these CGE papers were the importance of the distributional and efficiency impacts due to the allocation of emission permits. Additionally, Vlassis (2013) proposed a perfectly competitive general equilibrium model of international trade to analyse the welfare impacts of environmental policy coordination reforms. Keen and Kotsogiannis (2014) studied the Pareto-efficiency of trade instruments in global efficient climate policies through the use of a perfectly competitive general equilibrium model of international trade. By combining theoretical and empirical analysis, Larch and Wanner (2017) studied the effects of carbon tariffs on trade, welfare and carbon emissions by developing a multi-sector, multi-factor structural gravity model.

The extensive coverage of the interplay between environmental policy and trade has usually analysed welfare impacts in an aggregate manner, without deeping into the various channels through which welfare is affected. In fact, an in-depth perspective of the trade-environment repercussions on welfare has received less attention in the literature. To the best of this author's knowledge, the sole exceptions are Williams (1999), who used a second-best general equilibrium analysis and studied the various channels of welfare impacts caused by trade policies taking into account the pre-existing tax distortions in the labour market, and Parry (2001), who extended the Williams's contribution by numerically quantifying the significance of pre-existing factor taxation in the welfare effects caused by restrictive trade policies.

Against this background, the objective of this paper is to provide a detailed analysis of the complexity of the general equilibrium welfare impacts of environmental taxation, by using a second-best approach that captures the link between ecological taxes, trade operations and initial taxes of a small open economy. Among the welfare effects when an emission tax is implemented, the results enable identifying the impacts on the domestic economy that are channelled through the trade activity. In particular, apart from the primary impact on trade, which has traditionally been a latent impediment to international commitments, the model shows two additional general equilibrium trade contributions to welfare. The first is based on the tax revenues coming from abroad, which allow a cut in the (domestic) distortionary income tax. The second contribution shows the impact of a better environment on reducing labour supply and encouraging leisure after the detrimental effect of the environmental taxation on exports. The general equilibrium channels of trade and its effects on welfare proposed in this paper, commonly ignored by the (partial equilibrium) conventional wisdom, provide a better understanding of the consequences of an emissions tax in the case of exporting open economies. Finally, the model is accommodated to reflect an autarky situation that is used to compare with the open economy framework.

The rest of the paper is organised as follows. The next section describes the analytical general equilibrium model that explicitly defines the trade activity of the economy. Section 3 analyses the welfare impact of implementing an environmental tax on the polluting exported good and gives details about the second-best optimal taxation and the trade's partial equilibrium contribution to welfare. Section 4 adapts the model to the special case of autarky. The final section of the paper concludes.

2. The analytical model

The welfare effects of environmental taxes in an open economy are examined through a general equilibrium model. Parallel to Williams (1999), the model analyses the welfare effects in an open economy with pre-existing tax distortions. Unlike Williams' approach, focused on trade policies, the present framework incorporates environmental externalities and derives the welfare impacts when the burden of (domestic) environmental taxation is partially translated to external agents through increases in the effective price of exports.

For the sake of simplicity, the model is limited to showing two consumption goods: X, the production of which generates air pollution, and Y, the production of which does not generate the negative externality. There is a representative household in the economy whose utility comes from the two consumption goods (X and Y). Households also enjoy utility from leisure (l) and environmental quality (Q). The utility function responds to:

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

which is quasi-concave and continuous. Note that expression (1) assumes that environmental quality is a separable argument from consumption goods and leisure.[11]

The household's time constraint is defined as:

$$T = L_X + L_Y + l, \tag{2}$$

where T is the total time endowment, L_X and L_Y represent the amount of labour used in the production of X and Y, respectively, and $L_X + L_Y = L$.

In order to simplify the trade relations, X is assumed to be exported and Y is assumed to be imported. The domestic consumption of each good therefore responds to total production net of trade relations, in the form:

$$X = F_X(L_X) - M_X; \tag{3}$$

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

[11] Bovenberg and de Mooij (1994a, 1994b), Goulder *et al.* (1997), Parry *et al.* (1999) and Williams (2002, 2003), among others, use the separability assumption of environmental quality in general equilibrium approaches of environmental taxation. See, for example, Swartz and Repetto (2000) and Carbone and Smith (2008) for an analysis of non-separability between consumption goods and environmental quality.

