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Analyzing Macroeconomic Effects of Environmental Taxation in the Czech Republic with the Econometric E3ME Model*

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Abstract

Market-based instruments have gradually become a significant tool of environmental policy in central European countries. By using the structural macroeconometric E3ME model we compare two alternative green tax based policy frameworks in the Czech Republic. While the first imposes a tax on emissions of classical pollutants (particulates, sulphur dioxide, nitrous oxides, and volatile organic compounds), the second consists of carbon taxation intentionally set at the level equalizing environmental effect measured by externalities that are avoided as result of both reductions in emissions subject to taxation and ancillary effects. We also analyze impacts of revenue recycling. The comparison of economic impacts of both considered policy set ups indicates that policy aimed at the taxation of classical pollutants outperforms carbon policies in cases without revenue recycling. On the other hand, mainly due to significantly higher revenues from carbon taxation, when the revenues are recycled, a carbon taxation framework appears to be a better option.

1. Introduction

Environmental regulation has become an important part of policy being implemented in order to internalize externalities, reduce damage, and increase quality of life. These desirable effects are not however straightforward to achieve. Basically, whether policy would yield the effects or not would depend on behavioral responses, technology possibilities and the strictness of the instrument with respect to involved abatement costs.

So far environmental regulation in central planned CEE economies has been either very weak, or not properly enforced.[1] Although, we can find a huge number of environmentally-related levies introduced with hundreds of pollutants charged during

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[1] Despite bad air quality in the CEE region during the central planned period, we document a long history in environmental regulation and use of economic instruments. For instance, in the Czech Republic, the emission charge on airborne pollutants was already introduced in 1967. Although, the base rate of emission charge introduced in 1967 was based on abatement costs, if these costs were not possible to find “without disproportionally difficulties”, the rate was set at 100 CZK per tone of pollutant. Moreover, the charge was only levied on top of the emissions that exceeded the limit given by the law. On the other hand, an additional charge was levied on the top to base rate and calculated according to the air quality in specific areas, e.g. 100% in spa areas and 20% in industrial zones respectively; see more Máca et. al. (2009).

the transition period, these levies were neither effective, nor corresponding to the Pigovian rate.[2] Their real role has just remained to raise financial resources for environmental funds. Even this was done not by least costs; the most ineffective emission charges were connected with high administration and transaction costs, which were, in some cases, even higher than the collected revenues (Pavel and Vítek, 2009). Significant improvements in air quality were therefore reached mostly thanks to end-of-pipe installations involved by command-and-control regulation introduced in the 1990's. This, however, also involved high abatement costs without any improvement of firms' technologies.

Having ineffective and very costly economic instruments within the system, a question about optimal instrument design emerged. As a consequence of this policy, wider use of market-based instruments, in some cases introduced within revenue-neutral environmental tax reform (ETR), has been put forward. This was also the case of Czech policy. Since 2000, the Czech authorities started to prepare a concept of environmental tax reform mostly based on higher energy taxation, including the principle of revenue neutrality (see Brůha and Ščasný, 2005 for the details). Later on, the ETR's base moved towards carbon taxation, and more recently it has been relying on higher taxation on harmful airborne pollutants.

Environmental regulation is not, however, free of economic impacts. Intervention might harm the economy and reduce overall welfare; or, on the contrary, a double dividend might be reaped, technological progress enhanced or employment boosted. To evaluate the overall effect, economic models have been developed and gradually utilized.

A number of instruments allow the government to choose among a variety of environmental policy mixes. The impact of these instruments on the environment and the economy should play an essential role in making a decision about the particular mix of tools. Analyses of model-based policy scenarios and solution of "what if" questions are therefore a very useful approach to evaluating relevant policy impacts on the economy as whole.

When assessing the effects of particular intervention, running a structural macroeconomic model is a commonly adopted approach. This also holds for the CEE countries in that different types of macroeconomic models have been employed to assess the impacts in the area of monetary, structural or trade policies, or of the EU accession. Running a structural macroeconomic model has not however been the case so often while evaluating the impacts due to emission abatement or energy policies in CEE countries. In these cases linear programming or partial equilibrium models have been used instead. However, there are a few applications of structural macroeconomic modeling in the environmental area within the CEE region, in which the impacts of environmental policies have been assessed mainly by Computable General Equilibrium (CGE) models. Due to insufficient data and structural shocks during transition the more elaborated structural econometrically-based models have rarely been

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[2] To consult environmental effectiveness of these levies, one can compare their rates with abatement costs. This can be done by using abatement costs as reported, for instance, in the GAINS database, or shadow marginal abatement costs as estimated by the GEM-E3 CGE model (Van Regemorter, 2008). Regarding the Pigouvian rate, for instance, Zylicz (2002) found emission charge rates were one order lower than the Pigovian rate in Poland; Maca et al. (2009) draw similar conclusion by comparing actual emission charge rates and the values of respective external costs in several CEE countries.

used for environmental policy assessments, in many CEE countries not at all. This has also been the case of the Czech Republic.

To fill this gap, we use the E3ME model to assess the economic and environmental impacts of several – ETR relevant – policy scenarios for the Czech Republic. The E3ME[3] model, a *general Energy-Environment-Economy Model for Europe*, is an econometrically-based structural macromodel of Europe. It provides results for the case of the Czech Republic with respect to other economies in Europe. The parameters of the model for every country are estimated on historical time series assuming long-term relationships between economic variables. Therefore, the model differs from commonly used CGE models which are calibrated to gain equilibrium usually without econometric methods. The model, explicitly containing the links between energy, economy and the environment, is especially aimed at evaluation of environmental and energy policy. Therefore, employing the E3ME model in many respects fills the gap in up-to-date analyses of environmental taxes in the Czech Republic.

The novelties of our study are threefold: first, so far, a very restricted number of macro-econometric models have been applied in the environmental field at national level in the CEE region;[4] we apply the macro-econometric E3ME model in one of the CEE countries, namely the Czech Republic. Second, we update the Czech module of E3ME using very detailed environmental data and the most recent economic data, i.e. we use sector-specific pollutants of SO_2, NO_x, PM, CO, VOC, NH_3 and CO_2, the 2005 input-output table and updated parameter estimates. Third, we use the model to compare the impacts of taxes levied on harmful pollutants with the CO_2 tax. In fact, policies that mitigate climate change impacts are very likely to reduce other harmful pollutants. Similarly, policies that abate harmful pollutants such SO_x, NO_x or particulates may also change CO_2 emission levels. If the given model does not consider the ancillary effects, such evaluation would be incomplete.[5] Our model allows comprehensive assessment of the changes in all the above mentioned pollutants simultaneously. Moreover, we quantify respective damages due to changes in all of these pollutants in terms of external costs. This study therefore provides a rather complex impact assessment of emissions reduction which is the final novel contribution of this paper.

The paper is organized as follows: the second section provides a general overview of models applied for analysis of environmental policy, followed by a review of structural macroeconomic models employed in the case of the Czech Republic, in different fields of national policy, with particular focus on the environmental field. The third section provides a description of the methodology applied for the analysis, section four describes results from the E3ME model, for three different scenarios with the same effects on savings in external costs compared. Section five concludes.

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[3] See E3ME references at www.e3me.com; the E3ME model manual can be found at http://www.camecon-e3memanual.com/cgi-bin/EPW_CGI.

[4] For example, for the case of Poland, macro-econometric model W8D has been extended to capture impacts of CO_2 taxation (see Florczak, 2006). However in fact, macro-econometric models have been applied at EU level and used to assess the impacts of environmental policy in each Member State, including CEE countries (see below).

[5] See Barker and Rosendahl (2000).

2. Literature Review

2.1 Family of the Models

When addressing environmental policy, the linkages with the environment are a cornerstone of relevant economic models. Generally, there are two broad approaches in modeling the interaction between the environment, or a specific sector, such as energy, and the economy. Models putting emphasis on a detailed, technologically-based treatment of a sector are purely partial models to that sector, mostly lacking interactions and feedbacks with the rest of the economy. Benefiting from its bottom-up structure, a large amount of detail of the technologies available to that sector are embedded in the model structure; this is their main advantage. In general, these models allow description of the system by a wide range of technologies and factor mixes (such as fuel-mix of production in the case of the energy sector). As its disadvantage, this type of model lacks the framework to provide a comprehensive prediction of economic outcomes. Dynamic linear optimization or partial equilibrium models belong to this group.[6]

On the other hand, structural macroeconomic models are complex in their consideration of feedbacks and interactions between system components. They provide more precise predictions of macroeconomic developments given a particular set of assumptions and also give a better understanding of economy-wide implications of underlying economic processes. Moreover, depending on the level of disaggregation, the structural macroeconomic models allow for inspection of the influence of policy measures on chosen sectors, types of households or commodity trading. Therefore, structural macroeconomic models are a very useful tool in evaluating economic and environmental impacts in an integrated framework. A drawback of these models is however a relatively rudimentary treatment of each analyzed sector and the environment. The concerned sector –energy say– is described in a highly aggregated way usually by a neoclassical production function allowing substitution possibilities through substitution elasticities. However, most of these models do not include specific technologies in great detail and lack optimization processes to choose the best technology set, there are some applications that try to solve these drawback by having a specific module linked to the main parts of the model (such as the CGE GEM-E3[7] model, or the econometric E3ME model as examples).

These so-called top down models can be spilt into general equilibrium models and demand-driven Keynesian macroeconometric models. Of course, the classification has no sharp borders and present models usually have features of both groups; moreover there are a hybrid models as well (e.g. EUROGEM).

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[6] MESSAGE, EFOM-ENV, WASP, BALANCE are examples of supply optimization linear models. PRIMES (Capros, 2000), POLES (Criqui, Mima and Viguier, 1999), or TIMES (http://www.etsap.org/Tools/TIMES.htm) are examples of partial equilibrium energy models; while PRIMES is a modeling system that simulates a market equilibrium solution for energy supply and demand, POLES is an econometric, global energy partial equilibrium model. TIMES is an acronym of "The Integrated MARKAL-EFOM System" and as such combines the advantages of both the models it is build upon. For the case of the Czech Republic, EFOM-ENV has been regularly developed by Enviros, MESSAGE model has been constructed and applied for electric sector by Charles University Environment Center (see Ščasný et al., 2008; Rečka, 2009), and Bízek (2009) applies the GAINS model being developed by IIASA.

[7] For more detailed description of the model see: http://www.gem-e3.net/themodel.htm.

