Taxing Air Pollutants and Carbon Individually or Jointly: Results from a CGE Model Enriched by an Emission Abatement Sector

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Taxing air pollutants and carbon individually or jointly: results from a CGE model enriched by an emission abatement sector

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Abstract

We analyse the separate and collective impacts of emissions taxation to understand the internalisation effects of externalities. The analysis is carried out using a static computable general equilibrium model, with unemployment, bottom-up abatement technologies represented by a step function, and detailed emission coefficients. Environmental and health external costs are quantified using the ExternE's Impact Pathway Approach. Emissions, as a result of environmental taxation, fall through reduced output, production factor substitution, and increased end-of-pipe abatement activity. The analysis shows that a full internalization of environmental externalities can result in modest overall economic and environmental welfare gains. There are, however, differences in terms of employment and output, depending on what combination of taxes are applied, which sectors are covered, and how fiscal revenues are redistributed. Air quality benefits range from €35–75 per ton of CO_2 abated. Total environmental benefits always exceed GDP loss and the associated welfare loss.

Keywords

CGE modelling; Abatement sector; Carbon taxation; Air pollution charging; Environmental benefits; Bottom-up abatement technology

1. Introduction

There is a growing attempt in current modelling of taxation to make policy impact assessment more realistic through various kinds of enriched hybrid Computable General Equilibrium (CGE) models. Using such a hybrid approach, we addresses three important themes in economics and in the public policy debate: the ancillary benefits of carbon taxes, the concept of externalities, and the use of environmental taxes to address both environmental and economic problems, sometimes referred to as the double dividend.

Inadequately considered ancillary benefits leads to an incorrect assessment of the net costs of mitigation policies (Burtraw et al. 2003; Ščasný et al. 2015). As a consequence, the policy chosen to regulate one domain may exceed the national target set for another domain and could be unnecessarily expensive. While several papers have looked at the ancillary benefits of carbon taxes and local air pollution taxes separately the present paper is we believe the first of its kind that questions the ancillary benefits of various policies on both carbon and local air pollutants.

On externalities a significant body of literature has shown the quantitative importance of external effects, such as emissions of air pollutants. Yet governments have been reticent to impose charges on polluters at levels equal to the external costs, largely because they fear its disruptive effects on the economy. As a result, the degree of internalization of the externalities associated with air pollutants is very low. Given the importance of this issue it is surprising that no one has checked what impacts a full internalization of external costs of air pollution would have on the economy. This is the second reason for undertaking this study.

On the double dividend debate there is now a formidable European literature, largely focusing on the application of a carbon and/or energy tax (Markandya, 2009). A number of European models conclude that a switch in taxation from labour to carbon/energy increases employment and reduces carbon emissions. At the same time it increases GDP. Hence there is some degree of agreement on this 'good news'. The differences of opinion concern the size of the impacts on employment, output and emissions.

This paper looks at these issues in a somewhat more complex framework. It examines the implications of taxes on key local air pollutants (Policy A) or on carbon (Policy C) when tax levels are set at rates equal to estimated marginal damage costs. Needless to say these rates are much higher than those attempted in any economy. In the case of the carbon tax, a range is used that reflects the current consensus on the external costs from emissions of CO_2. In addition to analysing to what extent the taxes regulate air pollutants and GHG emissions two other aspects of the tax structure are explored. The first is the extent of coverage: whether all sources are taxed, or just some of them. In particular the inclusion or otherwise of mobile sources is an important dimension (Policy M). The second is how tax revenues are treated: they can be used to increase government expenditure or redistributed, and in case of the latter there are several ways to redistribute them. By this means we can see the additional impacts of each as well the joint effects of both taxes.

The analysis has been carried out for a small open European economy (Czech Republic) using a state-of-the-art Computable General Equilibrium (CGE) model enriched by three components.

First, to our knowledge, specifying the production function explicitly in terms of end-of-pipe pollution abatement within a CGE framework, makes this the first hybrid model that incorporates interactions of climate policy with other air pollutions on the one hand and three channels of emission reduction (output decrease, inputs substitution, abatement technologies) on the other. The special feature of a hybrid model is that it involves a combination of approaches. Hybrid CGE modeling is a combination of top-down approach (classical economic CGE) and bottom-up approach (engineer modeling). The top-down approach assumes smooth cost functions applied at an aggregate level, while a bottom up approach involves detailed step cost functions at a relatively disaggregated level (each step represent a different technology). In our case, the abatement sector is described via step function and other sectors via smooth function. A step production function in CGE modeling is not common. Specifically, we follow the novel approach as described in Kiuila and Rutherford (2013a; 2013b) and incorporate it into a CGE framework. The advantage of using the step function approach (bottom-up modeling) over a smooth function (top-down approach) is that a smooth function is not able to distinguish between technologies, i.e. single smooth technology (nested function) is assumed. A step function distinguishes between technologies, i.e. a single sector is represented by a number of technologies and the optimization process allows the best combination of those technologies to be chosen, ses further Kiuila and Rutherford (2013b).

Second, using a unique environmental database, the model includes five types of fuels (coal, oil, gas, biomass, and electricity) as factors, five local air pollutants (particulate matter- PM, SO_2, NOx, CO, volatile organic compounds - VOCs) and CO_2 emissions, with emission coefficients separately specified for each type of fuel, each economic sector and household, and each type of emission source (stationary, technology processes, and mobiles). This allows us to explicitly account for the difference in the abatement technology across sectors and energy types. We believe such CGE modelling of both local and global pollutants for several types of emission sources, with a wide range of abatement options and the fuel- and sector specific emissions of six pollutants, is the first of its kind.

Third, outside of the CGE model, we quantify environmental and health benefits attributable to emission reductions in local air pollutants. Following the ExternE's Impact Pathway Analysis the impacts on human health, building material, biodiversity, and crop yield are monetized by corresponding willingness-to-pay values.

Lastly the study is conducted in an economy that has been transformed from a centrally planned to market system. While the literature on ancillary benefits and tax incidence has grown immensely during past ten to twenty years, there are relatively few studies dealing with developing and transforming economies (Morgenstern 2000). Still, while the results are particularly relevant for an economy in transition they also hold to a considerable extent for all competitive small economies. The essential features of the technologies available to respond to the energy/carbon taxes and the responsiveness of the economy to taxes via international competition also hold across countries that have had a market economy for a much longer time.

The rest of the paper is structured as follows: Section 2 describes the model used, Section 3 sets out the options considered, Section 4 reports the main results and Section 5 concludes.

2. CGE model with abatement technologies

2.1 Model framework

The Czech economy is represented as a static Arrow-Debreu small-open economy. It consists of 20 sectors, 7 factors of production – capital (K), labour (L), five energy factors (E) represented by gas, coal, oil, biomass[1], and electricity – one representative household, and government.

The database of the CGE model is represented by an inter-industry transaction table supplemented with additional data on the stock of capital and labour and levels of pollution emissions. The input-output table describes the Czech economy at the end of the year 2005, which was the latest available and which is the benchmark equilibrium year. The benchmark also represents the business-as-usual scenario in our model. Table in Appendix gives a sectoral classification of the model. It provides the factors and materials (M) intensity and relative share of inputs demand per sector.

Like most CGE models, this one calculates the prices and volumes of production which equate demand with supply in all markets (except the labour market) and make marginal profits equal to zero in all sectors (further details can be found in the Technical Appendix[2] and in Kiuila, 2015). However, the market equilibrium condition does not apply to the labour market, where endogenous unemployment is considered. Furthermore the model allows for a current account imbalance, as well as other market imperfections (differentiated products between domestic and foreign markets and hence their imperfect substitutability, decreasing returns to scale in abatement sector).

