Decomposition of foreign trade in terms of new environmental policy: a CGE model for the Czech Republic

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Abstract

Pollution charges are directly applied on exported and domestic goods, but not on imported goods. Czech government plans to implement a carbon tax and to increase other environmental tax rates before 2016. We investigate how this decision will affect foreign trade of selected sectors in the country. Using computable general equilibrium modeling, we consider a small-open economy with endogenous unemployment, fixed trade balance, and ten sources of the government revenue. We distinguish six air-pollutants that can be created via combustion and non-combustion processes. Emission reduction is possible in the model through (i) substitution with less polluting inputs, (ii) a reduction of output level of the polluting goods, (iii) abatement possibility. The results shows that import of coal will decrease, but import of other goods should not be affected by the environmental policy. Export will decrease not only in energy sectors but also in chemical, mineral and metal sectors, but it will increase in light and biomass industries. The overall economic impact is rather negligible, but policy makers should consider a transitional support for selected sectors.

JEL classification: C68, Q43, Q58, J21
Key words: Computable general equilibrium modelling, environmental taxes, substitution, abatement
1 Introduction

The European Union has encouraged the use of market-based instruments in member states. Environmental taxes, according to Eurostat, refer to energy taxes, transport taxes and ecotaxes. Energy taxes have been implemented in the Czech Republic in 2008, according to European Commission’s tax policy. Czech government plans to implement a carbon tax and to increase other environmental tax rates before 2016. These taxes may increase costs of affected industries and reduce their economic performance, including international competitiveness. Our purpose is to verify if this is also the case for the Czech economy.

Using computable general equilibrium (CGE) approach, we will compare two distinct states of the economy, before and after the implementation or consideration of the reform. These models are able to quantify direct and indirect effects of emission charges on many aspects of the economy, like its structure, predicted change and the allocation of resources. CGE modeling, as any other economic modeling, is a simplification of reality. We are not able to replicate all details of reality with any model, but we may take into account the key characteristics of the economy. Our model is carefully designed in order to replicate important details of the Czech tax system. We distinguish 10 types of taxes, but we ignore export quotas and import tariffs because they were relatively small in 2005 for the Czech economy. The paper describes production and consumption process in the model, factors and goods markets, domestic and foreign trade, public and private demand. We provide a detailed description of the model in order to open a “black box” of CGE modelling.

The model for the Czech economy is the Arrow-Debreu model of a small-open economy. It has an aggregate representation of 20 sectors, 7 factors, 1 household and government corresponding to a standard structure of the Czech 2005 input-output table. An emission of the following air pollutions through a fuels combustion and technological process is determined by the model: SO$_2$, NO$_x$, CO$_2$, CO, PM, VOC. Emission reduction is possible through a substitution with less polluted production factors, a reduction of activity level, an increase of abatement activity. 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. 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 set at zero level. However, this will not apply to labour market, current account balance, and other parts of the model where market imperfections will be explicitly accounted for.

The general equilibrium approach provides a consistent and comprehensive framework for studying price-dependent interactions between the energy system and the rest of the economy. In addition, abatement sector in our model considers bottom-up technologies with decreasing returns to scale. Thus a combination of bottom-up and top-down modelling is applied. An outline of the paper follows. In section 2, we provide a policy background and discuss economic modelling of the Czech environmental policy. In section 3, we analyze the static setting of the model and describe the required data. A calibrated share form of the functions is applied, rather than traditional coefficient form. Next, in section 4, the simulation results are analysed. Finally, in section 5, we conclude.
2 Policy and Modelling background

There is a long history in environmental regulation and use of economic instruments in the Czech Republic (EC 2001). Pollution charges were gradually introduced since the 60s: air emission charges in 1967 and wastewater charges and 1979. However, in the centrally planned economy, environmental regulation played no significant role. The current tax system in the Czech environmental policy was introduced in the early 90s: emission charges for some air pollutants, air emission non-compliance fee, water charges, waste charges, charges for dispossession of agricultural and forest lands, and mining charges.

The Czech authorities started to prepare an ecological tax reform since 2000. Initial idea was based on higher energy taxation, then it was moved towards carbon taxation, and more recently it has been relying on higher taxation on air-pollutants. According to European Environment Agency, the Czech Republic has a comprehensive and complex system of environmental charges with relatively low rates (EEA 2008). Several products are subject to reduced VAT targeting energy conservation and/or environmental protection. The low level of environmental charges in 1991-2004 has not had any observable effect neither on energy demand nor on environmental quality.

The current tax structure and how far it is from the revenue optimal state will determine how new environmental taxes will affect the economy, including employment and competitiveness. Pollution charges are directly applied on exported and domestic goods, but not on imported goods. The magnitude of the competitiveness effects of higher environmental taxation depends, among other things, on the contribution of trade in pollution intensive products (i) to GDP and (ii) with countries where environmental taxes are not in place. The main commercial partners of Czech Republic are geographically close countries. The possibility of relocation of Czech firms in neighbour countries due to higher taxes is rather improbable, since those countries already has relatively high rates. The extent to which environmental taxes in Czech Republic would affect its competitiveness and trade level with its main partners would depend on the magnitude of the new rates, relating to the tax level observed in other countries.

Fiscal policy might harm the economy and reduce overall welfare; or, on the contrary, a technological progress might be enhanced or employment boosted. To evaluate the overall effect, economic models have been developed and gradually utilized. One of the very first CGE models of the Czech economy has been introduced by Martin and Skinner (1998). It is a static model of an open economy based on 1992 data. The production process is described by CES function, the consumption - by Cobb-Douglas, and no environmental feedbacks are considered. The Authors made a simulation of revenue neutral shifts in tax on electricity with associated tax reduction on labor. The results demonstrates that the tax shift can improve welfare.