Unlike the partial equilibrium models, CGE models are complex in their consideration of feedbacks and interactions between system components. CGE models are usually based on microeconomic neoclassical grounds and general equilibrium in the economy (see e.g. Rutherford and Paltsev, 1999). The equilibrium is characterized by market clearing where supply and demand are equal as a result of price adjustments. Given this feature, the general equilibrium models assume equilibrium solution under perfect competition. Moreover, as implied in their name, there is full employment in the economy. Production functions, as well as household preferences, are usually captured by nested constant elasticity of substitution functions. Usually the models assume constant return to scale. CGE models disaggregate producers, as well as consumers, and assess impacts of environmental policy on these groups. Because the economy reaches the equilibria in time, CGE models rather serve for medium and long term evaluations of environmental policy. Despite these drawbacks, CGE models have become a very interesting and widely used tool for the analysis of environmental policy.[8]

The latter class of models is more econometrically based. They usually consist of long-run time-series data. This data allows econometric estimations of considered equations, ordinarily without economic equilibrium assumptions. They are usually open and have little structural detail but the econometric specification allows for the analysis of dynamic year-to-year changes. Therefore, they are better suited for short and medium-run evaluations and forecasting. They provide the development of endogenous variables in time, also in states of the economic equilibrium.[9]

2.2 The Structural Models Employed in the Case of the Czech Republic

The structural economic models of the Czech economy have addressed different issues, particularly monetary, fiscal and environmental policy. They have also touched on the impacts of EU accession and EU policy.

The macroeconomic models in the field of monetary policy and inflation targeting range from small models provided, for example, by Stavrev (2000a, 2000b) or Beneš et. al. (2003) to stochastic general equilibrium models analyzed in Beneš et. al. (2005), or Musil and Vašíček (2008).

Other macromodels have been used in addressing fiscal policy. While examining the impacts of various fiscal consolidation programs, Hurník (2004) uses a non-stochastic dynamic general equilibrium model. Voňka and van der Windt (2005) introduce a static core CGE model of the Czech economy. Dybczak and de Haan (2005) use the quasi-dynamic version of this model to derive trajectories of public debt and macroeconomic adjustments. Generally, the structural models have, in connection with fiscal policy, mostly been used in evaluating the effects on macroeconomic stabilization, sustainable levels of government debt, and evolution of the pension system. Another approach has been adopted in studying long-term growth, structural

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[8] An example of environment/energy CGE models is GEM-E3 (Mayers and van Regemorter, 2008), or HONKATUKIA; see Bergman (2005) for a review of CGE modeling of environmental policy and resource management.

[9] HERMIN (Bradley et. al., 1995; 2006), E3ME (http://www.e3me.com), E3MG (http://www.e3mgmodel.com), LEAN-TCM (for example in Welsch and Ochsen, 2004), GINFORS (Meyer and Lutz, 2007), or NEMESIS (Brécard et. al., 2006) are the examples of such models.

change, and the economic impacts of the EU accession and transition processes. For this purpose, the economic modeling can be characterized by models of endogenous growth (Kejak and Vávra, 2002 or Kejak, Seiter and Vávra, 2004) or CGE models (Ratinger and Toušek, 2004) or by medium-scaled econometric models.

Kejak and Vávra (1999a), as an example of the latter case, introduced the macroeconometric model HERMIN for the case of the Czech Republic. The model was based on the grounds of Bradley (1995a) and carries mainly Keynesian features, especially income expenditure mechanisms generated by the absorption and income distribution subcomponents. On the other hand, the model has also neoclassical features, in particular on the supply side.[10] The Hermin model has been used for inspection of the main issues associated with the transition from a centrally planned to a market-based economy (Kejak and Vávra, 1999a) and further developed by Kejak and Vávra (1999b), Barry et. al. (2003), or Bradley et. al. (2006). The Hermin model has on several occasions been used for analysis of issues related to the environment.

Modeling the impacts of environmental policy by means of structural macromodels has developed especially in the last decade. The main reasons for previous failures in the Czech Republic were both the lack of quality in the data resulting from transition of the Czech economy from central planned to market based and gradual adjustments to international statistical definitions. For the evaluation of the impacts of environmental taxes, neoclassically-based mathematical models have been most widely used. In this class of models CGE models with a different degree of disaggregation and incorporated dynamic largely prevail. [11]

CGE models are particularly well suited for long-term policy evaluations. The economy is characterized by optimizing behavior of agents and the possibility of substitution between production factors is allowed. Martin and Skinner (1998) investigated the impacts of various revenue-neutral tax schemes on economic activity and society welfare evaluated by a Hicksian welfare measure. Brůha (2001) uses a static CGE model of a small open economy in the evaluation of effects of a 5% increase in fossil-fuel prices with a simultaneous decrease in labor taxes, overall remaining revenue neutral. Brůha et. al. (2002) introduces a dynamic CGE model. The model was predominantly adopted from Bovenberg and van der Ploeg (1994) and Bye (2002) and combined neoclassical attributes, like maximizing behavior of agents, with market imperfections on labor and goods markets. The production functions allow substitution between capital, labor and a composite of energy, foreign and domestic goods. The labor market is characterized by highly centralized workers bargaining with domestic producers about wages and quantity of labor. A strong assumption about internationally immobile labor has been incorporated in the model. The quality of the environment is a part of households' utility function that is discounted via a standard exponential function in time. The weak separability of the utility function assures that the state of the environment does not affect the dynamics of the model. Ščasný

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[10] The initial version divided the Czech economy into four sectors, the latter version provided by Bradley et. al. (2006) uses five sectors, when the sector of building and construction was earmarked as a separated fifth sector.

[11] Simpler input-output models are based on a chosen number of linear equations describing the relationships among sectors of the economy with fixed input coefficients and therefore they are commonly used in making analysis of short-term impacts, where substitution is less probable; for the Czech applications see Zimmermanová (2009) or Weinzettel and Kovanda (2009).

and Brůha (2003) used the model for simulations of tax changes for the labor market characterized both by nominally-fixed and price-indexed unemployment benefits. While using the aforementioned model, Ščasný and Brůha (2004) discuss impacts of environmental tax reform in the Czech Republic up to the year 2032. Various types of revenue-recycling mechanisms are consequently discussed. The model has further been developed by Brůha (in Pavel et. al., 2006), who incorporated a more elaborated structure of production functions, a more detailed structure of public finance, and imperfect competition of domestic exports. Labor supply is modeled as a standard decision process between labor and consumption.

The system of tradable emission permits is another popular economic tool of environmental policy. Čížek, Pur and Spitz (2008) use a CGE model to study impacts of the introduction of an emission trading system on the economy. The model contains a comprehensive description of the energy sector and is also able to capture a gap in domestic product caused by international competitiveness. The domestic regulation pushes domestic producers' costs up causing the domestic goods to be less competitive in comparison with foreign supply where firms are not faced with so stringent environmental regulation. The model also allows producers to reduce emissions either by a decline in their production or by changes in the energy intensity of production. The last issue that has been elaborated in connection with the environment is the impact of changes in oil prices. Such a CGE model is used in Dybczak, Vonka and van der Windt (2008).

The impacts of most recent environmental and energy policies on the Czech economy were comprehensively assessed by Europe-wide models developed outside of the Czech Republic. Kouvaritakis et al. (2005) evaluate the effects of implementation of the EU Energy Tax Directive (2003/96/EC), CO_2 tax and climate policies by GEM-E3, a macro-sectoral general equilibrium model. The same model, but benefiting from detailed technological and abatement costs information provided by the bottom-up GAINS model and from damage costs provided by the ExternE project series, is used by Van Regemorter (2008) and Pye et al. (2008) to evaluate the macroeconomic impacts for a revised National Emission Ceilings Directive (with and without the climate/energy package for 2020). Considering all possible options to abate emissions, i.e. end-of-pipe abatement, substitution between fuels and/or energetic vs. non-energetic inputs for production, or production or consumption decline, is the main improvement of this model. The macroeconomic impacts, including the effects on the Czech Republic, of more recent environmental policies have been also evaluated by macro-econometric models. For instance, ENTEC 2008 study uses the E3ME model to assess the impacts of revisions to the EU's Emission Trading System and Energy Taxation Directive, while the macro-econometric model GINFORS evaluates the effects of several environmental/energy policy scenarios (Meyer, Lutz and Wolter, 2005; Meyer and Lutz, 2007). However, neither of these models has evaluated the macroeconomic impacts in one specific CEE country in great detail. This study fills this gap.

3. Methodology and Model

3.1 General Feature

The structural macroeconometric model E3ME is employed for the analysis. E3ME is an econometrically-estimated model that encompasses both long-term behavior and dynamic year-to-year fluctuations. The endogenous variables are determined by a set of twenty two pairs of equations which are disaggregated into regions and then into sectors. The relationships among the time series are based on the concept of cointegration stemming from Granger (1983), Engle and Granger (1987) and Hendry et al. (1984). The basic idea behind the concept states that even two non-stationary time series can have stationary linear combinations characterizing long-run equilibrium between them.

Briefly, take two I(1) time series.[12] The time series are cointegrated if residuals from their linear combination are I(0) meaning that they oscillate around some level and tend to move backwards towards it. It signals a long-term relationship between time series. Analyses of cointegration between time series can be conducted by an Engel-Granger two step procedure. In the first step, depending on the incorporation of trend, the long-term relationship of two I(1) time series is inspected by estimating the following equations, usually by simple OLS procedure.[13]

$$y_t = \mu + \beta x_t + \varepsilon_t \tag{1}$$

The stationarity test, usually the ADF test (see Kao, 1999; Gutierrez, 2003), on the residuals has to be performed in order to find out the existence of a long-term relationship between time series. If the null hypothesis is rejected, the time series of residuals is stationary implying that residuals tend to fluctuate and move towards the equilibrium point. Granger (1983) or Engle and Granger (1987) show that cointegrated time series can always be represented by an error correction model and vice versa. If the time series of residuals is stationary, the error correction model is estimated in the second stage. Such a dynamic equation then takes the following form:

$$\Delta y_t = \gamma_0 \Delta x_t + \gamma_1 \Delta y_{t-1} + \delta(ECT_{t-1}) + u_t \tag{2}$$

where ECT_{t-1} presents the residuals from the equation [1] lagged by 1 period. ECT is the error-correction term showing the speed of convergence to the equilibrium and is restricted to take a value between zero and minus one.

In the few cases where a cointegrating relationship cannot be found, the IDIOM software which underpins E3ME allows the econometric equation to be replaced with a simpler specification, for example based on country or European averages, or linked to a similar variable.

Each equation of the E3ME model is specified by the abovementioned process, i.e. the long-term relationship is estimated in the first step, then the dynamic relationship is estimated by plugging the error-correction term from the first step. E3ME is a relatively ambitious modeling exercise, which expands the methodology of long-term modeling to incorporate developments both in economic theory and in applied econometrics. To be in line with economic theory, the values of most long-term and dynamic parameters are restricted as either positive or negative, e.g. prices have a negative effect on demand (see the E3ME manual for detail). Moreover the process maintains flexibility and ensures that the model is operational.

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[12] I(1) postulates non stationarity (presence of unit root) of time series in levels and stationarity in first differences.

[13] This is for the case of two time series. For the more sophisticated processes of analysis of more than two time series see for example Johansen (1988).

In the Czech Republic and other CEE countries, a shrinkage technique is used to estimate long-term behavioral parameters. This is described in Spicer and Reade (2005) but essentially involves adopting a western-European average. The underlying assumption is that there will be long-run convergence within Europe and this technique avoids using short time series from transition periods as the basis for estimating long-term outcomes.

This set of equations represents the core of the model. Generally, the model is solved for 29 regions of Europe, but it has been particularly extended and recalibrated for the Czech Republic.[14] While the other regions are calibrated on the input-output tables of the year 2000, in the case of the Czech economy the data were updated to the year 2005. Furthermore, the emission sub-block has been added in order to model emissions of classical pollutants by sector and to be able to model the growing taxes on these types of emissions.

