The Economic and Environmental Effects of Taxing Air Pollutants and CO2: CGE Model With Abatement Technologies And Sector-Specific Emission Coefficients

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Abstract

We analyze separate and collective impacts of local air emissions charges and CO_2 tax so as to understand the effects of a system of environmental taxes that reflects something close to the full internalization of external effects. The analysis was carried out using a static CGE model, with unemployment, bottom-up abatement technologies, and with sector- and fuel-specific emission coefficients. The model imposes environmental charges on several pollutants, as a result of which emissions can fall through three channels: reduced output, production factor substitution, and increased end-of-pipe abatement activity. The analysis shows that a full internalization of air pollution externalities can result in modest overall welfare gains. There are, however, differences in terms of employment and output impacts, depending on what combination of taxes are applied, which sectors are covered and how fiscal revenues are redistributed. Ancillary benefits of GHG mitigation related to air quality improvements exceed always GDP losses.

Keywords: CGE modelling; Abatement sector; Carbon taxation; Air pollution charging; Environmental benefits

1. Introduction

This paper brings together three important themes in the economics literature and in the public policy debate: the ancillary benefits (also referred to as co-benefits) of climate policy, the concept of externalities, and the use of environmental taxes to address both environmental and economic problems (sometimes referred to as the double dividend).

On the first, it is well known that climate change mitigation measures which result in reducing greenhouse gas emissions may also reduce emissions of other air pollutants, and as a result, improve air quality; conversely air quality improvement measures could also generate reductions in GHG emissions. Such multi-pollutant effects of policy has been measured in physical units to derive co-effects (for instance, Meyer et al. 1998) or in monetary terms to derive co-benefits (as, for instance, in Burtraw et al. 2003). The co-benefits have been quantified with (a) a linear programming partial equilibrium framework linked either to a macro economic model (Grossman et al. 2011) or to impact assessment modelling (e.g., Burtraw et al. 2003; Van Vuuren et al. 2006; Krook Riekkola et al. 2011; Rečka and Ščasný 2013), or (b) by use of a general equilibrium framework (e.g., Glomsrød et al. 1992; Scheraga and Leary 1993; the EPPA5 model developed within the MIT Joint Joint Program on the Science and Policy of Global Change, see Paltsev et al. 2005). For example, in a study for the EU, using a partial equilibrium energy model GAINS, Holland et al. (2011) estimate that the 2˚C stabilization scenario would also reduce SO_2 emissions by 60%, NOx by 46% and particulate matter by 19%. These reductions would lead to large health improvements and important co-benefits for ecosystems. The air quality co-benefits correspond to €43 billion per year by 2050 in the EU27 or around €24 for each ton of CO_2 reduced. Similar but less strong results are obtained by Markandya et al. (2009) for the EU, who show, however, much greater co-benefits benefits in fast growing countries such as China and India. These numbers demonstrate that the monetized co-benefits are very relevant to the policy discussion and need to be taken into account in determining the level of mitigation as well as the design of mitigation options. As pointed out by Burtraw et al. (2003), inadequately considered ancillary benefits could lead to an incorrect assessment of the net costs of mitigation policies and an incorrect identification of 'no regrets' levels of GHG mitigation, and, as a consequence, choosing a policy that would be unnecessarily expensive because of its failure to fully exploit potential ancillary benefits. For instance, Nam et al. (2013), by using the EPPA5 model, found that if China achieves its SO_2 and NOx emission reduction targets, as proposed in its 12 Five Year Plan, the corresponding carbon-mitigation potential exceeds China's official 17% CO_2 intensity reduction goal.

On the top of these co-benefits, GHG mitigation policies would also reduce the need to implement air quality regulation for other pollutants and thus avoid additional regulatory costs. To summarize, the existence of such benefits emphasizes the importance of exploiting synergies in the field of air pollution and climate change policies.

While the literature on ancillary benefits has grown immensely during past ten-twenty years, studies dealing with developing and transforming economies are relatively few (Morgenstern 2000). In the case of economies in transition we have Aaheim et al. (1997) and Aunan et al. (2000) who investigated the ancillary benefits of energy saving in Hungary. Ščasný et al. (2009) and Rečka and Ščasný (2013) examined the effect on and benefits due to both carbon emission and local air pollutants in the Czech Republic by a macro-econometric model and a linear optimization energy model, respectively, but neither one has paid a special attention to the ancillary benefits. Dudek et al. (2003) and Markandya et al. (2003) provide an analysis of ancillary benefits for Russia. The present paper is thus the first of its kind that question benefits of various policies on both carbon and local air pollutants using a standard modeling framework in a former transition economy, namely the Czech Republic.

On the externalities question, we also have a significant literature providing estimates of the quantitative importance of various external effects, such as emissions of key air pollutants. Yet governments have been reticent to impose charges on polluters at levels equal to the external costs, largely because they fear the disruptive negative effect on economy. As a result, the degree of internalization of the externalities of energy generation associated with air pollutants is very low. This holds even if the internalization estimate includes not only the air emission charges and any energy taxes but also the cross-subsidy for renewable energy (see Máca et al. 2012, Bye and Holmoy 2010). Moreover, due to the over-allocation of EU allowances for CO_2

emissions covering the 2005-2012 period, the externality related to climate change has not been internalized at all.

In addition to setting the prices right, the concept of externalities also allows us to express a wide range of physical co-effects in monetary terms and thus directly compare these effects with the economic costs involved. 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 part of the reason for 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 (for a recent summary see Markandya, 2009). A number of European models conclude that a switch in taxation from labor to carbon/energy will increase employment and reduce carbon emissions. At the same time it will increase GDP. Hence there is some agreement on this 'good news'. The differences are about the size of the impacts in employment, output and emissions. For the 1992 carbon/energy tax, which was assumed to rise to $10 per barrel of oil equivalent over about 7 years, the size of the employment impact ranged from 0.4 to 2.6 percent by the end of that period across the different models. This was for various groupings of EU countries and should therefore be treated with caution, but it is still instructive about the range of estimates. The GDP increases range from 0.4 to 2.2 percent. It is also interesting that more recent work, such as that carried out by the Danish national government to evaluate its carbon tax program *ex post* reveals impacts at the lower end of these ranges. Indeed rigorous evaluations of actual programs are very rare in this field and more are required.

This paper looks at the empirical issues in a somewhat more complex framework. We examine first the implications of taxes on key local air pollutants, without a carbon tax, to see what impacts they have on emissions and on key economic variables. The levels of the taxes are set at rates that correspond fully to the estimated marginal damage costs as given by recent European studies (see Preiss et al. 2008, Wissema and Dellink 2007, Kiuila and Markandya 2006); needless to say these rates are very much higher than any actually attempted in any economy. In addition we then superimpose a carbon tax, also set in a range that reflects the current consensus on the external costs from emissions of CO_2 through climate change. We do this to see the additional impacts as well as to understand the joint effects of the system of environmental taxes that reflects something closer to internalization of external effects in the case air emissions. [1]

In addition to the level of the taxes there are two other aspects of the tax structure that are explored in the paper. The first is the extent of coverage: whether the tax is on all sources or just some of them. In particular the inclusion or otherwise of mobile sources is an important dimension. The second is 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.

In summary we analyze seven scenarios:

a) Air pollution taxes at close to marginal damage levels on stationary emission sources (referred to in the paper as Scenario A)
b) CO_2 taxes at two different rates given in the literature on stationary emission sources (referred to as Scenarios B17 and B30)
c) CO_2 taxes on the higher rate given in the literature on stationary and mobile emission sources (referred to as Scenario B30M)
d) CO_2 taxes on the higher rate given in the literature **plus** taxes on air pollution at rates close to marginal damages with no recycling of revenues, with lump-sum recycling and with recycling via a payroll tax (referred to as Scenarios C30, C30-lsp and C30-ssp). In these last set of scenarios the carbon taxes are imposed on both stationary and mobile emission sources but the air quality taxes remain on only stationary sources.

This means that Scenario C30 consists of tax increases as assumed in Scenario A plus Scenario B30M. This allows us to evaluate the impacts of additional effects of different taxes and different levels of coverage and recycling without generating too many simulation results.