Bruha (2002) uses a CGE model of a small open economy in the evaluation of effects of increase in fossil-fuel prices in Czech Republic with a simultaneous decrease in labor taxes. The two possibilities of the state of labour market were considered: inelastic labour supply and labour-leisure choice. In both cases, the presence of the so called double dividend had not been proved. The different versions of the model has been frequently used by Czech researches to evaluate optimal taxation (Bruha and Scasny 2005).

Another inspected environmentally related issue, although not primarily, are prices of oil products. Janovskij and Rojicek (2004) presented the CGE model that is characterized by relatively rigid production side of the economy. The inputs and capital are assumed to be used in fixed proportions. There are sectoral exogenous wages and possibility for unemployment are taken into account. The simulation of increased oil prices showed a negative impact on trade balance, as expected. The improved version of the model is used by the Czech authorities to simulate energy policy Dybczak et al. (2008).
Summarizing, modeling the impacts of environmental policy in the Czech Republic has developed especially in the last decade. The main reasons for previous failures were (i) the lack of quality data resulting from transition of the Czech economy from central planned to market based and (ii) gradual adjustments to international statistical definitions. Our contribution to the modeling issues of environmental policy for the Czech economy covers several aspects. First, our CGE model directly takes into account different sources of air-pollution emission. Second, a more flexible demand system is incorporated compared to existing Czech models. Third, we consider ten types of taxes in the benchmark equilibrium: output tax, value-added tax, two types of emission charges, corporate income tax, personal income tax, two types of payroll tax, excise tax, and other tax on products. Next, unemployment is endogenously determined through a wage curve. Finally, the abatement technologies are taken into account. We explain these aspects detailed in the next two sections.

3 Static framework of the model

3.1 Data

CGE modeling requires a single period inter-industry transaction table, opposite to time series required by econometric modelling. The database for the Czech model is a single-year set of data based on national input-output table (IOT) supplemented with other data like data for stocks of capital and labour or pollution emission data. The latest available input-output table represents Czech economy at the end of 2005 and this will be our benchmark equilibrium.

Both, the rows and columns of the original Czech IOT represent products. We assume in the model that each sector produce a sector specific product and no other sector may produce the same product. This means that products classification in our model is the same as sectors classification. We have aggregated economy into four broad groups of products: energy, production, service, and transport. Finally, those four groups has been disaggregated into 19 products in the model based on economic characteristics (market power, protection, and the tradability of products) and environmental impacts (emission volume). The details of the classification are given in Table1. It includes 5 energy products that represents also secondary production factors.

The model takes into account both economy and pollution aggregation. For pollution aggregation, we have distinguished 6 air-pollutants and all other pollutions are ignored. We also distinguish 3 main sources of emission: energy combustion, non-energy combustion, and mobile sources. The data has been taken from the Air Pollution Emission Source Register (REZZO) provided by the authorized state institution Czech Hydro-Meteorological Institute. Some emissions of $PM$ and $VOC$ in the database are not relevant to any sources defined in our model and we have ignored it.

We have incorporated in the model emission coefficients instead of emission function. Producers and households are both considered as pollution emitters, i.e. we take into account emission coefficients per actor (19 producers,\footnote{Abatement sector does not create any emission.} and 1 household), per pollutant (6 air-pollutants), and per source (combustion of coal, gas, oil, biomass, non-energy combustion, and mobile sources). It requires mapping of the monetary flows from the IOT with consistent physical flows from environmental balance. Thus the relevant fuel
Table 1: Aggregation in the model

<table>
<thead>
<tr>
<th>#</th>
<th>final products</th>
<th>#</th>
<th>production factors</th>
<th>#</th>
<th>pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minerals</td>
<td>1</td>
<td>Labour (L)</td>
<td>1</td>
<td>SO2</td>
</tr>
<tr>
<td>2</td>
<td>Metallurgy</td>
<td>2</td>
<td>Capital (K)</td>
<td>2</td>
<td>NOx</td>
</tr>
<tr>
<td>3</td>
<td>Heating</td>
<td>3</td>
<td>Coal (C)</td>
<td>3</td>
<td>CO2</td>
</tr>
<tr>
<td>4</td>
<td>Energy intensive</td>
<td>4</td>
<td>Biomass (B)</td>
<td>4</td>
<td>CO</td>
</tr>
<tr>
<td>5</td>
<td>Energy non-intensive</td>
<td>5</td>
<td>Gas &amp; crude oil (G)</td>
<td>5</td>
<td>PM</td>
</tr>
<tr>
<td>6</td>
<td>Manufacturing</td>
<td>6</td>
<td>Coke &amp; petroleum products (F)</td>
<td>6</td>
<td>VOC</td>
</tr>
<tr>
<td>7</td>
<td>Chemicals</td>
<td>7</td>
<td>Electricity (E)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>9</td>
<td>Food</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Road transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Other transportation</td>
<td></td>
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</tr>
<tr>
<td>13</td>
<td>Market service</td>
<td></td>
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<tr>
<td>14</td>
<td>Public service</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>15</td>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Gas &amp; crude oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Coke &amp; petroleum products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Abatement</td>
<td></td>
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</tr>
</tbody>
</table>

consumption and the domestic production is combined with environmental data in order to calculate both sector-specific and energy-specific emission coefficients for the selected air pollutants. As a result we have 11 categories of emission coefficients.