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[1] In 2005, the share of renewable resources were only 4.3% on TPES, dominated mainly by biomass (3.9%) and large hydro power plants that share has been stable at 0.4% of TPES since 90's till now. This is the reason why other renewable resources are not included among the factors. Share of RES has been increasing in the Czech Republic since 2009 (see Rečka and Ščasný 2016) and reached 14.2% (biomass, wastes), 0.5% (hydro) and 0.9% (geothermal, solar, wind) of TPES in 2015 (OECD/IEA 2017).

[2] Available as Supplementary material.

Consumption and Government

Final domestic demand consists of household and government demand, representing respectively private and public consumption. All households are aggregated into one household, which receives income from employment, from the firms' profits (including income from capital) and from the government.

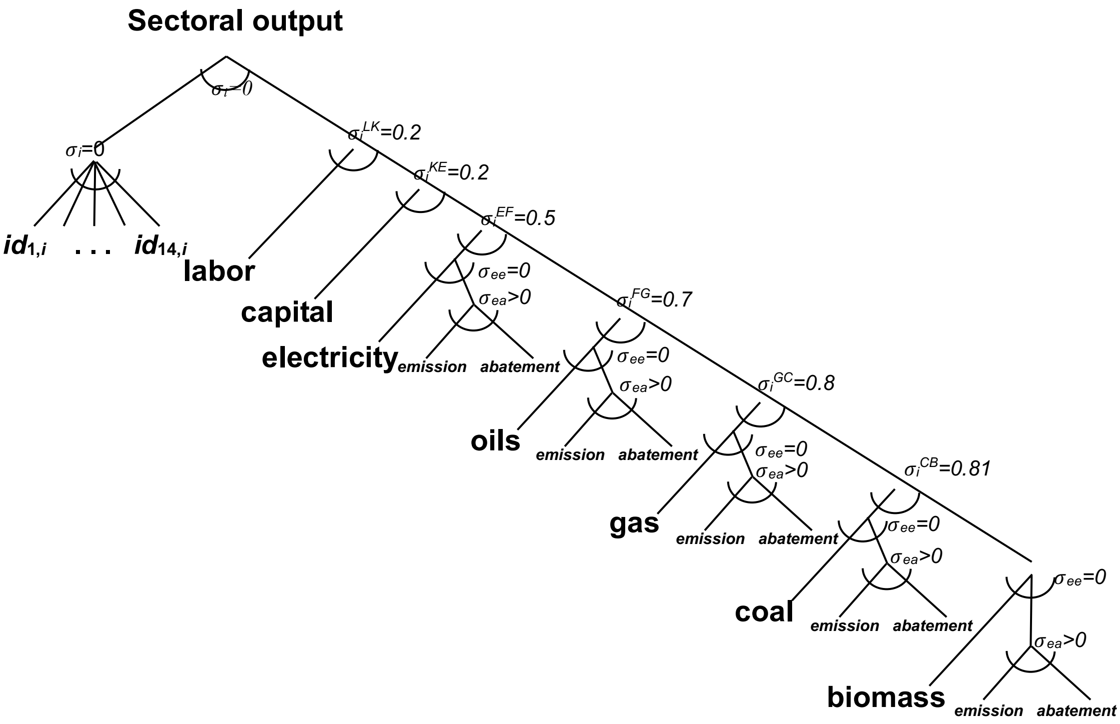
The government collects taxes, makes and receives transfer payments and purchases goods and services. Government expenditures are exogenous, with the revenue modelled in detail to reflect the Czech tax system. It includes nine tax categories: value added tax, excise tax, social security paid by employees and employers, personal income tax, capital income tax, emissions charges (including carbon), and other net taxes on products and production.

Producers

Producers are assumed to minimize costs subject to their output target and production function.

Sectoral output (except abatement, see subsection 2.2) is determined by a Leontief technology for 14 materials (intermediate demand) combined with a nested Constant Elasticity of Substitution (CES) structure (represented by 7 production factors). Figure 1 shows the production structure in schematic form. All factors of production are mobile between sectors within the domestic economy.

FIGURE 1. Production Structure



As far as the labour market is concerned, there is a fixed supply of labour and a nominal gross wage that responds to unemployment. A neoclassical assumption of flexible wages is replaced by a wage curve, which assumes that real wages are a declining function of the local unemployment rate. Thus high unemployment leads to lower real wages.[3] The intersection of this wage curve with the labour demand curve determines the employment level and labour cost. The labour supply curve determines the wage rate for any given employment level. Finally, the difference between labour supply and employment level determines unemployment. The first such wage curve was directly incorporated into CGE modelling by Rutherford and Light (2002)[4].

The five types of energy enter as inputs into a set of CES production functions. A CES function assumes a constant elasticity of substitution between production factors. In order to specify variable (non-constant) substitution possibilities between these factors, we employ (as is standard practice) a set of nested separable CES functions.

The general specification of CES cost functions is the same for all sectors, but parameters differ across the sectors.

A zero profit condition is applied for each sector under constant returns to scale, except the abatement sector, where decreasing returns to scale are applied.

Open economy

The model describes a small open economy. A single actor represents the rest of the world. The Czech Republic's export to the rest of the world is represented by a constant elasticity of transformation (CET) function, while the demand for its exports is infinitely elastic. When the elasticity of transformation is relatively high, there is little price

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[3] The model set the 2005 unemployment rate of 8 % as a baseline. The unemployment rate and labour market conditions in the Czech Republic are historically stable. Even when the crisis hit the economy (2008-2009) the unemployment rate barely reached 10 %. Prior to the crisis and more recently the Czech economy experienced an unemployment low of around 4-6 %. Thus we have not calibrated our model at any extreme value of unemployment.

[4] An alternative technique in the literature is to fix the nominal wage (Yin 2002). We preferred to use the Rutherford and Light technique, which is also the more popular (see Partridge and Rickman, 2010; Kuester et al., 2007; Bhattarai, 2008) as it provides the possibility of unemployment if the demand for labour (which is determined according to profit maximization conditions) is less than the available supply at a gross real wage.

difference between the domestic and international markets and small changes in the international price will result in big shifts in supply from one market to another. The elasticity of transformation is assumed to be equal to 4 for all sectors, based on values commonly used in the literature (Hillberry and Hummels, 2012).

Since the country exports and imports the same aggregate products, we assume, as is common to all such models, that there is imperfect substitutability between domestically produced goods and imported goods. An import demand function is defined, based on a CES function with the 'Armington assumption'. Under this assumption goods produced in the country can be sold at higher prices than world prices.

There are 1,259 endogenous variables in the model and the same number of equations. We choose to define the exchange rate as a numeraire. As a natural consequence (Walras' law), trade balance equation is dropped and the level of foreign savings is assumed to be fixed.

2.2 Emissions and pollution abatement

Emissions of SO_2, NOx, CO_2, CO, PM, VOCs are taken into account in the ways described below. Producers and households are both considered as pollution emitters. We take into account emission coefficients for each pollutant (6 types) per agent (19 producers and 1 household), and for each emission source (fuel combustion at stationary sources (separately for coal, gas, petroleum, and biomass), technological processes and mobile emission sources). As a result, the model contains more than 700 specific emission coefficients. These coefficients, expressed in tons of pollutant per unit of economic output, allows us to determine the increase in the production price due to any increased emission charge.