The analysis has been carried out for a small European economy (Czech Republic) using a state-of-the-art CGE model that allows for unemployment[2] in the labor market and

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[1] The revenue neutral model allows us to focus on the effect of a different structure of government subsidy/tax system on welfare, separating the fiscal effect coming from changing government revenues. (Martinez de Prera, 2000) In this paper, we focus on the direct effect of the structure of the fiscal policies on behaviours and thus keep the revenue neutrality in the model.

that includes options for abatement of a number of local pollutants in an innovative way that is explained below. The results demonstrate that the emission level of some pollutants, such as particulate matter (PM), has a strongly non-linear relationship with the emission charge rate. Using a unique environmental database, our energy-environment CGE model includes five types of fuels as factors, five local air pollutants (SO_2, NOx, PM, CO, VOCs) and CO_2 emissions, with emission coefficients separately specified for each type of fuel, each economic sector and household, and for three types of emission sources. Including the different emission coefficients across different energy source and sectors allows us to implicitly embed the difference in the abatement technology across sectors and energy type. We believe such CGE modeling 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. For this reason alone its results should be of particular interest.

The rest of the paper is structured as follows. Section II provides the institutional background, section III describes the model used, Section IV sets out the options considered, Section V reports the main results and Section VI sets out some conclusions and indications for future research.

2. Institutional background

There is quite a long tradition in the CEE region of using “market-based instruments” in environmental regulation, particularly air emission charges. These charges, however, have not been effective in achieving significant abatement; nor are they efficient with respect to correcting for negative externalities (Ščasný and Máca, 2009). Despite the fact that air pollution charges were among the first economic instruments introduced in the Czech Republic (as long ago as 1967, during the socially-planned system), the Czech Republic was one of the most polluted countries in Europe. Its economy was

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[2] The model set as a baseline the unemployment rate in 2005 (8%).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 to 10%. Prior to the crisis, in the boom the Czech economy experienced the lowest unemployment 5.8 % (OECD Economic Outlook database). Thus we have not calibrated our model at any extreme value of unemployment.

very intensive on pollution, natural resources and energy use; for instance, the Czech economy generated almost 16 tons of CO_2, 61 kg of PM or 0.2 kg of SO_2 per capita and used almost 500 tons per capita in the year 1990, i.e. the first year of economic and political transformation. To put it in perspective, the 16 tons of CO_2 in 1990 compares with 7.8 tones for the EU27 in 2008, with a level of GDP per capita that is more than 3 times higher than that of the Czech Republic in 1990.

Both the deep decline and re-structuring of the Czech economy in the first four years of the 90's caused a significant reduction in CO_2 emissions and total primary energy supply (by 23%, or 15% respectively). Moreover, as a response to the nation's bad air quality, a new Clean Air Act was introduced, based on a strict command-and-control regulation required polluters to fulfill emission targets by 1998. As a result the country saw large reductions in emissions of PM, SO_2 and NOx (by 90%, 86% and 47% respectively in 1999 compared to their 1990 levels).

Most of these improvements, however, occurred before 1994. Since that year CO_2 emissions and energy use have remained at a more or less stable level and the relative performance of both indicators has only improved thanks to increasing GDP. Newly introduced economic instruments in the 2000's were also ineffective due to low tax rates (energy taxes) and to the over-allocation of CO_2 allowances within the EU ETS. In the case of air pollutants only slight reductions were seen in the 2000s; once the operators fulfilled the emission limits set by the authority by 1998, the emission levels were reduced only slightly or not at all over whole 2000's.

Meanwhile, the Czech authorities discussed several options to make energy taxes and air emission charges more effective (Ščasný et al., 2009). At the end of 2000's, the Czech Ministry of the Environment made a proposal to increase the nominal rates for SO_2, NOx, PM and VOC emissions charges about 10-fold, but these rates would still represent only about 3% of pollutant-specific damage costs and, being well below the marginal costs of abatement, they did not motivate any abatement in emissions (Rečka and Ščasný, 2013). Nowadays, large stationary emission sources in the Czech Republic are regulated by several different instruments that include a tax on energy products and emission charges (both with quite small, ineffective rates), the EU ETS being enforced together with IPCC integrated permits and limits on pollutant concentration in flue gases.

It is clear from the above that the system of regulation of air pollution has not been that effective in the Czech Republic and has signs of being unclear and burdensome. There is therefore a strong desire to increase its efficiency.

At the same time there is a desire to reduce the heavy dependence on the taxation on labor; in the year 2005, about 50% of total public revenues were collected from labor taxation (personal income tax plus obligatory health and social insurance contributions). Tax on goods and services (value added tax, excise taxes, duties) brought about 28%, while taxation of profits contributed by 11%. The rest was collected from non-tax public revenues. The Czech government has made several attempts to introduce tax reforms that would shift the tax burden from direct taxation, especially from labor, towards to indirect taxes. These governmental attempts partly motivate the inclusion in this paper of a scenario that examines revenue recycling based on lowering labor taxation.

3. CGE model with abatement technologies

The Czech economy is described by a static Arrow-Debreu model of a small-open economy. It consists of 20 sectors, 7 factors of production – capital (K), labor (L), five energy factors (E) represented by gas, coal, oil, biomass, and electricity – one representative household, and government. The structure corresponds to that given by the Czech 2005 input-output table.

A sectoral classification of the model is described in Table 1, which provides the factors and materials (M) intensity and relative share of inputs demand per sector. For example, the labor share of total inputs used in the electricity sector (numbered by 19) is 6%, while capital, energy and other materials contribute 40%, 36% and 18% respectively in the production of electricity. This sector demands, however, only 1% of labor from the labor market, 4% of capital from the capital market, 12% of electricity from electricity market, and 1% of materials from the aggregated market of commodities.

<< TABLE 1. Products classification and input intensities >>

Emissions of SO_2, NOx, CO_2, CO, PM, VOCs are taken into account in the following ways. Emission reductions are possible through: (a) a substitution with less polluting production factors, (b) use of a technical abatement process, and (c) a reduction of the activity level. Producers and households are both considered as pollution emitters. We take into account emission coefficients per agent (19 producers and 1 household), per pollutant (6 types), and per source (3 emission sources that include fuel combustion at stationary sources, technological processes and mobile emission sources). Thus the model contains almost 1,500 specific emission coefficients. These coefficients are expressed in tons of pollutant per unit of economic output (GVA) that allows us to determine the increase in the production price due to any emission's charge.

The model can analyze a range of policy instruments, namely: emission charges, carbon and energy taxes, emissions permits, and command-and-control measures (e.g. 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 tax 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 (if any).

Like most CGE models, this one is based partly on the neoclassic theory of general equilibrium: it calculates the prices and volumes of production which equalize demand with supply in all markets and make marginal profits equal to zero in all sectors (further details can be found in the Technical Appendix[3]). For each good with an established positive price, aggregate demand equals to aggregate supply in equilibrium. In the situation of excessive supply the equilibrium price is set at zero. However, this equilibrium does not apply to the labor market, current account balance, and other parts of the model where market imperfections are explicitly accounted for.

Consumers

Final domestic demand is represented by households and government in order to distinguish between private and public consumption. All households in the economy have been aggregated into one household, which receives income from employment,

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[3] Available on request from the authors.

from a share of the firms' profits (including income from capital) and from the government. Private demand is represented by a Linear Expenditure System, while the public demand is described by a Leontief function (i.e. the relative shares are constant). The government collects taxes, makes and receives transfer payments and purchases goods and services. Expenditures by the government are exogenous but the revenue is modeled in detail to reflect the Czech tax system and includes nine tax categories. These are: value added tax, excise tax (for manufacturing goods, food and petroleum products), social security paid by employees, social security paid by employers, personal income tax, capital income tax, emission charges (including carbon tax), and other net taxes on products and production.

