Macroeconomic impact of electric power outage: simulation results from a CGE modelling experiment for Hungary

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Abstract

This paper presents the results of a CGE application that is used to measure and understand how sectoral shocks might influence the Hungarian economy, its economic agents and its different industries. The electricity outages are modelled by the decrease in the supply of energy. The capital stock in the energy industry is shocked, which leads to a decrease in the supply of energy. It is assumed that energy is a close complement to other goods both in production and consumption. In the base scenario a 2.08% decline in the supply of energy leads to a 0.53% decline in the GDP. Without price rigidities and other frictions, the adjustment is mainly driven by agents who can react at the lowest price. Therefore, this estimation should be considered as a lower bound on the real costs of adjustment. It is also shown that if prices are distorted, the costs of an outage are higher.

Introduction

Asymmetric or sectorial shocks actually occur regularly in modern economies. Their impact on the overall economy seems a more important issue today as economies are more globalized, and inter-sectorial (input-output) linkages lead to spillover effects in the economy. Even though it might be important from a historical point of view to understand how large those spillover effects are today in comparison to their values in the past, now we aim to come up with answers for a smaller subject: we argue that CGE models are adequate tools for measuring the size of those impacts. In this paper a CGE model application is introduced to measure the impact of a sectorial shock on the Hungarian economy.

Our work is partly motivated by a recent example of an electricity outage in Hungary. Due to the heavy storm on 17 August 2015 in Hungary, thousands of households were without electricity for days, because rain flooded the cellars of houses, where transformers were placed. According to the Budapest Business Journal[1], 9000 homes suffered from outage for a longer time, while in 47000 homes there were temporary blackouts. The Hungarian electricity supplier, ELMŰ paid a compensation of 5000 HUF (around 16 EUR) to the households, where electricity supply was stopped for more than 24 hours. The total damages caused by the storm are estimated to amount to 1.6 billion HUF (see MABISZ 2015).

This example motivated our work to a large extent as energy is one of the crucial inputs of production (and also an important product in consumption). In this paper we provide a CGE approach to measure the economic impacts of a sectorial shock, namely an electric power outage. The structure of the paper is as follows. In Section 1 a short summary is given on the existing approaches estimating the loss caused by an electricity outage. In Section 2 characteristics of electric power outages are described. Section 3 describes the energy producing sector of Hungary and a specification in more details of the estimation question. In Section 4 the main building blocks of the applied CGE model is described. In Section 5 the data background and the calibration work is shown. Also, the different scenarios are introduced here. In Section 6 the results of the simulations are presented. The final chapter concludes the paper.

1 Approaches of estimating the loss caused by an electricity outage

The costs of power outages are measured by different techniques. Reichl et al. (2013) analyse the existing assessment methods quantifying socio-economic effects of the outages. They introduce these measures on the example of Europe and emphasise that continuous electricity supply is essential for an economy; therefore, security measures must be made to provide uninterrupted supply.

They argue that there is an increasing need for securing continuous power supply, because electricity production and distribution is changing now in Europe: electricity markets are undergoing liberalization in EU member countries; and therefore, new regulations are needed for ensuring supply security. Second,

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[1] http://bbj.hu/budapest/storm-floods-the-streets-of-budapest_102670

inputs from renewable energy sources are growing, and these energy sources cannot be used continuously. Third, electricity consumption grows steadily as well; therefore, supply security is very important.

To create an efficient regulatory system for supply security, its value must be assessed. This value is often associated with the loss caused by the shortage of supply security. To model the economic loss caused by power outages, they distinguish three categories of effects of the electricity outages: direct costs, indirect costs and resulting long-term costs of macroeconomic relevance. Direct costs occur immediately after a natural disaster or technical problem causing the outage, while indirect costs are the results of direct effects, e.g. decline in production caused by the absence of electricity supply. Examples for long-term economic effects may be rising prices for production equipment because of the increased need for backup systems; or the availability of continuous electricity supply, which can be a major factor for a firm in choosing business location.

Several studies examined the effects of outages in the CGE framework. Rose et al. (2007) have investigated the impacts of an electricity outage caused by a terrorist attack on parts of the electricity supply system. They cite that costs of damages caused by outages are often measured only by the costs of precautionary actions made in order to avoid the outages. However, their paper gives attention to resilience of the economy on corporate, industrial or regional level, as well as indirect economic effects such as multiplying effects and general equilibrium effects; and they emphasise that these also need to be taken into account when estimating the costs of damages.

An electricity outage first of all has immediate, partial equilibrium effects, such as costs incurring from the damage caused in the equipment. These costs can be interpreted as loss in profits. In addition, there are other direct effects such as costs of backup-systems, rescheduling of production and increasing the capacities of the utility system. They measure the marginal value of the costs of electricity outage by the marginal reliability on electricity – the more capable the system is of adapting to the new circumstances, the less reliable it is on electricity; therefore, the smaller the loss is caused by the outage.

