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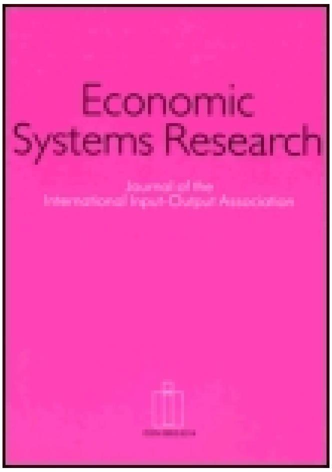

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SUPPLY-USE FRAMEWORK FOR INTERNATIONAL ENVIRONMENTAL POLICY ANALYSIS

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The technical variation between countries in the production of goods and services, in terms of not only input coefficients, but also emission coefficients, creates scope for international trade to reduce environmental pressures. For this purpose we extend the theory of trade and the environment as to accommodate technical variation between countries in production and emissions. We use and steer close to the extended input and output tables, which include emission data. By treating environmental standards analogous to capital and labor capacity constraints, the aggregation problem for economic and environmental measures gets the same format as the well-understood aggregation problem for labor and capital. In a pilot application we determine the gains to free trade in products and emission permits.

Keywords: Environmental input–output accounts; Environmental policy; Multi-economy systems; International trade

JEL Classification: Q56; Q51; F18; D57; D58

1. INTRODUCTION

Climate change presses for environmental policy analysis (IPCC, 2001). The recent economic literature stresses the importance of technical change for curbing emissions, and proposes policies that can achieve it (Nordhaus, 2007; Stern 2007; Acemoglu et al., 2012). Technical change (such as energy intensity reductions) takes place primarily in production, but also in consumption. While technical change that will facilitate massive implementation of clean technologies (such as electric cars) is still ‘on the way’, reallocation of production can alleviate environmental pressure in the short and middle run. Policy assessment studies confirm that environmental policies are more successful if incentives to innovate are combined with incentives to reallocate (e.g. the policy analysis for the energy sector by Fischer and Newell, 2008). Efficient allocation of production activities may aid the realization of international environmental policy targets, such as stipulated in the Kyoto Protocol (United Nations, 1997) and the EU climate and energy package (2009).[1]

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[1] An anonymous referee observed that by promoting minimal adverse effects on international trade and impacts on the rest of the world the Kyoto Protocol potentially bars efficient allocations. (S)he finds this no issue with our paper. Indeed, we show how member states can redirect mutual trade to reduce emissions, without changing net trade with the rest of the world. Among other targets, the EU package specifies a reduction target on greenhouse emissions of 20%. For more information, see: http://ec.europa.eu/clima/policies/package/index_en.htm.

To enhance environmental policy research, large efforts have been undertaken to create environmentally extended input–output accounts, facilitating policy analyses at international and interregional levels. This paper contributes a model for a direct, economic analysis of the environmentally extended tables. We integrate the complementarity approach to equilibrium (Ferris and Pang, 1997) and the input–output framework for economic and environmental accounts (Leontief, 1970), this results in a simple general equilibrium model, ready-to-use for practitioners. Unlike the existing multi-country general equilibrium analyses of environmental policy evaluations, such as GEM-E3 for the EU (Capros et al., 1999; Proost and Van Regemorter, 2004), our model directly extends input–output accounts of production and emissions, without the need to introduce proxies of the latter based on energy consumption. We intend to find an environmentally beneficial allocation of trade flows under different policy scenarios.

The simultaneous determination of economic and environmental comparative advantages requires a general equilibrium analysis that combines resource and environmental constraints with production and pollution coefficients and final demand patterns. The complementarity problem, a mathematical tool to solve big general equilibrium models (Ferris and Pang, 1997), is particularly useful for modern supply-use frameworks, where the number of techniques may be different than the number of products, contrary to classical input–output analysis. The complementarity problem will select the techniques. The availability of extended input and output tables, including emission data, makes it possible to fully integrate regulatory environmental constraints into the model in the same vein as the constraints on the traditional primary inputs, capital and labour. By treating environmental standards analogous to capital and labor capacity constraints, the aggregation problem for economic and environmental measures gets the same format as the well-understood aggregation problem for labor and capital in the theory of international trade. For example, when environmental constraints are tightened, new techniques may be selected. The tighter constraints will increase the cost of pollution (either by taxes or by higher prices for emission rights, depending on the institutional framework) and render new clean technologies profitable.

A subtle but important methodological issue remains. In our view, the economy is not necessarily in equilibrium. In fact, the gap between an observed allocation and the equilibrium is informative of its inefficiency. The advantage of equilibrium analysis is that by the endogeneity of prices and quantities it facilitates valuation of the trade-off between narrowly defined economic performance (GDP) and environmental scores. Our results measure the relationship between environmental measures and equilibrium performance. The benchmark equilibrium corresponds to but is not identical with the observed allocation, as allocative inefficiencies are removed. Strictly speaking our results on the connection between environmental policies and economic performance may be used as predictions of actual outcomes only if the allocative inefficiency remains the same. A full disequilibrium analysis would not have this limitation, but be sensitive to the model specification.

In Section 2 we review the relating literature and explain our contribution in more detail. In Section 3, we specify the supply-use framework, associate the general equilibrium model, and relate the specification to the linear programming approach. In Section 4 we explain how to account environmental policies, opening the road to environmental policy analysis. We offer an illustration of this method for an Institute for Prospective Technological Studies (IPTS) data set in Section 5. The last section concludes.

2. LITERATURE REVIEW AND CONTRIBUTION

To enhance environmental policy research at the European level, large efforts have been undertaken to create the environmentally extended input–output (EE-I–O) accounts for Europe (IPTS, 2006).[2] Eurostat (2011) has launched several projects to combine individual country supply and use tables (SUTs), extend them with emission data, and to create consolidated EU27 tables. The EXIOPOL[3] – project founded by the European Commission has integrated research efforts of institutions from different member states to set up a detailed EE-I–O data base, EXIOBASE (Tukker et al., 2009; 2013). This new data base will facilitate the estimation of environmental impacts and of external costs of different industries, final consumption activities and resource consumption for countries in the EU. On top of this the harmonized world input–output database has been created, including links to detailed socio-economic and environmental satellite accounts (Dietzenbacher et al., 2013). These new databases will facilitate not only national applications, such as multiplier analysis of demand-pull effects and the assignment of emissions to production and consumption activities, but also international analyses, e.g. of environmental footprints.