Producers

Producers are assumed to minimize costs subject to their production function. Total production of each sector is the sum of production of individual producers, however, the model assumes only a single producer for each sector. This means that the model does not allow for intra-industry competition, because there is a uniform price for the sector's output. Domestic competition comes only from other sectors and all firms are risk neutral. There are five categories of sectors:

- six types of energy (coal, biomass, gas and crude oil, coke and petroleum products, electricity, and heating);
- two types of services (market service and public service);
- two types of transportation (road and other);
- nine types of production (minerals, metallurgy, energy intensive production, energy non-intensive production, manufacturing, chemicals and petrochemicals, construction, food, and agriculture)
- pollution abatement

Sectoral output (except abatement) is determined by a Leontief technology for 14 materials (intermediate demand) combined with a nested CES structure (represented by 7 production factors). Figure 1 shows the schematic form of the production structure. All factors of production are mobile between sectors but labor and capital are only mobile domestically. In the case of the capital market, capital supply is fixed and demand is given by the CES production function. The market determines the price of capital so that demand and supply are equated.

As far as the labor market is concerned, there is assumed to be a fixed supply of labor and a nominal gross wage that responds to unemployment. The neoclassical axiom of flexible wages is suspended through the wage curve. This curve assumes that real wages are declining function of the local unemployment rate. Thus high unemployment leads to lower real wages. The intersection of this wage curve (not the supply curve) with the labour demand curve determines the employment level and labour cost. Labour supply curve determines wage rate for a given employment level. Finally, the difference between labour supply and employment level determines unemployment[4].

<< FIGURE 1. Production Structure >>

As far as the energy sector is concerned, the six 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 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. For example, coal and biomass enter at the bottom of the nest with a constant elasticity of substitution σ^{CB}. At the next level of the nested structure, gas and coal-biomass composite combine with another constant substitution elasticity σ^{GC}, etc. In the top nest, labor and composite capital-energy show trade off with a new value of σ^{LK}. In addition, there are 'feedstocks' -- i.e. goods and services such as heating that enter in the materials aggregate in the model using the Leontief function.

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[4] The first such wage curve was directly incorporated into CGE modelling by Rutherford and Light (2002). An alternative technique is to fix the nominal wage (Yin 2002). We followed the first technique, which is also the more popular (see Partridge, 2010; Kuester, 2007; Bhattarai, 2008) as it opens the possibility of unemployment if the demand for labor (which is determined according to profit maximization conditions) is less than the available supply at a gross real wage.

To summarize, the sector's objective is to minimize total cost for a given level of output, assuming free disposal. 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.

Pollution abatement

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). The way pathway (i) works is self-explanatory. 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 the pathway (iii) of end of pipe abatement there are 36 available abatement technologies for SO_2, 63 for NOx, and 61 - for PM_{10}. The data comes from "RAINS" - the bottom-up model developed by IIASA (Amann et al., 2004; more in Ščasný et al., 2010). We assume that the cost of abatement represents just a capital cost because no detailed information on other cost items is available. Emissions of CO_2 can be reduced through decreasing economic activity or fuel substitution, i.e. switching the energy source to cleaner one; as such, no end-of-pipe technology, such as carbon capture and storage, are implemented into our model.

There are a number of ways in which abatement technologies can be modelled.

We follow here an activity analysis approach as used by Kiuila and Rutherford (2013) 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 we have identified above. An alternative approach is to link CGE model with a bottom-up model in order to represent technologies explicitly (see Barker and Scrieciu 2010)[5].

Following the activity analysis, the abatement sector has a different structure from other sectors. 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 specific sector. There are only two inputs for abatement activity Q: capital and pollutants. 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.

The calibration of the abatement function is different from other production functions in the model. In this activity analysis approach we directly integrate a bottom-up cost curve into the CGE model. A disadvantage of this approach is the limited number of available technologies and once we have used all of them we have a bounded solution. An advantage is the possibility to identify active technologies in the counterfactual equilibrium. The potential to reduce pollution through technical abatement activities provides an upper bound on abatement in the model. The remaining part of pollution can be reduced only through decreasing economic activity or fuels substitution.

<< FIGURE 2a. Step versus smooth marginal cost curve >>

<< FIGURE 2b. Environmental instruments >>

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[5] Installations of abatement technologies can also be considered as inputs for the firms, as has been done within GEM-E3 model (Capros et al., 2008), rather than as an investment. The flexibility of this approach is limited and specifying explicitly marginal abatement cost (MAC) curve is data hungry. A precise and more flexible approach, and one requiring less data, is to specify the production function explicitly ~~in terms of pollution~~ abatement. To date, however, there have been only few such applications. The first was ~~by~~ Jorgenson and Wilcoxen (1990). Later Nordhaus and Yan *MC* mplemented a quadratic abatement cost curve. Ellerman and Decaux (1998) fitted simple analytical forms to a set of MAC curves and investigated the robustness of MACs with respect to abatement levels among regions. Hyman et al. (2002) implemented a constant elasticity of substitution abatement function. Dellink (2005) proposed an ordinary least square estimation to cover as much information as possible on the technical measures underlying the abatement options, while Revesz and Balabanov (2007) defined an average abatement cost function using a degree of abatement possibilities and a scaling factor.

Environmental policy

Four different environmental policies can be considered within the model. First, there are 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. 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. Emission charges imply that market price for good N grows to PN_2+t_{em}. The resulting gross welfare loss is the abatement expenditures (the dotted area) plus the market distortion (the dashed area). This is a result of a gain in a tax revenue (the grey rectangle) and loss in both producer and consumer surplus. The net effect on consumer surplus of the emission charges will be always negative. The net effect on producer surplus will depend on abatement possibilities and on the 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.

Second, the government can decide to tax the polluting goods directly as an output tax (t_n) and avoid the taxation of clean goods. Under this regulatory scheme, firms will never abate their emissions, because the tax is levied on the amount of output of polluting goods and this is independent from the abatement expenditures by firms. A similar interpretation can be applied for an excise tax.

Third, tradable emission permits can be implemented using emission quotas. One permit allows a sector to produce one unit of emission. Firms can obtain more permits by trading. The model allows for setting emission quotas using different regimes, but no international emission trading is possible. Firms can either buy all the permits they require through auctions, or the permit may be allocated for free based on past emissions (known as grandfathering). In either case a price emerges for permits, based on the demand and supply and that price is endogenous (opposite to the first policy instrument).

Fourth, revenue from emission charges (taxes) or auctioned emission permits can be recycled back to economy. Two recycling schemes are considered: lump-sum recycling and reduction of labor tax. In a system with lump-sum recycling, there is no difference between auctioned and grandfathered permits. In a system of labor tax reduction, we consider only a social security paid by employers.

The environmental instruments described above will lead to a different equilibrium. We start from the benchmark point, where environmental charges and output tax were already applied. Other described instruments of environmental policy were not applied in the Czech Republic at that period. Emission charges and auctioned permits would lead to the same equilibrium, if the issued permits are equal to the emission reduction under the tax scheme. Both instruments have an impact on the output of the firms who pay the charges (permits), but also on other firms as the prices of pollution intensive goods go up. The charges also impact on the trade sector, to the extent that they make imports more attractive relative to domestic goods, whose prices have risen.

Open economy

The model describes a small open economy. A new actor 'the world' represents rest of the world. The export supply is represented by a constant elasticity of transformation (CET) function, while export demand is infinitely elastic. When the elasticity of transformation is relatively high, there is little price 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 this 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 the goods produced in the country can be sold at higher prices than world prices to the extent that they are different from the corresponding goods in the world market. This implicit market power is expressed by elasticity of substitution equal 4 for all sectors (based on values in the literature), except the gas sector, where it is set at 20. This 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 that fuels (96% of supply).

Demand in the domestic market is met from domestic production and imports. Domestic supply depends on world prices and the elasticity of substitution as given above and domestic prices are determined so that domestic and imported supplies equal domestic demand. Neither export quotas nor import tariffs are present in the model (a free trade assumption), because they were relatively small in 2005 for the Czech economy. Thus c.i.f import prices are fixed and equal to f.o.b. export prices. We choose to define the exchange rate as a numeraire.

Computation of policy dividends

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 any improvements in environmental quality, *pink* is related to employment gains, *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 based on the results from our model.