However, outages also have indirect or general equilibrium effects. The authors measure general equilibrium effects via economic output loss through different channels: loss of the downstream consumer of a firm that suffered damages. Upstream suppliers of the damaged firm suffer from economic loss, as well, since the firm ceases to order input from them. The wages decreased in firms that suffered directly from the damage; therefore, other firms have to face losses of consumer demand because of lower wages. Investment also decreases because of the profit decrease of disrupted firms, and this results in reduced output, as well. Similarly, the increased costs of firms with damaged equipment reduce output and productivity. CGE models in general are adequate tools for measuring these indirect effects.

Xie et al. (2014) also investigate the effects of economic disasters in a CGE framework, with special regard to the positive effects of reconstruction after a disaster. They model the direct, immediate effects of the disaster with decreasing capital stock; however, reconstruction works reproduce this capital stock in the following years. The article introduces the model on the example of the 2008 Wenchuan earthquake, by comparing three scenarios: no disaster, disaster and reconstruction, and disaster but no reconstruction. They also emphasise the importance of economic resilience: they distinguish static and dynamic resilience. Static resilience means the ability to continue production after a shock caused by a disaster, while dynamic one means the speed by which the economy recovers after a shock.

A natural disaster affects the economy through more channels: if a production plant is damaged, production declines or stops; raw materials and the number of workers decrease. Capital stock also decreases; therefore, aggregate supply decreases. It affects the whole production chain, causes unemployment and thus lowers income, and because of low production tax income decreases, too. The disaster affects not only the sector where it caused damage, but also has external effects on other sectors. However, reconstruction after the disaster has positive supply and demand effects. On the supply side, reconstruction investments restore capital stock in the following periods; therefore, aggregate supply gradually increases. On the demand side, because of the need for reconstruction, investment demand grows, especially in areas damaged by the disaster. The government and the households also increase their demand for goods needed for reconstruction; therefore, aggregate demand increases, too.

The authors find that without reconstruction works every sector suffers from economic loss, ; however, with reconstruction investment demand increases immediately. Therefore, the output of the construction sector and building material industries grows in the first years following the disaster. Employment instantly decreases; however, with reconstruction works it grows gradually in the next years. Nevertheless, unemployment is still higher than in the scenario without natural disaster. Employment shifts from other sectors to the construction sector and building material industries because of the increased demand for workers in these sectors. The income of the residents decreases immediately, and remains lower than in the scenario without disaster in the next years. However, it increases gradually due to reconstruction, so the differences decrease.

Küster et al. (2007) investigate energy policy measures in a CGE framework, with special regard to their impact on labour market. Labour market imperfections are introduced to the model via wage curves and constraints on minimum wages. They analyse the effects of capital subsidies on the application of technologies that use renewable energy sources. Their findings indicate that these subsidies do not necessarily result in decreasing emission. Furthermore, they may have negative growth effects if they promote renewable energy sources that are not cost effective, thus increasing unemployment in skilled and unskilled labour, as well.

These examples show that CGE models with their rich details about the sectorial structure of the

economy provide adequate tools for understanding how the indirect effects of a sectorial shock spill over in the economies influencing (or, potentially harming) other industries. Their general equilibrium modelling framework makes it possible to understand how large those indirect effects are, and the estimation of the losses and damages that a disaster causes may go beyond the listing of the direct (recovery) costs.

2 Characteristics of electric power outages

As CGE models are very abstract tools to estimate real life events, it is important to understand what the main important questions are when a certain event is modelled. Definitely, in the case of electricity outages, the damages are strongly related to technical specifics: electronic appliances do not work without electricity. These technological connections pervade everyday life and are present basically at every activity. In order to find the most relevant mapping of an electricity outage to the language of the CGE models, we scrolled over some recent and very influential examples of such events. For example, in the USA electricity outages due to natural disasters are not rare. Hurricane Sandy in October 2012, for instance, caused power outages in 17 states with around 8 million homes losing electricity, many of them for more days.[2] That is why in 2013 a study was conducted by the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability (see Executive Office of the President (2013)) on the economic costs of these outages and the possible benefits of increasing the resilience of the electric grid to outages caused by severe weather.

One of the largest nuclear accidents, the disaster of the Fukushima Daiichi Nuclear Power Plant and the earthquake preceding it on 11 March 2011 caused a major shortage of electricity in Japan. Due to the earthquake and tsunami Tokyo Electric Power Company (TEPCO) and Tohuku Electric Power Company (Tohuku EPCO) lost 22% and 45% of their capacity, respectively. The service areas of the two companies suffered from losing electric power; this affected about 8.5 million households. Because of the damaged power plants rolling blackouts had to be initiated for 3 hours per day for two weeks after the earthquake in some areas.