Introducing the special ESR issue on carbon footprinting, Wiedmann (2009a, p. 176) stresses that ‘input–output analysis can contribute substantially if not decisively, to the practice of carbon footprinting at all levels’. Minx et al. (2009) present examples of multi-region input–output (MRIO) applications in different areas. Input–output analysis can be used for the screening of sectoral and corporate carbon footprints (Huang et al., 2009) as well as for the accounting for greenhouse gas emissions from a consumption perspective. Wiedmann (2009b) reviews recent MRIO models for consumption-based emission and resource accounting, providing examples of such analyses. Employing a fully coupled MRIO model for consumption-based accounting of CO_2 emissions, Davis and Caldeira (2010) show that, in 2004, 23% of global CO_2 emissions were traded internationally, primarily as exports from emerging markets to consumers of developed economies. Wilting and Vringer (2009) compare the outcomes of consumption-based and production-based approaches, going into their policy applications in environmental policies. Considering evidence from the UK on how policy evolved around consumption-based accounting, Wiedmann and Barrett (2013) conclude that environmentally extended MRIO models are capable of generating specific policy relevant information. Our paper adds to this literature by illustrating how the model could be used to gain insight in the allocation of competitive and environmental pressure under different policy scenarios.

Two recent papers should also be mentioned. Turner et al. (2012) find that the analysis of policy effects on economic and environmental trade balances requires a more flexible non-input–output model and introduce a degree of substitutability in the production and consumption functions. However, we show, perhaps surprisingly, that the input–output model does feature substitutability, through interregional reallocations and flexible general equilibrium prices. Douglas and Nishioka (2012) take into account the diversity in input

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[2] The Institute for Prospective Technological Studies, Seville, Spain is one of the eight Research Institutes of the European Commission.

[3] The abbreviation EXIOPOL refers to ‘a new environmental accounting framework using externality data and input–output tools for policy analysis’. It encompasses the IPTS accounts.

and emission coefficients to explain trade and the distribution of emissions, and find that differences in emissions intensity do not play a significant factor in determining patterns of trade. In our view the reason is that the emissions are not priced. We show how this can be done and would impact the pattern of trade.

The originality and usefulness of our model is that it shows how equilibrium allocations and prices (including of emissions) can be determined using the input and output data only, without augmenting specific–hence sensitive–computable general equilibrium model features. This distinction is similar to that of classical models vis-a-vis neoclassical models. Classical economics assumes constant returns to scale and is capable to explain the production structure and the distribution between factors on the basis of the supply side. If returns to scale vary, demand determines the local input coefficients and distribution; neoclassical economics shows the simultaneous determination of the allocation and prices. Since the models of international trade and pollution feature constant returns to scale, it is a challenge to analyze the issues with classical means, using only the input–output structure, and this paper accomplishes it.

We present a direct, economic analysis of the environmentally extended tables. We integrate the complementarity approach to equilibrium Ferris and Pang (1997) and the input–output framework for economic and environmental accounts Leontief (1970), this results in a simple general equilibrium model, ready-to-use for practitioners. Unlike the existing multi-country general equilibrium analyses of environmental policy evaluations, such as GEM-E3 for the EU (Capros et al., 1999; Proost and Van Regemorter, 2004), our model directly extends input–output accounts of production and emissions, without the need to introduce proxies of the latter based on energy consumption. We intend to find an environmentally beneficial allocation of trade flows under different policy scenarios. This aim is close to Duchin (2005), but her concept of comparative advantage is flawed by price dependency. A baseline is assumed for the factor prices, which is subsequently augmented with shortage premiums. The location of comparative advantages and the total factor commodity prices depend on the exogenous baseline and, therefore, are not determined by differences in resource abundance or technology.

The technical variation between countries in the production of goods and services, in terms of not only input coefficients, but also emission coefficients, creates scope for international trade to reduce environmental pressures. Copeland and Taylor (2005) have developed a neoclassical model to assess the environmental effects of trade, particularly on the developing world. In their view the developed world has a comparative advantage in capital intensive production–which is more polluting–but stricter environmental regulations drive pollution to havens in the developing world. Promoting free trade strengthens the first force and, therefore, is in the interest of the environment, particularly in the developing world. However, this argument hinges on the Heckscher–Ohlin hypothesis that factor abundance drives trade, assuming that all countries have access to state-of-the-art technology. It breaks down when developed economies have superior technology, particularly in terms of emissions.

Related, this neoclassical model is too stringent for empirical estimation. Copeland and Taylor (2005) make a short-cut by regressing emissions on capital–labor ratios and trade and confirm their theory that trade is good to the environment, but others arrive at opposite conclusions. Peters et al. (2011) find that between 1990 and 2008 the net emission transfers via international trade from developing to developed countries more than offset the Kyoto Protocol emission reductions and suggest that the effect of trade was detrimental. However, their result does not preclude that less trade would yield higher emissions.

For a proper analysis of the role of technology in trade and environmental policy the composition of trade is at least as important as the volume of trade. By mapping comparative advantages in production and emissions, environmental reallocation policy can be designed to reduce global pollution (Copeland and Taylor, 2005). This challenge is taken up now using the supply-use accounting framework and showing how pollution regulations can be allocated efficiently. A pilot application to three countries demonstrates the feasibility of our methodology.

Recently input–output and general equilibrium analyses have moved closer. Shestalova (2001), ten Raa and Mohnen (2001, 2002), ten Raa and Pan (2005) and ten Raa and Shestalova (2011) analyzed trade flows with a linear program that maximizes the levels of domestic final demands. This paper closes the gap entirely by constructing the supply and demand functions which are implicit in the input and output tables of economies and determining the equilibrium prices that match supply and demand. We provide an economic theoretic foundation to the linear programming approach by showing its equivalence with the equilibrium analysis. We also demonstrate that the complementarity problem approach to supply-use accounts facilitates environmental analysis of large international economic systems.

3. BASE MODEL

3.1. Input–Output Accounts

Building bricks of the national accounts of an economy (we use this terminology even when an economy is a region) are the SUTs, **V** and **U**, respectively. The columns of these tables display the respective outputs and inputs of the industries. Industries may produce varieties of products, and the varieties may overlap, as is the case in national accounts. The dimension of a supply or use table is product by industry, where 'industry' stands for activity. In a micro framework it would be a reporting accounting unit, say a firm, while in a macro framework it would be an aggregate of firms. Aggregation involves loss of information and is possible but not necessary to run our model.[4] Moreover, new technologies can be analyzed in the activity framework by augmenting columns. Running a model at a more disaggregated level (capturing technology differences between firms) would bring scope for pollution reductions within national industries in addition to the opportunities due to international trade. Since we ignore these domestic reallocations, our analysis is conservative.