3.2 Core of the Model

In this section the equations which significantly influence the final outcome are presented. The rest of the core equations of the E3ME model can be found in *Appendix*. The aggregate energy demand equations represent an important link between economic output and energy demand. The equations are estimated in regions for all sectors in the following form:

$$\ln(FR0_i) = \alpha_1 + \alpha_2 \ln(FRY_i) + \alpha_3 \ln(PREN_i) + \alpha_4 \ln(FRTD_i) + \\ + \alpha_5 \ln(ZRDM) + \alpha_6 \ln(ZRDT) + \alpha_7 \ln(FRK_i) + \varepsilon_t \qquad (3)$$

$$\Delta\ln(FR0_i) = \beta_1 + \beta_2 \Delta\ln(FRY_i) + \beta_3 \Delta\ln(PREN_i) + \beta_4 \Delta\ln(FRTD_i) + \\ + \beta_5 \Delta\ln(ZRDM) + \beta_6 \Delta\ln(ZRDT) + \beta_7 \Delta\ln(FRK_i) + \\ + \beta_8 \Delta\ln(FR0(t\text{-}1)_i) + \beta_9 \Delta\ln(ECT(t\text{-}1)) \qquad (4)$$

where the restrictions on parameters are: $\alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7 \leq 0$; $\alpha_2, \beta_2 \geq 0$; and $0 > \beta_9 > -1$.

Energy demand in sectors (*FR*0)[15] is therefore positively dependent on the level of activity of the sector (*FRY*)[16], and negatively dependent on total investment of the analyzed sector (*FRK*), energy-efficient investments to R&D of that sector (*FRTD*), EU R&D investment in machinery (*ZRDM*) and EU R&D investment in transport (*ZRDT*). The R&D investments in the EU to machinery and transport reflect spillover effects. The asymmetry allows a negative relationship, but no positive as a result of non-reversibility of energy savings induced by rising energy prices (*PREN*).[17] Generally, the improvements in technologies lead to lower energy demand, all other things being equal.

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[14] The E3ME model has been designed, developed and is maintained by Cambridge Econometrics who updated its current Czech module in collaboration with Charles University Environment Center and the University of Economics in Prague. E3ME has been used in many national applications and more recently in assessing the energy-climate package for the European Commission.

[15] The energy demand equation is mainly based on the work Barker, Ekins and Johnstone (1995) and Hunt and Manning (1989).

[16] Usually approximated by gross output of the sector, in the case of households, the activity is approximated by consumer expenditures.

[17] See (Gately, 1993; Walker and Wirl, 1993; Grubb,1995) for further research on this topic. *PREN* is the price ratio of energy to total price level.

In addition to the aggregate energy demand function, E3ME also contains disaggregated energy demand functions for the four main energy carriers, i.e. coal, heavy fuel oil, natural gas and electricity. Therefore, equations (5) and (6) are estimated four times for each fuel as follows:

$$\ln(FRF_i) = \gamma_1 + \gamma_2 \ln(FR0_i) + \gamma_3 \ln(PFRF_i) + \gamma_4 \ln(FRTD_i) + \\ + \gamma_5 \ln(ZRDM) + \gamma_6 \ln(ZRDT) + \gamma_7 \ln(FRK_i) + \varepsilon_t \quad (5)$$

$$\Delta\ln(FRF_i) = \delta_1 + \delta_2 \Delta\ln(FR0_i) + \delta_3 \Delta\ln(PFRF_i) + \delta_4 \Delta\ln(FRTD_i) + \\ + \delta_5 \Delta\ln(ZRDM) + \delta_6 \Delta\ln(ZRDT) + \delta_7 \Delta\ln(FRK_i) + \\ + \delta_8 \Delta\ln(FRF(t\text{-}1)_i) + \delta_9 \Delta\ln(ECT(t\text{-}1)) \quad (6)$$

where the restrictions on parameters are: $\gamma_3, \gamma_4, \gamma_5, \gamma_6, \gamma_7, \delta_3, \delta_4, \delta_5, \delta_6, \delta_7 \leq 0; \gamma_2, \delta_2 \geq 0;$ and $0 > \delta_9 > -1$.

The demand for fuels (*FRF*) is only positively dependent on overall demand for fuels estimated in equations (3) and (4). On the other hand, the demand for a particular fuel is, in line with economic theory, assumed to be negatively dependent on its price (*PFRF*). The negative relationship with both sectoral (*FRTD* and *FRK*) and EU (*ZRDM* and *ZRDT*) investment and R&D is due to assumed higher energy efficiency in new products.

The consumption block of the model is very important for such types of models.[18] The reason is that consumption usually represents between 50 and 60 percent of final demand. In contrast to previous equations, the aggregated consumption is estimated for the whole region.

$$\ln(RSCP) = \zeta_1 + \zeta_2 \ln(RRPDP) + \zeta_3 \ln(RRLR) + \zeta_4 \ln(CDEP) + \\ + \zeta_5 \ln(ODEP) + \zeta_6 \ln(RVD) + \varepsilon_t \quad (7)$$

$$\Delta\ln(RSCP) = \eta_1 + \eta_2 \Delta\ln(RRPDP) + \eta_3 \Delta\ln(RRLR) + \\ + \eta_4 \Delta\ln(CDEP) + \eta_5 \Delta\ln(ODEP) + \eta_6 \Delta\ln(RVD) + \\ + \eta_7 \Delta\ln(RUNR) + \eta_8 \Delta\ln(RPSC) + \eta_9 \Delta\ln(ECT(t\text{-}1)) \quad (8)$$

where the restrictions on parameters are: $\zeta_2 = 1, \zeta_6, \eta_2, \eta_6 \geq 0; \zeta_3, \eta_3, \eta_7, \eta_8 \leq 0;$ and $0 > > \eta_9 > -1$.

Real per capita consumption (*RCSP*) is dependent on real gross disposable income (*RRPDP*) and household wealth per capita (*RVD*) where, in accordance with economic theory, it is presumed to be a positive relationship. The life-cycle theory postulates $\zeta_2 = 1$. In the case of the real interest rate (*RRLR*), only a negative influence is allowed, as a higher interest rate leads to a restriction in borrowing and lower consumption. To capture all the possible changes in consumption patterns, the variables on dependency ratios of both children (*CDEP*) and elderly people (*ODEP*) are added. In the case of the dynamic error correction equation, the changes in the unemployment rate of the country (*RUNR*) are a proxy for uncertainty of consumers, assuming a negative relationship.

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[18] In example, the HERMIN model calibrated on the case of Czech economy.

Consumption is further disaggregated in 42 goods/sectors that cover all types of consumer goods and services (see *Appendix*). Consumption estimated by product is found to add up to the total, with the discrepancy being stored in the unallocated row.

The next part of GDP is determined by the investment equations (see *Appendix A*) that are generally characterized by a relatively high volatility in the data and have a relatively low impact on the results in this paper. Investments in industrial sectors are positively dependent on output of the industry both in the long-term and in the short-term. In the short term the ratio of actual/normal output is considered to capture the effect of the temporarily increased capacity and a positive relationship is assumed. Further investment is assumed to be positively dependent on real labor costs, where a substitution effect between labor and capital is reflected. On the other hand, the price of the investments influences investment demand negatively.[19]

Investments in dwellings represent a large part of total investment and are therefore tracked in special equations in the E3ME model. Unlike industrial investments, investments in dwellings are made by households. The long-term demand for housing is expected to be positively related to real gross disposable income. The interest rates also affect the investments, but in a negative way, which is in line, for example, with feasibility of mortgages. The dependency ratios are incorporated to capture the effects of changing population. Government consumption is exogenously given.

The rest of GDP is represented by trade. The modeling of trade has also become a very important issue as a result of deepening international linkages. The export and import equations in the E3ME model are distinguished for intra- and extra-EU trade. The intra-EU export equations can be seen in (9) and (10), the exports outside the EU in (11) and (12):

$$\begin{aligned}\ln(QIX_i) = {} & \mu_1 + \mu_2 \ln(QZXI_i) + \mu_3 \ln(PQRX_i/EX) + \mu_4 \ln(PQRZ_i/EX) + \\ & + \mu_5 \ln(YRKC_i{*}YRKS_i) + \mu_6 \ln(YRKN_i) + \mu_7\, SVIM + \varepsilon_t\end{aligned} \tag{9}$$

$$\begin{aligned}\Delta\ln(QIX_i) = {} & \nu_1 + \nu_2\, \Delta\ln(QZXI_i) + \nu_3\, \Delta\ln(PQRX_i/EX) + \\ & + \nu_4\, \Delta\ln(PQRZ_i/EX) + \nu_5\, \Delta\ln(YRKC_i{*}YRKS_i) + \nu_6\, \Delta\ln\,(YRKN_i) + \\ & + \nu_7 \Delta SVIM + \nu_8\, \Delta\ln(\mathrm{QIX(t\text{-}1)}) + \nu_9\, \Delta\ln(ECT(t\text{-}1))\end{aligned} \tag{10}$$

$$\begin{aligned}\ln(QEX_i) = {} & \xi_1 + \xi_2 \ln(QWXI_i) + \xi_3 \ln(PQRX_i/EX) + \\ & + \xi_4 \ln(PQRE_i/EX) + \xi_5 \ln(YRKC_i{*}YRKS_i) + \xi_6 \ln(YRKN_i) + \\ & + \xi_7\, SVIM + \varepsilon_t\end{aligned} \tag{11}$$

$$\begin{aligned}\Delta\ln(QEX_i) = {} & \pi_1 + \pi_2\, \Delta\ln(QWXI_i) + \pi_3\, \Delta\ln(PQRX_i/EX) + \\ & + \pi_4\, \Delta\ln(PQRW_i/EX) + \pi_5\, \Delta\ln(YRKC_i{*}YRKS_i) + \pi_6\, \Delta\ln(YRKN_i) + \\ & + \pi_7 \Delta SVIM + \pi_8\, \Delta\ln(QEX(t\text{-}1)) + \pi_9\, \Delta\ln(ECT(t\text{-}1))\end{aligned} \tag{12}$$

where the restrictions on parameters are: $\mu_3 + \mu_4 = 0$, $\xi_3 + \xi_4 = 0$, $\mu_2, \mu_4, \mu_5, \mu_6, \nu_2, \nu_4, \nu_5, \nu_6, \xi_2, \xi_4, \xi_5, \xi_6, \pi_2, \pi_4, \pi_5, \pi_6 \geq 0$, $\mu_3, \nu_3, \xi_3, \pi_3 \leq 0$; and $0 > \nu_9, \pi_8 > -1$.

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[19] For further information on investment determination see Barker and Peterson (1987).

Intra-EU exports of the products of the industry (*QIX*) are therefore positively dependent on competing export prices of other EU countries (*PQRZ*), utilized ICT technological progress (*YRKC* represents ICT technological progress and *YRKS* is a measure of skills), non-ICT technological progress (*YRKN*), and domestic demand in other EU regions calculated by multiplying export shares by net domestic output and converted to real prices (*QZXI*). On the contrary, exports are negatively dependent on export prices (*PQRX*).