In these expressions, M_X are the exports of the economy and M_Y are the imports. In addition, $F_X(L_X)$ and $F_Y(L_Y)$ are the production functions that in case of not being homogenous of degree one, will generate profits (π) that are assumed to be an income of households. By normalising wages to one, profits can be written in the following way:

$$\pi = P_X F_X(L_X) + P_Y F_Y(L_Y) - L_X - L_Y, \tag{5}$$

where P_X is the price of X and P_Y is the domestic price of Y.

The production of X generates pollution and therefore reduces environmental quality. The model assumes that Q responds to a negative relationship with the production of the polluting good:

$$Q = \bar{Q} - F_X(L_X) = \bar{Q} - (X + M_X), \tag{6}$$

where $F_X(L_X) \leq \bar{Q}$, so that $Q \geq 0$. Environmental quality is equal to the difference between an initial exogenous level ($\bar{Q}$) minus the quantity of the dirty good produced. In expression (6), the units are equivalent so that the production of one unit of X reduces the baseline level $\bar{Q}$ by exactly the same amount.

Pre-existing tax distortions come from an initial income tax, which taxes all household income (labour earnings and profits) at a proportional rate τ_L. By normalising wage to one, the consumers' budget constraint can be written as:

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

where G is a government lump-sum transfer to households, which is assumed to be constant in real terms:

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

The model does not incorporate trade barriers and the trade relations of the economy are assumed to be balanced so that:

$$P(M_Y)M_Y - P_X M_X = 0, \tag{9}$$

where $\frac{\partial P(M_Y)}{\partial M_Y} \leq 0$. In this expression, $P(M_Y)$ is the world price for the imported good which is decreasing with the amount of imports, and P_X is the price of one unit of the exported good X.

Households maximise utility (1) subject to their time constraint (2) and budget constraint (7), by taking the income tax rate, the government transfers, the prices of final goods, profits and environmental quality as given. This yields the corresponding first-order expressions for consumers:

$$U_V V_X = \lambda P_X;\ U_V V_Y = \lambda P_Y;\ U_V V_l = \lambda(1 - \tau_L),$$

denoting the subscripts on U and V partial derivatives and λ being the marginal utility of income. The uncompensated Marshallian demand functions for both the consumption goods and leisure are then derived by applying these consumers' first-order conditions, together with the households' time constraint (2) and the households' budget constraint (7):

$$X(P_X, P_Y, \tau_L, \pi, Q);\ \ Y(P_X, P_Y, \tau_L, \pi, Q);\ \ l(P_X, P_Y, \tau_L, \pi, Q).$$

3. Effects of taxing the polluting good

3.1. Welfare measurement

The analytical model described above is used to measure the welfare consequences of an emission tax implemented on the dirty-exported good. Specifically, the model assumes a tax rate falling on the production of X (τ_X), and this implies that both domestic demand and external demand support the burden of the environmental taxation. Indeed, taxing the exported good raises its effective price and consequently, this measure creates a disincentive for both internal consumption and exports. However, as the interest lies in analysing the impacts on the internal economy that implements the environmental tax, the following welfare analysis is limited to showing the effects on domestic agents.

The emission tax modifies expression (5) corresponding to the firms' profits, as follows:

$$\pi = (P_X - \tau_X) F_X(L_X) + P_Y F_Y(L_Y) - L_X - L_Y. \tag{5'}$$

Meanwhile, the government budget constraint is now modified to:

$$G = \tau_L (L + \pi) + \tau_X F_X(L_X). \tag{8'}$$

In this situation, the first-order conditions for firms' profits maximisation are:

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

$$P_Y = \frac{1}{\frac{\partial F_Y}{\partial L_Y}}, \tag{10}$$

where P_X is the tax-inclusive price of good X.

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

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = P_X \frac{dX}{d\tau_X} + P_Y \frac{dY}{d\tau_X} + (1 - \tau_L)\frac{dl}{d\tau_X} - \frac{1}{\lambda}\frac{\partial U}{\partial Q}\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right). \tag{11}$$

Taking the total derivative of the domestic consumption of good X (expression (3)) with respect to τ_X, substituting it into equation (10) for the price of X and solving for $\frac{dL_X}{d\tau_X}$, gives the following expression:

$$\frac{dL_X}{d\tau_X} = (P_X - \tau_X)\left[\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right], \tag{12}$$

and a similar procedure for good Y gives rise to:

$$\frac{dL_Y}{d\tau_X} = P_Y(\frac{dY}{d\tau_X} - \frac{dM_Y}{d\tau_X}). \tag{13}$$

Totally differentiating the consumers' time constraint (2) with respect to τ_X, using $\frac{dT}{d\tau_X} = 0$, introducing expressions (12) and (13), and then subtracting the result in (11) yields:

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = [\tau_X - \tau_P]\left[\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right] + P_Y\frac{dM_Y}{d\tau_X} - P_X\frac{dM_X}{d\tau_X} - \tau_L\frac{dl}{d\tau_X}, \tag{14}$$

where $\tau_P = \frac{1}{\lambda}\frac{\partial U}{\partial Q}$ is the *Pigouvian tax level* that measures the marginal damage due to air pollution arising from the effects of the polluting good on utility.