The dimensions may vary across economies. This is best appreciated in the context of micro data, where 'industries' are firms. Some economies have more firms than others and the product dimensions may differ as well, but tradable commodities have the same dimension across economies, even when they are not produced in some economies, such as wine. Interregional balances are expressed in product units of tradable commodities and there is no need to harmonize industry classifications (ten Raa, 1995). If, however, the industry classifications are uniform and match the commodity classification, then one can postmultiply the SUTs by the inverse supply table and use gross outputs instead of activity

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[4] Although the theory does not require aggregation, it may still be handy to do it in practical applications, as otherwise the dimension of the model becomes very large.

levels as the allocation variable. In this case the supply use framework is equivalent to the (commodity) technology-based input–output model.

Subtraction of use from supply defines the net output table of an economy: $\mathbf{V}-\mathbf{U}$. Summation of net output across industries, which is achieved by post-multiplication of $\mathbf{V}-\mathbf{U}$ with the unit vector $\mathbf{e}$ (of which all entries are equal to 1), defines final demand. This vector depicts the national product by product. Summing across products, which is achieved by pre-multiplication with the unit row vector, defines value-added, at least if the data are in current values. This row vector depicts the national income by industry. Since the sum of row totals equals the sum of column totals, we hereby confirm the macro-economic identity between national product and national income.

3.2. Supply Functions

The use and make tables, augmented with the factor input tables, describe the production technology and allow us to define the supply function for each industry. The first industry (corresponding to the first column of the SUTs) produces outputs, $\mathbf{v}_{\cdot 1}$, from intermediate inputs, $\mathbf{u}_{\cdot 1}$, and factor inputs, capital and labor, K_1 and L_1, respectively. Assuming constant returns to scale, it is also possible to produce output $\mathbf{v}_{\cdot 1}s_1$ from the inputs $\mathbf{u}_{\cdot 1}s_1$, K_1s_1 and L_1s_1, where $s_1 \geq 0$ represents the activity level. For example, if $s_1 = 1.1$, activity 1 is operated at a 10% higher level than observed. Assuming free disposal, it is possible to produce less output with more input. The assumption of constant returns to scale is typical in neoclassical growth accounting. Firms do not meet this assumption, but in competitive economies they must operate at minimum average cost and the industry output varies the number of firms. This mechanism of entry and exit yields constant returns to scale at the level of the industry. Burnside (1996) and Basu and Fernald (1997) estimated the returns to scale for the US manufacturing industries and conclude that the most robust evidence suggests the typical industry displays constant returns.

We now set up the supply function of industry 1. Denote the product prices by row vector $\mathbf{p}$, the rental rate of capital in this industry by r_1, and the economy-wide wage rate by w. We assume that capital is immobile but labor is mobile between industries.[5] Value-added equals $\mathbf{p}(\mathbf{v}_{\cdot 1}-\mathbf{u}_{\cdot 1})s_1$, factor costs are $(r_1K_1+wL_1)s_1$, and the difference is profit. If the prices are such that value-added exceeds factor costs, the profit maximizing activity level would be infinite. If value-added equals factor costs, the profit maximizing activity level would be any. If value-added is less than factor costs, the profit maximizing activity level would be zero. The assumption of profit maximization is typical in economic models and reasonable in a static setting adopted here.[6] This completes the verbal description of the supply function and we will now spell it out.

The first case (where value-added exceeds factor costs and an infinite activity level is most profitable) is inconsistent with equilibrium on the factor markets (where supply is finite) and can be ruled out. Hence, $\mathbf{p}(\mathbf{v}_{\cdot 1}-\mathbf{u}_{\cdot 1}) \leq r_1K_1+wL_1$. The second and third cases can be summarized by the condition that $\mathbf{p}(\mathbf{v}_{\cdot 1}-\mathbf{u}_{\cdot 1}) < r_1K_1+wL_1$ implies $s_1 = 0$. All

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[5] In other words, we assume capital is industry specific (machines and equipment installed for the production of given commodities). We also assume that neither capital nor labor moves between countries, a classical assumption in international trade, which is reasonable in the short run.

[6] However, in a dynamic setting, it may not necessarily hold in each period.

this can be consolidated by the following condition:

$$s_1 \geq 0, r_1K_1 + wL_1 - \mathbf{p}(\mathbf{v}_{\cdot 1} - \mathbf{u}_{\cdot 1}) \geq 0, [rK_1 + wL_1 - \mathbf{p}(\mathbf{v}_{\cdot 1} - \mathbf{u}_{\cdot 1})]s_1 = 0. \tag{1}$$

According to this condition, profits are nonpositive, and if they are negative, the activity level will be zero. This, indeed, describes what profit maximizing producers would undertake. They avoid activities which would incur losses.

Condition 1 states that there is *complementarity* between activity level s_1 and the value of the *loss function* $r_1K_1 + wL_1 - p(\mathbf{v}_{\cdot 1} - \mathbf{u}_{\cdot 1})$, meaning that if one of the inequalities in 1 has slack (the entity is positive) the other has no slack (the entity is zero). We have the same for the other industries: $[r_2K_2 + wL_2 - \mathbf{p}(\mathbf{v}_{\cdot 2} - \mathbf{u}_{\cdot 2})]s_2 = 0$, and so on. By nonnegativity of the constituent factors, all these products are zero if and only if their sum is zero: $[r_1K_1 + wL_1 - \mathbf{p}(\mathbf{v}_{\cdot 1} - \mathbf{u}_{\cdot 1})]s_1 + [r_2K_2 + wL_2 - p(\mathbf{v}_{\cdot 2} - \mathbf{u}_{\cdot 2})]s_2 + \cdots = 0$, or, using matrix notation (row vector $\mathbf{r}$, diagonal matrix $\mathbf{K}$, row vector $\mathbf{L}$ and column vector $\mathbf{s}$), $[\mathbf{rK} + w\mathbf{L} - \mathbf{p}(\mathbf{V} - \mathbf{U})]\mathbf{s} = 0$. This equality means that vectors $\mathbf{rK} + w\mathbf{L} - \mathbf{p}(\mathbf{V} - \mathbf{U})$ and s are *orthogonal*; this condition is denoted by $\mathbf{s} \perp [\mathbf{rK} + w\mathbf{L} - \mathbf{p}(\mathbf{V} - \mathbf{U})]$. Summarizing, the extension of supply condition 1 to all industries of the economy can succinctly be written as the following complementarity condition:

$$\mathbf{0} \leq \mathbf{s} \perp (\mathbf{rK} + w\mathbf{L} + \mathbf{pU} - \mathbf{pV}) \geq \mathbf{0}. \tag{2}$$