Furthermore, extra-EU exports (*QEX*) are positively dependent on the rest of the world activity index (*QWXI*) and the rest of the world price index (*PQRE*). In the abovementioned equations the variable *SVIM* records progress on the EU internal market and *EX* represents the exchange rate.

In the trade equations, exports and imports are treated as if they take place through a European "pool". Export and import equations are constructed so that the analyzed region delivers/takes commodities from that pool.[20] Export equations contain two effects, the price effect and the income effect. The import equations are very similar (see *Appendix*).

The model further consists of price equations. Endogenously given prices enter the aforementioned equations. For the sake of simplicity, we describe in the text only the determination of domestic prices; export and import price equations can be found in *Appendix*.

Domestic price equations are presented in (13) and (14).

$$\begin{aligned}\ln(PYH_i) &= \psi_1 + \psi_2 \ln(YRUC_i) + \psi_3 \ln(PQRM_i) + \psi_4 \ln(YRKC_i{*}YRKS_i) + \\ &+ \psi_5 \ln(YRKN_i) + \psi_6 \ln(PQRM_{oil}) + \varepsilon_t \end{aligned} \qquad (13)$$

$$\begin{aligned}\Delta\ln(PYH_i) &= q_1 + q_2\,\Delta\ln(YRUC_i) + q_3\,\Delta\ln(PQRM_i) + \\ &+ q_4\,\Delta\ln(YRH_i{*}YRKS_i) + q_5\,\Delta\ln(YRKN_i) + q_6\,\Delta\ln(PQRM_{oil}) + \\ &+ q_7\,\Delta\ln(YYN_i) + q_8\Delta\ln(PYH(t\text{-}1)) + q_9\,\Delta\ln(ECT(t\text{-}1))\end{aligned} \qquad (14)$$

where the restrictions on parameters are: $\psi_1, \psi_2, \psi_3, \psi_4, \psi_5, \psi_6, q_1, q_2, q_3, q_4, q_5, q_6 \geq 0$; and $0 > q_9 > -1$.

Prices of domestic sales to the domestic market (*PYH*) are positively dependent on unit costs of production (*YRUC*) consisting of input costs, tax costs and labor costs, the prices of imported goods (*PQRM*), ICT technological progress (*YRKC*), skills (*YRKS*), non-ICT technological progress (*YRKN*), imported prices of fuels ($PQRM_{oil}$) and the ratio of actual to normal output in the industry (*YYN*).

The domestic price equations are based on the premises of firms maximizing profits, where firms optimize the bundle of inputs to production respecting their prices. The first-order conditions in profit maximizing set up leads to the following relationship.

$$p \cdot \left(1 - \frac{\theta_j}{\varepsilon}\right) = \frac{\partial C_j}{\partial y_j}\left(y_j, w, q, k_j\right) \qquad (15)$$

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[20] The equations are based on the work of Ragot (1994).

where $\theta = \log y/y_j$ is the conjectural elasticity of total output to own output of the sector, ε is the price elasticity of market demand, C is the cost function with y_j, k_j, w and q, which denotes the output and the capital stock of the sector, and the price of labor input or the vector of other input prices respectively. If $\theta = 1$, the market is monopolistic, whereas $\theta = 0$ indicates perfect competition.

Econometrically-estimated equations use proxy variables for the abovementioned relationship. The costs of labor and other inputs are elaborated via unit costs. Import prices are added separately in order to capture international competitiveness effects; the capital stock is measured by the measures of technological progress in E3ME. Higher unit costs and investment (quality improvements) are expected to lead to higher prices. The basic model assumes that each country in the EU is small in relation to the overall EU market. The market is presumed to be oligopolistic. Many of the sectors are treated as the price of their production is created more or less by mark ups to production costs, some prices are treated as exogenous to the model. Restrictions are imposed to force price homogeneity and exchange rate symmetry on the long-term equations.

Other EU import prices and prices abroad, affect import prices of the Czech Republic in a positive way. Technological progress implies a higher quality product that can command higher prices (see *Appendix*).

The level of employment and labor participation rates are also determined endogenously in the model (see *Appendix* for more detail). Employment in each sector increases with growing production and decreases with growing wage. The effects of technology on employment are ambiguous; new machinery may require skilled labor, but may also replace existing jobs.[21] The participation rate equation is derived from reservation wage theory by Briscoe and Wilson (1992). The participation rate is estimated separately for males and for females, but explanatory variables are not gender specific.

Industrial average earnings are estimated in equations (16) and (17).

$$\begin{aligned}\ln(YRW_i) &= d_1 + d_2 \ln(YRWE_i) + d_3 \ln(YRXE_i) + d_4 (LYR_i - LYRE_i + \\ &+ LPYR_i - LAPSC) + d_5 \ln(RUNR) + d_6 \ln(RBEN_i) + d_7\, LAPSC + \\ &+ d_8\, ARET + \varepsilon_t \end{aligned} \tag{16}$$

$$\begin{aligned}\Delta\ln(YRW_i) &= g_1 + g_2 \Delta\ln(YRWE_i) + g_3 \Delta\ln(YRXE_i) + \\ &+ g_4 \Delta\ln(LYR_i + LYRE_i + LPYR_i - LAPSC) + g_5 \Delta\ln(RUNR_i) + \\ &+ g_6 \Delta\ln(RBNR_i) + g\, \Delta LAPSC + g_8 \Delta ARET + g_9 \Delta(LAPSC) + \\ &+ g_{10} \Delta\ln(YYN_i) + g_{11} \Delta\ln(YRW(t-1)) + g_{12} \Delta\ln(ECT(t-1)) \end{aligned} \tag{17}$$

where the restrictions on parametrs are: $d_2 + d_3 + d_4 = 1$ (price homogeneity), g_2, g_3, g_4, g_6, d_2, d_3, d_4, $d_6 > 0$; d_5, $g_5 < 0$; and $0 > g_{12} > -1$.

In the equations, the bargaining system of unions is reflected. Gross nominal average earnings (*YRW*) determination is positively affected by worker productivity measured by relationship of industrial output (*LYR*), employment in the sector (*LYRE*),

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[21] For more details on long term relationship in determination employment see Gardiner (1994) and Barker and Gardiner (1994).

prices of production (*LPYR*) and an adjusted consumption deflator (*LAPSC*). Wage rates in the wider economy, i.e. both in other sectors (*YRWE*) and regions (*YRXE*) together with unemployment benefits (*RBNR*) further positively affect average earnings. Another important factor is the unemployment rate (*RUNR*) whose effect on earnings is presumed to be negative, in accordance with the work of Blackaby and Manning (1992). The employer taxes only affect the wage rate through consumer prices. The estimates of average wages are an important part of the employment equations. The other explanatory variables are the adjusted wage retention rate (*ARET*) and the ratio of normal to actual output (*YYN*), which should indicate the position in the economic cycle. The effect of these variables is ambiguous.

E3ME includes measures of endogenous technological progress for each sector and country. Technological progress is assumed to be a function of accumulated investment, enhanced by R&D. For each sector, E3ME includes two measures, based on ICT and non-ICT investment; these are defined as:

$$T_j = const + \alpha \cdot d_t(\tau_1) \qquad \text{and}$$
$$d_t(\tau_1) = \tau_1 d_{t-1}(\tau_1) + (1-\tau_1)\ln(GI + \tau_2 RD_t) \tag{18}$$

where *T* is the technology index, *GI* is sector gross ICT and non-ICT investment, and *RD* denotes R&D spending. Parameter τ_1 is set to 0.3 and gives the relative weights of current and past investments. Parameter τ_2 is set to 1 for the ICT index and zero for the non-ICT indices.

3.3 Application to Scenarios

The E3ME model has been used to find out the effects of two different policy schemes with similar impacts measured by positive externalities implied by reductions in emissions. The first scenario that consists of taxation of classical pollutants is compared to a scheme where a carbon tax is introduced. The ways how the results are influenced are very similar. While a carbon tax affects prices of fuels according to carbon content of the relevant fuel, emission taxes affect the price via emission coefficients calculated for each fuel and sector.[22]

The tax is imposed on domestic production in the Czech Republic and on importers, exports are excluded from taxation. As a result of higher prices, consumption of fuels is directly negatively influenced (eq. (3) (4), (5), and (6)). However, the equations allow for switching in fuels. Fuels users consequently pass higher prices of fuels into prices of their final production (eq. (13) and (14)). Depending on price elasticities, the composition of final consumption will be affected. Generally, overall price level increases implying lowering real disposable income and aggregate consumption (eq. (7) and (8)). Therefore, also GDP will be lowered. A negative effect on GDP is also a possible result of worsening international price competitiveness leading to lowering in intra and extra Community exports (eq. (9), (10), (11) and (12)). On the other hand, when revenues are recycled via employees' social security contributions, real incomes will be boosted with positive impact on aggregate consumption and GDP. When revenues are recycled via reductions in social contributions paid by employers, labor costs are lowered resulting in higher employment and more favor-

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[22] The relevant data have been obtained from Czech Hydro-Meteorological Institute.

able prices of domestic production (eq. (13) and (14)), growing international price competitiveness leading to improvements in the trade balance (eq. (9), (10), (11) and (12)), and growing consumption in comparison to cases where no recycling mechanism is assumed. In the long term, higher consumer prices will lead to higher wage claims (eq. (16) and (17)).

4. Modeling Results

4.1 Scenario Definition

Environmental policy aimed at pollution abatement usually affects several pollutants, with effects that would most likely differ in absolute and relative magnitudes for all concerned pollutants. Moreover, except the main environmental impact domain, which is targeted by the policy's primary intention, the policy measure might generate wide ancillary effects. For example, a policy aimed at improving air quality might reduce or increase emissions of greenhouse gasses. Several studies (e.g. Barker and Rosendahl, 2000; Kouvaritakis et al., 2005; Van Regemorter 2008; or Pye at al., 2008) document that the ancillary effects are positive, i.e. these policies can lead to decreases in both types of polluting substances.

The main aim of this paper is to evaluate the economic and environmental impacts of two different environmental policies considered for one transition country, namely the Czech Republic, which would be similar with respect to the environmental effect. However, how can we compare the effects of two policies that differ in impact on various pollutants such as SO_2, NO_X, VOC, NH_3, particulates, and CO_2? To do this, one would need to have a common denominator that would allow for aggregation of such various physical effects into one measure. To fulfill this goal in our study, we measure environmental impacts by externalities that are avoided as a result of the applied policy measure. More specifically, we multiply each tonne of pollutant that would be abated and thus not released into the atmosphere by an average generic value of damage cost per respective pollutant, as derived by the ExternE method for the case of the Czech Republic.[23]

Each scenario under our evaluation is therefore defined in such a way that would lead to an identical cumulative saving in the external costs. Each policy generates a cumulative welfare effect, due to emissions abatement over the years of 2010 to 2020 that is of about 2.3 billion euros. If the state authority was concerned just about environmental welfare, and not about physical reductions in certain substances or additionally generated public revenues, they would be indifferent among these policies. The policy with minimum impact on the preferred economic variable would therefore outperform its alternatives.