### 3.2 Production

A combined Leontief technology and a nested-CES production structure (Figure 1) is used to determine the output for each sector:

- Intermediate demand $ID_{j,i}$ is composed of 14 non-energy inputs between which there is a zero elasticity of substitution. We may describe it by Leontief structure:

$$ID_{j,i} = id0_{j,i} \frac{N_i}{n0_i}$$

where $id0_{j,i}$ is the benchmark intermediate demand on input $j$ by sector $i$, $N_i$ is the output of sector $i$, $n0_i$ is the benchmark output.

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2 This section refers to 19 sectors out of 20. The abatement sector has a different characteristic and it will be discussed in a separate section.

3 Following Boehringer, Rutherford, and Wiegard (2003), we use a calibrated share form of the functions, rather than traditional coefficient form. Both forms give the same results, but the first form simplifies calibration process.
Demand on production factors - primary and secondary factors in Table 1 - is described by nested separable-CES structure in order to specify non-constant substitution possibilities between factors. For example, coal and biomass enter at the bottom nest with a constant substitution elasticity $\sigma^{CB}$. We may describe it with the following unit cost function:

$$PCB_i = \left( \theta_{c,i} \left( \frac{PA_c + t_c b_i + \text{NUM}}{pe_{0c,i}} \right)^{1-\sigma^{CB}} + (1 - \theta_{c,i}) \left( \frac{PA_b + t_b b_i + \text{NUM}}{pe_{0b,i}} \right)^{1-\sigma^{CB}} \right)^{\alpha_i/(1-\sigma^{CB})}$$

where $PCB_i$ is an implicit price of coal and biomass in the output price of sector $i$, $PA_c$ and $PA_b$ are a price of coal and biomass respectively, $pe_{0c,i}$ and $pe_{0b,i}$ represent benchmark prices, $t_c b_i$ and $t_b b_i$ are emission charges as a result of consumption of coal and biomass respectively, $\text{NUM}$ is a price index, $\alpha_i$ is returns to scale parameter$^4$, $\sigma^{CB}$ is the elasticity of substitution between coal and biomass in sector $i$, $\theta_{c,i}$ is a value share of coal in the coal-biomass composite$^5$. At the next level of the nested structure, gas and coal-biomass composite combine with another constant substitution elasticity $\sigma^{GC}$, etc. In the top nest, labour and composite capital-energy shows trade off with a new value of $\sigma^{LK}$:

$$PLK_i = \left( \theta_{l,i} \left( \frac{PL(1 + sp)}{pl0} \right)^{1-\sigma^{LK}} + (1 - \theta_{l,i})(PKE_i)^{1-\sigma^{LK}} \right)^{1/(1-\sigma^{LK})}$$

where $PLK_i$ is an implicit price of labour in the output price of sector $i$, $PKE_i$ is an implicit price of capital in the output price of sector $i$, $PL$ is a uniform gross wage, $sp$ is a payroll tax rate applied on employers, and $pl0$ is a benchmark labor cost. This is the final production factor composite.

In the last stage of creating the gross product, producers in each sector combine purchases of products of other sectors with the purchase of a composite factor and no substitution is possible. Such specification of technologies allow the comprehensive representation of the substitution possibilities in production through: (i) interfuel substitution within the energy aggregate and (ii) substitution between energy and other production factors. The model does not allow for intra-industry competition, because there is a uniform price for the sectors output. Domestic competition comes only from other sectors. The firms are risk neutral.

Both, primary and secondary, production factors are assumed to be homogenous and perfectly mobile between sectors, but primary factors are only mobile domestically.

$^4$We assume constant returns to scale for 19 sectors, i.e. $\alpha_i = 1$.

$^5$Theta is defined as the value of the factor added divided by the value of all factors taken into account until this stage of production process. This parameter substitutes two traditional parameters of CES function: scaling parameter and distribution parameter.
3.2.1 Labour market

The neoclassical axiom of flexible wages is suspended in our model where endogenous unemployment is determined through the wage curve (Figure 2). This curve captures a relationship between unemployment and wage level:

\[
\frac{PL(1 - tl)(1 - sl)}{w_0} = \left( \frac{U/u_0}{\sum_i DL_i / \sum_i dl_0} \right)^{\mu}
\]

where \( U \) and \( u_0 \) is total unemployment in counterfactual and benchmark equilibrium respectively, \( DL_i \) and \( dl_0 \) is employment per sector \( i \) in counterfactual and benchmark equilibrium respectively, \( tl \) personal income tax rate, \( w_0 \) is the benchmark gross wage, parameter \( \mu \) is an unemployment elasticity of wage. This equation describes how the price of labour is affected by unemployment rate. We distinguish four components of the labor price: personal income tax \( tl \), payroll tax applied on employees \( sl \), payroll tax applied on employers \( sp \), and endogenous gross wage \( PL \). This means that a net wage is \( PL(1 - tl)(1 - sl) \) and a labor cost is \( PL(1 + sp) \).

The wage curve hypothesis (Blanchflower and Oswald 1995) states that wages are negatively correlated with local unemployment rates: high unemployment leads to lower wages. Unemployment will be the difference between labour force and wage curve. No voluntary unemployment is possible, because there is no labour-leisure choice in the model. This means that exogenous labour force specifies a fixed labour supply \( ls \). Market clearing condition requires that labour supply equals to labour demand \( \sum_i DL_i \), specified from cost function \( 1 \) and unemployment \( U \), defined by \( 2 \).