However, these planned blackouts were not in every area and next day's rolling blackout was announced the day before, which caused confusion. Therefore, the government called upon people to reduce their consumption of electricity to avoid further rolling blackouts. The target was a 15% cut in peak consumption of energy in the areas of TEPCO and Tohuku EPCO. Business facilities also had to conserve electricity by e.g. adjusting business hours or saving on air conditioning. For large firms with more than 500kW of demand the 15% conservation between July and September was obligatory. Electricity utility companies had to post forecasts of daily electricity using and reserve capacity ratio on their websites. The Ministry of Economy, Trade and Industry gave coupons to people who could save the target amount of energy.

The campaign was successful: electricity conservation ratios – the amount of electricity consumption spared compared to last year's consumption – of households were 7.4% for whole Japan and 11.7% and 8.9% in TEPCO's and Tohuku EPCO's service areas right after the disaster. The total savings in summer consumption of 2011 compared to 2010 were 19% in Tokyo and 18% in Tohuku areas. Large firms (with a higher than 500 kW contract demand) saved 27% and 18% in the two areas, respectively. Small firms saved 19% and 17%, while households conserved 11% and 18%, as well. In the third area, Kansai, where energy conservation was voluntary, there was still an 8% reduction (see Murakoshi et al. 2012 and Kimura and Nishio 2013). This is an interesting example revealing that differences in adjustments of actors might be an important issue.

Large electricity outages do not only happen overseas. A major electric power outage occurred in Europe on 4 November 2006, when the Ems Overhead Powerline Crossing in Germany was disconnected to allow a ship to pass under the cables. Although this was a planned and prepared event, it caused an interruption of the East-West power flows of international power trade. The Western area suffered from a frequency drop and electric power supply was stopped for about 15 million households in Europe (see UCTE Final Report 2007).

These important examples show that electricity outages in most developed countries are usually one-time events – even if they are expected or unexpected. However, there are examples of regular electricity outages, too. In Albania around 98% of the electricity production comes from hydropower, with the most important plant being on the River Drin (see EBRD 2008). Therefore, production highly depends on weather conditions. Before 2008 the yearly amount of energy produced varied between 3000 and 6000 GWh. Since electricity consumption is growing in Albania, and due to changes in the amount produced, electricity import varied strongly, as well. In very dry years insufficient production could lead to electricity shortages, e.g. in 2007 a drought caused major electricity outages of 16 hours a day in some areas (Ebinger 2010). In 2006 electric power shortages cost 1% of GDP growth in Albania, while according to estimations total protection from electricity outages would have cost 1.6 billion dollars.[3] Energy security is thus a very important issue in Albania, and actions were taken to adapt energy production to the variable weather and changing climate. In 2008 the Albanian government signed a contract to build a new hydropower plant that started to operate in 2013 (see IFC 2013). In 2014 reforms of the electricity sector were started to increase supply reliability.[4]

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[2]http://nation.time.com/2012/11/26/hurricane-sandy-one-month-later/

[3]http://www.balkaninsight.com/en/article/albania-doing-little-to-quell-growing-demand-for-electricity

[4]http://albaniaenergy.org/acerc\%20english-2/Project\%20Platform/Articles/Reforms\%20on\%20Electricity\ %20Sector\%20in\%20Albania.html

As these examples show in most situations electric power outages unexpectedly lead to a discontinuation of the otherwise ongoing economic activities. These sudden and usually not foreseen changes in the supply (or availability) of electricity influence households' behaviour, as many different activities from household work to recreational activities require energy. Production process might also be interrupted in an unexpected way resulting in loss of inputs (producing waste product), losing work-time and lower supply of product. Even if a list with all the different aspects of an outage were long, one common feature of these aspects is that they appear in almost every segment of the economy. The costs related to outages are far more widespread in the whole economy than the direct costs of recovering the materialized productive capital of the energy system. Therefore, understanding how large those indirect effects could be is a useful task.

It is also apparent that in most cases electricity outages occur unexpectedly and have serious impact on everyday life for a shorter or longer horizon. However, when electricity outages are present for a longer time period, sooner or later they will be expected. It is reasonable to assume that this latter case can be described only if expectations are formed endogenously in the given estimation approach. In this latter case, regular outages may be discouraging investment and will influence allocation decisions made in time. In our application we aim to model the economic costs of an unexpected electricity outage that is present for a shorter time horizon (up to a few months). We will not take into account how the longer presence of shortage in electricity influences future plans and the dynamics of an economy. Therefore, the electricity outage is modelled by the decrease in the supply of energy. As it seems from the above examples, sometimes electricity outages are frequent (for a short period of time, like in the Japan case) but each occasion lasts only for a few hours. This is dramatically different from the scenario when electricity is not available for complete days or even weeks (like in the European example). Unfortunately CGE models are not detailed enough to make reasonable difference between these two scenarios. Nonetheless, they must be distinguished in the application as these require different responses from the agents. A one-time large shock will result in the loss of inventories, producing waste instead of valuable products and the complete loss of work-time. The substitutability of electricity in these cases depends upon previously established solutions, like former adaptation of uninterruptible power supply systems, to a great extent. However, as an opposite "scenario", when electric outage is present for a few months but only up to a few hours each day, the damages are different and adjustment to the shock could happen with re-organising economic activities.