This expression is shorthand for three equations, nonnegativity of activities, nonpositivity of profits, and their mutual orthogonality. A consequence of the orthogonality is the national income identity:

$$\mathbf{p}(\mathbf{V} - \mathbf{U})\mathbf{s} = (\mathbf{rK} + w\mathbf{L})\mathbf{s} \tag{3}$$

3.3. Demand Functions

The supply functions of the industries take care not only of the products supplied, but also of intermediate demand. Industry 1 demands product quantities listed in vector $\mathbf{u}_{\cdot 1}s_1$ and likewise for the other industries. What remains is final demand. This consists of domestic final demand (private and public consumption and investment) and net exports (exports minus imports). Let us first look at the SUTs. Observed net output equals $(\mathbf{V} - \mathbf{U})\mathbf{e}$, where $\mathbf{e}$ is the unit vector. It comprises domestic final demand, vector $\mathbf{f}$, plus net exports, the residual $(\mathbf{V} - \mathbf{U})\mathbf{e} \ - \mathbf{f}$. Throughout this paper we treat trade as the residual between net output and domestic final demand, eliminating trade variables using the material balances of the economies.

How are consumption and trade reformulated for arbitrary prices, $\mathbf{p}$, $\mathbf{r}$ and w? We assume that domestic final demand can be represented by Leontief preferences. This conservative approach steers demand close to what is observed. Moreover, ten Raa (2008) provides a theoretical underpinning by showing that absent consumers demand information (taking intersections over all possible household preferences) this representation delineates the set of preferred consumption bundles, hence demand. It follows that domestic final demand is determined by the maximization of expansion factor c in vector $\mathbf{f}c$. It is constrained by the budget.

International trade theory assumes balance of payments between imports and exports. Then the budget for domestic final demand is equal to national income. In equilibrium analysis the budget is determined by the income derived from the available resources, $\kappa\mathbf{Ke}$ and $\lambda\mathbf{Le}$, where factors $\boldsymbol{\kappa}$ (a diagonal matrix) and λ include idle capital and labor; for example, if the capital utilization rate is 82% in industry 1, then $\kappa_1 = \frac{1}{.82} = 1.22$. Indeed, consumers decide on the basis of prices, not the producers actions, **s**, and their demands, **Ks** and **Ls** for final inputs. However, in reality countries run a trade deficit or surplus, allowing them to consume more or less. We preserve this imbalance – which can be rationalized in a dynamic setting with intertemporal capital markets – by assuming that any net imports vector with the same value as the observed net imports vector is in the budget. Hence the budget is $(\mathbf{r}\kappa\mathbf{K} + w\lambda\mathbf{L})\mathbf{e} + \mathbf{p}[\mathbf{f} - (\mathbf{V} - \mathbf{U})\mathbf{e}]$, where $\mathbf{f} - (\mathbf{V} - \mathbf{U})\mathbf{e}$ is the observed net import vector and its value is the allowed debt, to cofund domestic consumption. Equating consumption expenditure to the budget, we obtain that the level of consumption is determined by the equation $\mathbf{pf}c = (\mathbf{r}\kappa\mathbf{K} + w\lambda\mathbf{L})\mathbf{e} + \mathbf{p}[\mathbf{f} - (\mathbf{V} - \mathbf{U})\mathbf{e}]$. This is the *expenditure–income identity*.

To treat demand symmetrically with supply, we replace the expenditure–income identity by a complementarity condition:

$$0 \leq c \perp \mathbf{pf}c - (\mathbf{r}\kappa\boldsymbol{K} + w\lambda\mathbf{L})\mathbf{e} - \mathbf{p}[\mathbf{f} - (\mathbf{V} - \mathbf{U})\mathbf{e}] \geq 0 \tag{4}$$

In expression 4 expenditure $\mathbf{pf}c$ may seem to exceed income, but then the complementarity condition pushes c back to zero. As industries transform factor and produced inputs into products and condition 2 shows complementarity between their activity levels and the loss function (the difference between the values of the inputs and the outputs), the domestic final demand sectors transform a consumption bundle (the input) into factor services (the output). The loss function is the difference between the value of the input (expenditure) and the output (income). The expenditure–income identity is thus cast in the complementarity framework, which will admit easy solution. Another advantage is that expression 4 accommodates the situation where the budget for consumption is negative because of an overwhelming obligation to export (the value of the net exports exceed factor income). Direct application of the expenditure–income identity would produce a negative value for consumption, which is impossible, while the complementarity condition correctly equates it to zero.[7] Although this analysis rules out consumption substitutabilities, it does not require a representative consumer. As ten Raa (2008) has shown, this model is the reduced form of an economy with many consumers who have Leontief preferences (possibly idiosyncratic) and it provides a lower efficiency bound for more general economies. This completes the representation of the supply and demand functions.

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[7] This kind of situation can be observed only if the observed prices are extremely distorted–deviating from the cost structure like condition 2 – and some economy not only subsidizes other economies in real terms (exporting big quantities), but also nominally (charging too low prices, not covering production costs), a practice not observed in competitive economies. Incidentally, the accommodation of a negative budget is a two-way street in the sense that there is deviation from the expenditure–income identity if *and only* if income is negative. The proof of this statement is simple. If there is deviation, then the loss function in condition 4 is positive and, by condition 4, consumption c is zero. Hence expenditure $\mathbf{pf}c$ is zero, and it is the remaining part of the loss function that is positive: $-(\mathbf{r}\kappa\mathbf{K} + w\lambda\mathbf{L})\mathbf{e} - \mathbf{p}[\mathbf{f} - (\mathbf{V} - \mathbf{U})\mathbf{e}] > 0$. Multiplying through by -1 we conclude that income must be negative. Positive income will be fully spent, reflecting monotonicity of the preferences.

3.4. Equilibrium Prices

The next step is to equate supply with demand by choice of the prices. Prices are determined by interregional markets. We must index the economies.[8] The data of an economy are its use and supply tables, the factor employment row vectors and utilization rates, and its domestic final demand vector. Formally, an *economy* i is the septuple $(\mathbf{K}^i, \boldsymbol{\kappa}^i, \mathbf{L}^i, \lambda^i, \mathbf{U}^i, \mathbf{V}^i, \mathbf{f}^i)$ of capital and labor employment vectors and utilization rates, use and supply tables, and domestic final demand vector. These data are nonnegative and the capacity factors (the inverse capacity utilization rates given by the second and fourth components) are greater than or equal to one. For each economy the capital or labor employment vector is positive and domestic final demand is nonzero. The first component of an economy is a diagonal matrix (dimension the number of industries in economy i), the second a scalar, the third a row vector (dimension the number of industries in economy i, but can be generalized to a matrix when there are different types of labor, as in ten Raa and Pan, 2005), the fourth a scalar, the fifth and the sixth are product by industry tables and the seventh is a product vector. Unlike for industries, we impose the same number of products on each economy, by admitting zero rows across the use and make tables and domestic final demand of an economy. The corresponding product will remain absent from such an economy.