3.2.2 Capital market

Capital market is simplified in the model, because no capital formation is taken into account endogenously neither in static nor in recursive-dynamic models. This means that capital supply \( (ks) \) is fixed (Figure 3). We define 'capital' as sum of fixed capital \( (f_k) \) and net operating surplus \( (\pi) \), because there is no profit under a constant returns to scale. In reality firms have profit and in order to take it into account we reformulate a profit condition: \( \pi + TC = TR \), i.e. to be able to generate revenue \( TR \), it requires to have \( (\pi + TC) \). There are few possibilities how to implement profit into CGE model:
• If profit is a parameter in the model, then it creates distortions in the economy similar to taxes.

• If profit is a variable in the model, then we have to include it into production function.
  – If we include $\pi$ as a single production factor into production function, then it is difficult to interpret this ‘factor’ because there is no optimal amount of surplus but the more surplus we have, the better we are.
  – If we aggregate $\pi$ with $f_k$, we treat it as a capital factor. Another reason for doing this aggregation is that quality of capital data is usually poor, then it is better to have aggregated values (i.e. gross operating surplus) rather than disaggregated.

The cost of capital includes net price of capital ($PK$) and corporate income tax ($tk$). The tax base should be net operating surplus. Because $\pi$ is aggregated with fixed capital in the model, the tax base should be also modified - gross instead of net operating surplus. This also implies to modify the official tax rate in order to get a proper tax revenue from a corporate income tax.

Demand on capital $DK_i$ is specified from CES unit cost function:

$$DK_i = dk0_i \left( \frac{PLK_i}{PKE_i} \right)^{\sigma_{iK}^{LK}} \left( \frac{PKE_i * pk0}{PK(1 + tk)} \right)^{\sigma_{iK}^{KE}} \frac{N_i}{n0_i}$$

where $pk0$ is the benchmark price of capital, $\sigma_{iK}^{KE}$ is an elasticity of substitution parameter between capital and energy in sector $i$. This parameter should be relatively small when capital supply is fixed. The capital is supplied by households, thus capital income is subject of personal income tax $tl$, the same as labour income.

### 3.2.3 Energy market

The intermediate energy demand is divided in the model into feedstocks and fuels. The feedstocks are energy goods and service (eg. heating), which enter the material aggregate in the model using Leontief function. The fuels are energy goods and service (eg. coal) which enter the factors aggregate in the model.
using CES function. This distinction between different types of energy goods and service is essential in the model in order to distinguish sources of air pollutions. Thus the energy market is defined in the model as a market for gas, coal, biomass, other fuels, and electricity. This means that market for heating is defined as a non-energy market.

Consumption of energy factors require to pay price $P_{A_{en}}$ and emission charge rate $t_{e_{en,i}}$. The tax base is quantity (not value) of energy consumed (Figure 6). Each energy factor enters nested production function on a different stage of the nest (Figure 1). For example, demand on electricity is described by the following formula:

$$DE_{en,i} = de0_{en,i} \left( \frac{PLK_i}{PEF_i} \right)^{\sigma_i^{LK}} \left( \frac{PK_i}{PEF_i} \right)^{\sigma_i^{KE}} \left( \frac{PEF_i \cdot pe0_{en,i}}{PA_{en}} + t_{e_{en,i}} \cdot PNUM \right)^{\sigma_i^{EF}} \frac{N_i}{n0_i}$$

where $DE_{en,i}$ is a demand on energy factor $en$ (it is electricity in our example) per sector $i$, $PEF_i$ is an implicit price of electricity in the output price of sector $i$, $pe0_{en,i}$ is the benchmark price of energy in sector $i$, $\sigma_i^{EF}$ is an elasticity of substitution parameter between electricity and petroleum products in sector $i$.

Energy supply is endogenously determined by production function in the same way as for other goods in the model. This means that energy sectors has a double role in the model. Once they enter as production factors (demand side) and also they enter as production sectors (supply side). Market clearing condition requires that supply (including imported energy) equals to demand (including private and public consumption).

### 3.2.4 Zero-profit condition

A zero profit condition is applied for each sector under constant returns to scale:

$$PN_i * N_i \leq \sum_j PA_j * ID_{j,i} + PL(1 + sp)DL_i + PK(1 + tk)DK_i + \sum_{en} (PA_{en} + t_{e_{en,i}} \cdot PNUM)DE_{en,i}$$

where $PN_i$ is a producer price of output $i$, $PA_i$ is a seller price of product $i$. The right hand side represents total cost $TC_i$ for the given output level. The sector’s objective is to minimize total cost:

$$\min TC_i \text{ s.t. } f(ID_{j,i}, DL_i, DK_i, DE_{E,i}, DE_{F,i}, DE_{G,i}, DE_{C,i}, DE_{B,i})) \geq N_i$$

where $f(.)$ is a Leontief production function, $g(.)$ is a nested CES production function. The conditional demand functions $(ID_{j,i}, DL_i, DK_i, DE_{en,i})$ represent demands conditional on the requirement that the output level $N_i$ is produced. Thus there is no way to produce the same amounts of outputs at a lower total cost.