As CGE models are best used to understand the indirect, economic impacts of sectorial shocks of moderate size, it is more reasonable to assume that there are regular bottleneck capacities in the economy, which lead to regular but not very long-lasting electricity outages. As an approximation let us assume that due to some unexpected event (like a natural disaster) shortage of electricity occurs, which needs time to fully recover. Therefore, electricity is not available for two hours every day for three months (outside heating season). This is basically a 1/48 size decrease in the supply of electricity. Therefore, we build our application to measure the economic costs of a 1/48 decrease in the supply of electricity.

3   Energy sector in Hungary

Energy production is one of the most capital-intensive industries in Hungary. Its contribution to the national gross value added is bit less than 3%, whereas its share in the total employment is a bit less than 1%, which basically means that its labour productivity (as measured by the ratio of gross value added and employment) is approximately three times higher than the national average. These statistics are summarised in Table 1. However, the economic importance of the sector goes much beyond its relative size to the whole economy.

Table 1: The energy sector in Hungary, 2010

	Total Economy	Electricity, gas, steam and air-conditioning	Share (%)
Gross Value Added (billion HUF)	22 775	658	2,89
Capital (billion HUF)	205 454	7 034	3,42
Employment (ths)	4 055	38	0,94
Capital/Labour ratio (mHUF/head)	51	185	
Labour costs (thsHUF/year/head)	2 957	5 414	

Source: Use tables, National Accounts Statistics, published by the CSO

Energy is one of the most important intermediate inputs of production; it is basically used in all productive industries with varying intensities. A bit less than two thirds of the sector's total output is used for intermediate consumption. 30% is purchased by households and 0,5% is purchased by the governmental institutions (see Table 2).

It is important to note that the expression "energy sector" is used to indicate in this paper the "35: Electricity, gas, steam and air-conditioning" industry of the economy. Even though this paper only aims at understanding what the relevant impacts of an electricity outage are on the economy, our database does not make it possible to distinguish between electricity production, distribution (NACE 35.1) and gas production

and distribution (NACE 35.2) and air-conditioning (NACE 35.3) industries. This is taken into account with much care in the simulations. At this point it is important to understand that energy products, in general, are tradeable without a doubt. However, as data shows much part of the international trade of this sector is related to the import and export of gas, electricity is traded only in a much smaller part.

Table 2: Use and supply of energy products, 2010

	In value (bHUF)	Share (%)
Intermediate consumption	1 133	63,6
Households	533	29,9
Governments	8	0,5
Investment	0	0,0
Export	107	6,0
Total	*1 781*	*100,0*
Domestic production	1 599	89,8
Import	182	10,2
Total	*1 781*	*100,0*

Source: Input-output tables, National Accounts Statistics, published by the CSO

Energy is used in all industries. The share of energy in the total costs of production varies between 0.06% and 8,9% (see Table 3). It takes its highest values in the energy production sector (35), natural water (36), chemical products (20) and basic metals (24) industries. Interestingly, the third most energy-intensive sector is a services sector; it is the "93: Sporting services and amusement and recreation services", where 7.5% of all costs of production related to energy. It takes its lowest values mostly in other service industries. The national average is 2%.

The share of energy input in the costs of intermediate inputs is 3.56%, which means that electricity is used more intensively than an "average intermediate input". This also reveals that the importance of this sector goes much beyond its size.

Table 3: Sectoral average shares of energy costs in production

	Total Costs	Materials' costs
minimum of shares	0,31	0,41
maximum of shares	8,85	18,88
simple average of sectoral shares	2,32	4,53
standard deviation of shares	2,06	3,93

Source: own calculation based on Input-output tables, CSO of Hungary

Nonetheless, the energy dependences of the industries are quite different. As our kernel estimation shows (see Figure 1), there are a few industries with relatively higher energy intensity, but in most of the sectors the share of energy in total costs of production varies between 0 and 4%.