First we model the factor markets. The equilibrium rates of return on capital equate demand, $\mathbf{K}^i\mathbf{s}^i$, with supply, $\boldsymbol{\kappa}^i\mathbf{K}^i\mathbf{e}$. The latter is assumed to be inelastic.[9] Hence the capital market is represented by the complementarity condition that supply covers demand and excess supply means the price is zero:

$$\mathbf{0} \leq \mathbf{r}^i \perp \mathbf{K}^i(\boldsymbol{\kappa}^i\mathbf{e} - \mathbf{s}^i) \geq \mathbf{0}. \tag{5}$$

The labor market of an economy is modeled in the same vein. Analogous to condition 5 we have the following condition 6:

$$0 \leq w^i \perp \mathbf{L}^i(\lambda^i\mathbf{e} - \mathbf{s}^i) \geq 0. \tag{6}$$

Equations 5 and 6 treat capital and labor as being immobile between economies. This condition can be altered as well. We will do so explicitly for the environmental stock constraints, which will be modeled analogous to that of capital and labor.

Turn to the tradable products markets. We need no bilateral trade information. For each economy net exports are the difference between net output and domestic final demand, $(\mathbf{V}^i - \mathbf{U}^i)\mathbf{s}^i - \mathbf{f}^i c_i$. If all economies are encompassed, as in world models, the net export vectors sum to zero. Otherwise there is a rest of the world, and we preserve the aggregate net exports to the rest of the world, allowing for free trade between the economies considered. To compute equilibrium, we need *no* information on the distribution of exports and imports of economy i between intra-regional trade (i.e. to or from the other economies considered) and trade with the rest of the world (i.e. with the economies not considered). Equilibrium product prices equate aggregate net exports to zero (for a world model) or to the observed aggregate net exports to the rest of the world (for multiregional models which do not cover the entire world). Aggregate net exports, $\sum[(\mathbf{V}^i - \mathbf{U}^i)\mathbf{s}^i - \mathbf{f}^i c_i]$, may exceed zero or the

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[8] Strictly speaking we should have done it at the outset, but the analysis thus far holds for any of the economies and it would have been superfluous to carry the index i of a typical economy.

[9] It would require an intertemporal model to analyze its response to prices through the process of investment.

observed aggregate net exports to the rest of the world, $\sum[(\mathbf{V}^i - \mathbf{U}^i)\mathbf{e} - \mathbf{f}^i]$), but products for which there is such excess supply must be free (carry a zero price). This is written succinctly by the following complementarity condition:

$$\mathbf{0} \leq \mathbf{p} \perp \sum[(\mathbf{V}^i - \mathbf{U}^i)(\mathbf{s}^i - \mathbf{e}) - \mathbf{f}^i(c_i - 1)] \geq 0 \tag{7}$$

The pair of nonnegativity inequalities in condition 7 implies that each term in the inner product of the price row vector and the excess supply vector is zero. Hence each product in excess supply is free.

It is easy to accommodate nontradable products in the model. Such products are treated as being differentiated by economy and their material balances are not pooled across economies. For example, if product 1 is nontradable, then $[(\mathbf{V}^i - \mathbf{U}^i)\mathbf{e} - \mathbf{f}^i]_1 = 0$ and the first component of the complementarity condition 7, $p_1 \perp \sum[(\mathbf{V}^i - \mathbf{U}^i)(\mathbf{s}^i - \mathbf{e}) - \mathbf{f}^i(c_i - 1)]_1$, is replaced by $0 \leq p_1^i \perp [(\mathbf{V}^i - \mathbf{U}^i)\mathbf{s}^i - \mathbf{f}^i c_i]_1 \geq 0$, for all i.

In our general equilibrium analysis all prices are endogenous, in fact the shadow prices associated with the supply–demand inequalities. Tariffs can be modeled similarly as the shadow prices of restrictions to free trade, but we focus on the interplay between trade and the environment rather than political–economy protections.

3.5. The Connection with Linear Programming

In the linear programming approach the levels of final demand, c_i, are maximized subject to mutual proportions, $c_i = \gamma_i c_1$ (with $\gamma_1 = 1$). For each set of weights (γ_i) the linear program maximizes c_1 subject to the material and factor balances, which are the right-hand side constraints in 5–7. The first order conditions of this linear program is condition 2 plus a price normalization constraint. The weights are adjusted as to meet the balance of payment constraints, which are given by the expenditure–income constraints or complementarity condition 4. It follows that a solution of the adjustment process of linear programs fulfills the equations of the present equilibrium model. Conversely a solution to the equilibrium model fulfills the material, factor and balance of payment constraints of the limit linear program.

To establish full equivalence it remains to show that a solution to the equilibrium model maximizes the levels of final demand. This is done by adaptation of Debreu's (1951) proof of the first welfare theorem, who argues that demand is such that superior commodity bundles must be more expensive and that the latter property implies the violation of some material feasibility constraint. Suppose greater levels of consumption c_i' than the equilibrium levels would be possible. Then for each economy, by Equation 4, $\mathbf{p}\mathbf{f}^i c_i' - (\mathbf{r}^i \boldsymbol{\kappa}^i \mathbf{K}^i + w^i \lambda^i \mathbf{L}^i)\mathbf{e} - \mathbf{p}[\,\mathbf{f}^i - (\mathbf{V}^i - \mathbf{U}^i)\mathbf{e}] > 0$, provided that $\mathbf{p}\mathbf{f}^i > 0$, for which a reasonable, sufficient condition is $\mathbf{f}^i > 0$ (meaning that every component is positive). Summing these inequalities over economies and substituting condition 7 for the leading term, $\sum \mathbf{p}\mathbf{f}^i c_i'$, $\sum\{\mathbf{p}[(\mathbf{V}^i - \mathbf{U}^i)(\mathbf{s}^i - \mathbf{e}) + \mathbf{f}^i] - (\mathbf{r}^i \boldsymbol{\kappa}^i \mathbf{K}^i + w^i \lambda^i \mathbf{L}^i)\mathbf{e} - \mathbf{p}[\mathbf{f}^i - (\mathbf{V}^i - \mathbf{U}^i)\mathbf{e}]\} = \sum[\mathbf{p}(\mathbf{V}^i - \mathbf{U}^i)\mathbf{s}^i - (\mathbf{r}^i \boldsymbol{\kappa}^i \mathbf{K}^i + w^i \lambda^i \mathbf{L}^i)\mathbf{e}] > 0$. Substituting the macro identities 3, one for each economy, $\sum(\mathbf{r}^i \boldsymbol{\kappa}^i \mathbf{K}^i + w^i \lambda^i \mathbf{L}^i)(\mathbf{s}^i - \mathbf{e}) > 0$. Hence some $\mathbf{K}^i(\mathbf{s}^i - \mathbf{e})$ or $L^i(\mathbf{s}^i - \mathbf{e})$ must be positive, in violation of the factor balances of the linear program, which are the right-hand side constraints in Equations 5 and 6.