### 3.3 Consumption

Final domestic demand is represented by households and government in order to distinguish between private and public consumption. There is only one representative household in the model. This means that all households in the economy has been aggregated into one household and no distribution analysis will be possible. Investments are part of exogenous demand together with stocks.
3.3.1 Households

The firm’s profits, defined as a gross operating surplus, are redistributed to households. The households also receive a lump-sum transfer from the government:

\[ Y_H = (1 - tl) \left( PL(1 - sl)(ls - U) + PK * ks - \sum_i PA_i(1 + tvai)inv0_i \right) + PNUM*dtax \]

where \( Y_H \) is households disposable income, \( tvai \) is a value added tax rate per commodity \( i \), \( inv0_i \) is exogenous demand on investments, \( dtax \) are net nominal transfers including social security benefits. Consistent with the standard neoclassical assumption, consumers maximize their utility \( U_H \) subject to a budget constraint:

\[ \max U_H = \prod_i (HD_i - \gamma_i)^{\beta_i} \]

s.t. \( PA_i(1 + tvai)HD_i \leq Y_H \)

where \( HD_i \) is a household demand for commodity \( i \), \( \gamma_i \) is a subsistence demand for commodity \( i \), \( \beta_i \) is marginal budget shares with \( \sum_i \beta_i = 1 \) and \( 0 < \beta_i < 1 \). This is a Stone-Geary utility function with a quasi-homothetic preferences. The consumers allocate the residual income \((Y_H - \sum_j PA_j(1 + tvaj)\gamma_j)\) in the fixed proportion \( \beta_i \):

\[ HD_i = \gamma_i + \frac{\beta_i}{PA_i(1 + tvai)} \left( Y_H - \sum_j PA_j(1 + tvaj)\gamma_j \right) \]

This demand function is a linear function of income and prices and hence it is known as the Linear Expenditure System (LES). It allows for some flexibility relative to income elasticities \( \eta_i \): LES is appropriate to describe a demand on necessity and superior goods, but not inferior goods. Taking into account all the limitations of this function, it is unlikely to hold across all commodities or consumers. Thus LES provides a more realistic model when the level of aggregation is relatively high like in our model where we have 1 household and 19 goods.

In order to calibrate this function, we need to ensure the \( \beta \)’s add to unity. Using definition of the average budget share \( \theta_i \), the following relation holds: \( 1 = \sum_i \eta_i * \theta_i^{\beta_i} \). The calibrated income elasticity (\( \hat{\eta}_i \)) should satisfy the following condition:

\[ \hat{\eta}_i = \frac{\eta_i}{\sum_j \eta_j * \theta_j^{\beta_j}} \]

Thus, calibrated marginal propensity to consume depends on income elasticity and average propensity to consume: \( \beta_i = \hat{\eta}_i * \theta_i^{\beta_i} \). The strictness of constant \( \beta_i \) implies linear Engel curve.

3.3.2 Government

The government collects taxes, makes and receives transfer payments, and purchases goods and services. Public consumption \( GD_i \) is described by Leontief function, because there is no evidence that government consumption has any substitution:

\[ GD_i = g\theta_i \frac{YG}{\sum_j PA_j(1 + tvaj)gd0_j} \]
where \( gd_0 \) is benchmark public consumption of product \( i \), \( YG \) is government disposable income:

\[
YG = \sum_i gd_0i \ast PA_i(1 + tvai)
\]

In order to capture the implications of new environmental policy on the efficiency of public fund rising, the model incorporates the following features of the Czech tax system:

- **Value added tax:** \( VAT = \sum_i tvai \ast PA_i(HDi + GD_i + inv0_i) \), where \( tvai \) is a VAT rate. The tax paid by firms is defined with other net taxes on products.
- **Excise tax:** \( EXT = \sum_i tx_i \ast PNUM \ast A_i \), where \( tx_i \) is an excise tax rate, \( A_i \) is a market supply per good \( i \). This is a tax on products including energy tax.
- **Other net taxes on products:** \( OPT = \sum_i ta_i \ast PA_i \ast A_i \), where \( ta_i \) is a cumulative tax rate for other taxes on products less subsidies.
- **Social security:** \( SSC = \sum_i (sp + sl)PL \ast DL_i \). This is a quasi-tax. Social security benefits go to households through a lump-sum transfer.
- **Personal income tax:** \( PIT = tl(\sum_i PL(1 - sl)DL_i + PK \ast DK_i + PA_i(1 + tvai)inv0_i) \). We have assumed that the tax is paid on both incomes: labour and capital.
- **Capital income tax:** \( CIT = \sum_i tk \ast PK \ast DK_i \). This tax is treated in the model as a capital input tax, i.e. \( tk \) affects a zero-profit condition in the model, not income-balance.
- **Emission charges:** \( EMT = \sum_{en,i} te_{en,i} \ast PNUM \ast DE_{en,i} + \sum_i tp_i \ast PNUM(D_i + Z_i) \), where \( Z_i \) is export, \( D_i \) is production that stay in the country, \( tp_i \) emission charge as a result of non-energy consumption.
- **Other net taxes on production:** \( OT = \sum_i tn_i(PD_i \ast D_i + Z_i \ast ER \ast pw_i) \), where \( tn_i \) is a cumulative tax rate for other taxes on production less subsidies, \( PD_i \) is a price index for domestically-consumed local goods, \( pw_i \) is world price parameter, \( ER \) is an exchange rate.

The government deficit is one of the three macro balances and we will discuss it in the section \textbf{3.6}. No utility function is defined for the government, because there is no economic interpretation for government welfare.

### 3.4 Trade

The model describes a small open economy, i.e. infinitely elastic both world export demand and import supply curves. The world price \((pw_i)\) is a parameter in the model, because the Czech economy as a small economy does not have a market power on the world markets. This means that there is no explicit neither world export demand function nor world import supply function in the model.