Scenario 1 describes our base policy scenario. This policy is based on a significant increase in actual charges on emissions of particulates, sulphur dioxides,

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[23] We assume following unit damage costs: 8,371 € per t of SO_2, 9,359 € per t of NO_x, 19,126 € per t of PM, 21,962 € per t of NH_3, 990 € per t of VOC and 20 € per t of CO_2. These values come from the latest ExternE research carried out within the NEEDS project. The external costs are derived for the emissions released in the Czech Republic by updated EcoSenseWeb tool and using an impact pathway approach (Preiss et al., 2008; also in Maca et al., 2009). In fact, various impact assessment models report a wide range of CO_2 damage cost magnitudes. Its variance results from uncertain effects and enhanced adaptation of the system in the long-run horizon. Moreover, modeling has to rely on normative assumptions, particularly on a discount rate, a form of discount function and equity weighting, which an analyst has to decide only arbitrarily on.

Table 1 Emission Charges and Carbon Tax for the Years 2010–2020 (nominal eur per tone of pollutant)

	Actual rates 1997–2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Scenario 1												
Particulates	106	148	148	803	1 458	2 113	2 768	3 422	3 422	3 422	3 422	3 422
SO_2	35	49	49	152	255	358	462	565	565	565	565	565
NO_x	28	40	40	257	475	693	911	1 129	1 129	1 129	1 129	1 129
VOC	71	99	99	764	1 428	2 093	2 758	3 422	3 422	3 422	3 422	3 422
Scenario 2[a]												
Carbon tax	n.a.	0.7	0.7	3.2	5.8	8.3	10.8	13.3	13.3	13.3	13.3	13.3
Scenario 3[a]												
Carbon tax	n.a.	0.6	0.6	3	5.3	7.6	9.9	12.2	12.2	12.2	12.2	12.2
EU ETS reference												
Allowance price	n.a.	19.0	19.5	20.0	20.5	21.0	21.6	22.1	22.7	23.3	23.9	24.5

Notes: For conversion, the exchange rate of 28.342 CZK per EURO is assumed. Carbon tax is set per tone of CO_2.

[a] The charge is levied on stacionary emission sources only in Scenario 2 and on stacionary sources and transport in Scenario 3.

nitrous oxides, and volatile organic compounds; for instance, the nominal rate on SO_2 is increased 14 times within 8 years, and the rate on NO_x is 40 times larger. These rates are determined at the level to reach marginal shadow prices, i.e. marginal abatement costs, as derived by the GEM-E3 CGE model for the reference with the climate/ /energy 2020 package (Van Regemorter, 2008) that would be required to meet the national emission ceilings in the Czech Republic. These rates are gradually increasing until they reach these values in 2016, after which they are nominally fixed. Only stationary sources are subject to taxation meaning that the transport sector, non-energy use and households are excluded from taxation.[24] This policy was considered for the second phase of the environmental tax reform by the Czech Ministry of the Environment in May 2009.[25]

Scenario 2 and *Scenario 3* are based on carbon taxation. Their rates are endogenously derived by the model considering two criteria: first, these rates should result in as much the external costs avoided over the 2010–2020 period as *Scenario 1* would do; secondly, the trend in tax rate growth should mimic the trend given by the weighted rate of the bundle of pollutants regulated under *Scenario 1*.[26] For better comparison with *Scenario 1*, only stationary sources are subject to taxation under *Scenario 2*, whereas the objects of taxation in *Scenario 3* also encompass the transport sector (still non-energy sector and households being exempted).

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[24] As a result, only a part from all emissions is taxed; it is about 17% of PM, 83% of SO_2, 46% of NO_x and 8% of VOCs (see Ščasný and Píša, 2009 for details).

[25] However, in August–September 2009, the Czech Ministry of the Environment revised its proposal and suggested less strict emission tax rates.

[26] Emission charges of the main four pollutants are weighted by a ratio of emissions of the respective pollutant in the bundle of all four pollutants. Growth rates of the resulting composite "charge" are then used to derive the rates of carbon tax.

Figure 1 Public Revenues Generated by Emission/Energy Tax

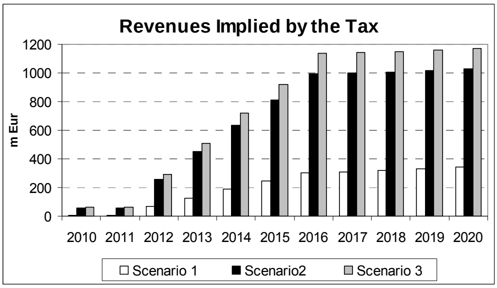
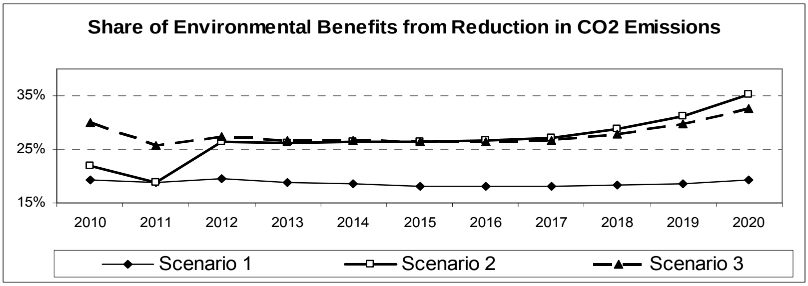


Figure 2 Share of Environmental Benefits from CO_2 Reduction for Air Quality or Carbon Policies



For all evaluated scenarios, we assume an exogenous allowance price of CO_2 emission that is released by the EU ETS sectors (displayed in the last row of *Table 1*).[27]

We predict additional public revenues from emission taxes of 2.24 bn. euros up to 2020. Carbon taxes would generate in total 7.31 bn. euros, or 8.32 bn. euros respectively;[28] *Figure 1* displays the annual flows of revenue. Related to GDP, additional public revenues would amount at their maximum 0.2% of GDP in *Scenario 1*, while *Scenario 2* and *Scenario 3* would generate before the revenue recycling of about 0.6%, or 0.7% of GDP respectively. For each scenario we assume two variants – with and without revenue recycling. In former cases – hereinafter labeled with "RR" adding, the additional revenues are recycled via reduction in social security contributions paid by employers in order to ensure the revenue neutrality principle. Scenarios based on carbon taxation therefore have larger potential for revenue recycling, and thus reaping potential double dividends.

4.2 Environmental Effects

All the scenarios generate strong ancillary effects. In fact, if harmful classical pollutants were taxed, their reduction would contribute more than 80% of the in-

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[27] An exogenous allowance price of CO_2 emissions is used as given by the PRIMES model (Capros et al., 2008 for DG TREN).

[28] The difference in public revenues for our two types of policies is due to a mixture of several effects: the tax rate where effectiveness is given by respective costs of abatement, the mass of regulated emissions that is for the case of CO_2 under Scenario 2 and 3 about 300 times larger than the mass of regulated classical pollutants under Scenario 1, and unit damage costs per pollutant that are two to three times larger for classical pollutants compared with CO_2.

crease in total environmental welfare, while the rest is provided by CO_2 reductions involved by air-quality specific policy. On the other hand, if carbon was taxed, i.e. in *Scenario 2* or *Scenario 3*, the reduction in classical pollutants would still contribute 65% to 80% of total environmental benefits. In other words, the ancillary effect presents only about 23% of direct environmental benefits for the air-quality specific scenario, however, the ancillary effects are almost 2.5 times larger than the direct effects for the carbon-specific scenarios. Neglecting ancillary effects would thus result in significant underestimation of environmental benefit; by about 18% in *Scenario 1*, or by 72% in the case of our carbon-specific policies (see *Figure 2*).

Most of the benefits are brought by reductions in SO_2 (from 30% to 50% of total avoided damages) and NO_x (25% to 30%), while benefits from PM reduction are very small (2–7%) and from VOC and NH_3 are negligible. Reductions in CO_2 emissions contribute 18% to 32%.

We confirm the strongest effect of evaluated policies compared with BAU for SO_2 emissions in the period when the real rates reach their maximum (by almost 11% in *Scenario 1* to 8% for carbon scenarios). In all cases, gradual increases in charges/ /taxes causes emissions to reduce. The U-shape of the emission reduction curve results from two joined effects: first, due to the price level increase, the rates will start to fall after 2017 in real terms,[29] second, the economy adapts to the exogenous (policy) shock. *Figure 3* reports the effects of each scenario on each emission; policy aiming at air quality results in a relatively large decrease in classical pollutants, while carbon-specific policies decrease relatively more the emissions of CO_2.

Both emission and carbon taxation would especially reduce the use of coal; by 6%, or 7.5% respectively. Decline in coal use would, however, diminish when the tax rates stop increasing. Use of gas is reduced by 1%, or 2% respectively, and electricity consumption goes down by 2%, or 3% respectively (see *Figure 4*).

In *Scenario 1*, the price of most fuels is only slightly increased – up to 1% compared with BAU – with an exception for coal, where the price rises by 10%. The price of crude oil falls by 13% in its minimum. Carbon taxation would have a larger effect on fuel prices than air-quality policy. The price of most fuels rises by 10%, of coal by 20–30%, whereas the price of middle distillates does not change; *Figure 5* displays the fuel price effect for *Scenarios 1* and *2*. *Scenario 3* results in a slightly smaller price increase for coal, gas and electricity, on detriment of a small price increase of middle distillates. Revenue recycling does not bring any significant effect on fuel prices if compared with the effects in scenarios without revenue recycling.