A special feature of the model is accounting for emissions of five local pollutants as well as CO_2. The model imposes charges and taxes on these emissions, as a result of which emissions can fall though: (i) reduced output of the polluting goods, (ii) substitution with less polluting inputs, and (iii) installation of end-of-pipe abatement technologies (only for SO_2, NOx and PM due to data availability). How pathway (i) works is self-explanatory – emission stemming from mobile sources or from technological processes can be reduced directly if output of particular sector is reduced. As far as substitution with less polluting inputs is concerned (pathway (ii)) this takes place through the nested CES functions described above. Emissions can be reduced through (a) inter-fuel substitution within the energy aggregate and (b) substitution between energy and other factors. Finally, for pathway (iii) of end of pipe abatement there are 36 available abatement technologies for SO_2, 63 for NOx, and 61 for PM_{10}[5] these technologies have cumulative abatement capacity of 21.06 kt, 79.3 kt, and 19.6 kt, respectively.

Emissions of CO_2 can be reduced through decreasing economic activity or fuel substitution, i.e. switching to a cleaner energy source; as such, no end-of-pipe technology, such as carbon capture and storage, is implemented into our model.

There are a number of ways in which abatement technologies can be modelled. Technologies can be represented explicitly in a bottom-up model, as in Barker and Scrieciu (2010), but this approach would require consistent linking of the bottom-up model and the CGE model. Installations of abatement technologies can also be considered as inputs for firms, as has been done within the GEM-E3 model (Capros et al., 2008). However, the flexibility of this approach is limited and specifying explicitly marginal abatement cost curve is a data hungry process. A precise, more flexible, and less data demanding approach is to specify the production function explicitly in terms of pollution abatement (Jorgenson and Wilcoxen, 1990; Nordhaus and Yang, 1996; Hyman et al., 2002; Dellink 2005; or Revesz and Balabanov, 2007). This approach requires estimating or otherwise fitting a cost curve, and to date, there have been only a few such applications. We follow this approach as developed by Kiuila and Rutherford (2013a; 2013b) in order to directly implement a bottom-up function based on engineering data for pollution abatement process into a CGE model. Such a structure allows our model to impose environmental levies on several pollutants, as a result of which emissions can fall through the three pathways identified above. We consider this as the best way to model abatement given the data available.

Following the activity analysis, the abatement sector has a different structure from other sectors. Output of 19 production sectors is determined by a Leontief technology

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[5] The data comes from "RAINS" - the bottom-up model developed by IIASA (Amann et al., 2004).

for 14 materials (intermediate demand) combined with a nested CES structure represented by seven production factors, as shown in schematic form in Figure 1. The output from sector 20 (the abatement sector) is an input to the other 19 sectors (marked as “abatement” in Figure 1). Each of 19 sectors could generate emissions of pollutants, while the 20th sector has a different structure. We assume that the abatement possibilities are related to the whole economy, i.e. the marginal cost of abatement is applied for the whole economy rather than for a specific sector. There are only two inputs for the abatement activity Q: capital and pollutants. Thus the abatement sector operates the abatement technologies and other sectors pay for abatement service if they decide to use it instead of paying a tax for the emissions they generate.[6]

Instead of taking a smooth cost function, we have applied a step function (Figure 2a). Each step of this function is described by a Leontief function (the approach is known as activity analysis). Substitution possibilities between inputs (capital versus emission) are described by the characteristics of available technologies, including those which are inactive in the benchmark. Figure 2b relates to Figure 1 through the nest, where producers choose between emission of pollutants (marked as “emission” in Figure 1) and abatement (“abatement” in Figure 1). If they choose to emit more, they have to pay higher charges or taxes for emission. If they choose to abate, they have to pay for abatement. In addition they may choose to reduce the output (“sectoral output” in Figure 1) in order to reduce the emission of pollutants.

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[6] Previous models have used other representations of energy technologies to track changes in emissions. One is through a soft link (Kumbaroğlu and Madlener, 2003; Vrontisi et al., 2016), another through a hard-link (Helgesen, 2013), and a third through the integration of an emission-extended bottom-up energy system model and a top-down economic model (Böhringer and Rutherford, 2008). None of them, however, included end of pipe abatement into their modelling framework. We further approach the abatement technologies by explicitly following an activity analysis approach as discussed in Kiuila and Rutherford (2013a).

FIGURE 2a. Step versus smooth marginal cost curve

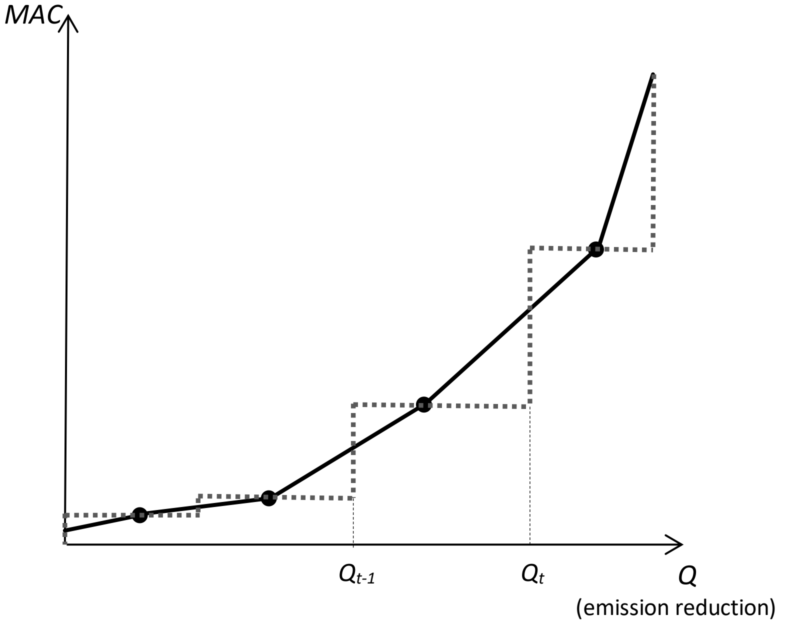
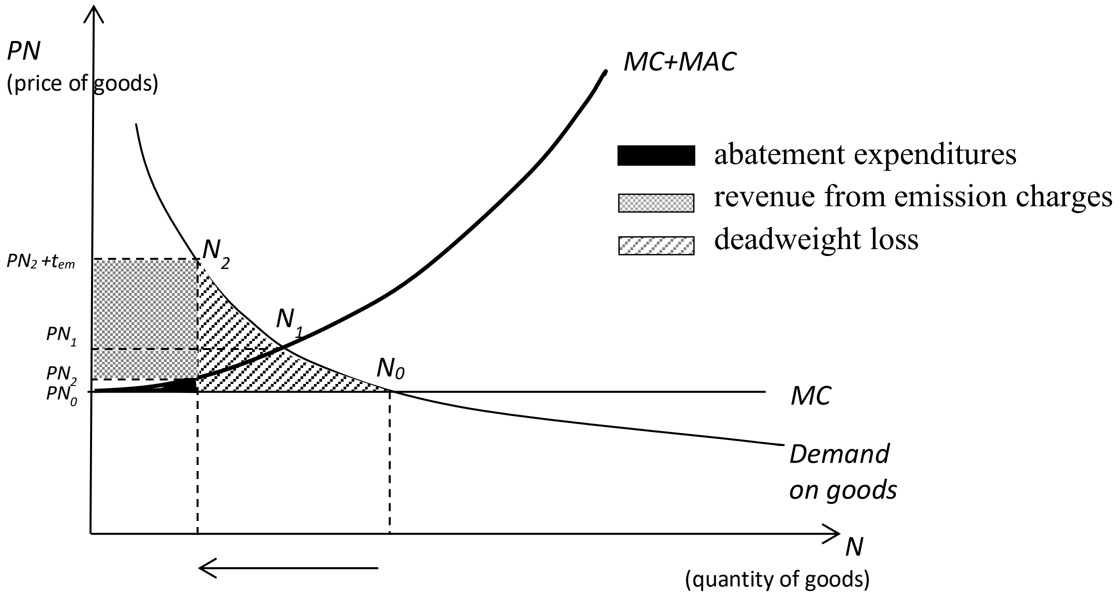


FIGURE 2b. Influence of emission charges on market of goods (if production process generates pollutions)



PN_0 - initial market price (consumer price = producer price)
PN_1 - new market price due to volunteer abatement (the marginal cost will increase by MAC)
($PN_2 + t_{em}$) - consumer price when government implement emission charges (t_{em})
PN_2 - producer price when government implement emission charges (t_{em})

2.3 Environmental Policy

The model can be used to analyse a range of policy instruments, namely: emission charges, carbon and energy taxes, emissions permits, and emission limits. Energy and pollution taxes increase the costs of affected industries and may reduce their economic performance, including international competitiveness. On the other hand, the revenue generated by the energy tax allows a reduction in other distortionary taxes in the economy. Hence the model allows for the possibility of a double dividend.