4 Model description

We apply a dynamic CGE model for estimating the impact of an electricity outage. The core of the model is a standard, static CGE model which has been modified for the purpose of this analysis in the following aspects:

1. Firms utilize two primary factors in production, namely labour and capital. However, unlike in a standard CGE model, in our application capital is not mobile across sectors. Capital is given by past investment and depreciation in each sector, only labour input is free to adjust to the shocks.
2. Labour market is modelled following efficiency wage theories, which make it possible to simulate the impact on (involuntary) unemployment, as well.
3. Recursive dynamics has been added to follow how investment decisions influence the path of capital.

Finally, the energy sector is modelled differently from the rest of the economy, as the counterfactual scenarios are drawn by adding exogenous shocks to the energy supply system (through a decrease in the productive capital stock of this sector). We describe briefly each block of the model below.

4.1 The static model

The core of the CGE model is a set of static equations describing the behaviour of the agents, their decisions about consuming, producing goods and services. As a result of their decision, the flows are completely determined and influence the time path of the stock variables as it is shown in the section on dynamics.

Figure 1: Histogram and kernel density of sectoral average shares of energy costs in production
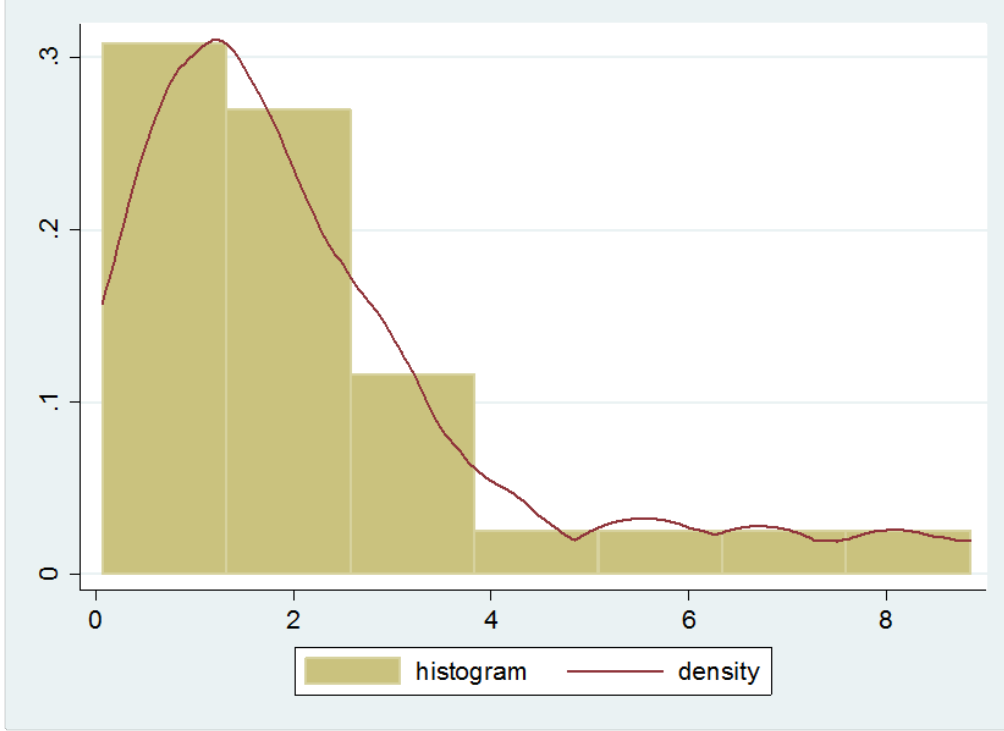
4.1.1 Household behaviour

The representative household shares its income between savings and consumption. The primary income of the household equals the income generated in production, since the household is the only owner of factors of production. It pays tax on the income of primary factors of production, and furthermore, it receives a transfer from the government. In the static CGE framework savings are exogenous; however, in our application the savings rate (ssp) is driven by the past real interest rate. Knowing the savings rate, savings of the household S_p are given as an exogenously determined share of its primary income:

$$Sp = ssp \cdot \left(\sum_j GOP_j + w \cdot L \right)$$

Disposable income of the household (N) is therefore given by subtracting savings and taxes (Td_h) from primary income and transfers (Tr) given to the household:

$$N = \left(\sum_j GOP_j + w \cdot L \right) - Sp - \sum_h Td_h + Tr$$

The household decision is described in a three-tier nested structure (see Figure 2). At the bottom level the household decides about its consumption of every good but energy. At the second level consumption is divided between energy and a composite of other goods. Finally at the top level the decision about aggregate consumption and leisure is made. This makes it possible to parameterize the elasticity of substitution between energy and other goods independently of the substitution between other goods.