Differentiating the government budget constraint (8´), using $\frac{dG}{d\tau_X} = 0$, subsequently substituting into the total derivative of the demand for leisure $l(P_X, P_Y, \tau_L, \pi, Q)$, which is equal to $\frac{dl}{d\tau_X} = \frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \tau_L}\frac{d\tau_L}{d\tau_X} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} + \frac{\partial l}{\partial Q}\frac{dQ}{d\tau_X}$, and operating terms gives:

$$\frac{d\tau_L}{d\tau_X} = -\frac{X + M_X + \tau_X\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right) - \tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{d\pi}{d\tau_X}(\frac{\partial l}{\partial \pi} - 1) + \frac{\partial l}{\partial Q}\frac{dQ}{d\tau_X}\right]}{L + \pi - \tau_L\frac{\partial l}{\partial \tau_L}}. \tag{15}$$

Substituting expression (15) into the preceding expression for $\frac{dl}{d\tau_X}$, introducing the result into expression (14), using $\frac{dQ}{d\tau_X} = -\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right)$, and finally grouping terms yields:

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = \underbrace{[\tau_X - \tau_P]\left[\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right]}_{dW^P} + \underbrace{\left[P_Y\frac{dM_Y}{d\tau_X} - P_X\frac{dM_X}{d\tau_X}\right]}_{dW^T} +$$

$$\underbrace{(\mu - 1)\left[X + M_X + \tau_X\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right) + \tau_L\frac{d\pi}{d\tau_X}\right]}_{dW^R} -$$

$$\underbrace{\mu\tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} - \frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right)\right]}_{dW^I}. \quad (16)$$

This expression monetarily quantifies the welfare general equilibrium impact of the tax on X, which is obtained through a calculation of the marginal welfare effect of implementing the environmental taxation.

In expression (16) above, μ is the *marginal cost of public funds* and responds to:

$$\mu = \frac{\tau_L\frac{\partial l}{\partial \tau_L}}{(L+\pi) - \tau_L\frac{\partial l}{\partial \tau_L}} + 1. \quad (17)$$

Note that this is a partial equilibrium concept as it does not take into account the indirect effects of labour taxation on the emission tax revenues. The marginal cost of public funds shows the efficiency cost of an additional monetary unit of public revenues obtained by an increase in the income tax rate. In particular, the quotient in (17) is the welfare loss from a marginal increase in the income 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. The cost to consumers is therefore equal to the deadweight loss (the quotient) plus the additional income (one) of a marginal increase in the income taxation.

In expression (16) the total welfare effects of the environmental taxation are decomposed into four different components: the *primary welfare effect* (dW^P), the *trade-substitution effect* (dW^T), the *revenue-recycling effect* (dW^R) and, finally, the *tax-interaction effect* (dW^I). The *primary welfare effect* is the partial equilibrium impact of implementing τ_X previously defined in prior literature, which is equal to the difference between the private costs of taxation and the social costs of the externality. The former is obtained by multiplying the tax rate on X by the reduction in the production of the polluting good; the latter is derived from multiplying the Pigouvian tax rate by the decrease in the production of X.

The second component in expression (16), dW^Tor the *trade-substitution effect*, is a welfare element that has not appeared in the previous contributions of the second-best literature, which have focused on the welfare impacts of environmental taxes in closed economies. This component captures the influence of the emission taxation on the trade balance. In specific terms, the trade-substitution effect is equal to the difference between the marginal change in imports, valued at the internal price, minus the marginal change in exports, valued at the effective price (i.e. final price including the environmental tax rate). Note that the trade-substitution effect is a partial equilibrium measurement, as it does not take into account the interactions of the emission tax with the pre-existing tax system.