4. EXTENSION TO ENVIRONMENTAL POLICIES

4.1. Environmental Policy Restrictions

The simplest way to incorporate environmental constraints in equilibrium analysis is to treat the environment, or at least the part that may be damaged, as a resource, just like capital or labor. In addition to a capital employment matrix and a labor employment row vector, $\mathbf{K}^i$ and $\mathbf{L}^i$, respectively, we have an environment employment vector $\mathbf{M}^i$, which records the damage to the environment by industry.

Typically the elements are emissions. The total emission in economy i is $\mathbf{M}^i\mathbf{e}$. Different types of environmental damages can be extended by extending $\mathbf{M}^i$ to a matrix. Invoking the assumption of constant returns to scale, an increase in each industry's activity results in a proportional increase of both the output and the emissions produced by the industry.

Environmental policies can be modeled by means of alternative constraints on emissions. Therefore, emissions enter our model both as a (negative) output produced together with the industrial output and as an endowment factor constrained by environmental policy. If the damage to the environment may not exceed a fraction μ^i of the observed level in economy i (a vector in case of different types of damages), the constraints are given by the second inequalities in conditions 8, one for each economy.

$$0 \leq t^i \perp \mathbf{M}^i(\mu^i\mathbf{e} - \mathbf{s}^i) \geq 0. \tag{8}$$

The prices t^i in conditions 8 are analogous to the prices of labor and capital and thus measure the marginal economic value of relaxing the environmental constraint. If it is high in say economy 1 and low in say economy 2, then the marginal benefit of allowing one more unit of pollution in economy 1 would be greater than the marginal cost of restricting pollution by one unit in economy 2. In other words, it would be beneficial to shift pollution from the economy with a low environmental price (economy 2) to the economy with a high environmental price. An international market for emission rights would bring about such a reallocation. Speculators would buy emission rights where they are inexpensive and resell them where they are expensive. Formally this amounts to a replacement of the national environmental conditions 8, by the international condition:

$$0 \leq t \perp \sum \mathbf{M}^i(\mu^i\mathbf{e} - \mathbf{s}^i) \geq 0. \tag{9}$$

The development of the model generates ever higher levels of efficiency and, therefore, can be applied to assess the allocative inefficiencies in the observed economies, both nationally and internationally. First we have is the transition of the observed economies, $(\mathbf{K}^i, \kappa^i, \mathbf{L}^i, \lambda^i, \mathbf{M}^i, \mu^i, \mathbf{U}^i, \mathbf{V}^i, \mathbf{f}^i)$, to their competitive counterparts, $(\mathbf{K}^i\hat{\mathbf{s}}^i, \mathbf{e}, \mathbf{L}^i\hat{\mathbf{s}}^i, 1, \mathbf{M}^i\hat{\mathbf{s}}^i, 1, \mathbf{U}^i\hat{\mathbf{s}}^i, \mathbf{V}^i\hat{\mathbf{s}}^i, \mathbf{f}^i c_i)$. Here $\mathbf{s}^i$ and c_i are the equilibrium values of the model comprising Equation 2 (and similar for all other industries, in all economies), Equation 4 (for each economy and with the environmental proceeds added to the factor income), and Equations 5–8 (for all i). A hat denotes placement of on the diagonal of a matrix. This first transition reallocates activities within and between economies according to the principle of comparative advantage in production. The gains to free trade are reflected in the consumption levels, c_i. The elimination of the allocative inefficiencies also accommodates the meeting of tighter environmental constraints, $\mu^i < 1$.

The second transition comes with the replacement of the system of national environmental conditions 8 by the single, international condition 9. Since the constraint in the latter is more lax from an economic point of view (the feasible set of allocations gets bigger when constraints are pooled), but not from an environmental perspective (the total use of the environment remains the same), further efficiency gains are made and reflected in even higher consumption levels. A fine example of this transition is the clean development mechanism (CDM) of the Kyoto Protocol (1997). The CDM permits firms of economies where emission reductions are costly, particularly the developed economies, to contribute to reductions elsewhere, in economies where they are relatively cheap, notably developing countries.

In the short run emission caps or tradable permits are not available in all countries. The model can handle situations where only a subset of countries implements environmental policies by modifying the constraints 8 or 9. In particular, if only a subset of countries have an emission cap with tradable permits, such as in the case of the Kyoto Protocol, condition 8 should include only the restrictions on the participating countries, and no restrictions on the other countries. Similarly, the case of tradeable permits in a subset of countries can be accommodated by modifying condition 9 to remove the terms corresponding to non-participating countries. In the same vein, the formulae for the environmental conditions can be modified for the situation in which there are different policies (with different emission caps and/or permits) in different subsets of countries. Thus, the model can also serve for the analysis of regional policies, for example EU-ETS or the Australian and New Zealand carbon market.