First, at the top level, the household maximises its intratemporal utility by making choices on aggregate consumption (C) and leisure (FT), subject to its budget and time constraint contracted here:

$$\max \left(\Omega \cdot C^{\rho_L} + (1 - \Omega) \cdot FT^{\rho_L} \right)^{\frac{1}{\rho_L}} \tag{1}$$

$$s.t. \quad PC \cdot C + (1 - \tau d_L) \cdot w \cdot FT = (1 - \tau d_L) \cdot w \cdot TT + Y_0 \tag{2}$$

where PC is the consumer price index and C is aggregate consumption. Y_0 indicates income coming from other sources than work and TT indicates total disposable time that can be divided between labour and leisure. τd_L is the direct tax rate on labour income and w is the price of labour. The substitutability of labour and leisure is given by the parameter ρ_L, therefore the elasticity of substitution between the two factors is $\frac{1}{1-\rho_L}$. The share parameter Ω determines the relative weights of the two goods in the aggregate utility function.

Solving the utility maximizing problem of the household we get the decision about leisure time (FT) that depends on the elasticity of substitution, the share parameter and the relative prices of the two goods:

Figure 2: Nesting structure of consumption goods and leisure
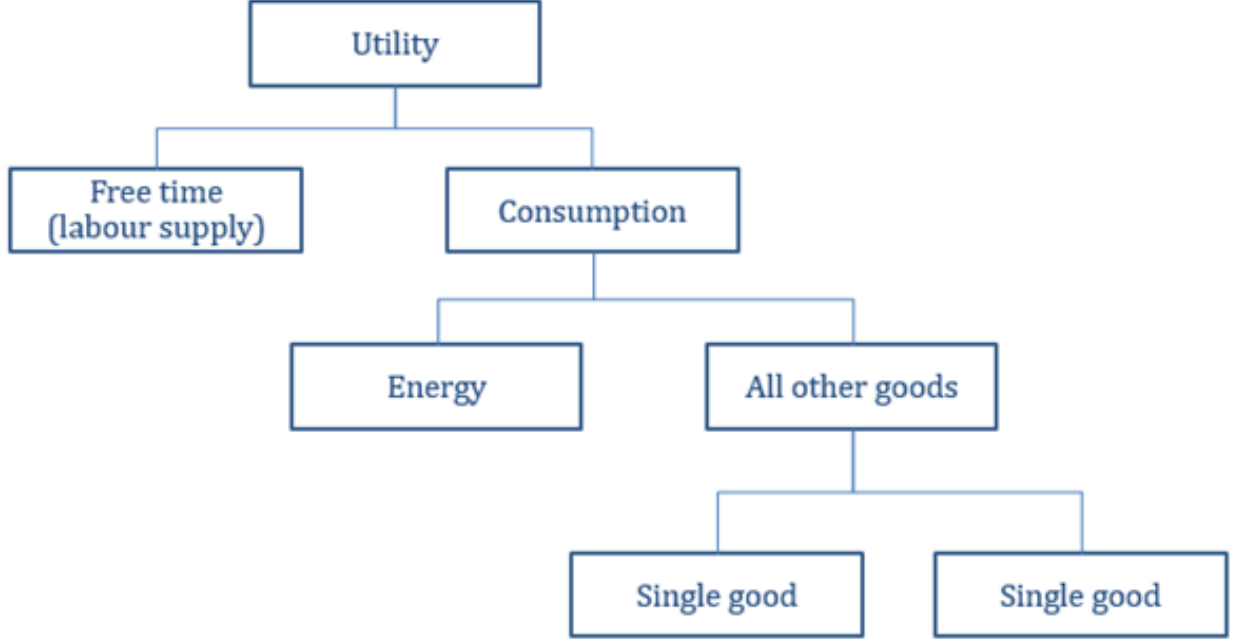
$$FT = \left(\frac{(1 - \tau d_L) \cdot w}{PC} \cdot \frac{\Omega}{1 - \Omega} \right)^{\frac{1}{\rho_L - 1}} \cdot C \tag{3}$$

Finally, labour supply (H) of the household can be written as:

$$H = (TT - FT) \tag{4}$$

At the second level aggregate consumption is divided between the consumption of energy products and all other goods by a CES function.

Finally, at the third level, the household decides about the consumption of all goods but energy. Consumption demand of the household is determined by a consumer basket of minimum cost that is needed to reach the utility level derived above. Thus, the cost-minimizing problem of the household is given as follows:

$$\max \left[\sum_i \alpha_i \cdot X p_i^\rho \right]^{1/\rho}$$

where Xp_i is the amount consumed from good i. As we treat the cost of aggregate consumption $PC \cdot C$ as given, the household's budget constraint can be written as:

$$C \cdot PC = \sum_i pq_i \cdot Xp_i$$

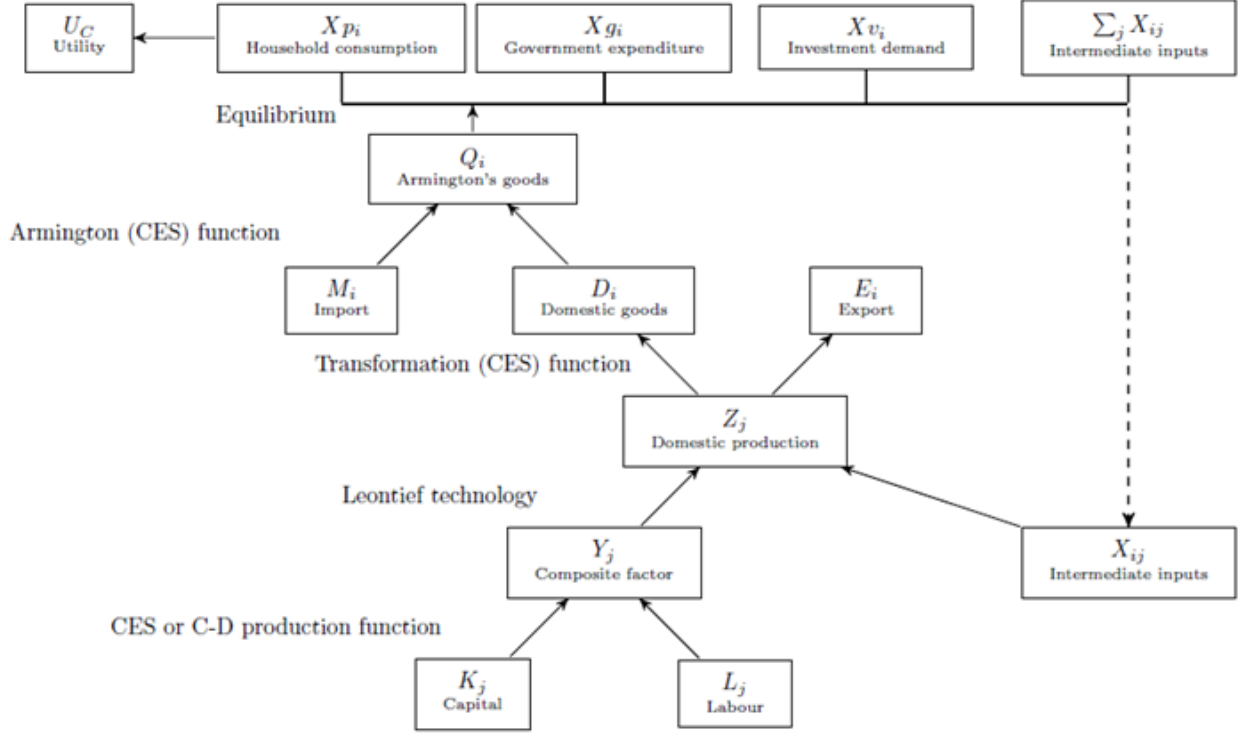The demand of the household from good i can thus be derived as:

$$Xp_i = G_i \cdot C \cdot PC^{\frac{1}{1-\rho}} = G_i \cdot N \cdot PC^{\frac{\rho}{1-\rho}} \tag{5}$$

where

$$
\begin{aligned}
N &= C \cdot PC \\
G_i &= \left(\frac{pq_i}{\alpha_i} \right)^{\frac{1}{\rho - 1}} \\
PC &= \left(\sum_i pq_i \cdot \left(\frac{pq_i}{\alpha_i} \right)^{\frac{1}{\rho - 1}} \right)^{\frac{\rho - 1}{\rho}} = \left(\sum_i pq_i \cdot G_i \right)^{\frac{\rho - 1}{\rho}}
\end{aligned}
$$

Since PC is the weighted geometric mean of the prices of the goods, it can actually be regarded as a price index.

Figure 3: Production and use of goods in the tradeable industries

4.1.2 Production block

The relationships between factors of production and the goods produced follow the structure of the standard CGE models. Therefore, the products of different sectors are used for intermediate inputs and for final use, as well. The structure of the relationships is shown in Figure 3.

1. First, primary factors of production (capital (K) and labour (L_j) are aggregated to a composite factor of production (Y_j) using CES function. Thus, the elasticity of substitution between labour and capital can be parameterized.

2. The domestic output of goods (Z_j) is determined using the composite factor Y_j and intermediate inputs for production ($\sum_j X_{ij}$). We assume Leontief technology at this level. Therefore, both the composite factor and the intermediate inputs are used in fix shares in the production of goods.

3. Domestic output Z_j is sold both at home (D_i) and abroad (E_i). The usual transformation function is used to split domestic production between domestic sale and export. The transformation function utilizes the price differences between domestic sale and foreign sale, and it assumes final elasticity of substitution, thus avoiding perfect specialization (thus reaching a "corner solution") in the production of the goods.