In the case of emission charges and the carbon tax (t_{em}), agents have a choice to undertake abatement (more energy efficient production or less pollution intensive inputs) or to pay charges on their emissions. Abatement technologies are used until the marginal abatement cost (MAC) equals the price of emissions. The abatement cost MAC shifts the sectoral supply curve MC upward. The price for the good N being produced goes up from PN_0 to PN_1, as shown in Figure 2b, if abatement is implemented freely. However, producers will not abate voluntarily because that creates an additional cost. Thus government should implement charges or permits for emission in order to provide incentives for producers to reduce emission. Emission charges imply that market price for good N grows to PN_2+t_{em}, where PN_2 is producer price. The resulting gross welfare loss is abatement expenditures (the black area). Adding market distortion (the dashed area) we will get net welfare loss. This is a result of a gain in tax revenue (the grey rectangle) and loss in both producer and consumer surplus. The net effect on the consumer surplus of the emission charges will be always negative. The net effect on producer surplus will depend on abatement possibilities and on own-price elasticity. When a sector is very capital intensive, the elasticity of supply will be small and the sector will have to absorb an important part of the increase in marginal cost ($MAC+t_{em}$). The total effect of emission charges and taxes is a reduced output level in addition to reduced emission level.

Revenue from emission charges and carbon taxes can be recycled back to the economy. Two specific recycling schemes are considered: lump-sum recycling and reduction of labour tax. With a labour tax reduction, we consider only the social security paid by employers. Without recycling, additional revenues from emissions charges are spent by the public sector.

We start from the benchmark point where environmental charges and output tax as of 2005 were already applied. Increased local air emission and carbon taxes have an impact on the output of the firms who pay the tax, but also on other firms as the prices of pollution intensive goods go up. The taxes also impact on the trade sector, to the extent that they make imports more attractive relative to domestic goods, the prices of which have risen.

2.4 Benefits

Ligthart and van der Ploeg (1999), following Bovenberg and van der Ploeg (1996), distinguish four types of dividend to indicate the various components of social welfare, as described in Figure 3. The *Green* dividend corresponds to improvements in environmental quality, the *pink* one is related to employment gains, the *red* is associated with public consumption, and *blue* is attributed to (economic) profits. Linghart and van der Ploeg (*ibid.*) then define three double dividends. An *'employment double dividend'* exists if the green and pink dividends occur together. A *'social double dividend'* is secured if both the green and red dividends are positive. And a '*triple dividend*' is obtained if the green, pink, and red dividends are simultaneously realized. We follow this approach in our paper to investigate all three double dividends.

Economic welfare is measured as equivalent variation (EV). The EV depends on utility function and in addition the curvature of indifference curve plays a key role. The parameter responsible for the curvature of the Stone-Geary utility function used in our model is given by the subsistence demand that represents 25% of benchmark disposable households' income.[7]

The environmental benefits are computed outside of the model; this means that the benefits are only a reporting variable which does not affect any decision variable in the model. Abated emissions of air pollutants (the benchmark level *minus* net emission)

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[7] While the equivalent variation depends directly on households demand level only, GDP measures total value of output at producer price, i.e. a value-added approach is applied, and it depends on value of output, value of intermediate consumption, and net indirect taxes.

reduce damage and thereby increase the environmental benefits. These benefits usually refer to the ancillary benefits.[8] To derive this benefit in money terms, we use the damage factors as derived in the ExternE's impact pathway approach (Weinzettel et al. 2012, Ščasný et al., 2015): 637,000 Kč (€21,400) per ton of particulate matters, 310,000 Kč (€9,270) per ton of SO_2, 277,000 Kč (€10,400) per ton of NOx, and 700 Kč (€23.5) per ton of CO_2 (all in Euro 2005 prices).[9] These damage factors are based on parametrised quantification of the impacts that were modelled by EcoSense's integrated atmospheric dispersion and exposure assessment model. It uses air transport models to control changes in the atmospheric concentration of pollutants at the local, regional and global level and then determines a range of impacts on human health, buildings and materials, biodiversity, and crop yields using concentration-response functions for each impact category. The estimated physical impacts are then monetized using valuation methods. Impacts on mortality are monetized by quantified.[10]

For reporting purposes, the total welfare is a sum of the equivalent variation and the environmental benefits.

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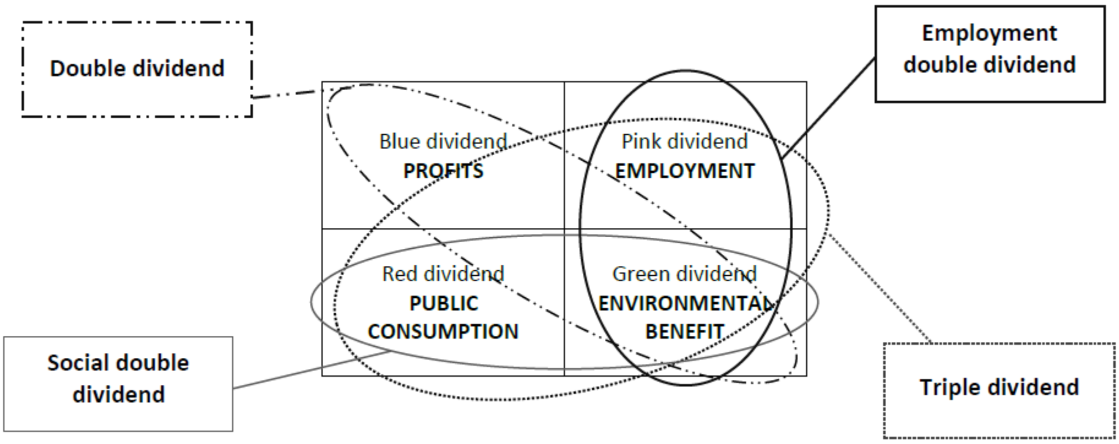
[8] The term ancillary benefits refers to those secondary or side effects of mitigation policy on problems that arise subsequent to the proposed mitigation policy (IPCC, 2001). Reductions in local air pollution associated with less use of fossil fuels due to greenhouse gas (GHG) mitigation are referred to as ancillary benefits. Conversely air quality improvement measures would generating reductions in GHG emissions, making the latter the ancillary benefit of air quality policy. In contrast, following the definition by IPCC (2001), the term "co-benefits" refers to the non-climate benefits of GHG mitigation policies explicitly incorporated into the initial creation of mitigation policies. Thus the term co-benefits reflects that most policies designed to address GHG mitigation also have other, often at least equally important, rationales involved at the inception of these policies".

[9] There has been long-standing discussion on economic standing – whose benefits and costs counts in the benefit-cost analysis, see, for instance, Gayer and Viscusi (2016). We account for all benefits regardless who is the recipient of the damage.