The *revenue-recycling effect*, dW^R, reflects the positive welfare impact of substituting the distortionary income tax by the environmental taxation. This efficiency improvement is equal to the product of the marginal revenue from the emission tax (in square brackets) and the welfare loss due to income taxation: $(\mu - 1)$. In contrast to the conventional approaches, the revenue-recycling effect in equation (16) distinguishes between revenues attributed to domestic economy and revenues attributed to exporting activity.

The last component in (16) contains the *tax-interaction effect*, dW^I. This element measures the welfare loss generated by the emission tax on the labour market, which is channelled through an increase in final prices that also reduces real wage, decreases benefits and improves environmental quality. All these impacts discourage labour supply, which simultaneously generates an increase in leisure. And any change in the labour supply-leisure decisions causes two different general equilibrium impacts on welfare. The first is based on the fact that as income tax revenue is directly related to the labour supply, when the labour supply increases (decreases) there is a simultaneous increase (decrease) in taxation revenues. The second impact is explained by the difference between the private cost of leisure (wage net of taxation) and its social cost (pre-tax wage), being the latter higher than the former. As a result of these two general equilibrium channels, when leisure increases there is an associated welfare loss, which is captured by the tax-interaction effect.

By considering the assumption that goods X and Y are equal substitutes for leisure, the tax-interaction effect can alternatively be written as (see the appendix for the details on derivation): [12]

$$dW^I = -(\mu - 1)\left[\gamma_X \frac{dP_X}{d\tau_X} + \gamma_Y \frac{dP_Y}{d\tau_x}\right] - \mu\tau_L\left[\varepsilon_{lm}\gamma_l \frac{d\pi}{d\tau_X}\right] + \mu\tau_L \frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right), \quad (18)$$

where ε_{lm} is the uncompensated after-tax income elasticity of leisure. Also in expression (18), γ_X, γ_Y and γ_l are the shares of consumption goods X and Y and leisure, respectively, in relation to pre-tax household income.

In expression (18), the tax-interaction effect is composed by three different elements. The first one captures the negative influence on welfare of the marginal changes in consumption prices, which are directly related to the consumption share of each good. The second element shows the negative influence of the lower benefits on the tax-

[12] Previous literature has shown that a polluting good being a relative complement to leisure implies a lower welfare cost of environmental tax than a polluting good being a relative substitute for leisure (see, for instance, Parry, 1995). Other studies assume equality in the substitution between consumption goods and leisure de facto, as this property is always accomplished in a homothetic utility function that defines weak separability between leisure and consumption goods (see for instance Bovenberg and de Mooij, 1994a). On the other hand, the neutral assumption of identical substitution between the consumption goods and leisure has also been used in Williams (1999, 2002).

interaction effect when the environmental tax is implemented, which directly depends on the uncompensated elasticity of leisure with respect to after-tax income and the proportion of leisure related to pre-tax household income. In particular, the higher the income elasticity of leisure and the higher the leisure share, the higher the welfare loss will be. Finally, the third element in (18) is the influence of the tax on reducing the production of the polluting good (i.e. increasing environmental quality) and its positive effects on welfare. Note that if environmental quality is assumed not to exert any influence on the consumer's labour-leisure decision, this component would be null, and the positive effect of reducing the environmental externality would not appear in the tax-interaction effect. When the environmental quality is taken into account, expression (18) shows that the negative impact on welfare of τ_X is (at least partially) counterbalanced.

3.2. Second-best optimal emission taxation

In a second-best setting, the neutral tax on good X (τ_X^*) is the level of emission taxation that ensures a null marginal change in welfare while considering the existence of an initial pre-existing tax on income. By setting expression (16) equal to zero, using expression (18) and then solving for τ_X yields:

$$\tau_X^* = \frac{1}{\mu\left(\frac{dX}{d\tau_X}+\frac{dM_X}{d\tau_X}\right)}\left[\tau_P\left(\frac{dX}{d\tau_X}+\frac{dM_X}{d\tau_X}\right) - P_Y\frac{dM_Y}{d\tau_X} + P_X\frac{dM_X}{d\tau_X} - (\mu-1)\left(X+M_X+\tau_L\frac{d\pi}{d\tau_X}\right) + (\mu-1)(\gamma_X\frac{dP_X}{d\tau_X}+\gamma_Y\frac{dP_Y}{d\tau_X}) + \mu\tau_L\varepsilon_{lm}\gamma_l\frac{d\pi}{d\tau_X} - \mu\tau_L\frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X}+\frac{dM_X}{d\tau_X}\right)\right]. \quad (19)$$

On the right-hand side, the first term in the square brackets is the contribution of marginal damages to optimal taxation; the second and third terms represent the trade contributions to the optimal tax level; subsequently there is the (negative) influence of the revenue-recycling effect; the rest of terms in expression (19) capture the influence of the tax-interaction component, comprising specifically the positive effect to τ_X^* due to the changes in final prices and benefits, and the negative effect to optimal tax rate of changes in the demand for leisure.