A domestic firm produces a composite commodity \((N_i)\) that can be exported \((Z_i)\) or sold in the domestic market \((D_i)\). Rather than to assume a rigid dichotomy between tradable and nontradable goods, producers are viewed as producing a differentiated product for domestic and international markets. Their problem is to choose that combination of domestic and international products that minimizes costs. Thus export supply is represented by a constant elasticity of transformation (CET) function in order to show the
relationship between markets destination. The elasticity of transformation $\sigma^z_i$ shows a degree of transformability of $N_i$ between supply on foreign markets

$$Z_i = z0_i \left( \frac{pw_i \ast ER(1 - tn_i) - tp_i \ast NUM}{PDZ_i} \right)^{\sigma^z_i} \frac{N_i}{n0_i}$$

and supply on domestic markets

$$D_i = d0_i \left( \frac{PD_i(1 - tn_i) - tp_i \ast NUM}{PDZ_i} \right)^{\sigma^z_i} \frac{N_i}{n0_i}$$

where $PDZ_i$ is a composite transformation price, $z0_i$ is benchmark export of output $i$, $d0_i$ is benchmark domestic product supplied on domestic markets, $ER$ is an exchange rate. The price of exported goods is determined by the world price level only (Figure 4), but the price of $D_i$ depends on both domestic and world price (Figure 5).

Exchange rate in the model is neither the price of the foreign exchange nor a signal to agents, because the model contains no assets or money. It is a 'macro' variable (with units of domestic currency per unit of foreign currency) that equilibrate exogenous trade balance, rather than a financial variable. Thus there is an implicit functional relationship between exchange rate and trade balance. Changes in the exchange rate work only by changing the relative prices of traded and non-traded goods on domestic markets (affecting export supply and import demand). Increasing foreign savings yields an appreciation of the exchange rate (the price of non-traded goods rises relative to the price of traded goods). Exports fall (as producers shift production toward domestic markets) and imports rise (as consumers shift demand in favor of imports) bringing the trade balance into equilibrium with the new exogenous higher level of foreign savings.

In order to avoid over-specialization that occurs in neoclassical models with homogenous products, we use Armington assumption to define demand on imported products $M_i$:

$$M_i = m0_i \left( \frac{PDM_i}{pw_i \ast ER} \right)^{\sigma^m_i} \frac{A_i}{a0_i}$$

where $PDM_i$ is a price for the Armington composite good, $A_i$ represents supply of product $i$, $m0_i$ is a benchmark import of product $i$, and $\sigma^m_i$ is an elasticity of substitution between demand on imported and domestic products.

Because products are differentiated by country (the Czech Republic and the rest of the world), the 'law of one price' does not hold in the model. This means that each sector as whole can be a price-maker (i.e. $PD_i > pw_i \ast ER$) but the specific producer can only be a price-taker. In case of a lack of foreign corresponding goods, the domestic producers are independent, to the extent that they are not limited by the world price but only by the consumers budgets. Although the greater the difference between foreign price and the domestic price, the lower will be sales for the domestic producers.

Domestic output net of export ($D_i$) should be equal to demand on domestic output as shown on Figure 5. Both $D_i$ and $Z_i$ are subject of taxation. We assume that output taxes ($tp_i$ and $tn_i$) are applied on producers. Thus $PD_i$ represents a price index for domestically-sold local goods net of taxes on production. There are neither export quotas nor import tariffs in the model (a free trade), because there were relatively small rates in 2005 for the Czech economy. Thus c.i.f import prices are fixed and equal to f.o.b. export prices.

Supply ($A_i$) on domestic market include both imported ($M_i$) and domestic products ($DA_i$). This trade is also a subject of taxation. We assume that excise taxes ($tx_i$) and other taxes on products ($ta_i$) are applied
Figure 4: Foreign market on exported products from Czech Republic

Figure 5: Czech domestic market on domestic products
directly on sellers, but VAT and some emission charges are applied on buyers. Thus $PA_i$ represents a price for domestically-consumed both imported and local goods net of taxes on products. This is shown on Figure 6. Market clearance requires that supply minus demand is non-negative for all goods and factors:

$$A_i \geq \sum_j ID_{j,i} + \sum_{en} DE_{en,i} + HD_i + GD_i + inv0_i$$

The demand side of this trade is defined by domestic consumers, but supply is defined by domestic and foreign producers. This means that taxes on products affect directly imported goods, but not exported. The price on domestic market is determined through the arbitrage condition that shows a relationship between seller price and Armington price:

$$(PA_i(1 - ta_i) - tx_i \times PNUM)A_i \leq PD_i \times DA_i + pw_i \times ER \times M_i$$

Thus a partial insulation of the domestic price system from changes in world prices is possible through the Armington assumption. Implicit market-power depends on Armington elasticity of substitution.

### 3.5 Environment

Commodity $i$ represents either polluting or clean good. The division is determined by emission level. The model calculates emission of each pollutant by summing up the types of emissions listed in the section 3.1:

$$HEM_{em} = \sum_{en} HD_{en} \times h_{en,em}$$

$$SEM_{em,j} = pem_{en,j}(D_j + Z_j) + \sum_{en} DE_{en,j} \times sc_{en,em,j}$$

where $HEM_{em}$ and $SEM_{em,j}$ are emission levels of pollution $em$ created by households and sector $j$ respectively, $h_{en,em}$ and $sc_{en,em,j}$ represent emission coefficients related to households and sectors respectively. We ignore emission created through a public consumption and investment process. Households are responsible for emission created due to energy consumption $HD_{en}$. Producers can create pollution either due to both energy consumption $DE_{en,j}$ and production process $N_j$. 

![Figure 6: Domestic market on domestic and imported products](image-url)
Total emission may fall in the model as a result of (i) reduced production of the polluting good, (ii) substitution with less polluted inputs, i.e. reduced demand on polluting goods, (iii) increased abatement activity. We consider the following instruments to achieve this goal: emission charges or other taxes applied on polluting goods (e.g. excise tax). If the government decides to tax the polluting goods directly as an output tax $tn_i$, then we 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 of the abatement expenditures by firms. Similar interpretation can be applied for excise tax $tx_i$.