[10] The EcoSenseWeb1.3 tool was developed within the EU-funded NEEDS project (Preiss and Klotz 2008), recently its Web2 version is being developing; see http://ecosenseweb.ier.uni-stuttgart.de. The loss due to increased mortality is estimated using the Value of Life Year (Desaigues et al. 2011) and Value of Statistical Life, while increased morbidity is valued by willingness to pay and cost-of-illness values corresponding to each health outcome (Máca et al. 2017). Crop losses are valued by the international market prices. The impacts on building materials are assessed using replacement and maintenance costs; the assessment of biodiversity impacts is based on restoration costs (see Preiss and Klotz 2008).

FIGURE 3. Composition of Social Welfare and Corresponding Dividends



Source: Based on Bovenberg and van der Ploeg (1996) and Lindhert and van der Ploeg (1999).

3. Definition of Scenarios and Choice of Parameters

3.1. Benchmark Scenario and Choice of Elasticities

A constant rate across the sectors is assumed for the Armington elasticities σ_i^A and for the elasticity of transformation σ_i^T. We use $\sigma_i^A=4$ and $\sigma_i^T=4$ for all sectors, except for the gas sector, where $\sigma_i^A=20$. This value which represents very limited market power for the Czech gas sector (it covers also crude oil) is explained by the extreme import dependence of the country on these fuels (96% of supply).

The values of income elasticities are based on estimates by Ščasný et al. (2013). The level of the unemployment elasticity of wage (μ = 0.1) is based on the estimation by Blanchflower (2001). With respect to elasticities of substitution, it is a standard to choose their values in such a way as to replicate as closely as possible any empirical estimates of own- and cross-price elasticities. The following values have been adopted uniformly for the production tree: $\sigma_{CB}=0.81$, $\sigma_{GC}=0.8$, $\sigma_{FG}=0.7$, $\sigma_{EF}=0.5$, $\sigma_{KE}=0.2$, $\sigma_{LK}=0.2$.[11]

All tax rates were kept at the benchmark level in the baseline scenario. Effective tax rates are applied for VAT and capital tax (*tk* = 10%) in order to keep consistency with the data in the IOT and national accounts. The tax base for personal income tax is 10.2%, the rates for payroll taxes are 12.5% (paid by employees) and 32.5% (paid by employers). An excise tax is only applied to manufactured goods (1.7%), food (3%), and petroleum products (49%).

Emissions charges were applied in the Czech economy only on stationary emission sources of production, meaning that mobile sources and households' emissions were not charged in the benchmark. The benchmark rates of emission charges in 2005 are 1000 Kč (€30) per tonne of SO_2, 3,000 Kč (€90) per t PM, 800 Kč (€24) per t NOx, and 600 Kč (€18) per t CO, and there is no carbon tax in the benchmark. These tax rates are subtracted from the unit damage values to get the effect of full internalisation policy scenario (see Section 2.4 for the unit damage values).

The benchmark also represents the business-as-usual scenario in our model.

3.2. Policy scenarios

The policies that we model are **additional** to the ones that were already in place in the year 2005. The policy scenarios do not take into account any other instruments that might have been implemented and enforced since 2006.

First we examine the implications of taxes only on emissions of key local air pollutants (Policy A) or only on carbon (Policy C) stemming from stationary sources. The taxes are set at rates equal to the estimated marginal damage costs.

Next we examine the implications of taxing both local pollutants and carbon emissions (Policy A+C).

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[11] A sensitivity analysis shows that the model is sensitive to the elasticities of substitution: the higher the values of elasticities of substitution, the lower the cost of environmental policy. We also perform sensitivity analysis based on $\sigma_i^A=4$ for all sectors. The results are qualitatively same as for the base assumption, except the effect on GAS sector that is still positive but much smaller in magnitude (it is about five times smaller for carbon tax and by about a half for a combined policy).

In addition to the scope of the taxes, i.e. whether they regulate air pollutants, GHG emissions, or both, two other aspects of the tax structure are explored. The first is the extent of coverage: whether the carbon tax is imposed on the stationary emission sources (policies A or C) or whether mobile sources are also taxed (policies are marked with M when they are taxed).[12] The second is the way in which tax revenues are treated.

This gives rise to a number of combinations, summarised in Table 1. The first scenario (A) increases actual air emission charges to the level of external costs that emissions of SO_2, NOx, and PM cause. The next two scenarios assume only a carbon tax at a rate of €17 (C17) or €30 (C or C30) per tonne of CO_2[13] respectively. Both Policy A and policies C impose a tax on stationary emission sources only. Comparing the effects of A and C, we examine whether taxing carbon or local air pollutants at the rate of external costs bring overall benefits. Scenario C+M extends the coverage of taxed subjects and imposes the carbon tax as described by C also on the emissions from mobile sources. By comparing C and C+M we can see the marginal effect of extending subjects that are taxed.

Scenario A+C assumes joint taxation of local air pollutants and CO_2 emissions. By comparing A+C with A we can see the effect of adding a carbon tax on stationary sources (Policy C) to the local pollution taxes. Similarly, by comparing A+C with C we get the marginal effect of a local pollution tax (i.e. Policy A) on top of a carbon tax. Policy A+C+M extends the coverage of Policy A+C by taxing carbon stemming from mobile sources, or of Policy C+M by taxing air pollutants (Policy A).

In addition we are also able to analyse the way in which any tax revenues are treated: they can be used to increase government expenditure or they can be redistributed and if the latter there are several ways of redistributing them (policies with or without recycling). Hence the remaining scenarios consider a revenue neutral tax reform when all additional revenues are recycled either through a lump-sum payment to households

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[12] Since emissions of air quality pollutants stemming from mobile sources are controlled by technology standards, such as EURO standards applied on vehicles in the EU, it is not realistic to assume this tax is imposed on mobile sources.

[13] The rates of carbon tax correspond to a carbon price estimated by the European Commission for a 20% or a 30% emission reduction target (EC 2010), equal to €17 or €30 per tonne CO_2 respectively. These rates also cover a range of marginal abatement costs as reviewed by Carraro and Favero (2009), corresponding to the estimates of the social cost of carbon. See, for instance, a review by Tol (2009).

(*ls)*, or through cuts in obligatory health and social security contributions paid by employers (h*sc)*. These alternatives are considered for the scenarios A, A+C, and A+C+M.

TABLE 1. Definition of policy scenarios

Acronym of the policy	Air pollutant tax		CO_2 tax		Revenue recycling
	tax rate	Imposed tax on	tax rate	Imposed tax on	
A	full int	comb	NA	NA	no
A_ls	full int	comb	NA	NA	lump sum
A_hsc	full int	comb	NA	NA	hsc
C17	NA	NA	17€	comb	no
C	NA	NA	30€	comb	no
C+M	NA	NA	30€	comb+mobile	no
A+C	full int	comb	30€	comb	no
A+C_ls	full int	comb	30€	comb	lump sum
A+C_hsc	full int	comb	30€	comb	hsc
A+C+M	full int	comb	30€	comb+mobile	no
A+C+M_ls	full int	comb	30€	comb+mobile	lump sum
A+C+M_hsc	full int	comb	30€	comb+mobile	hsc

Note: NA: Not applied; "*comb*" and "*mobile*" denote combustion of fossil fuels in stationary emission sources (power plants), or mobile sources (transport), respectively; "*full int*" refers to full internalisation of the external costs, that is, the rates of air pollutant tax equals to the damage costs; "*hsc*" is revenue recycling through obligatory payments to health and social security insurance paid by employers, and "ls" recycles the revenues via lump-sum. Following rates are assumed to tax local pollutants: €21,389 per t of PM, €10,409 per t of NOX, and €9,267 per t of SO2 (all in 2000 Euro).