4.3 Macroeconomic Impacts

Overall, the macroeconomic impacts in the scenarios are very small. In the first phase, GDP is slightly increased up to 0.05%, then, GDP is lower than BAU –especially in *Scenario 3* – up to 0.08% at its lowest point. The revenue recycling avoids losses to GDP; it is higher in the BAU during the entire analyzed period. Without revenue recycling, *Scenario 1* is better for GDP, however, recycling the revenues

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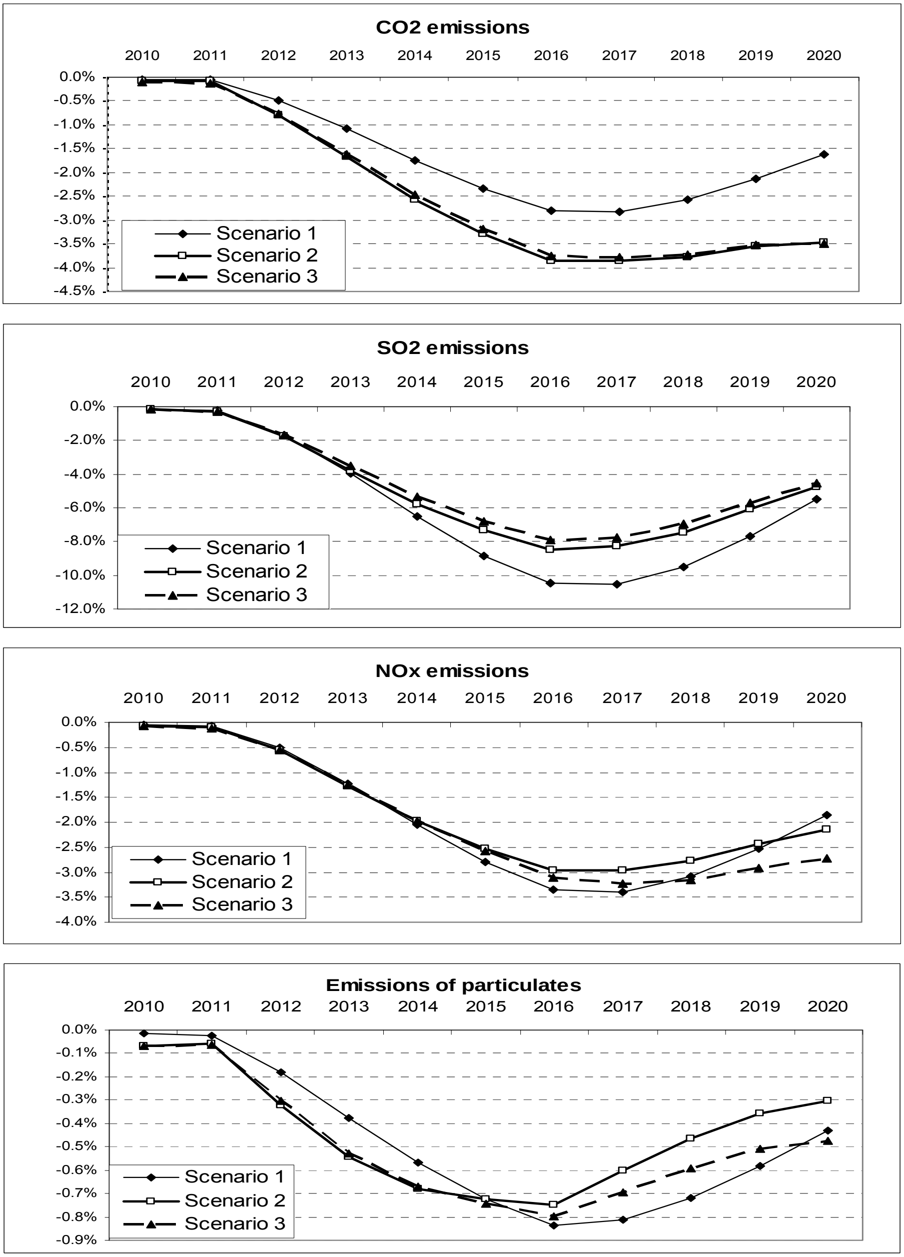
[29] Even though the emission charges are suggested to increase in line with inflation up to 2016, raw fuel prices will increase at a faster rate in the baseline, meaning that the charges fall – compared with BAU – in relative terms over the analyzed period.

Figure 3 Reduction in CO_2, SO_2, NO_x and Particulates Emissions Compared to BAU



CO2 emissions

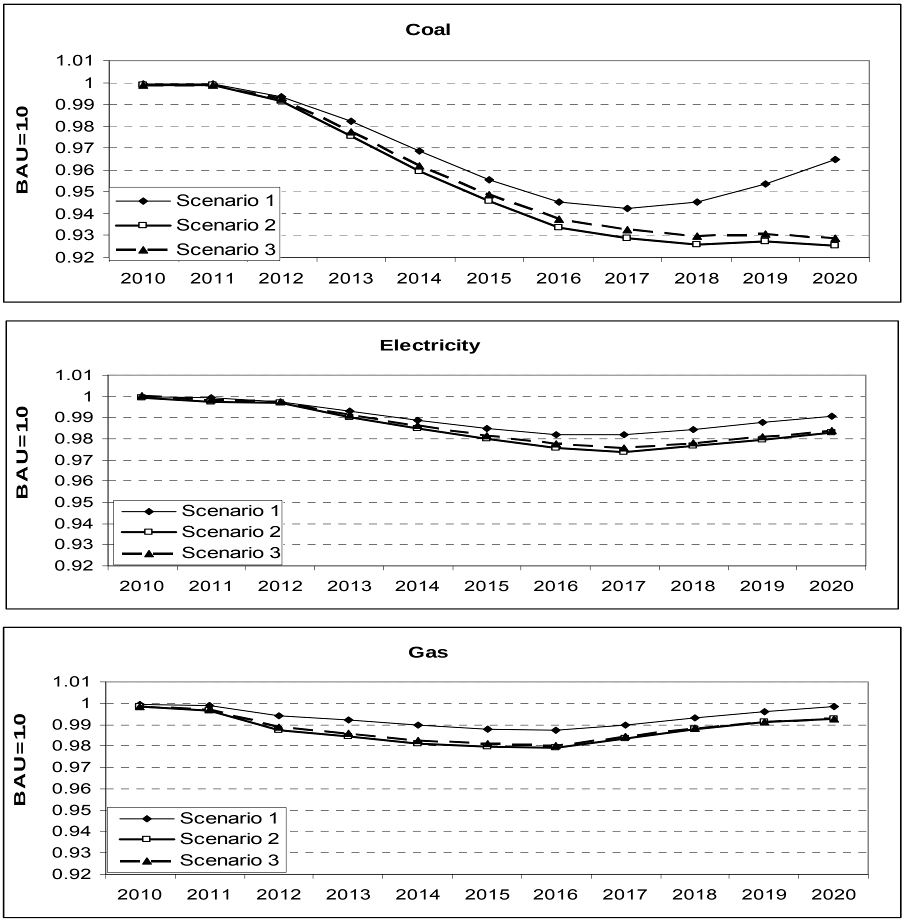
SO2 emissions

NOx emissions

Emissions of particulates

make carbon taxation better than air-quality policy in the longer horizon, i.e. after 2018. Overall the positive effect is a result of positive effects on the trade balance, mainly due to the negative effect on imports. This is confirmed when we look at overall production; economic output slightly declines by about 0.02% in each sce-

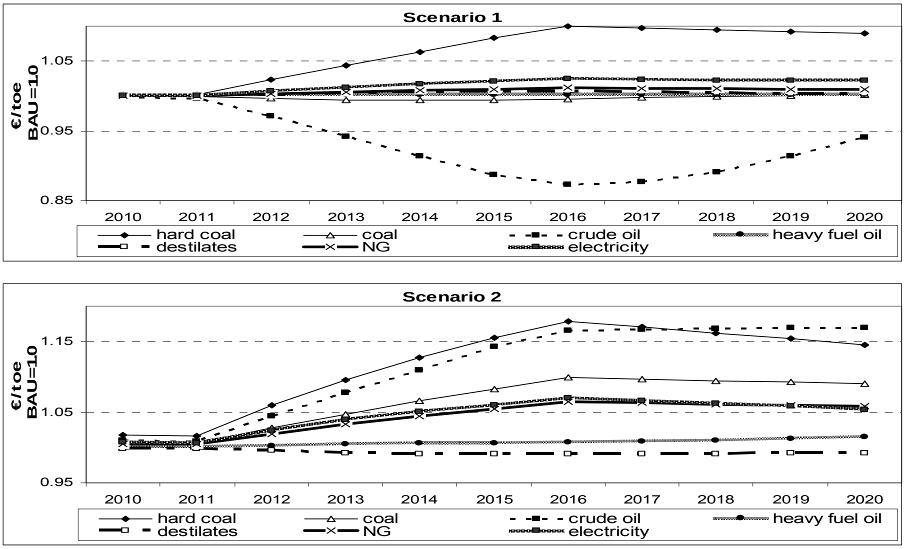
Figure 4 Energy Use per Fuel Compared to BAU



nario without revenue recycling. However, revenue recycling reverses this trend and results in slightly higher output than under BAU.

We predict similar effects, as in the case of output, on consumption. Lower aggregate consumption results especially from the lower purchasing power of consumers with lower disposable income. Scenarios without revenue recycling result in a small decline in consumption and carbon policies involve larger negative effects than air-quality policy as introduced in *Scenario 1*. Revenue recycling leads to enhanced domestic demand by bringing more favorable domestic prices of consumption and therefore increasing disposable income of consumers, especially in the case of carbon policies. The changes in the structure of consumption indicate slight growth in consumption of food in all cases. Consumption of electricity is substituted by gas that is a relatively clean fuel in comparison with, for example coal. Therefore, with environmental regulation, natural gas becomes relatively cheaper. Specifically in *Scenario 3*, i.e. taxation of carbon including also the transport sector, this would be a substitution between consumption of petrol and rail travel.

Figure 5 Price of Fuel, BAU = 1



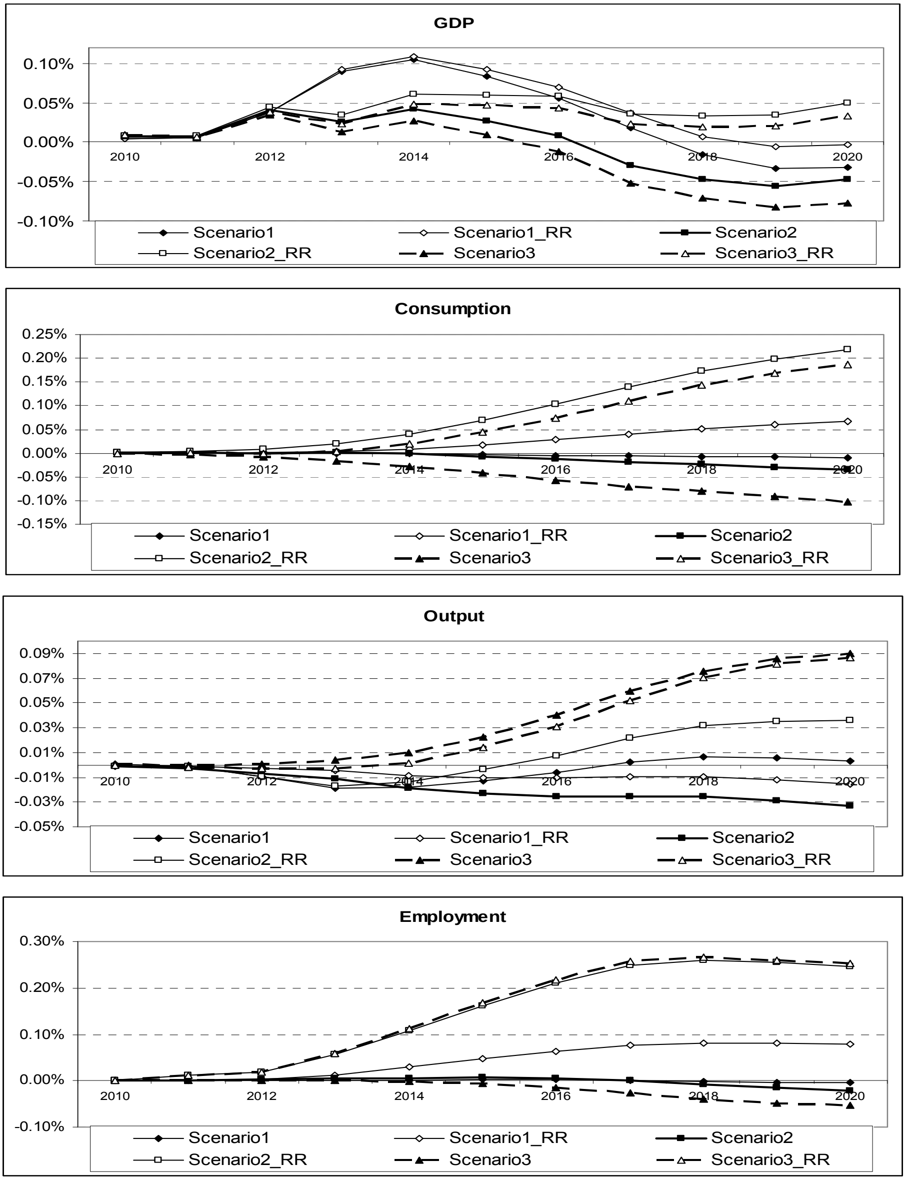
Emission taxation does not bring any significant effect on employment. Carbon taxation would reduce employment, mostly in *Scenario 3* by 0.05% at the end of the analyzed period. All negative effects on employment are, however, very small in absolute and in relative terms. A different picture is given by policies with revenue recycling that boosts employment; the effect of *Scenario 1* is rather small, up to 0.1%, but carbon policies increase the employment by 0.25%, bringing about 14,000 new jobs. Consequently, unemployment is slightly increased without revenue recycling – maximally in *Scenario 3* of about 0.7%, but revenue recycling reduces unemployment by 1.1% (0.07% points) in *Scenario 1*, and 3.6% (0.23%p), or 3.7% (0.24%p) respectively under carbon policies (see *Figure 6*).