Emission charges $t_{em}$ can be applied on stationary sources of emission (energy and non-energy combustion) according to the following scheme:

$$t_{en,j} = \sum_{em} t_{em} \times sc_{en,em,j} \quad \text{and} \quad t_{pj} = \sum_{em} t_{em} \times pem_{em,j}$$

where $t_{en,j}$ is emission charge rate applied on sector $j$ due to emission created through energy consumption $en$, $t_{pj}$ is emission charge rate applied on sector $j$ due to emission created through non-energy consumption. Thus charge rates $t_{en,j}$ and $t_{pj}$ are not uniform, but depends on emission coefficients. The $t_{en,j}$ is expressed as a percentage rate of the price $PA_{em}$ (Figure 6) and it is applied on buyers. The $t_{pj}$ is a percentage rate of the price $PD_j$ (Figure 5) or $pw_j$ (Figure 4) and it is applied on sellers.

Implementation of emission charges means that firms will make abatement cost (more energy efficient production or less pollution intensive inputs) and will pay emission charges on the remaining emissions per unit of output. The abatement cost shifts the supply curve upward. 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 elasticities. When sector is very capital intensive, the elasticity of supply will be small and this sector will have to absorb an important part of the increase in marginal cost. The total effect of $t_{em}$ is a reduced output level $N_i$ in addition to reduced emission level.

If the abatement technologies are available, then sectors have a choice either to abate or to pay emission charges. We have taken data from bottom-up model GAINS. In order to incorporate bottom-up technologies directly into our CGE model, a step function is applied. This means that we use activity analysis to capture abatement possibilities by Leontief technologies that are active or inactive in equilibrium depending on their probability. The lack of data for all pollutions implies that we apply abatement technologies only for $SO_2$, $NOx$, and $PM$, i.e. there are no abatement possibilities in the model for $CO_2$, $CO$, and $VOC$. Also we assume a zero production level for abatement sector in the benchmark equilibrium because no data are available.

A pollution abatement service is modelled using two inputs: capital and fixed technical potential. The potential to reduce pollution through technical abatement activities provides an upper bound on abatement. The remaining part of pollution can be reduced only through decreasing economic activity. When abatement capacity is in fixed supply, a constant returns to scale production function exhibits decreasing returns to scale in the variable input (capital). An arbitrage condition determines an optimal level of abatement:

$$PNUM \times t_{em} \leq PK \times mac_{t,em} + PC_{t,em}$$

where $mac_{t,em}$ is marginal abatement cost per technology $t$ and pollution $em$, $PC_{t,em}$ is a fictitious price of abatement capacity. This means that abatement technologies are not related to specific sectors but to aggregate emission sources. If the detailed data were available, we would be able to identify optimal abatement level for each sector.
3.6 Macro closure

The introduction of a new actor, the ‘world’, does rise a problem what to do with the balance of trade. The simplest solution is to assume that the trade balance is exogenous. The resulting flow of funds is a foreign savings. The trade balance can be seen as simply the income-expenditure constraint of the new actor. The ‘world’ does not appear to be an optimizing entity in any sense, but simply demands and supplies traded goods at world prices.

Three macro balances should be considered with any CGE model: private savings by households, public savings by government, and foreign savings. The saving-investment account implies that the savings from various sources should be spend on capital goods (investment). Given that IOT is balanced, determining two of the macro balances necessarily determines the third.

Treating the balance of trade \( ca \) as exogenous means that the budget constraint of one actor should include this exogenous transfer, for example, the government:

\[
YG = tax - ca \times ER - dtax \times PNUM
\]

where \( tax \) means the government revenue from taxes (see section 3.3.2), \( dtax \) are net transfers to households. The last parameter helps to deal with public and private savings, i.e. we split savings between government and households through the following closure rule:

\[
dtax = yb0 - (1 - tl)(ls - U) \times (1 - sl) + ks - \sum_i inv0(i)(1 + tva_i)
\]

Thus a foreign closure is warranted in our model through the fixed trade balance constraint, but the government and households closures are warranted through fixed transfers. An economic equilibrium consists five conditions: market clearance, zero-profit, income balance, irreversibility, and free disposal. All these conditions are applied in our model.

4 Simulation analysis

We present simulation results for the new tax rates that Czech government is going to implement before 2016. The results for other scenarios are treated as a part of sensitivity analysis. The BAU scenario corresponds to our benchmark equilibrium.

4.1 Scenarios

The benchmark trade balance is positive for the Czech economy, but it will be changed in the scenarios endgenously because according to Walra’s law we may drop one equation. No changes in productivities or elasticities are considered compared to the benchmark level. We have assumed a constant level of elasticities of substitution across the sectors due to lack of estimated data: \( \sigma_{LK} = 0.2, \sigma_{KE} = 0.2 \), \( \sigma_{EF} = 0.5, \sigma_{FG} = 0.7, \sigma_{GC} = 0.8, \sigma_{GB} = 0.81 \). Also a constant rate across the sectors is assumed for Armington elasticities and elasticity of transformation. When elasticity of transformation is relatively high, there is a little price differentiation between domestic and international markets. If \( PD_i \) a little bit goes down relative to \( pw_i \times ER \), it will result large changes in the allocation of production to export versus domestic
Table 2: Percentage change of emission charge rates in real term from benchmark rates