4. Key Results

The results of the complex set of scenarios investigated are divided into the environmental effects, the economic effects and the effects in terms of the different dividends as described earlier in the paper. Details are given in Tables 2, and 3. Here we focus on results likely to be of interest to policy makers.

Environmental Effects

The environmental effects are laid out in Table 2. One clear finding is the higher impact of pollution taxes than CO_2 taxes on both pollution and CO_2 emissions. For example NOx[14] emissions fall by around half and CO_2 emissions by around one third with the set of pollution taxes, while the fall with a CO_2 tax is 13-20 percent for NOx and 22-30 percent for CO_2. Thus if only one set of taxes can be applied, from an environmental point of view it would be better to go for local pollution taxes.

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[14] NOx has been chosen as representative of the local pollutants. Similar results hold for other local pollutants.

TABLE 2. Percentage Deviations in Emissions from BAU (or compared to the 1990 base)

	A	A_ls	A_hsc	C17	C	C+M	A+C	A+C_ls	A+C_hsc	A+C+M	A+C+M_ls	A+C+M_hsc
Total effect including the abatement												
NOx	-49.5	-49.3	-49.1	-13.1	-17.0	-19.8	-53.0	-52.5	-52.2	-56.1	-55.4	-55.0
SO_2	-58.0	-57.9	-57.9	-26.5	-34.6	-34.3	-64.4	-64.2	-64.1	-64.3	-64.2	-64.0
PM	-54.4	-54.1	-53.9	-6.7	-8.9	-10.3	-56.8	-56.2	-55.7	-58.4	-57.6	-57.0
VOC	-6.8	-6.4	-6.0	-3.4	-4.6	-7.8	-8.2	-7.2	-6.3	-11.5	-10.4	-9.3
CO	-5.3	-4.9	-4.6	-2.2	-3.6	-6.4	-7.6	-6.7	-6.0	-10.5	-9.5	-8.6
CO_2	-32.4	-32.3	-32.2	-22.2	-28.9	-29.7	-39.0	-38.7	-38.6	-39.9	-39.5	-39.3
CO_2, 1990 base	-45.2	-45.1	-45.0	-36.9	-42.3	-43.0	-50.5	-50.3	-50.2	-51.2	-51.0	-50.8
Effect excluding the end-of pipe abatement												
NOx	-21.5	-21.2	-21.1	-13.1	-16.9	-19.7	-24.9	-24.4	-24.1	-27.9	-27.3	-27.0
SO_2	-48.0	-47.9	-47.9	-26.5	-34.6	-34.3	-54.3	-54.2	-54.1	-54.3	-54.1	-54.1
PM	-12.8	-12.4	-12.3	-6.6	-8.9	-10.3	-15.1	-14.4	-14.0	-16.6	-15.8	-15.3

Note: Scenarios labelled by A refers to policies imposing tax on local air quality pollutants stemming from stationary combustion emission sources with the rates equal to the external costs associated with respective pollutant, while C and C17 refers to carbon tax with the rate at 30€, and 17€, respectively, imposed on combustion processes.

A second question that comes up naturally is what happens when both local pollutants and CO_2 are taxed together as opposed to only one or the other being taxed. Taxed together the impact is greater on both emissions, as one would expect, but the additional effect is asymmetrical: adding a CO_2 tax on top of a pollution tax has a much smaller effect than adding a pollution tax on top of a CO_2 tax. This may be due to complex output and general equilibrium effects, with each comparison in any case starting with a different baseline reduction. To a policy maker one would say that going for 'full taxation' – i.e. covering both local and CO_2 emissions will reduce total local emissions by a few percentage points compared to a 'local pollution sources only' tax but by a significant amount compared to a CO_2 only tax.

A third question any policy maker might ask is about the impacts of coverage: how much does it matter whether mobile are sources are covered by the CO_2 tax? It turns out that including mobile sources does not make a big difference: CO_2 emissions fall by about one percent more and local pollutants by one to two percent more. Related to that a policy relevant question is how much difference does it make what rate of tax is imposed on CO_2? Here it turns out that a tax rate of 30€/ton as opposed to 17€/ton reduces CO_2 emissions by an additional 7 percent and those of other pollutants by an additional 2-8 percent. Finally we can inform the policy maker that the method of recycling of the tax revenues from the taxes makes little difference to the environmental impact.

An additional point of interest to various stakeholders would be to find out where the reductions in emissions come from as a result of the pollution or other taxes. As noted there are three pathways for emissions reductions: a reduction in output, a switch to less polluting inputs and end of pipe abatement of emissions. All three play an important role but our hybrid CGE model model has been innovative in showing the relative importance of end of pipe abatement. Depending on the scenario, this turns out to account for around 16% of total SO_2 emissions reductions, 50-57% of NOx reductions and 71-77% of PM reductions (compare the lower and the upper part of Table 2).

The effect on energy use is important and ranges betwen a reduction of 5 % (C17) and 12.5 % (A+C+M). The largest effect of the taxes is on coal, where carbon taxes could cause a reduction of 24-32 %, pollution charges a reduction of up to 38%, and the two instruments combined reduce coal demand by 45 %.

Economic Effects

The economic effects are reported in Table 3. They give the changes in major macroeconomic indicators including; GDP, unemployment, welfare as measured in terms of equivalent variation (but without environmental benefits), environmental benefits in monetary terms and total welfare including environmental benefits. All policy scenarios show a decline a GDP of between 0.5 and 1.9 percent, the larger declines arising when both sets of taxes are imposed. These are not large declines and furthermore GDP as a measure of welfare is flawed, but it is still politically significant.

TABLE 3. Macroeconomic indicators [% BAU]

	A	A_ls	A_hsc	C17	C	C+M	A+C	A+C_ls	A+C_hsc	A+C+M	A+C+M_ls	A+C+M_hsc
GDP	-0.7	-0.7	-0.5	-0.5	-1.0	-1.2	-1.7	-1.7	-1.1	-1.8	-1.9	-1.1
GDP change [bln. CZK]	-21.8	-21.9	-13.5	-16.2	-29.9	-35.2	-49.6	-49.9	-32.1	-55.1	-55.4	-33.2
GDP level [bln. CZK]	2961.7	2961.5	2970.0	2967.3	2953.5	2948.2	2933.9	2933.6	2951.3	2928.4	2928.1	2950.3
Consumer price Index	1.1	1.1	1.2	0.5	0.8	0.9	1.8	1.9	2.0	1.9	2.0	2.2
Output	-0.2	-0.2	0.2	-0.1	-0.2	-0.3	-0.6	-0.6	0.3	-0.7	-0.6	0.5
Export	-0.2	0.0	0.7	0.0	-0.1	0.0	-0.8	-0.4	1.1	-0.7	-0.2	1.7
Import	-0.2	0.0	0.7	0.0	-0.1	0.0	-0.6	-0.2	1.4	-0.5	0.0	2.0
Private Consumption	-3.5	-2.3	-1.6	-1.5	-2.5	-3.2	-5.2	-2.8	-1.2	-5.9	-2.9	-0.9
Public Consumption	2.5	0.0	0.0	2.7	3.9	5.2	5.2	0.0	0.0	6.5	0.0	0.0
Corporate income Tax	-5.5	-5.3	-4.0	-2.7	-4.2	-5.1	-8.2	-7.9	-5.2	-9.0	-8.7	-5.3
Excise Tax	-4.8	-4.5	-4.2	-2.4	-3.6	-5.6	-6.3	-5.7	-4.9	-8.4	-7.7	-6.7
Personal income tax	-4.7	-16.8	-2.5	-1.8	-3.0	-3.8	-6.8	-32.2	-2.2	-7.6	-39.5	-1.9
Social security contributions	-0.7	-1.1	-6.9	0.5	0.5	0.4	-0.9	-1.6	-13.7	-1.0	-1.9	-17.0
Value added tax	-3.7	-2.7	-2.0	-1.7	-2.7	-3.4	-5.7	-3.6	-2.2	-6.3	-3.7	-1.9
Revenues from enviro taxes [bln. CZK]	1.0	1.0	1.0	21.9	32.9	44.2	25.1	25.1	25.1	36.5	36.6	36.8
Demand for labour	-0.3	-0.5	0.2	0.2	0.2	0.2	-0.4	-0.7	0.8	-0.5	-0.9	1.1
Labour cost	-0.4	-0.6	-2.2	0.3	0.3	0.2	-0.5	-0.9	-4.2	-0.6	-1.0	-5.1
Unemployment, % change from 8 % at the benchmark	3.8	5.6	-2.8	-2.5	-2.5	-2.1	4.8	8.5	-9.1	5.3	9.9	-12.1
Unemployment rate [in percent]	8.3	8.4	7.8	7.8	7.8	7.8	8.4	8.7	7.3	8.4	8.8	7.0
Health and social insurance			-10.2						-21.2			-26.4
Welfare (EV) [bln. CZK]	-50.3	-33.8	-22.9	-22.2	-36.3	-46.3	-76.2	-41.6	-18.6	-86.5	-43.2	-14.5
Environmental benefits [bln. CZK]	112.3	111.9	111.7	46.5	60.5	63.4	125.0	124.1	123.6	128.3	127.3	126.6
Total welfare [bln. CZK]	62.1	78.1	88.8	24.3	24.2	17.2	48.7	82.5	104.9	41.8	84.1	112.2