There is a minor (smaller than 0.01%), negative effect of all revenue recycling variants on investment due to changes in the labor/capital costs ratio. The effect of variants without revenue recycling is however negligible.

4.4 Sectoral Effects

The output effect on electricity production, i.e. the part of the power sector that produces more tradable goods compared to heat, is slightly negative, while the output in heat production and refineries would slightly rise due to gas becoming relatively cheaper. *Scenario 1* (emission taxes) affects heat and refinery more, but positively, while carbon policies affect more, and negatively, the electricity sector. All the effects are quite small, up to 0.4% compared to the BAU. The effect of emission charging on energy-intensive sectors, such as iron and steel, or non-ferrous metals is generally neutral, while carbon taxation would affect these sectors more negatively, still very small in magnitude (up to 0.1%). The revenue recycling would not affect output in these particular sectors that much, but the overall effect on the entire economy would become positive, mainly due to increases in service sectors.

Figure 6 Macroeconomic Impacts on GDP, Output, Consumption and Employment



5. Conclusion

We use an updated version of the macro-econometric E3ME model to evaluate two types of policies that are identical with respect to the reached environmental benefits in cost terms. These policies, however, differ in environmental effects measured by magnitude of emission reduced in each pollutant. *Scenario 1* is based on significantly increased emission charges with rates that match the marginal abatement costs to reach the national emission ceiling, as estimated by the GEM-E3 model. In fact, this is the policy that the Czech Ministry of the Environment considered for the second phase of environmental tax reform in May 2009. Following the trend rate of growth, we endogenously derive the rates of carbon taxes that would generate the same amount of avoided damages, i.e. welfare benefits due to reduced emissions. This is a base for two alternative scenarios that tax carbon released by stationary sources and by all sectors. All scenarios assume an exogenous ETS allowance price.

We predict that policy aiming at improving air quality, i.e. *Scenario 1*, reduces relatively more classical pollutants than CO_2 emissions and brings less revenue than the two alternative carbon policies. Ancillary effects, i.e. the reduction in emissions that has not been intended to be the direct effect of policy, should not, however, be neglected in any impact assessment. Indeed, neglecting the ancillary effects would result in underestimation of the environmental benefit by about 18% in *Scenario 1* and as much as 72% in the case of the carbon-targeted policies we analyzed in this paper.

Regarding the impact on the use of energy, we predict significant negative effects from emission or carbon taxation on the use of all types of energy, especially on the use of the relatively dirty carrier that is coal; coal use would be reduced due to the introduced measures in the evaluated scenarios by about 6% to 7.5%. The decline would, however, diminish when the tax rates stop to increase. This gives a clear signal for effective environmental policy; if the authority wishes to permanently reduce the consumption of dirty inputs, the tax rates should not decline in real terms as is the case in our scenarios after 2016.

In general, the macroeconomic impacts of the evaluated scenarios are small. We actually predict a positive impact of *Scenario 1* on GDP, up to 0.1% relative to BAU. The positive effect on GDP is smaller for carbon policy under *Scenario 2*, whereas including transport subject to carbon taxation would result in decreasing GDP by 0.08% at its lowest level. Revenue recycling avoids, however, any decline in GDP and results in a higher level of economic output during the entire analyzed period. Emission taxation does not bring any significant effect on employment, while carbon taxation might reduce employment, mostly in *Scenario 3,* by 0.05%. All negative effects on employment are, however, very small, both in absolute and relative terms. On the contrary, policies with revenue recycling boost employment; although the effect in *Scenario 1* is rather small, up to 0.1%, carbon policies increase employment by 0.25%, bringing about 14,000 new jobs. Consequently unemployment is slightly increased without revenue recycling (maximally by 0.7%), but the revenue recycling reduces unemployment, especially under carbon policies, by 3.7% at the maximum. The power sector is affected slightly by up to 0.4%; the output of electricity is reduced, while the output of heat and refineries is increased in line with higher demand for gas. The effect of emission charging on energy-intensive sectors is generally neutral, while carbon taxation affects these sectors negatively, still very small, in the magnitude of up to 0.1%.

This is in line with the results found elsewhere; for instance, Van Regemorter (2008) uses the GEM-E3 CGE model to evaluate the impacts of two policies that would reach the national emission ceiling for the Czech Republic; the first assumes a moderate climate policy imposing a CO_2 tax of 20 euros per ton of CO_2 to all energy consumption in the baseline, while the climate/energy 2020 package is assumed in the second baseline. Our reference scenario is more comparable with the former, less strict, baseline, whereas the rates we use in our *Scenario 1* are based on marginal shadow costs estimated with the latter, stricter, baseline. Our results should be broadly comparable with our estimates lying between those estimated by the GEM-E3 model. Such an interval of impacts given by the Van Regemorter study would be bounded by -0.14% to -0.02% for GDP, -0.30% to -0.16% for private consumption, or -0.06% to -0.01% for employment. Our results for *Scenario 1* without revenue recycling are a bit more positive for GDP, marginally comparable for private consumption and comparable for employment. Our results are comparable even for GDP, if we compare the impacts at the end of analyzed period, which is the period any CGE model requires to reach a new long-term equilibrium. None of the effects predicted by these two models significantly differs; in both cases the overall effect is small.

Lower aggregate consumption results especially from lower purchasing power of consumers with lower disposable income. One might therefore pay attention for any desirable effects of these policies on distribution and equity. In fact, Brůha and Ščasný (2004; 2006) use a micro-simulation model to evaluate the distributional and social effects of energy taxation and confirm negative effects on certain types of households, especially on retired and single families with children. Linking evaluation of macroeconomic impacts by macro structural models with the microsimulation model presents our future research plan.

To conclude, if the authority is reluctant to recycle revenues of environmental policies, then air-quality policies outperform carbon policies with respect to the impacts on GDP. In addition the potential of tax reform to boost employment cannot be utilized. However, recycling the revenues makes carbon taxation more beneficial than air-quality policy in the longer horizon; GDP and employment are simultaneously increased. Moreover, policies based on emission taxes might involve high administration and transaction costs associated with emission control and monitoring, as found for instance by Pavel and Vítek (2009) in the case of actual emission charges enforced in the Czech case. CO_2 emissions can be easily accounted from fuels, where consumption is reported anyway, or from registers prepared on the basis of EU ETS Directive. If the change in welfare caused by emission abatement is of concern to the authority, there is not much appeal for higher emission charging, if carbon taxation is politically feasible. The impacts at local level might, however, result in the preference for these instruments.

APPENDIX

Core of the E3ME model

A. Disaggregate consumption

$$W_i(\ln(CR_i) - \ln(RMAC)) = \theta_1 + \theta_2 \ln(RMAC) + \\ + \theta_3 \ln(PRCR_i) + \theta_4 \ln(CDEP) + \theta_5 \ln(ODEP) + \varepsilon_t$$

$$W_i(\Delta\ln(CR_i) - \Delta\ln(RMAC)) = \iota_1 + \iota_2 \Delta\ln(RRPDP) + \\ + \iota_3 \Delta\ln(PRCR_i) + \iota_4 \Delta\ln(RRLR) + \iota_5 \Delta\ln(PRSC) + \iota_6 \Delta\ln(CDEP) + \\ + \iota_7 \Delta\ln(RUNR) + \iota_8 \Delta\ln(RPSC) + \iota_9 \Delta\ln(ECT(t\text{-}1))$$

where the restrictions on parameters are: $\theta_3, \iota_3, \iota_4, \iota_5, \iota_7 \leq 0$; and $0 > \iota_9 > -1$, *CR* is consumer expenditure on the particular commodity, *RMAC* is multiplicative average of real consumption, *PCR* is the prices of commodities, *CDEP* and ODEP are the dependency ratios of children and elderly people respectively, *RRPDP* is real gross disposable income per capita, *PRCR* is the real price of consumption, *RRLR* is the long--run interest rate and *PRSC* is the consumer price deflator.

B. Industrial Investment

$$\ln(KR_i) = \kappa_1 + \kappa_2 \ln(YR_i) + \kappa_3 \ln(PKR/PYR_i) + \\ + \kappa_4 \ln(YRWC_i) + \kappa_5 \ln(PQRM_{oil}) + \varepsilon_t$$

$$\Delta\ln(KR_i) = \lambda_1 + \lambda_2 \Delta\ln(YR) + \lambda_3 \Delta\ln(PKR/PYR_i) + \\ + \lambda_4 \Delta\ln(YRWC_i) + \lambda_5 \Delta\ln(PQRM_{oil}) + \lambda_6 \Delta\ln(RRLR) + \\ + \lambda_7 \Delta\ln(YYN_i) + \lambda_8 \Delta\ln(KR(t\text{-}1)) + \lambda_9 \Delta\ln(ECT(t\text{-}1))$$

where the restrictions on parameters are: $\kappa_2, \kappa_4, \lambda_2, \lambda_4, \lambda_7 \geq 0$, $\kappa_3, \lambda_3, \lambda_6 \leq 0$; and $0 > \lambda_9 > -1$. *KR* is investment expenditure of the sector, *YR* is industry output, *PKR/PYR* is the relative price of investment, *YRWC* is real labor costs, $PQRM_{oil}$ is the headline oil price, *RRLR* is the real rate of interest and *YYN* is the ratio of actual to normal output.