<< FIGURE 3. Composition of Social Welfare and Corresponding Dividends >>

In our case, economic welfare, employment gains and public consumption are derived directly from the model. However, the environmental benefits are computed outside of the model. We consider that each unit of emission causes damage to human health, crops and loss of biodiversity i.e. negative external costs. Abated emissions therefore reduce such damages and thereby increase the environmental benefits. To derive this benefit in money terms, we multiply the volume of avoided emissions by the corresponding unit damage as estimated using the ExtemE method in the EU-wide research projects NEEDS and CASES (Weinzettel et al. 2012, Preiss et al. 2008). Specifically, we use following damage factors: for PM of €21,400 per ton, €9,270 for

SO_2, €10,400 for NOx and €23.5 for ton of CO_2 (all expressed in Euro 2005 prices). The environmental benefit based on these values is then included in the net changes in economic welfare.

4. Definition of Policy Scenarios

The primarily goal of our study is to analyse direct and ancillary effects of energy-climate policy package and air quality charges policy that would fully internalise external costs. Table 2 provides data on energy use and emissions from different sources and sectors for the base year, 2005. It shows that combustion of fossil fuel: ([1] in Table 2) accounts for most of the energy use and also for the highest share of emissions of CO_2, SO_2 and NOx in the Czech Republic. Mobile sources (row [2] in Table 2) and technological processes (row [3]) each account for about 10% of energy use and households for about 13%.

<< TABLE 2: Energy use and releases of pollutants by emission sources, Czech Republic >>

The environmental and economic effects of the regulation that was enforced in the base 2005 year are implicitly included in Social Accounting Matrix and hence embodied in the baseline scenario. The policies that we model are additional to the ones that were already in place in the year 2005. Our policies however do not assume other instruments that might have been implemented and enforced since 2006.

In our policy scenarios, we impose a tax on carbon with or without the simultaneous taxation of air pollutants and each of these policies is assumed to be introduced in the two most-energy intensive emission segments, i.e. fuel combustion [1] and mobile sources [2] related to business activity (Table 2). These two segments are responsible for almost 80% of total energy use, as well as a major part of CO_2, SO_2 and NOx emissions, and about a half of particulate matters. Thus they play the key role in environmental and energy policy.

The 19 producing sectors contribute differently to releases of pollutants that are regulated within our policy scenarios, as shown in Table 3. For example, fuel combustion in electricity and heat sectors is responsible for a majority of CO_2 emission released from these two emission segments, 45% and 18%, respectively. Mobile sources in total are responsible for only 15% of regulated CO_2 emission, and majority of them are generated by road transport, 5%.

<< TABLE 3: Energy use, CO_2 and air emission by sector as percentage of totals from all sectors >>

Overall then we define seven policy scenarios as detailed in Table 4. First scenario (A) increases actual air emission charges at the level of external costs that emissions of SO_2, NOx, and PM cause, that are €9,270 per tonne of SO_2, €10,400 per tonne of NOx and €21,400 per ton of particulate matters (based on the impact pathway approach of the ExternE method, see Preiss et al. 2008; Weinzettel et al. 2012). The actual rates of emission charges in the year 2005 are subtracted from the levels of externalities to get net effect of policy.

The next three scenarios assume only a carbon tax. In scenarios B17 and B30 the carbon tax is levied on emissions from fuel combustion only, while scenario B30M extends the coverage of taxed subjects and imposes the carbon tax also on emissions from mobile sources. The rates of carbon tax correspond to a carbon price as it has been estimated by the European Commission for a 20% or a 30% emission reduction target (EC 2010), that equal to €17 or €30 per tonne CO_2 respectively. These rates also cover quite well a range of marginal abatement costs as reviewed, for instance, by Carraro and Favero (2009), and correspond to the estimates of social cost of carbon, see, for instance, a review by e.g. Tol (2009).

Scenario (C30) combines two other scenarios: A and B30M. While in the scenario B30M we examine what is an effect of extending coverage of a carbon tax subjects to include mobile sources, in C30 we aim to assess effect of a policy that extends the tax base by imposing a tax on both carbon and air pollutants. We wish to examine in particular whether the effect of policy that tax carbon and air pollutants are different than a sum of effects of two separate scenarios.

The five policy scenarios described above (A, B17, B30, B30M and C30) do not assume any revenue recycling. The last two scenarios consider a revenue neutral tax reform and recycle all additional revenues either via a lump-sum payment to households (*C30-lsp)*, or via cuts in social security contributions paid by employers (*C30-ssc)*.

<< TABLE 4: Definition of policy scenarios >>

Overall, these policies imply direct costs related to the tax and charge payments in a range of 40 bln CZK (B17) to 172 bln. CZK (C30) that corresponds to a range of 0.5% to 2.0% of before-policy total costs (defined as total intermediate consumption plus labour and capital costs, net taxes and imports). Most of the sectors would bear costs less than 1% of before-policy costs, exceptions being the direct costs of (petro) chemicals, metallurgy and road transport. We also see that while the tax and charge burden could be up to 67% and 83% of the pre-policy level in the two power sectors: electricity and heating respectively. The direct costs however do not assume any behavioural response of agents, nor do they reflect general equilibrium effects and thus the direct costs should not be interpreted as the economic costs of policy.

5. Key Results

The analysis of the scenarios is divided into the four sections. All estimates are reported as percentage deviations from the BAU, which corresponds to the benchmark level in our analysis (i.e. the current systems of taxes and control).

5.1. Energy demand

The impacts of the different taxes on energy demand, including public consumption, are shown in Figure 4. We note the following:

a. The reduction in total energy demand is greater with pollution charges than with carbon tax.

b. A carbon tax at 17€/ton reduces total energy demand by 5%. Raising the tax to 30€/ton makes the reduction slightly larger at 7% and extending coverage to mobile sources raises it further to 8%. Thus the extension of coverage to mobile sources only has a small impact on energy demand.

c. Combining the pollution taxes and a carbon tax of 30€ makes the reduction in energy demand equal to 14% to 15%, depending on how the tax revenues are redistributed.

d. The largest effect of the taxes is on coal, where pollution charges could cause reductions by 40% and carbon taxes by 25-30%. The two instruments combined cause a reduction in coal demand by 45%.

e. The demand for petroleum products is affected notably when the carbon tax is extended to mobile sources.

<< FIGURE4. Energy consumption [% BAU] >>

<< TABLE 5: Percentage Deviations in Emissions from BAU >>

5.2. Environmental benefits and ancillary effects

As the policies intend, the volume of emissions is reduced with introduction of a carbon tax and air emission charges (see Table 5). We note that all scenarios suppose pricing of pollutants via taxes with rates that correspond to environmental damage, i.e. the external costs, attributable to concerned pollutant. While Scenario A imposes a tax on local air pollutants released from the stationary sources, scenarios B's impose carbon tax of 17€ per ton of CO_2, or 30€ respectively. Scenarios C's assume both types of pollutants are taxed with same rates as in Scenario A or B30. These policies, similarly as Scenario B30M, introduce then a stricter regulation not only on combustion sources, but also on transport. The following are worth noting:

a. Pollution taxes reduce emissions of the three local pollutants that are taxed (NOx, SO_2 and PM) by 58%. The carbon tax alone reduces these emissions by varying amounts: 7-10% for PM, 13-20% for NOx, and 26-35% for SO_2. Thus a higher carbon tax contributes to an additional reduction of 2-3% for PM, 8-9% for SO_2 and 4-7% for NOx. When both taxes are imposed together – C30 scenarios – the reductions in local pollutants go up from 58% to 61-64%.

b. The emissions of VOCs are also reduced even though there is no direct charge on VOC imposed in the policy scenarios, owing to the fact that VOCs emissions are directly related to energy from combustion sources.

c. The reduction in CO_2 is 34% when pollution charges are applied alone and 22-29% when CO_2 taxes are imposed alone. When both sets of taxes are imposed together the reduction in CO_2 is 41%.

d. If a policy is one of imposing a tax on carbon only (scenarios B17, B30, B30M), then the effect on PM is quite small, regardless of how stringent the carbon policy is and whether transport is taxed as well. However, if we impose a charge on local pollutants, including PM, (that is Scenario A and Scenario C30), then PM emissions are reduced by a proportionally larger amount (-60% compared to -10% in B's scenarios). Since our scenarios are imposing taxes on combustion processes sources only, including stationary and mobile, the affected tax bases are basically energy carriers. Due to the energy price increase, consumption of coal and oil is reduced more under A and C's scenarios than under "B" scenarios, reflecting the higher PM-intensity of coal and oil carriers. Consequently, taxation of local pollutants results in a larger reduction in labor demand and hence higher unemployment. This implies that, due to the non-linear tax interdependency, a policy that increases the price of PM-intensive goods would increase the distortion of the tax system significantly more than a policy that imposes tax on carbon only. Furthermore its policy effectiveness is compromised as a result. In fact, it seems that the carbon tax slightly increases labor demand, and hence can be welfare enhancing (see the assessment of dividends below).

e. As far as emissions reductions are concerned, the inclusion of mobile sources makes only a small difference.

f. As noted there are three pathways for reduction emissions. The relative importance of each of these is shown in Figure 5, which plots the respective shares for scenario C30 (similar results hold for the other scenarios). The figure shows that abatement technology is responsible for 10% reduction of SO_2 emission, 28% of NOx emission and 42% for PM. Output and factor mix changes account of 54% of the SO_2 reductions, 35% of the NOx reductions and just under 20% of the PM reductions. The dark bar in Figure 5 shows the remaining (net) emissions after the taxes have been imposed.