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>BAU</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>0</td>
<td>19</td>
<td>91</td>
<td>153</td>
<td>214</td>
<td>272</td>
<td>329</td>
<td>746</td>
</tr>
<tr>
<td>SO2</td>
<td>0</td>
<td>19</td>
<td>91</td>
<td>153</td>
<td>214</td>
<td>272</td>
<td>329</td>
<td>746</td>
</tr>
<tr>
<td>NOx</td>
<td>0</td>
<td>17</td>
<td>94</td>
<td>149</td>
<td>214</td>
<td>265</td>
<td>326</td>
<td>742</td>
</tr>
<tr>
<td>VOC</td>
<td>0</td>
<td>19</td>
<td>91</td>
<td>153</td>
<td>214</td>
<td>272</td>
<td>329</td>
<td>746</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
</tr>
<tr>
<td>CO2</td>
<td>0</td>
<td>500</td>
<td>603</td>
<td>619</td>
<td>633</td>
<td>644</td>
<td>655</td>
<td>669</td>
</tr>
</tbody>
</table>

absorptions, because of high degree of transformability. We have assumed $\sigma^i = 4$ and $\sigma^m = 4$ for all sectors, except gas sector, where $\sigma^m_G = 20$. Czech economy can be considered as a price-taker in the gas sector because 96% of supply depends on import.

The values of income elasticities are based on estimations by Scasny (2006). There is one inferior good, natural gas, but households does not consume this product directly. All other products are normal goods and are appropriate for LES function. The level of unemployment elasticity of wage ($\mu = 0.1$) is based on estimation by Blanchflower (2001). Our sensitivity analysis shows that the model is robust to the level of this elasticity but it is sensitive to elasticities of substitution. The cost of environmental policy will be lower, the higher values of elasticities of substitution.

All tax rates are kept on the benchmark level in BAU scenario. Effective tax rates are applied for VAT and capital tax ($tk = 10\%$) in order to be consistent with data of IOT and National Accounts. The tax base for personal income tax $tl = 10.2\%$ is both the gross wage adjusted by social security contribution and the capital income adjusted by investments (otherwise PIT is overrated). The benchmark rates for payroll taxes are $sl = 12.5\%$ and $sp = 32.5\%$. Excise tax $tx_i$, according to official rates, is only applied on manufactured goods (1.7%), food (3%), and petroleum products (49%). It is applied directly on sellers in the model, but it also affects buyers depending on the price elasticities. Other net taxes on both products $ta_i$ (including VAT paid by firms) and production $tn_i$, are defined as residuals.

Emission charges are applied only on stationary sources of producers. This means that mobile sources and households emission are free of charge according to the Czech environmental policy. The following rates are implemented in thousands of Czech crowns per tonne of pollutant$^6$:

$$
t_{SO_2} = 1 \quad t_{PM} = 3 \quad t_{CO} = 0.6
\quad t_{NO_x} = 0.8 \quad t_{VOC} = 2 \quad t_{CO_2} = 0
$$

We consider seven scenarios with new emission charge rates based on the proposition of the Czech Ministry of Environment in the “Air Quality Act 2009”. The proposition assumes to replace $CO$ tax with $CO_2$ tax, to exclude non-energy emission from $CO_2$ tax, and to increase rates according to Table 2. Original time-path, proposed by the Ministry, assumes that scenario I will be implemented in 2015, scenario II - 2016, etc. However, our model is static and we implement all scenarios only for one period.

All prices in the model are expressed in nominal 2005 level and unit normalization is applied following the Harberger convention. The model considers neutrality of money, but in order to take into account a price

$^6$The exchange rate in 2005 was 1 EURO = 29.8 CZK
changes within scenarios simulation, we use the Laspeyres price index $P_{NUM}$ to be able to get a real prices:

$$P_{NUM} = \frac{\sum_i PA_i(1 + tvai)hd0_i}{\sum_i ph0_i \times hd0_i}$$

Also quantity taxes should be multiplied with the price index in order take into account possible price change in the economy. Thus all prices in the model are nominal until we do not divide them by $P_{NUM}$. No inflation is taken into account because the model can only determine relative prices.

Thus the new nominal charge rates, proposed by the Czech Ministry of Environment, were deflated by CPI in order to express rates in 2005 price level. The index was estimated by Scasny et al. (2009).

4.2 Results

Three sector are very polluting intensive: electricity, heating, and metal. Other polluting intensive sectors are mineral, chemical, petro, coal, and public service. The contribution of trade in very polluting intensive products to GDP is relatively low - below 10%. If we take into account all polluting intense sectors, then the contribution is 30%. The magnitude of the competitiveness effects of higher environmental taxation depends, among other things, on this contribution.

For a numeraire we have set exchange rate. The numeraire choice is simply reporting issue and has no implications for model results, because CGE models determine relative prices only. Th one equation is redundant in the model according to Walra’s law because we have the same number of variables and equations. So the trade balance equation is dropped and the fixed exchange rate helps to achieve endogenous trade balance.

The results shows that the new tax rates decrease a trade balance (by 10% for scenario I) but it will be still positive. We present the results relative to BAU.

5 Conclusion

The simulation of the environmental policy for the Czech economy shows .... We have made this conclusion by comparing the difference between the BAU with alternative scenarios.

Producers would substitute emission intensive production factors (like coal) with other factors. We predict the largest decrease in output for chemistry and coal extraction. Coal -as one of production factor- becomes relative expensive with respect to price of other factors, which result in smaller demand on coal and consequently reduction in production of coal sector. Output of forestry, i.e. biomass production, would rise.

The increase in emission charges should not slow down economic growth of the Czech Republic, but policy makers should consider a transitional support for selected sectors (chemical and coal).
Figure 7: Export relative to BAU scenario
Figure 8: Decomposition of export in the scenario I
Figure 9: Import relative to BAU scenario
Figure 10: Decomposition of import in the scenario I
Figure 11: Domestic price $P_D$, relative to world price $p_w \times ER$.
References