In the absence of pre-existing tax distortions in the economy, that is $\tau_L = 0$ and $\mu = 1$, the optimal tax level simplifies to:

$$\tau_X^* = \frac{1}{\left(\frac{dX}{d\tau_X}+\frac{dM_X}{d\tau_X}\right)}\left[\tau_P\left(\frac{dX}{d\tau_X}+\frac{dM_X}{d\tau_X}\right) - P_Y\frac{dM_Y}{d\tau_X} + P_X\frac{dM_X}{d\tau_X}\right], \quad (19')$$

that corresponds to the first-best (partial equilibrium) optimal taxation.

The differences between expression (19) and (19') are the (negative) revenue-recycling components and the (positive) tax-interaction components, which disappear in a first world setting. If these two effects together are positive, the second-best neutral tax rate will be higher than the neutral tax in a first-world and the other way round.

3.3. The trade-substitution effect

From the welfare impact of environmental taxation (expression (16)), the trade-substitution effect is defined as:

$$dW^T = P_Y\frac{dM_Y}{d\tau_X} - P_X\frac{dM_X}{d\tau_X}\,. \quad (20)$$

Totally differentiating expression (9) for the balanced trade with respect to τ_X yields:

$$M_Y P'(M_Y)\frac{dM_Y}{d\tau_X} + P(M_Y)\frac{dM_Y}{d\tau_X} - P_X\frac{dM_X}{d\tau_X} - M_X\frac{dP_X}{d\tau_X} = 0, \quad (21)$$

where $P'(M_Y)$ is the marginal change in the world price for the imported good Y. This expression is equivalent to:

$$\frac{dM_Y}{d\tau_X} = \frac{P_X\frac{dM_X}{d\tau_X} + M_X\frac{dP_X}{d\tau_X}}{M_Y P'(M_Y) + P(M_Y)}\,.$$

By substituting this result into expression (20), it follows that:

$$dW^T = \underbrace{P_X}_{EEP} \underbrace{\left[\frac{P_Y \left[1 + \frac{M_X}{P_X} \frac{\frac{dP_X}{d\tau_X}}{\frac{dM_X}{d\tau_X}} \right] - (M_Y P'(M_Y) + P(M_Y))}{M_Y P'(M_Y) + P(M_Y)} \right]}_{RPD} \underbrace{\frac{dM_X}{d\tau_X}}_{MEC}, \quad (22)$$

where the trade-substitution effect has been broken down into three multiplicative elements. The first one is the *effective export price* (EEP), showing the price of exported good. The second element is the *rate price difference* (RPD) of imports, containing the difference between the effective internal price for the imported good, which is equal to the price of imports (P_Y) plus the change in exports in real terms ($\frac{M_X}{P_X} \frac{\frac{dP_X}{d\tau_X}}{\frac{dM_X}{d\tau_X}}$), and the effective world price for imports, which is equal to the world price plus the marginal change in the world price multiplied by imports (or the marginal change in the cost for the imported goods), in relation to (i.e. divided by) the world effective price. Finally, the last element in equation (22) shows the *marginal exports change* (MEC) when the environmental tax is implemented.

Given that the emission tax increases the effective price of exports, the economy loses competitiveness in the external markets and this implies that $MEC = \frac{dM_X}{d\tau_X} < 0$.[13] The rate price difference is expected to be positive if the economy is importing from abroad ($RPD > 0$).[14] Furthermore, the effective (tax-inclusive) export price is a non-negative element ($EEP = P_X > 0$).

[13] This assumption follows the conventional wisdom that increasing the cost of exported goods hinders firms' ability to compete in global markets, which is believed to be linked to a decline in exports (Jaffe *et al.*, 1995).

[14] As the model assumes perfect homogeneity between the domestically-produced good Y and imports from abroad (M_Y), imports are explained by a price difference making goods coming from the external markets more competitive than the internal ones.