<< FIGURE5. Sources of Reductions in Emissions and Net Emissions Remaining >>

g. We compute cost of carbon as GDP loss per ton of CO_2 abated due to given policy. The abatement cost is the lowest under B17 scenario (about €19 per tonne) and the largest under C30 and C30-lsp (€47) due to larger negative effect of pollution taxation on GDP (see Table 6).

h. The effect of a policy can be also expressed in terms of environmental benefits measured as the reduction in external costs attributable to local air pollutants and CO_2 emissions avoided. The effect varies between 67-69€ (A-policies) and 110€ per ton of CO_2 avoided (C-policies). Adding to this a welfare impact due to reduction in consumption, the total welfare effect would be positive and range between 12€ (B30M) and 61€ per ton CO_2 avoided (C30-ssc).

i. If we consider all policies in terms of their carbon mitigation, the ancillary benefits of carbon mitigation (related to air quality impacts) would be the lowest for carbon pricing (B-policies), 29€-31€ per t CO_2 avoided. Local pollutant regulation (A-policy) would generate the highest ancillary benefits - 69€ per t of CO_2 avoided. Policy that simultaneously regulates both types of pollutants will generate then slightly lower ancillary benefits.

<< TABLE 6: Economic effects in Euro per ton of CO_2 avoided (Euro 2005) >>

j. Our analysis does show is that a policy of taxing only local pollutants (Policy A) exceeds the effect of all policies that are pricing carbon (Policies B's). Policy A would generate GDP loss of 31€ per t of CO_2 avoided, but it would also avoid externalities of about 90€ per t of CO_2 and yield total welfare of +51€ per t CO_2. On the other hand, B-policies would generate loss of GDP in a range of 19€ to 30€ per t of CO_2, avoid externalities of 67€-69€ and yield welfare gain of 12€ to 25€ per t of CO_2 abated. In this respect, a policy that prices local pollutants is economically more efficient than policies that tax carbon. Policy A is also more environmentally effective with respect to local pollutants and CO_2 reductions.

We also find that the emission reductions of simultaneous taxation of local pollutants and CO_2 (C30 scenario) would exceed the welfare gain of policy A or of policy B30M when introduced separately. It is true that the GDP loss with the

C30 scenario is larger (47€ versus 19€ to 31€ per t CO_2 avoided), but due to larger emission reductions, the welfare effect of Policy C30 exceeds the effect on welfare of all B-policies. Policy C is even welfare improving – resulting in higher total welfare than Policy A – if the tax revenues are recycled via lowering labor taxes. Positive effect on welfare requires that we consider both welfare from reduced consumption and welfare from environmental benefits.

5.3. GDP and Its Components

Components of GDP

Emission tax policies have their winners and their losers (Table 7). These results are quite intuitive: 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. Table 7 provides a colour-coded guide to the expected impacts for seven scenarios. The results are fairly similar across all the scenarios, with a few exceptions. 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. Output is reduced most in the energy intensive sectors (*Chemicals*, *Metallurgy*) and in sectors that supply emission-intensive energy factors (*Coal*, *Electricity* and *Petroleum)*. On the other hand, output is increased in *Gas* and *Forest* that supply environmentally-friendly energy. *Manufacturing* and other energy less intensive sectors (*Clothes*) would also benefit from emission taxation. Outputs in *Other transportation*, *Construction*, *Market and Public services*, and *Minerals* are not affected by emission taxing policies. An unusual sector is *Paper*. Although this sector consumes about 6% of total energy, it is responsible only for 1% of CO_2 emissions and the taxes analysed do not have a major impact on its output. This is a consequence of large share of biomass use in this sector. Except for three sectors, mobile sources taxation does not change sector outputs very much (compare B30 and B30M). Those three sectors are *Road transportation*, *Petroleum products and Agriculture*. While the output in the first is reduced due to higher costs of petroleum products, output in the second one is reduced as a consequence of reduced demand in the first one.

<< TABLE 7: Percentage Changes in Output from BAU >>

If we extend coverage of taxation to include both local pollutants and carbon taxes the sectoral effects are magnified (compare B30M with the C scenarios). Output of the losers is reduced further, and production of the winners is increased more. However, there are few sectors that were not affected by carbon taxing B-scenarios at all and that are now affected largely under C scenarios. Specifically, outputs in *Agriculture* and *Food* are reduced by 20% and 10% respectively, while the effect of carbon taxation on that sector was only -1%. This is a consequence of their large intensity on emission of air quality pollutants, but not on carbon emission.

The effect of the two recycling schemes appears especially in more labour-intensive sectors such as *Clothes* and *Manufacturing*. In those sectors, the output is increased when recycling via payroll tax, because of the decrease in burden of the labour taxation. *Road transportation* and *Coal* are also labour-intensive sectors (with labour shares higher than 20%) and the revenue recycling via payroll tax indeed increases slightly their output. This effect, however, is not sufficiently strong to balance large negative effect of higher energy prices caused by emission taxes. A small increase in *Coal* production and substitution between labour and the energy-capital composite are the reasons of reduced outputs in *Gas* and *Biomass* which are also very small in absolute terms compared to output of *Coal*.

The largest effect of emission taxation on output across all sectors is in *Gas* sector, where it can amount in some increase to more than 100%. We should note that this sector depends completely on the international market, because 96% of supply is imported. Thus, a huge relative increase of output is a consequence of a very small share (below 0.1%) of this sector in aggregate output.

Changes in GDP and Other Macroeconomic Measures

Table 8 summarises the changes in main macroeconomic indicators. We draw the reader's attention to the following:

a. The effect on GDP is negative in all cases, but quite small, ranging from -0.5% (B17) to 2.5% (B30M and C30). The lower rate of carbon tax alone reduces GDP by 0.5% and almost doubling the rate of carbon tax causes a 1% fall in GDP.

Local pollution taxes reduce GDP by 1.4% and combining the two taxes reduces GDP by 2 -2.5%. Recycling tax revenues via payroll tax cuts makes the reduction about 0.5% less than in the case of no recycling or lump-sum recycling.

b. Both imports and exports are affected by taxation policies slightly and by the same magnitude, so the trade balance is little affected by the tax changes.
c. Private consumption is reduced more significantly and the range of reduction is wide across the scenarios: from a low of 1.5% (B17) to a high of 5.9% (C30). A carbon tax by itself reduced consumption the least (1.5 to 2.5%) and a local pollution tax reduces it by 3.5%. Taking the two taxes together we get the large reduction of 5.9%, when there is no revenue recycling. With lump sum recycling the reduction is 3.8% and with recycling via a payroll tax it is 2.3%.
d. As expected, public consumption increases when taxes are collected and not recycled. When the taxes are recycled, however, the level of public consumption falls by 2.4 to 2.6%.
e. The effects on unemployment are varied and important. The high local pollution taxes would increase unemployment by 7.9% (note this is an increase on a per cent figure). The carbon taxes by themselves, however, 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 10.2% (C30, when the revenues are not recycled) or 13.3% (C30-lsp, when the revenues are recycled through a lump sum tax). Imposing carbon tax and air emission charges simultaneously (Scenario C30), generates about 31 billion CZK of additional revenue (or, an equivalent of 1.0% of GDP), which can be either used to cut social security contributions paid by employee by 19% (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). On the other had if the revenues from the joint taxes are recycled through lower social security quasi-taxes (C30-ssc), there is a fall in unemployment of 3.1%.
f. Finally we consider the effects on welfare. Conventionally welfare is measured in terms of the equivalent variation gains or losses, which take account of consumption of the goods and services in the input-output system. If we do

that we have losses given in the row "Welfare (EV))", ranging from 22.2 billion CZK (0.7% of benchmark GDP) to 85.5 billion CZK (2.9% of benchmark GDP). Such a measure, however, fails to take account of the environmental benefits generated by the reductions in emissions. If these reductions are valued at their marginal damages (see Section III) we get benefits ranging from 43.8 billion (B17) to around 132 billion CZK (across the three C Scenarios). These benefits are greater than the losses in EV in all cases. Hence all the policies have an environmental benefit that exceeds the EV loss, but the greatest is in the case of Scenario C30-ssc (when both local and carbon taxes are imposed and the revenues recycled through lower labour cost).