4.2. The Full Model

Either model, with the environmental constraints separate or pooled, can be summarized by the general complementarity problem:

$$\mathbf{0} \le \mathbf{z} \perp \boldsymbol{\Phi}(\mathbf{z}) \ge \mathbf{0} \tag{10}$$

In problem 10, vector $\mathbf{z} = ((\mathbf{s}^i, c_i, \mathbf{r}^i, w^i, t^i)_{i=1,\dots,I}; \mathbf{p})$ lists the components of all variables. Here I is the number of economies. The emission prices t^i are replaced by a single scalar t preceding $\mathbf{p}$ if the national environmental conditions 8 are pooled into the international condition 9. Vector $\boldsymbol{\Phi}(\mathbf{z})$ lists the respective loss functions and complementarity problem 10 can be presented piecemeal because it is equivalent to $\mathbf{0} \le \mathbf{z}^1 \perp \boldsymbol{\Phi}^1(\mathbf{z}^1) \ge \mathbf{0}, \mathbf{0} \le \mathbf{z}^2 \perp \boldsymbol{\Phi}^2(\mathbf{z}^2) \ge 0$ for any partition of the variables and the function, $\mathbf{z} = (\mathbf{z}^1, \mathbf{z}^2)$ and $\boldsymbol{\Phi} = (\boldsymbol{\Phi}^1, \boldsymbol{\Phi}^2)$. The expressions for the loss functions were derived earlier and can be found in Equations 2 and 4 (with the environmental proceeds added to the factor income), Equations 5, 6,[10] 8 or alternatively 9, and 7. For the case of national pollution caps we have

$$\mathbf{0} \le \mathbf{s}^i \perp (\mathbf{r}^i\mathbf{K}^i + w^i\mathbf{L}^i + t^i\mathbf{M}^i + \mathbf{p}\mathbf{U}^i - \mathbf{p}\mathbf{V}^i) \ge \mathbf{0}, \quad i = 1, \dots, I,$$

$$0 \le c_i \perp \mathbf{p}\mathbf{f}^i c_i - (\mathbf{r}^i\mathbf{K}^i + w^i\mathbf{L}^i + t^i\mu^i\mathbf{M}^i)\mathbf{e} - \mathbf{p}[\mathbf{f}^i - (\mathbf{V}^i - \mathbf{U}^i)\mathbf{e}] \ge 0, \quad i = 1, \dots, I,$$

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[10] Here, we present the formulation with immobile factor inputs; however, as explained earlier, this assumption can be easily altered.

$$\begin{aligned}
&\mathbf{0} \leq \mathbf{r}^i \perp \mathbf{K}^i(\kappa^i \mathbf{e} - \mathbf{s}^i) \geq \mathbf{0}, \quad i = 1, \ldots, I,\\
&0 \leq w^i \perp \mathbf{L}^i(\lambda^i \mathbf{e} - \mathbf{s}^i) \geq 0, \quad i = 1, \ldots, I,\\
&0 \leq t^i \perp \mathbf{M}^i(\mu^i \mathbf{e} - \mathbf{s}^i) \geq 0, \quad i = 1, \ldots, I,\\
&\mathbf{0} \leq \mathbf{p} \perp \sum [(\mathbf{V}^i - \mathbf{U}^i)(\mathbf{s}^i - \mathbf{e}) - \mathbf{f}^i(c_i - 1)] \geq \mathbf{0}.
\end{aligned} \tag{11}$$

For tradable permits not only the last component in Equation 11 but also the next to last is subjected to summation, employing $\sum \mathbf{M}^i(\mu^i \mathbf{e} - \mathbf{s}^i)$ of Equation 9 instead, and a common scalar t replaces t^i in the second component. Then the trade surplus includes the amount of trade in permits.

5. ILLUSTRATION

We demonstrate the applicability of the model in a simple example, featuring three developed economies, namely Belgium, Denmark and Spain. This admittedly odd combination serves a pilot study because their data sets have been completed and made available to us. The main purpose of the paper is to exposit how (environmental) input–output accounts can be used for general equilibrium analysis of environmental policies and the extension to an interregional model of all EU member states is straightforward once comprehensive member states data become available. For the sake of simplicity, we restrict our attention to the main greenhouse gas, CO_2, which accounts for about 80% of greenhouse pollution of the EU-15 (Gielen and Kram, 1998). We first describe the data and then compare the model outcomes under alternative environmental policy assumptions. The case of no environmental policy will serve as the benchmark for the cases of national emission caps and an international emission cap with tradable permits. Our simple model will prove capable of producing similar insights as those in other, more complicated models, but again, the purpose of the exercise is only to illustrate the applicability of the model.

5.1. Data

The data, provided to us by the IPTS, are based on the national and environmental accounts of each country, published by Eurostat for the year 2000. The use and supply tables, **U** and **V**, incorporate 59 products and industries. The tables are expressed in producer prices. The supply tables of the Eurostat are published in producer prices, while the use tables were estimated by the IPTS. For Denmark the data have been converted into euros using the average exchange rate of 2000.[11] We treat the commodities with negligible values of the observed net export as non-tradable.[12] The trade with the rest of the world has been held fixed at the observed level.

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[11] Since we consider the aggregated production technology for each industry, the analysis does not account for within industry reallocations and environmental improvements.

[12] In this application, nontradable commodities are: secondary metals, water, sewerage, transportation, real estate, education, healthcare, public services, services of membership organization and private households, and other services.

TABLE 1. Effect of environment policy targets on expansion factors.

	Spain	Denmark	Belgium
Kyoto targets	$+15\%$	-21%	-7.5%
Emission limits μ	0.85	0.79	0.86
Scenarios			
(a) Unrestricted	1.049	1.133	1.115
(b) National caps	0.878	0.945	1.119
(c) International permits trade	0.903	1.015	1.094
(d) Spain opts out	1.058	1.144	1.067

Labor data (number of employed persons) originate from the EU KLEMS data. Labor unemployment rates in 2000 were: Belgium 6.9%; Denmark 4.3% and Spain 11.1% (Eurostat, 2010). These percentages represent ‘unemployed persons as a percentage of the labor force, where the labor force is the total number of people employed and unemployed’. The total private capital stock in each country comes from the Kiel Institute of the World Economy’s Database on Capital Stocks in OECD countries. As usual, capital employment data are a bottleneck. Since no detailed capital employment data were available by industry (in our industry classification), capital employment has been allocated across industries proportionally to the industrial gross operating surpluses, assuming capacity utilization rates around 0.82, in accordance with the EU average utilization rates for that period World Bank (2010).

The environmental impact data come from the database of the IPTS, that builds upon the environmental accounts published by the Eurostat. We focus on CO_2-emissions and assume the policy parameters, emission limits μ^i, to reflect the respective Kyoto targets on the reduction of greenhouse gas emissions.[13] The original Kyoto targets (-7.5% for Belgium and -21% for Denmark, and $+15\%$ for Spain) specify the percentage of the emission reduction compared to the level of 1990, while our data corresponds to 2000. Therefore, we have transformed them by the following formula: $\mu_{2000} = \mu_{1990}/(1+g)$, in which the superscripts refer to the two base years, and g denotes the change in the CO_2 emission level between these years. The data on g are derived from EEA (2002): 7.7% for Belgium, -0.4% for Denmark and 34.9% for Spain. Plugging these values into the 1990–2000 transformation formula above yields the values of μ^i reported in Table 1. Because the initial level of emissions in Spain in 1990 was low, therefore, Spain was not required to decrease the level and the value of the Kyoto target was positive for Spain. However, after the rapid increase of emissions in the period 1990–2000, surpassing the target, Spain faces a relatively stringent constraint in 2000.