Note: Scenarios labelled by A refers to policies imposing tax on local air quality pollutants stemming from stationary combustion emission sources with the rates equal to the external costs associated with respective pollutant, while C and C17 refers to carbon tax with the rate at 30€, and 17€, respectively, imposed on combustion processes. Scenarios labelled with "M" also impose carbon tax on mobile sources (i.e. transport). The terms "ls" and "hsc" denote to the recycling additional revenues via lump-sum or lowering the obligatory payments to health and social security insurance paid by employers, keeping the revenue neutrality.

The effects on unemployment are varied and important. The local pollution taxes increase unemployment by 3.8%[15]. On the other hand carbon taxes by themselves result in a small *decline* in the unemployment rate, as the tax shifts demand away from the more energy intensive goods to the more labour intensive ones. The two taxes taken together, however, cause an increase in unemployment of between 5.3% (A+C+M, when the revenues are not recycled) and 9.9% (A+C+M_ls, when the revenues are recycled through a lump sum tax). Imposing carbon and air emission charges simultaneously (Scenario A+C+M), generates additional revenue equivalent of 1.2% of GDP, which can be either used to cut social security contributions paid by employees by 21% (from 35 to 28 percent points of gross wage), or to provide a lump-sum payment to households (that is an equivalent of 2.1% of household consumption). If the revenues are recycled through lower health and social security quasi-taxes, there is a fall in unemployment of 2.8 % (A), 9.1 % (A+C) and 12.1 % (A+C+M), respectively.

Another important result relates to the monetary value of the environmental benefits of the policy in terms of reduced damages against the loss of welfare from other economic sources. This loss is measured in terms of the equivalent variation (EV) of changes in outputs and prices of traded goods and services. Here there is a clear dominance of the environmental benefits over the losses EV in all cases. The net benefits are greatest when both sets of taxes are applied yielding an increase in net welfare of about 2-4 percent. In those cases, a greater net benefit is derived when the taxes are recycled through a cut in health and social security contributions compared to the case of recycling through a lump sum distribution.

The emissions taxes have quite intuitive winners and losers (Table 4): output is reduced in the sectors with high emission coefficients and high energy intensity and the size of the effect increases with the level of the emissions charge and the carbon tax.

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[15] Note the effect on unemployment is an increase on a per cent figure, so if unemployment was 8% in the benchmark, the actual increase of 3.8% change is +0.31% of labour force (resulting in the rate of 8.31 per cent).

TABLE 4: Percentage Changes in Output from BAU

	A	A_ls	A_hsc	C17	C	C+M	A+C	A+C_ls	A+C_hsc	A+C+M	A+C+M_ls	A+C+M_hsc
CHEMICALS	-51.0	-51.3	-52.2	-29.3	-40.7	-40.0	-61.5	-61.9	-63.1	-61.2	-61.7	-63.1
COAL	-38.5	-38.5	-38.6	-24.4	-32.0	-32.5	-45.7	-45.5	-45.8	-46.3	-46.2	-46.5
ELECTRCITY	-25.2	-25.1	-25.4	-16.3	-23.1	-22.4	-35.5	-35.3	-35.7	-34.9	-34.7	-35.1
METALLURGY	-14.6	-14.5	-14.5	-5.9	-10.5	-9.7	-22.3	-22.2	-22.1	-21.7	-21.5	-21.4
PETRO	-8.5	-8.3	-8.3	-4.2	-6.2	-9.5	-11.2	-10.6	-10.6	-14.5	-13.8	-13.8
HEAT	-7.6	-7.5	-7.3	-3.5	-5.5	-5.6	-10.4	-10.3	-9.9	-10.5	-10.4	-9.9
TRANSP_ROAD	-0.7	-0.3	0.1	-0.1	-0.2	-4.6	-1.1	-0.3	0.5	-5.6	-4.7	-3.7
PAPER	-3.5	-3.4	-3.8	0.3	0.2	-0.1	-4.3	-4.1	-4.9	-4.5	-4.3	-5.1
FOOD	0.4	0.8	0.8	0.6	0.8	-0.9	0.6	1.5	1.5	-1.2	-0.1	0.0
AGRICULTURE	1.2	1.5	1.3	1.0	1.5	-1.1	1.9	2.5	2.1	-0.8	-0.1	-0.5
SERVICES	-0.3	0.1	0.5	0.2	0.2	0.1	-0.5	0.4	1.2	-0.7	0.4	1.4
CONSTRUCTION	-0.2	-0.2	-0.1	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.2	-0.2	0.0
TRANSP_OTHER	1.1	0.8	0.7	1.2	1.9	1.1	2.4	1.7	1.3	1.6	0.8	0.4
MINERAL	2.5	2.5	1.8	1.6	2.2	1.1	2.8	2.7	1.2	1.7	1.6	-0.3
SERVPUBLIC	0.7	-0.7	-0.4	1.4	2.0	2.7	2.1	-1.0	-0.3	2.8	-1.0	-0.2
FORESTRY	1.7	1.6	0.6	3.4	5.0	5.7	3.9	3.8	1.6	4.6	4.5	1.8
MANUFACTUR	5.7	6.0	7.3	3.1	4.2	5.0	5.9	6.4	9.1	6.8	7.4	10.7
CLOTHES	8.4	9.1	12.4	4.3	6.7	7.5	12.2	13.8	21.4	13.2	15.3	25.1
GAS	69.8	65.4	37.0	32.1	52.4	69.0	113.0	101.5	35.8	138.2	122.0	35.4

Note: Domestic production of GAS sector represents only 4% of gas supply. A light grey colour represents a reduced output, a dark grey an increased output and no colour represents the sectors where there is minimal change.
Scenarios labelled by A refers to policies imposing tax on local air quality pollutants stemming from stationary combustion emission sources with the rates equal to the external costs associated with respective pollutant, while C and C17 refers to carbon tax with the rate at 30€, and 17€, respectively, imposed on combustion processes. Scenarios labelled with “M” also impose carbon tax on mobile sources (i.e. transport). The terms “ls” and “hsc” denote to the recycling additional revenues via lump-sum or lowering the obligatory payments to health and social security insurance paid by employers, keeping the revenue neutrality.