C. Investment in Dwellings

$$\ln(RDW) = l_1 + l_2 \ln(RRPD) + l_3 \ln(RRLR) + l_4 (CDEP) + l_5 \ln(ODEP) + \varepsilon_t$$

$$\Delta\ln(RDW) = m_1 + m_2 \Delta\ln(RRPD) + m_3 \Delta\ln(RRLR) + m_4 \Delta\ln(CDEP) + \\ + m_5 \Delta\ln(ODEP) + m_6 \Delta\ln(RUNR) + m_7 \Delta\ln(PRSC) + m_8 \Delta\ln(RDW(t\text{-}1)) + \\ + m_9 \Delta\ln(ECT(t\text{-}1))$$

where the restrictions on parameters: $l_2, m_2 \geq 0$; $l_3, m_3, m_6, m_7 \leq 0$, and $0 > m_9 > -1$, *RDW* is investment in dwellings, *RRPD* is real gross disposable income, *CDEP* and *ODEP* are dependency ratios, *RUNR* is regional unemployment rates and *PRSC* is the consumer price deflator.

D. Intra and Extra – EU import Volume

$$\ln(QIM_i) = \rho_1 + \rho_2 \ln(QRDI_i) + \rho_3 \ln(PQRM_i) + \rho_4 \ln(PYH_i) + \rho_5 \ln(EX) + \\ + \rho_6 \ln(YRKC_i * YRKS_i) + \rho_7 \ln(YRKN_i) + \rho_8 \, SVIM + \varepsilon_t$$

$$\begin{aligned}\Delta\ln(QIM_i) &= \varsigma_1 + \varsigma_2\,\Delta\ln(QRDI_i) + \varsigma_3\,\Delta\ln(PQRM_i) + \varsigma_4\,\Delta\ln(PYH_i) + \\ &+ \varsigma_5\,\Delta\ln(EX) + \varsigma_6\,\Delta\ln(YRKC_i{*}YRKS_i) + \varsigma_7\,\Delta\ln(YRKN_i) + \varsigma_8\,\Delta SVIM + \\ &+ \varsigma_9\,\Delta\ln(QIM(t\text{-}1)) + \varsigma_{10}\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

$$\begin{aligned}\ln(QEM_i) &= \sigma_1 + \sigma_2 \ln(QRDI_i) + \sigma_3 \ln(PQRM_i) + \sigma_4 \ln(PYH_i) + \\ &+ \sigma_5 \ln(EX) + \sigma_6 \ln(YRKC_i{*}YRKS_i) + \sigma_7 \ln(YRKN_i) + \sigma_8\, SVIM + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln(QEM_i) &= \tau_1 + \tau_2\,\Delta\ln(QRDI_i) + \tau_3\,\Delta\ln(PQRM) + \tau_4\,\Delta\ln(PYH_i) + \\ &+ \tau_5\,\Delta\ln(EX) + \tau_6\,\Delta\ln(YRKC_i{*}YRKS_i) + \tau_7\,\Delta\ln(YRKN_i) + \tau_8\,\Delta SVIM + \\ &+ \tau_9\,\Delta\ln(QEM(t\text{-}1)) + \tau_{10}\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where the restrictions on parameters are: $\rho_3 + \rho_4 = 0$, $\sigma_3 + \sigma_4 = 0$, $\rho_2, \rho_4, \varsigma_2, \varsigma_4, \sigma_2, \sigma_4, \tau_2, \tau_4 \geq 0$, $\rho_3, \rho_5, \rho_6, \rho_7, \varsigma_3, \varsigma_5, \varsigma_6, \varsigma_7, \sigma_3, \sigma_5, \sigma_6, \sigma_7, \tau_3, \tau_5, \tau_6, \tau_7 \leq 0$; and $0 > \varsigma_{10}, \tau_{10} > -1$, *QIM* is intra-EU imports of the industry, *QRDI* is sales to domestic markets of the industry, *PQRM* is import prices of the industry, *PYH* is the price of home sales by domestic producers, *YRKC* is ICT technological progress, *YRKS* is skills, *YRKN* is non-ICT technological progress and *SVIM* records progress on the EU internal market. In the above equations, three price effects can be seen. One is via import prices, the second is due to prices of sales and the last effect is the price of the domestic currency, i.e. exchange rate.

D. Hours Worked

$$\ln(YRH_i) = \upsilon_1 + \upsilon_2 \ln(YRNH_i) + \upsilon_3 \ln(YRKC_i{*}YRKS_i) + \upsilon_4 \ln(YRKN) + \varepsilon_t$$

$$\begin{aligned}\Delta\ln(YRH_i) &= \varphi_1 + \varphi_2\,\Delta\ln(YRNH_i) + \varphi_3\,\Delta\ln(YRKC_i{*}YRKS_i) + \\ &+ \varphi_4\,\Delta\ln(YRKN) + \varphi_5\,\Delta\ln(YYN_i) + \varphi_6\,\Delta\ln(YRH(t\text{-}1)) + \varphi_7\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where restrictions on parameters are: $\upsilon_2, \varphi_2 = 1$, $\upsilon_3, \upsilon_4, \varphi_3, \varphi_4 \leq 0$; and $0 > \varphi_7 > -1$, *YRH* is average hours worked per week in the sector, *YRNH* is normal hours worked, (i.e. what people expect to work) *YRKC* is ICT technological progress, *YRKS* is skills and *YRKN* is non-ICT technological progress.

E. Employment in Industrial Sectors

$$\begin{aligned}\ln(YRE_i) &= \chi_1 + \chi_2 \ln(YR_i) + \chi_3 \ln(YRWC_i) + \chi_4 \ln(YRH) + \\ &+ \chi_5 \ln(PQRM_{oil}) + \chi_6 \ln(YRKC_i{*}YRKS_i) + \chi_7 \ln(YRKN_i) + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln(YRE_i) &= p_1 + p_2\,\Delta\ln(YR_i) + p_3\,\Delta\ln(LYLC_i) + p_4\,\Delta\ln(YRH_i) + \\ &+ p_5\,\Delta\ln(PQRM_{oil}) + p_6\,\Delta\ln(YRKC_i{*}YRKS_i) + p_7\,\Delta\ln(YRKN_i) + \\ &+ p_8\,\Delta\ln(YRE(t\text{-}1)) + p_9\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where the restrictions on parameters are: $\chi_2, p_2 \geq 0$; $\chi_3, \chi_4, p_3, p_4 \leq 0$; and $0 > p_9 > -1$, *YRE* is employment in sectors, *YR* is real output in the sector, *YRWC* is real wage costs, *YRH* is average hours worked, $PQRM_{oil}$ is import prices of oil products and *LYLC* is real wage costs.

F. Export and import price equations

$$\begin{aligned}\ln(PQRX_i) &= \omega_1 + \omega_2 \ln(PQRY_i) + \omega_3 \ln(PQRE_i) + \omega_4 \ln(PQWE_i) + \\ &+ \omega_5 \ln(EX) + \omega_6 \ln(YRULT_i) + \omega_7 \ln(YRKC_i{*}YRKS_i) + \omega_8 \ln(YRKN_i) + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln(PQRX_i) = {} & a_1 + a_2\,\Delta\ln(PQRY_i) + a_3\,\Delta\ln(PQRE_i) + a_4\,\Delta\ln(PQWE_i) + \\ & + a_5\,\Delta\ln(EX) + a_6\,\Delta\ln(YRULT_i) + a_7\,\Delta\ln(YRKC_i{*}YRKS_i) + \\ & + a_8\,\Delta\ln(YRKN_i) + a_9\,\Delta\ln(PQRX(t\text{-}1)) + a_{10}\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

$$\begin{aligned}\ln(PQRM_i) = {} & b_1 + b_2\ln(PQRF_i) + b_3\ln(PQRE_i) + b_4\ln(PQWE_i) + \\ & + b_5\ln(EX) + b_6\ln(YRUL_i) + b_7\ln(YRKC_i{*}YRKS_i) + b_8\ln(YRKN_i) + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln(PQRM_i) = {} & c_1 + c_2\,\Delta\ln(PQRF_i) + c_3\,\Delta\ln(PQRE_i) + c_4\,\Delta\ln\,(PQWE_i) + \\ & + c_5\,\Delta\ln(EX) + c_6\,\Delta\ln(YRUL_i) + c_7\,\Delta\ln(YRKC_i{*}YRKS_i) + c_8\,\Delta\ln(YRKN_i) + \\ & + c_9\,\Delta\ln(PQRM(t\text{-}1)) + c_{10}\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where the restrictions on parameters are: $\omega_2 + \omega_3 + \omega_4 = 1 - \omega_6$; $\omega_2 + \omega_3 + \omega_4 = \omega_5$; $b_2 + b_3 + b_4 = 1 - b_6$; $b_2 + b_3 + b_4 = b_5$; $\omega_2, \omega_3, \omega_4, \omega_5, \omega_6, \omega_7, \omega_8, a_2, a_3, a_4, a_5, a_6, a_7, a_8, b_2, b_3, b_4, b_6, c_2, c_3, c_4, c_6, \geq 0$; $b_7, b_8, c_7, c_8 \leq 0$; and $0 > a_{10}, c_{10} > -1$. *PQRX* is the price of exports of the sector, *PQRY* is other EU export prices, *PQRE* is the rest of the world prices, *PQWE* is the world commodity price index, *EX* is the exchange rate, *YRULT* is unit labor and tax costs, *YRKC* is ICT technological progress, *YRKS* is skills, *YRKN* is non-ICT technological progress and *PQRF* is other EU import prices.

G. Labor Supply (Participation Rates, LRP)

$$\begin{aligned}\ln(LRP/(1\text{-}LRP)) = {} & h_1 + h_2\ln(RSQ) + h_3\ln(RWSR) + h_4\,(RUNR) + \\ & + h_5\ln(RBNR) + h_6\ln(RSER) + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln(LRP/(1\text{-}LRP)) = {} & i_1 + i_2\,\Delta\ln(RSQ) + i_3\,\Delta\ln(RWSR) + i_4\,\Delta\ln(RUNR) + \\ & + i_5\,\Delta\ln(RBNR) + i_6\,\Delta\ln(RSER) + i_7\,\Delta\ln(LRP(\text{-}1)/(1\text{-}LRP(\text{-}1))) + \\ & + i_8\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where the restrictions on parameters: $h_2, h_3, i_2, i_3 > 0$; $h_4, h_5, i_4, i_5 < 0$; and $0 > i_8 > -1$, *RSQ* is total gross industry output, *RWSR* is the real retained wage rate, external industry wage rates, *RUNR* is the unemployment rate, *RBNR* is the ratio of social benefits paid to households to nominal wages and *RSER* represents economic structure as ratio of service industrial output to non-service output.

H. The Normal Output Equations

$$\ln(YRN) = n_1 + n_2\ln(YRY) + n_3\ln(YRX) + \varepsilon_t$$

$$\begin{aligned}\Delta\ln(YRN) = {} & o_1 + o_2\,\Delta\ln(YRY) + o_3\,\Delta\ln(YRX) + o_4\,\Delta\ln(YR(t\text{-}1)) + \\ & + o_5\,\Delta\ln(ECT(t\text{-}1))\end{aligned}$$

where the restrictions on parameters: $n_2, n_2, o_2, o_3 \geq 0$; and $0 > o_5 > -1$, *YRN* is normal industrial output, *YRY* is the arithmetic average of industrial output in other sectors, *YRX* is the arithmetic average in the same sectors but other countries and *YR* is gross industry output.

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