Jointly, the three components in expression (22) made a negative contribution to welfare,[15] the magnitude of which depends on the combination of three well-known factors: the effective cost of exports, the imports' price differential and the exports response to τ_X. The higher (lower) the effective export price and the higher (lower) the rate price difference of imports, the higher (lower) the welfare loss for a given marginal change in exports. Alternatively, the higher (lower) the rate price difference of imports and the higher (lower) the marginal change in exports, the higher (lower) welfare loss for a given effective export price.

By adopting the assumption of small economy (i.e. absence of market power in both the imported good Y and the exported good X), the world price would not suffer any change after implementing the (national) environmental tax on X ($P'(M_Y) = 0$), and similarly the economy is price-taker in the exported good ($\frac{dP_X}{d\tau_X} = 0$). In this situation, expression (22) simplifies to:

$$dW^T = \underbrace{P_X}_{EEP} \underbrace{\left[\frac{P_Y - P(M_Y)}{P(M_Y)}\right]}_{RPD} \underbrace{\frac{dM_X}{d\tau_X}}_{MEC}. \qquad (22')$$

Alternatively, from expression (21) it can also be written:

$$\frac{dM_X}{d\tau_X} = \frac{1}{P_X}\left[\left(M_Y P'(M_Y) + P(M_Y)\right)\right]\frac{dM_Y}{d\tau_X} - \frac{M_X}{P_X}\frac{dP_X}{d\tau_X}.$$

Substituting this equation into expression (20) for the trade-substitution effect, it follows that:

$$dW^T = \underbrace{\left[P_Y - \left(M_Y P'(M_Y) + P(M_Y) - \frac{M_X\left(\frac{dP_X}{d\tau_X}\right)}{\frac{dM_Y}{d\tau_X}}\right)\right]}_{IPD} \underbrace{\frac{dM_Y}{d\tau_X}}_{MIC}, \qquad (23)$$

[15] This negative contribution of environmental taxation to welfare reconfirms the results in Larch and Wanner (2017) that empirically showed a detrimental welfare impact of carbon tariffs.

where the trade-substitution effect has been divided into two different components. The first is the *import price difference* (*IPD*) containing the difference, in absolute terms, between the internal price of the imported good and the effective price for imports minus the change in the terms of trade ($\frac{M_X\left(\frac{dP_X}{d\tau_X}\right)}{\frac{dM_Y}{d\tau_X}}$). The second term in expression (23) is the *marginal imports change* (*MIC*) that shows the marginal (negative) impact of the pollution taxation on imports.[16]

If the economy does not exert any influence on the world price for the imported good ($P'(M_Y) = 0$) and is price-taker in the market of the exported good ($\frac{dP_X}{d\tau_X} = 0$), expression (23) simplifies to:

$$dW^T = \underbrace{[P_Y - P(M_Y)]}_{IPD} \underbrace{\frac{dM_Y}{d\tau_X}}_{MIC}. \qquad (23')$$

The trade-substitution effect described above captures the detrimental welfare impact when an environmental tax is applied to the polluting-exported goods. Although this component does not reflect general equilibrium channels, such as the revenue-recycling effect and the tax-interaction effect, this partial equilibrium outcome is consistent with the widespread idea that any policy affecting (i.e. increasing) the price of the exporting industries negatively affects the internal economy and domestic welfare.

4. Autarky situation

To delve into the influence of trade on welfare, next consider the case of a closed economy. This situation implies a reformulation of expression (16) to accommodate the welfare impacts of emission taxes in an autarky situation, as follows:

[16] Note that based on the assumption of balanced trade (expression (9)), any change in exports is linked to a change in imports in the same direction to maintain the trade equilibrium.

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = \underbrace{[\tau_X - \tau_P]\left[\frac{dX}{d\tau_X}\right]}_{dW^P} + \underbrace{(\mu - 1)\left[X + \tau_X\left(\frac{dX}{d\tau_X}\right) + \tau_L\frac{d\pi}{d\tau_X}\right]}_{dW^R} -$$

$$\underbrace{\mu\tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} - \frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X}\right)\right]}_{dW^I}, \qquad (24)$$

where the various transmission mechanisms through which the trade activity alters welfare do not prevail.