<< TABLE 8: Macroeconomic indicators [% BAU] >>

5.4. Dividends of the 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 8, we conclude the employment double dividend is only present in the case of carbon taxes alone (B17, B30, B30M) or in the case of carbon tax and environmental charges with recycling of revenues via lower labour cost (C30-ssc). The social double dividend is reaped under all scenarios except the two that recycle revenues, where the equal yield constraint is applied. The triple dividend is only obtained in the case when the carbon taxes are imposed by themselves (scenarios B). Ligthart and van der Ploeg (1999) refer also to a "blue dividend" when conventional economic welfare is raised. In no case we get this; we would argue, however, that the failure to get a blue dividend is not such a matter of concern. For example Heerden at al. (2006) found a triple dividend when environmental taxes are recycled through a reduction in food prices.

6. Conclusions

This paper has analyzed the impacts of local emissions charges based on marginal damages and charges on CO_2 for a small open economy, namely the Czech Republic. Previous studies had estimated that CO_2 taxes imposed at a European or even world-wide level would reduce emissions of CO_2 as well as associated local pollutants. But there have been no known studies looking at the combination of emission charges plus CO_2. The examined emission charges were set equal to the estimated marginal damages and were much higher (more than two orders of magnitude) than existing taxes.

The analysis was carried out using a static CGE model[6], with endogenous unemployment and with a bottom-up abatement technologies module attached to it. The model considers carbon taxes alone and emissions charges alone, as well as cases where the both instruments were imposed simultaneously. These taxes were examined in conjunction with different recycling options for the tax revenues. Taking account of the abatement technologies into the economic activity has enabled us to conduct more refined analysis compared to the existing literature.

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

In terms of the effects on the economic variables, the most serious is the impact on GDP. The high levels of emission charges would reduce GDP by around 1.4%. The range of CO_2 taxes would make smaller reductions in GDP (0.5% to 1.2%) but the combined taxes could have an impact as large as 2.5%. Moreover some sectors (i.e.

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[6] The model is calibrated to parameter based on the values in 2005, and thus answers the question, what would happen if a certain type of policy is implemented when the economy is in the situation as it was in 2005. The static model allows us to examine the details of the Czech economy and enviromental technology situations. On the contrary a fully dynamic model would allow us to explicitly embed the capital accumulation and change in consumption and production behaviour. However mentioned in Babiker et al. (2011), the fully dynamic model assumes the forward-looking of the agents, and some parts of the model have to be simplified.

those that are highly dependent on fossil fuels) would be much more significantly impacted. Notable among these are chemicals, coal and agriculture. Thus any government contemplating such a tax shift would have to prepare a phase in period that allowed these sectors to adjust to the higher taxes, with possible lower rates during a transition period.

Other significant impacts are in terms of unemployment. The emission charges would raise unemployment if they were implemented without reduction of payroll taxes. Unemployment decreases either when carbon tax is implemented alone or when labor costs are decreased. When the labor cost decrease, labor demand naturally increases. On the other hand, when only carbon tax is implemented, the increase in output in the labor intensive sector actually increases, and thus, consequently labor demand, as a whole, increases. However, once the emission charges are combined with carbon taxation, most of the sectors decrease their output and overall labor demand decreases. Most importantly, there are also environmental benefits that, when measured in money terms using separable welfare function are greater than the economic losses. These gains are greatest when both taxes are imposed with the revenues recycling through a reduction in payroll taxes.

While these conclusions are important, we feel that further work is needed in several areas. Market for emission permits should be added, labor-leisure choice is important to consider, and dynamic modeling will allow us to provide a long-term analysis.

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Tables

TABLE 1. Products classification and input intensities

Sector No.	Name of the product	CPA code	Inputs intensity [%]				Share of inputs demand [%]			
			K	L	E*	M	K	L	E*	M
1	Minerals	26	19	13	4	64	2	2	1	2
2	Metallurgy	27	10	6	8	76	2	1	4	4
3	Heating	40.3	13	8	27	51	1	0	3	1
4	Energy intensive	17,20,21	13	11	12	64	2	2	6	3
5	Energy not intensive	18,19,22	11	15	0	74	1	2	0	2
6	Manufacturing	12-14,16,25,28-37	10	10	1	79	13	17	5	32
7	Chemicals & petrochemicals	24	15	8	19	58	2	1	7	2
8	Construction	45	13	10	2	75	7	7	4	11
9	Food	15	11	8	1	80	3	2	1	6
10	Agriculture	1.5	28	16	5	51	3	2	2	2
11	Road transportation	60	22	20	9	49	4	4	5	2
12	Other transportation	61-64	29	9	2	60	9	4	2	5
13	Market service	40.2,41,50-55,65-74	28	16	2	54	37	27	7	21
14	Public service	75-99	19	34	8	39	11	26	16	7
15	Coal	10	29	20	6	45	1	1	1	0
16	Biomass	2	39	13	27	20	1	0	2	0
17	Gas & crude oil	11	56	5	38	1	0	0	0	0
18	Coke & petroleum products	23	3	1	79	16	0	0	23	0
19	Electricity	40.1	40	6	36	18	4	1	12	1
20	Abatement	NA	100	0	0	0	0**	0	0	0
	Total						100	100	100	100

Note: Inputs intensities are represented by net values.

*Energy factor composite does not include Heating (it is a part of materials in the model).

** There is no abatement process in the benchmark.

TABLE 2. Energy use and releases of pollutants by emission sources, Czech Republic 2005 [%].

Emission sources	Energy use	CO_2	PM	SO_2	NOx
[1] fuel combustion (sectors)	67	64	23	84	41
[2] mobile sources (sectors)	11	11	19	0	37
[3] technological processes (sectors)	9	14	10	6	8
[4] fuel combustion (households)	8	6	41	10	3
[5] mobile sources (households)	5	5	7	0	12
Total	100	100	100	100	100

TABLE 3. Energy use, CO_2 and air emission by sector as percentage of totals from all sectors

CGE sector	ENERGY USE		CO_2		PM		SO_2		NOx	
	comb	mobile	comb	Mobile	comb	Mobile	comb	mobile	comb	mobile
Minerals	0.5	0.2	0.3	0.2	0.3	1	0.2	0	0.1	0.5
Metallurgy	6	0.1	5	0.1	1	0.3	3	0	1	0.2
Heating	17	0.1	18	0.1	10	0.2	34	0	11	0.2
Energy intensive	9	0.2	1	0.2	6	0.5	2	0	1	0.5
Energy not intensive	0.1	0	0.1	0	0	0.1	0	0	0	0.1
Manufacturing	2	1	1	1	2	3	1	0	1	2
Chemicals & petrochemicals	5	0.1	6	0.1	3	0.2	9	0	4	0.2
Construction	0.2	1	0.1	1	0.4	3	0.1	0	0.1	3
Food	2	1	1	1	2	2	2	0	1	2
Agriculture	0.3	1	0.2	1	2	12	0.3	0	0.1	16
Road transportation	0.4	6	0.3	5	0.1	15	0.1	0.1	0.2	13
Other transportation	0.1	1	0.1	2	0.1	2	0	0	0	4
Market service	3	2	4	2	2	5	2	0	1	4
Public service	2	1	1	1	2	2	1	0	0.5	2
Coal	2	0.1	1	0.1	1	0.3	6	0	2	0.3
Biomass	0	0.1	0	0	0.2	0.2	0	0	0	0.3
Gas & crude oil	0	0	0	0	0	0	0	0	0	0
Coke & petroleum products	1	0	1	0	0.2	0	0.5	0	0.3	0
Electricity	36	0	45	0	25	0	41	0	30	0
TOTAL	**86**	**14**	**85**	**15**	**56**	**44**	**100**	**0**	**52**	**48**