Dividends of Policy

We now return to the different kinds of dividends defined in Ligthart and van der Ploeg (1999) (see Figure 3). Based on the results in Table 3, we conclude the employment double dividend is only present in the case of carbon taxes alone or with recycling of revenues via lower labour cost (hsc scenarios), in particular with scenario A+C+M_hsc, which reduces unemployment by one tenth. The double dividend holds only in these scenarios. Without revenue recycling or with recycling via lump-sum payments, taxation of local pollutants results in a larger reduction in labour demand and hence higher unemployment. The reason is that, due to the non-linear tax interdependency, a policy that increases the price of particulates-intensive goods increases the distortion of the tax system significantly more than one that imposes tax on carbon only.

The social double dividend (when improvements in environmental quality are combined with increased public consumption) is reaped under all scenarios except the two that recycle revenues, where an equal yield constraint is applied. The triple dividend is only obtained when the carbon taxes are imposed by themselves (scenarios C's). Ligthart and van der Ploeg (1999) refer also to a "blue dividend" when conventional economic welfare is raised. We do not see this in any of the scenarios but would argue that this is not a matter of concern.

The net benefits (equivalent variation *plus* avoided environmental damage) are the greatest when both taxes are imposed with the revenues recycling through a reduction in payroll taxes and these benefits always exceed the negative effect on GDP.

The ancillary benefits related to air quality impacts on health and the environment are in a range of 36–75 € per each tonne of CO_2 avoided, see Table 5. A stand-alone taxation of carbon (B) generates the lowest benefits that are 36 €, whereas taxing local pollutant individually (A) results in the highest ancillary benefits, 75€ per tonne of abated CO_2. A policy that imposes taxes on both types of pollutants jointly generates local air benefits at 68 € / t CO_2 abated.

TABLE 5. Economic effects in Euro per ton of CO_2 avoided (Euro 2005)

	A	A_ls	A_hsc	C17	C	C+M	A+C	A+C_ls	A+C_hsc	A+C+M	A+C+M_ls	A+C+M_hsc
GDP benefit	-19.1	-19.4	-11.9	-20.7	-29.4	-33.8	-36.2	-36.6	-23.7	-39.3	-39.9	-24.0
Total welfare	54.5	62.0	82.3	31.0	23.8	16.5	66.5	74.4	34.9	29.8	60.5	81.1
Economic welfare (EV)	-44.2	-36.7	-16.5	-28.4	-35.7	-44.4	-24.7	-16.8	-56.2	-61.8	-31.1	-10.5
Environmental benefits – air quality improvements	75.2	75.2	75.2	35.9	36.0	37.3	67.7	67.7	67.7	68.1	68.1	68.1
Environmental benefits – climate change impacts avoided	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5

Note: exchange rate of 29.78 CZK per Euro (2005) is used. Scenarios labelled by A refers to policies imposing tax on local air quality pollutants stemming from stationary combustion emission sources with the rates equal to the external costs associated with respective pollutant, while C and C17 refers to carbon tax with the rate at 30€, and 17€, respectively, imposed on combustion processes. Scenarios labelled with “M” also impose carbon tax on mobile sources (i.e. transport). The terms “ls” and “hsc” denote to the recycling additional revenues via lump-sum or lowering the obligatory payments to health and social security insurance paid by employers, keeping the revenue neutrality.

5. Conclusions

This paper has analysed the impacts of local emissions charges based on marginal damages and charges on CO_2 for a small open economy, namely the Czech Republic.

The analysis was carried out using a static CGE model, with endogenous unemployment and a bottom-up abatement technologies module. The special feature of our approach is developing and using *a hybrid model* that involves a combination of top-down approach (classical economic CGE) and bottom-up approach (engineer modeling). In our case, the abatement sector is described via a step function at a relatively disaggregated level where each step represent a different technology, while other economic sectors are described via smooth cost function, as typical for CGE modelling. This model considers carbon taxes alone and emissions charges alone, as well both instruments imposed simultaneously. These taxes and charges were examined in conjunction with different recycling options for the tax revenues.

The results show that setting local emissions taxes equal to marginal damages would make major reductions in the taxed pollutants (NOx, SO_2 and PM), as well as complementary pollutants such as VOCs. These emission charges also result in major reductions in CO_2 even though it is not taxed directly. Conversely a tax on CO_2 by itself reduces the local pollutants (though not as much as the emission charges), while reducing CO_2 by less than that obtained from the emission charges. When local pollution charges and CO_2 taxes are combined the effect on local emissions is less than the sum of the two taxes together but more than that of each of them individually. These taxes also reduce the energy demand from fossil fuel sources (particularly coal) significantly.

In terms of the effects on the economic variables, the most notable is the impact on GDP. The high levels of emission charges would reduce GDP by around 0.7%. The CO_2 taxes would reduce GDP by between 0.5% and 1.2%, but the combined taxes could reduce GDP by as much as 1.9%. Moreover fossil fuel dependent sectors such as chemicals, coal, power and metallurgy are most affected.

While the loss of GDP is important it is a misleading evaluation of the policy, because it does not take account of the environmental benefits. These benefits are greater than the economic losses measured in GDP giving an overall net benefit. The net benefit is greatest when both taxes are imposed with the revenues recycling through a reduction in payroll taxes.

Other significant impacts are in terms of unemployment. The emission charges raise unemployment if they are implemented without the reduction of payroll taxes. Unemployment decreases either when carbon tax is implemented alone or when labour costs are decreased. When only a carbon tax is implemented, the increase in output in the labour intensive sector actually increases, and consequently labour demand, as a whole, increases. However, once the emission charges are combined with carbon taxation, most of the sectors decrease their output and overall labour demand decreases.

The competitiveness of environmental policy is a complex issue but our model allows for competitiveness to be affected when domestic taxes raise the costs of productions for goods where emissions are particularly high. This is a fundamental part of our model where international trade is open and based on competitive factors. We do have some effects on the taxes on competition and economic performance but they are not strong. The results show that the imports should not be affected by the analyzed policies, except for coal. Exports will increase in the non-energy-intensive and the biomass industries, but will decrease in the chemical, the coal, and the metal industries. The overall effect on the trade balance is slightly negative. We conclude that investments in energy-saving technologies are necessary in order to preserve international competitiveness. For further discussion we refer to Kiuila (2015).

These results are particularly relevant for an economy in transition they also hold to a considerable extent for all competitive small economies. The essential features of the technologies available to respond to the energy/carbon taxes and the responsiveness of the economy to taxes via international competition also hold across countries that have had a market economy for a much longer time. We develop specific hybrid model that addresses the abatement by novel approach that also allows to derive the environmental benefits.

While these conclusions are important, we feel that further work is needed in several areas. The market for emission permits should be added, labour-leisure choice is important to consider, and a dynamics version of the model developed. The EU ETS scheme, introduced in 2005, was not included in the model. Due to the very low market price of EU allowances and an over-allocation of allowances in the Czech Republic, introducing the EU ETS into our scenarios would not change the results much. Including it to define the benchmark would depend on how the carbon tax was applied. If our carbon tax became a floor price its effects would be slightly less than those predicted in the model, given that the price of a ton of CO_2 is currently under €5/ton CO_2. If the sector were exempt from the tax, however, the impacts of a carbon tax would be very much less. Future ETS prices, however, could change and that would have to be taken into account.

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