By comparing the open economy (expression (24)) and the autarky (expression (16)), the welfare-damaging trade-substitution effect (dW^T)[17] does not appear in the closed model. Moreover, the autarchic situation does not include some general equilibrium channels inherent to export activity. In particular, the positive primary welfare effect due to exports is not present in expression (24). In addition, the revenue-recycling effect has a lower tax-base in autarky, implying a lower welfare contribution than in the open model. Finally, the positive tax-interaction effect of emission taxation on reducing exports and improving environmental quality do not prevail in an autarchic situation. The combination of the (opposite sign) trade transmission mechanisms does not allow to clearly determine and compare which situation is preferable in terms of welfare. Whether emission taxation has a greater, equal, or lower welfare impact in autarky than in an open economy depends on the sign of the following components:

$$[\tau_X - \tau_P]\frac{dM_X}{d\tau_X} + P_Y\frac{dM_Y}{d\tau_X} - P_X\frac{dM_X}{d\tau_X} + (\mu - 1)\left[M_X + \tau_X\left(\frac{dM_X}{d\tau_X}\right)\right] + \mu\tau_L\left[\frac{\partial l}{\partial Q}\left(\frac{dM_X}{d\tau_X}\right)\right] <=> 0, \qquad (25)$$

where a negative, null and positive value of expression (25) implies, respectively, a lower, equal and higher welfare in autarky compared to the open case.

The autarchic second-best optimal emission tax is obtained by setting expression (24) equal to zero, using expression (18), and then solving for τ_X:

[17] See Section 3.3 for details.

$$\tau_X^* = \frac{1}{\mu\left(\frac{dX}{d\tau_X}\right)}\left[\tau_P\left(\frac{dX}{d\tau_X}\right) - (\mu - 1)\left(X + \tau_L \frac{d\pi}{d\tau_X}\right) + \right.$$

$$\left.(\mu - 1)(\gamma_X \frac{dP_X}{d\tau_X} + \gamma_Y \frac{dP_Y}{d\tau_X}) + \mu\tau_L\varepsilon_{lm}\gamma_l \frac{d\pi}{d\tau_X} - \mu\tau_L \frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X}\right)\right]. \qquad (26)$$

The right-hand side contains (square brackets) the contribution of marginal damages to optimal taxation, the (negative) influence of the revenue-recycling effect and the influence of the tax-interaction component, comprising specifically the positive effect to τ_X^* due to the changes in final prices and benefits, and the negative effect to optimal tax rate of changes in the demand for leisure. Notice that the second-best optimal level of taxation in the closed economy will be greater, equal or lower than in the open economy depending on the sign of expression (25).

In the absence of pre-existing tax distortions, that is $\tau_L = 0$ and $\mu = 1$, the optimal tax level simplifies to:

$$\tau_X^* = \frac{1}{\left(\frac{dX}{d\tau_X}\right)}\left[\tau_P\left(\frac{dX}{d\tau_X}\right)\right], \qquad (26')$$

that corresponds to the first-best (partial-equilibrium) optimal taxation in autarky.

5. Conclusions

Environmental taxation affects the competitiveness of a small country without power in the global market. The expected negative impacts on the domestic economy have proven to be a major argument for exporting-oriented countries to reject international climate agreements. As ecological measures increase the effective price of the exported goods, aprioristic views of environmental regulations postulate reductions in exports and negative welfare impacts in open economies.

The model presented in this paper focuses on this issue. In particular, it uses a general equilibrium perspective to analyse the impact of an environmental tax by capturing the interactions with the existing tax system. In contrast to prior literature, the study explicitly defines the links between the domestic economy and the external sector, as well as environmental externalities in the calculation of welfare impacts. It also takes an in-depth look at the repercussions of emission taxes by disentangling various channels of affectation on private welfare.

Environmental regulation in the context of an open economy involves a more complex process of welfare consequences than previous contributions, based on closed economies, have suggested. In particular, the trade welfare impact is explained by the negative influence of taxation on an economy's terms of trade and exports, as has been claimed by some national authorities in international climate forums. However, the paper shows that this is only part of the total effects involved. Indeed, the conventional arguments used to reject ecological agreements have neglected the potential positive influence of environmental taxes on generating tax revenues, and their ability to replace other pre-existing distortionary taxes. Furthermore, the impacts on the labour supply-leisure choice that reinforce the welfare loss have usually not been taken into account when analysing ecological measures applied to exporting economies.

By comparing the open economy model with the equivalent autarky model, it is possible to examine the general equilibrium implications of trade and its contribution to private welfare. In particular, whether emission taxation has higher or lower welfare impacts in a closed economy depends on the relative magnitude of opposite (positive/negative) effects. Although these results are not conclusive, they identify the transmission channels of emission taxes and give insights about the complexity of the underlying factors affecting domestic welfare in open economies. This evidence points out the complicated set of relations behind the welfare impacts caused by pollution regulation in open exporting countries.