Note: emission and energy use by technological processes and by households are excluded

TABLE 4. Definition of policy scenarios

	BAU (benchmark)	Scenarios						
		A	B17	B30	B30M	C30	C30-lsp	C30-ssc
Carbon tax [rate in € per t]								
CO_2	-	-	17	30	30	30	30	30
Subjects taxed	-	-	combustion	combustion	combustion & mobile	combustion & mobile	combustion & mobile	combustion & mobile
Charge on AQ emission [rates in € per t]								
PM	101	21 389	-	-	-	21 389	21 389	21 389
SO_2	34	9 301	-	-	-	9 301	9 301	9 301
NOx	27	10 409	-	-	-	10 409	10 409	10 409
VOC	67	-	-	-	-	-	-	-
Subjects taxed	combustion & technological	combustion	-	-	-	combustion	combustion	combustion
Policy parameters								
Revenues recycled	no	no	no	no	no	no	lump-sum	labour

Note: BAU scenario also includes a charge on CO emissions. Its rate of 20 € per ton is very small and the charging CO emissions generates negligible revenue. Air emission charge rates correspond to the nominal rates as valid since 2003 to date.

TABLE 5. Percentage Deviations in Emissions from BAU (Except last Row)

	A	B17	B30	B30M	C30	C30-lsp	C30-ssc
NOX	-58	-13	-17	-20	-64	-63	-63
SO_2	-58	-26	-35	-34	-64	-64	-64
PM	-58	-7	-9	-10	-61	-61	-61
VOC	-13	-3	-5	-8	-17	-16	-15
CO_2	-34	-22	-29	-30	-41	-41	-41
CO_2, 1990 base	-46	-37	-42	-43	-52	-52	-52

TABLE 6. Economic effects in Euro per ton of CO_2 avoided (Euro 2005)

	A	B17	B30	B30M	C30	C30-lsp	C30-ssc
GDP loss	31	19	26	30	47	47	37
Total welfare	51	25	18	12	29	48	61
Avoided external costs (benefits due to air quality and GHGs reductions)	90	67	67	69	110	110	110
Ancillary benefits (related to air quality improvements)	69	29	29	31	62	62	62

TABLE 7: Percentage Changes in Output from BAU

	A	B17	B30	B30M	C30	C30-lsp	C30-ssc
CHEM	-51	-29	-41	-40	-61	-61	-62
COAL	-40	-24	-32	-33	-47	-47	-47
ELEC	-23	-16	-23	-22	-33	-33	-34
AGRICUL	-19	1	2	-1	-20	-19	-20
PETRO	-16	-4	-6	-10	-20	-20	-20
METAL	-11	-6	-11	-10	-18	-18	-18
TRANSPR	-10	0	0	-5	-13	-13	-12
FOOD	-9	1	1	-1	-10	-9	-9
HEAT	-8	-4	-5	-6	-11	-11	-10
PAPER	-4	0,3	0,2	-0,1	-5	-5	-5
TRANSP	-0,2	1	2	1	-0,1	-1	-1
CONSTR	-0,2	0,0	0,0	0,0	-0,3	-0,3	-0,1
SERV	0,0	0,2	0,2	0,1	-0,4	0,4	1
SERVPUB	0,2	1	2	3	1	-1	-1
MINERAL	1	2	2	1	0,1	0,1	-1
FOREST	2	3	5	6	5	5	3
MANUF	10	3	4	5	11	12	14
CLOTHES	12	4	7	8	17	19	26
GAS	121	32	52	69	206	192	102

Note: Domestic production of GAS sector represents only 4% of gas supply.

TABLE 8. Macroeconomic indicators [% BAU]

	A	B17	B30	B30M	C30	C30-lsp	C30-ssc
GDP	-1.4	-0.5	-1.0	-1.2	-2.5	-2.5	-2.0
GDP [bln. CZK]	-42	-16	-30	-35	-75	-75	-58
Price Index	1.6	0.5	0.8	0.9	2.4	2.5	2.6
Output	-0.2	-0.1	-0.2	-0.3	-0.6	-0.6	0.3
Export	1.2	0.0	-0.1	0.0	1.1	1.4	2.9
Import	1.2	0.0	-0.1	0.0	1.1	1.4	3.0
Private Consumption	-3.5	-1.5	-2.5	-3.2	-5.9	-3.8	-2.3
Public Consumption	0.1	2.3	3.1	4.3	2.0	0	-0
Corporate income Tax	-7.9	-2.7	-4.2	-5.1	-11.2	-10.9	-8.6
Excise Tax	-9.1	-2.4	-3.6	-5.6	-11.9	-11.4	-10.6
Personal income tax	-7.1	-1.8	-3.0	-3.8	-9.9	-31.8	-5.9
Social security contributions	-1.5	0.5	0.5	0.4	-1.9	-2.5	-13.1
Value added tax	-3.9	-1.7	-2.7	-3.4	-6.4	-4.6	-3.2
Demand for labour	-0.7	0.2	0.2	0.2	-0.9	-1.2	0.3
Labour cost	-0.8	0.3	0.3	0.2	-1.1	-1.4	-4.3
Unemployment	7.9	-2.5	-2.5	-2.1	10.2	13.3	-3.1
Welfare (EV) [bln. CZK]	-50.8	-22.2	-36.3	-46.3	-85.5	-55.6	-34.0
Environmental benefits [bln. CZK]	119.0	43.8	57.0	60.1	132.7	132.0	131.5
Total welfare [bln. CZK]	68.2	21.6	20.7	13.9	47.2	76.3	97.4