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[13] The Kyoto targets cover emissions of the six main greenhouse gases, namely: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). The total value of greenhouse gas emissions is constructed as a weighted average of each gas emissions with global-warming potentials as weights. The targets specify the percentage of reductions of the total emission level to be achieved in the period 2008–2012 compared to the level of 1990. In addition to these national caps, there is the EU trading scheme currently covering only CO_2 emissions of major installations. Not all industries are covered by the EU emission trading scheme.

5.2. Results

Table 1 shows the resulting expansion factors under four scenarios: (a) no environmental constraint (our benchmark), (b) national caps on CO_2, (c) international trade in CO_2 permits under a common cap and (d) when one national cap is removed. It is a comparison between scenarios (a) and (b) highlights the trade-off between the strength of the pollution caps and the resulting equilibrium consumption. While without emission caps, the model results in the expansion of consumption in all the three economies, this is no longer the case under environmental constraints. Interestingly, the expansion factor for Belgium increases. This phenomenon is explained by the shadow prices of CO_2 emissions in the three countries, which are 1.52 for Belgium, 1.58 for Denmark and 2.36 for Spain. The minimum price in Belgium reveals a low environmental cost, which attracts production.

Scenario (c) mimics international trade in permits. The expansion factors of Denmark and Spain increase, while the expansion factor of Belgium decreases compared to the national scenario (b). Free trade in emission permits reallocates production between countries and changes industry outputs and prices. This terms-of-trade effect may be unfavorable. The shadow prices of CO_2 emissions under (b) and (c) support this explanation. The maximum price in Spain means that the (environmental) cost of production is high in Spain, harming its terms of trade under (b), contrary to Belgium. In scenario (c), free trade in emission permits relieves the constraint on Spain and the situation reverses.

The final scenario (d), suggested by a referee, analyzes the Pollution Haven Hypothesis by letting an economy opt out. The suggested economy is the one with the highest growth in emissions, Spain. The scenario is hypothetical, because Spain is part of the EU trading scheme, but demonstrates how our model can handle this issue. We maintain the assumption that the other two countries adhere to the national caps under scenario (b). The theory predicts that the removal of one-country cap will improve this country welfare, but it can either improve or worsen the welfare in other countries. Indeed, we observe that the expansion factor of Spain is now the highest of all the scenarios, however, the situation differs in the other two economies: Denmark gains, while Belgium, with its emission cost, looses.

Table 2 shows the 15 aggregated industry activity levels. Comparison between scenarios (a) and (b) reveals that the introduction of national caps will reallocate the most polluting industry, ‘electricity, gas, water’, from Denmark and Spain to Belgium. Production of the next most polluting industries, ‘metal products’ and ‘non-metallic products’, will also reduce substantially under scenario (b), with only Denmark maintaining the same expansion level. Our assumption that capital is immobile between industries solves the problem of corner solutions frequently encountered in input–ouput models, the tendency of linear models to yield specialization in production. Zero activity is still obtained for ‘textile and wearing apparel’ in Denmark under scenario (a), suggesting that absent environmental policies Denmark could gain from reducing that industry. However, since this industry is relatively clean, pollution caps render it competitive under scenario (b).

The tradability of permits increase total output, through more specialization according to comparative advantages. Denmark, with its coal plants, would reduce electricity production. Finally, Spain’s opting out would boost it output and increase the shadow prices of emissions in the other economies, weaken their industries to different extents and prompting further reallocations.

TABLE 2. Industry expansion factors for Spain (ES), Denmark (DK) and Belgium (BE) in the scenarios (a) unrestricted, (b) national caps, (c) international permits trade and (d) Spain opts out.

	(a)			(b)			(c)			(d)		
Scenario:	ES	DK	BE	ES	DK	BE	ES	DK	BE	ES	DK	BE
Agric., forestry and fishing	1.2	0.2	1.2	1.0	1.2	0.1	1.1	1.2	0.0	1.2	0.2	1.2
Mining and quarrying	1.0	1.2	1.2	0.6	0.7	1.2	0.6	1.0	1.2	1.0	1.2	1.2
Food, beverages and tobacco	1.2	0.2	1.2	0.7	1.2	1.2	1.1	0.1	1.2	1.2	0.2	1.2
Textiles, wearing apparel	1.1	0.0	1.2	1.0	1.2	0.6	1.0	1.2	0.7	1.2	0.0	1.0
Wood, pulp and publishing	1.0	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2	1.0	0.8	1.2
Non-metallic mineral prod.	1.2	1.2	0.9	0.8	1.2	1.0	1.1	1.2	0.4	1.2	1.2	0.9
Metal products	1.0	1.2	1.2	1.0	1.2	0.6	1.0	1.2	0.6	1.1	1.2	0.9
Machinery	1.0	1.2	1.2	0.8	1.2	1.1	0.9	1.2	1.1	1.0	1.2	1.2
Electricity, gas and water	1.0	1.2	1.2	0.9	0.5	1.2	1.0	0.1	1.2	1.1	0.7	1.1
Construction	1.2	1.2	0.4	0.8	1.2	1.2	0.8	1.2	1.2	1.2	1.2	0.4
Trade, hotels and restaurants	1.2	1.0	0.8	1.0	1.0	0.7	1.1	1.0	0.7	1.2	1.1	0.8
Transport, post and telecom.	1.1	0.9	1.2	0.9	1.2	1.0	1.1	1.1	0.7	1.1	0.9	1.1
Financial services	1.2	1.1	0.8	1.0	0.3	1.2	1.1	0.3	1.2	1.2	0.5	1.2
Other business services	1.0	1.1	1.2	0.8	1.1	1.1	0.9	1.1	1.1	1.0	1.1	1.1
Other services	1.0	1.1	1.1	0.9	1.0	1.1	0.9	1.1	1.0	1.1	1.1	1.0

6. CONCLUSION

The complementarity problem approach to supply-use accounts traces reallocations in response to environmental policies in multi-country systems, such as the EU. Environmental regulatory constraints are incorporated in the same vein as primary input constraints and the approach – which combines the strength of general equilibrium analysis and linear programming – determines the economic and environmental gains to free trade in products and emission permits.

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