The model used extends the scope of the ecological taxation literature, by adding trade welfare effects to the well-known domestic welfare effects. For further inquiry into this issue, however, the substitution possibilities between domestic and foreign goods might largely influence the welfare impacts of environmental taxation. Additionally, a multi-country general equilibrium analysis of the welfare effects able to explicitly capture the interconnections between trade partners would improve the definition of welfare interdependences when environmental measures are multilaterally implemented.

Finally, empirical research on all these questions seems to be crucial to clarify the potentialities of applying environmental measures and facilitate its acceptation for national authorities. All these analyses were beyond the scope of this paper.

Appendix (Derivation of equation (18))

The tax-interaction effect in expression (16) is defined as:

$$dW^I = \mu\tau_L\left[\frac{\partial l}{\partial P_X}\frac{dP_X}{d\tau_X} + \frac{\partial l}{\partial P_Y}\frac{dP_Y}{d\tau_X} + \frac{\partial l}{\partial \pi}\frac{d\pi}{d\tau_X} - \frac{\partial l}{\partial Q}\left(\frac{dX}{d\tau_X} + \frac{dM_X}{d\tau_X}\right)\right]. \quad \text{(A.1)}$$

Using the Slutsky equation, it follows that:

$$\frac{\partial l}{\partial P_X} = \frac{\partial l^c}{\partial P_X} - \frac{\partial l}{\partial m}X, \quad \text{(A.2)}$$

$$\frac{\partial l}{\partial \tau_L} = \frac{\partial l^c}{\partial \tau_L} - \frac{\partial l}{\partial m}(L+\pi), \quad \text{(A.3)}$$

where the superscript c denotes the corresponding compensated demand and m is after-tax household income: $m = (1-\tau_L)(L+\pi)$.

Taking a total derivative of the utility function (1) with respect to τ_L, maintaining the levels of utility and environmental quality constant, and subsequently substituting the consumer's first-order conditions yields:

$$\frac{\partial l^c}{\partial \tau_L} = -\frac{\partial l^c}{\partial(1-\tau_L)} = \frac{\partial X^c}{\partial(1-\tau_L)}\frac{P_X}{(1-\tau_L)} + \frac{\partial Y^c}{\partial(1-\tau_L)}\frac{P_Y}{(1-\tau_L)}. \quad \text{(A.4)}$$

Using the Slutsky symmetry property:

$$\frac{\partial l^c}{\partial P_X} = \frac{\partial X^c}{\partial(1-\tau_L)} \ , \tag{A.5}$$

$$\frac{\partial l^c}{\partial P_Y} = \frac{\partial Y^c}{\partial(1-\tau_L)} \ . \tag{A.6}$$

The neutral assumption that consumption goods are equal substitutes for leisure implies that:

$$\frac{\partial X^c}{\partial(1-\tau_L)} \frac{(1-\tau_L)}{X} = \frac{\partial Y^c}{\partial(1-\tau_L)} \frac{(1-\tau_L)}{Y}. \tag{A.7}$$

Substituting equations (A.3), (A.4), (A.5), (A.6) and (A.7) into (A.2) and arranging terms gives:

$$\frac{\partial l}{\partial P_X} = \frac{\partial l}{\partial \tau_L} \frac{X}{L+\pi}. \tag{A.8}$$

And following a similar procedure for good Y:

$$\frac{\partial l}{\partial P_Y} = \frac{\partial l}{\partial \tau_L} \frac{Y}{L+\pi} \tag{A.9}$$

Bearing in mind that π represents pre-tax profits and m is after-tax income, it follows that:

$$\frac{\partial l}{\partial \pi} = (1-\tau_L) \frac{\partial l}{\partial m}.$$

And this expression can be transformed as follows:

$$\frac{\partial l}{\partial \pi} = (1-\tau_L) \frac{\partial l}{\partial m} \left(\frac{(1-\tau_L)(L+\pi)}{l} \right) \left(\frac{l}{(1-\tau_L)\,(L+\pi)} \right) = \varepsilon_{lm} \gamma_l. \tag{A.10}$$

Finally, substituting expressions (A.8), (A.9) and (A.10) into (A.1), using expression (17) that defines the marginal cost of public funds and grouping terms yields equation (18).

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