Figures

FIGURE 1. Production Structure

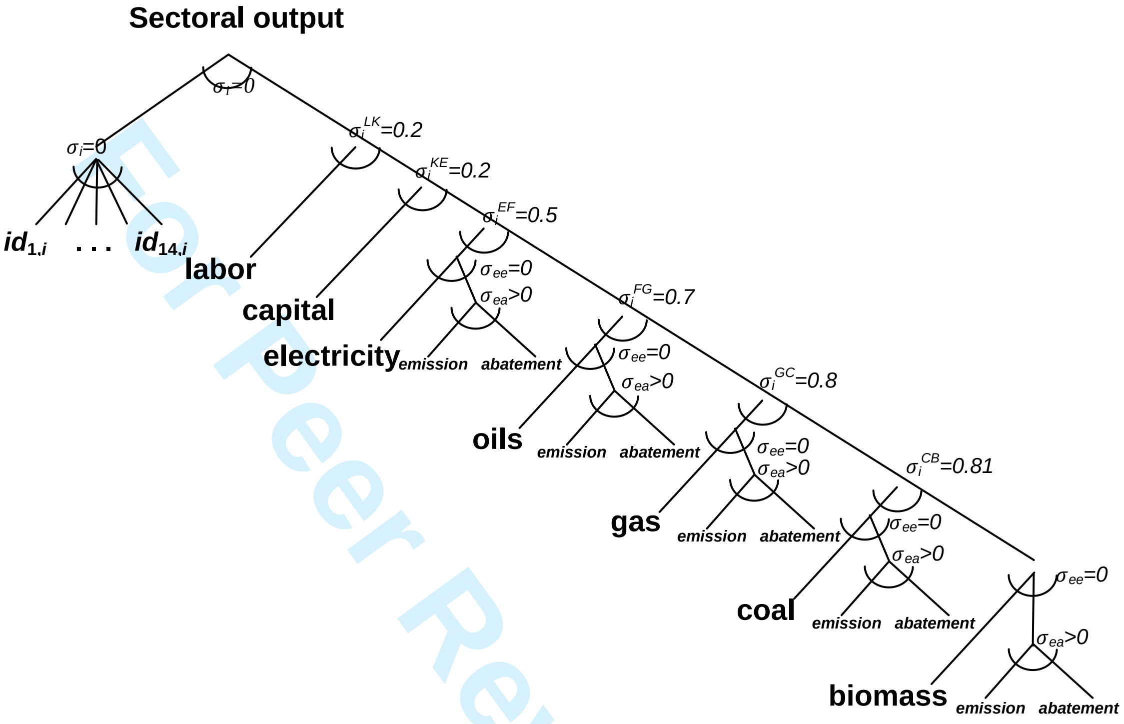


FIGURE 2a. Step versus smooth marginal cost curve

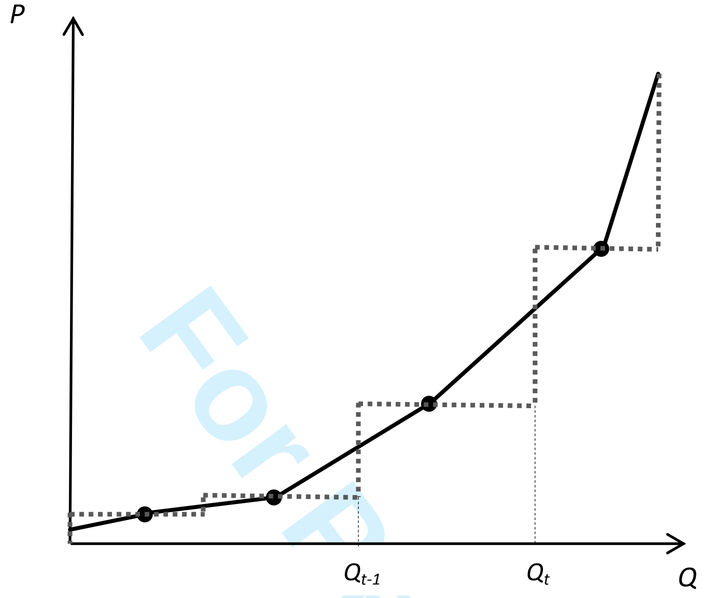


FIGURE 2b. Environmental instruments

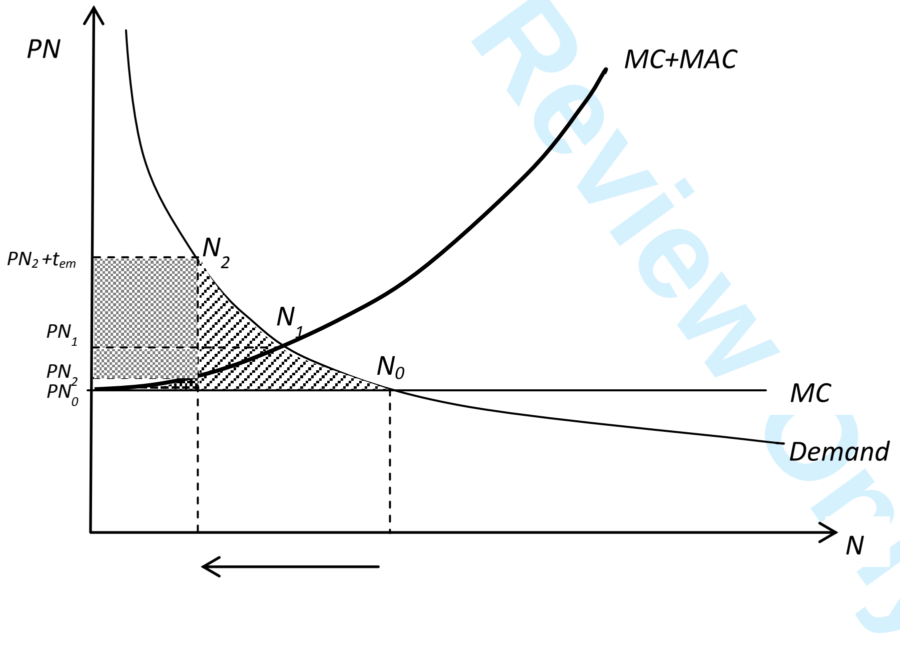
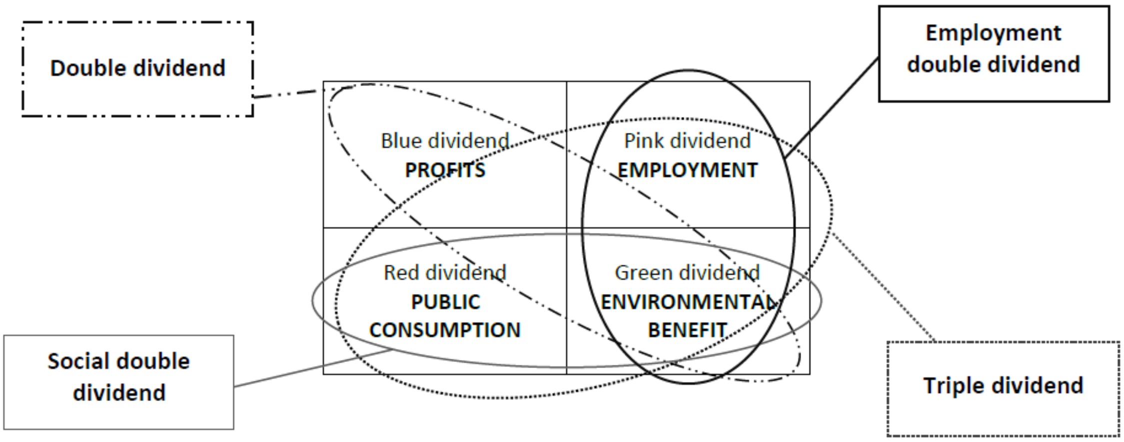


FIGURE 3. Composition of Social Welfare and Corresponding Dividends



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

FIGURE 4. Energy consumption [% BAU]

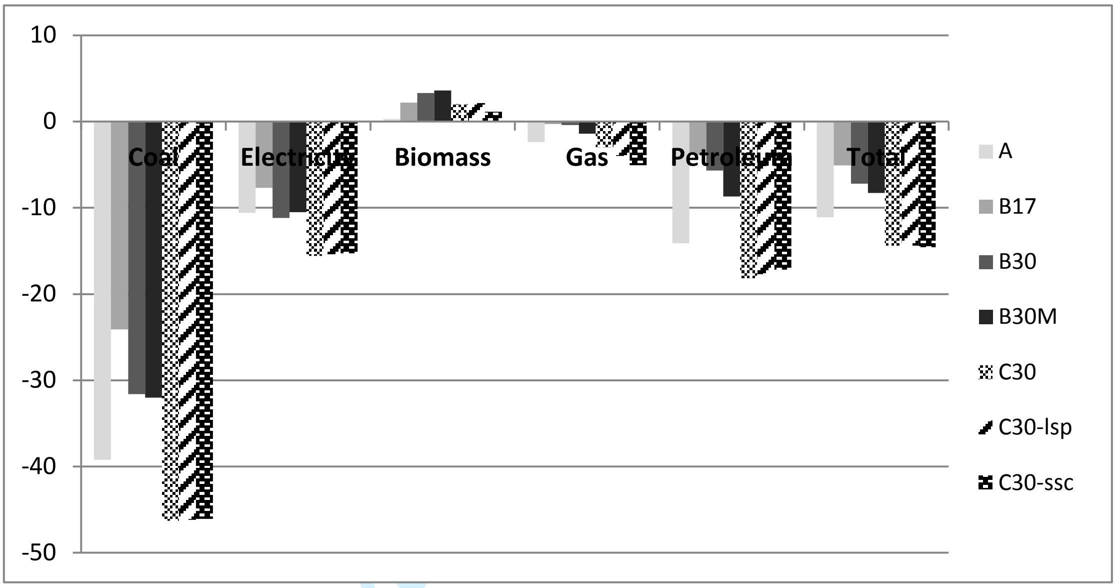


FIGURE 5. Sources of Reductions in Emissions and Net Emissions Remaining (% of BAU)