4. The goods finally consumed are either produced domestically or imported. Goods for final use are aggregated by Armington's aggregation functions from domestic goods (D_i) and import goods (M_i). This method is similar to the transformation function approach: by introducing final price elasticities, domestic and foreign goods are considered as not perfect substitute to each other.

5. The composition of domestic demand is the following: private consumption (Xp_i), government expenditure (Xg_i), investment demand (Xv_i) and intermediate inputs ($\sum_j X_{ij}$).

6. Aggregate utility (U_c) of the household is originated from the goods consumed by it (Xp_i).

Technically, the production decision is modelled in a nested structure. Firms take the prices of inputs and the prices of their products as given at every decision level. At the first level firms use primary factors of production (labour and capital) to obtain the composite factor. The technology of production is described by a CES production function. Thus, the problem of the firms can be written as the following (note, that capital is given):

$$\max py_j \cdot Y_j - w \cdot L_j$$
$$s.t. Y_j = \left(alpha_j K_j^{\rho_j} + (1 - alpha_j)L_j^{\rho_j}\right)^{1/\rho_j}$$

The demand for labour can be derived from the profit maximization of the firms, thus gross operating profit is defined by

$$GOP_j = py_j Y_j - wL_j$$

It is important to note here that there is no market for capital in our model because we assumed that the amount of capital is given by past decisions on investment and depreciation (however, the whole process is completely exogenous). The income share of the capital is modelled as gross operating profit and is given to the households, it forms part of their primary income.

At the second level firms produce their goods from the composite factor of production and intermediate inputs. At this level aggregation is modelled by Leontief technology, assuming that the composite factor and the intermediate inputs are used at fixed ratios in production. The demand function of factors and the supply function of products are derived from the profit maximization decisions defined below:

$$\max_{Z_j, Y_j, X_{ij}} \quad \Pi_j^z = Z_j \cdot pz_j - \left(py_j \cdot Y_j + \sum_i pq_i \cdot X_{ij} \right)$$

$$s.t. \quad Z_j = \min \left(\frac{X_{1,j}}{ax_{1,j}}, ..., \frac{X_{N,j}}{ax_{N,j}}, \frac{Y_j}{ay_j} \right)$$

where $Z_j \cdot pz_j$ is the value of domestic output, $py_j \cdot Y_j$ refers to the costs of the composite factors and $pq_i \cdot X_{ij}$ are the costs of intermediate goods used in production.

In the production function ax_{ij} and ay_{ij} are the shares of the factors in the production process where $\sum_i ax_{ij} + ay_j = 1$. At the optimum point it holds that:

$$\frac{X_{i,j}}{ax_{i,j}} = \frac{Y_j}{ay_j} \quad \forall i,j$$

Thus, the demand for intermediate goods and the composite factor can be written as follows:

$$X_{ij} = ax_{ij} \cdot Z_j, \quad \forall i,j$$
$$Y_j = ay_j \cdot Z_j, \quad \forall j$$

There is perfect competition in the market for goods, therefore the profit of the firms is zero. Thus, the cost of a unit of produced goods is the following:

$$pz_j = ay_j \cdot py_j + \sum_i ax_{ij} \cdot pq_i, \quad \forall j \tag{6}$$

Foreign trade is modelled assuming that Hungary is a small, open economy. Therefore, by assumption the world price of export and import goods are exogenous and given in foreign currency. The real exchange rate is applied to calculate the price of export and import goods in terms of domestic currency:

$$pm_i = pWm_i \cdot \varepsilon$$
$$pe_i = pWe_i \cdot \varepsilon$$

The balance of trade is introduced as foreign savings S_f to the model and is also expressed in foreign currency:

$$Sf = \sum_i pWm_i M_i - \sum_i pWe_i E_i$$

In the case of tradable goods those produced domestically and imported goods are not perfect substitutes; therefore, we need to define a composite good that embodies the relationship between domestic and imported goods. With this aim, the so-called Armington aggregation function is defined as follows:

$$Q_t = \gamma_t \cdot \left(\delta m_t \cdot M_t^{\eta_t} + \delta d_t \cdot D_t^{\eta_t} \right)^{1/\eta_t}, \quad \forall t \tag{7}$$

where the parameter η_t indicates the substitutability of foreign and domestic goods. From these functions demand for domestic and imported goods can be derived:

$$D_t = \left(\gamma_t^{\eta_t} \cdot \delta d_t \cdot \frac{pq_t}{pd_t} \right)^{\frac{1}{1-\eta_t}} \cdot Q_t, \quad \forall t \tag{8}$$

$$M_t = \left(\gamma_t^{\eta_t} \cdot \delta m_t \cdot \frac{pq_t}{pm_t} \right)^{\frac{1}{1-\eta_t}} \cdot Q_t, \quad \forall t \tag{9}$$

Domestic goods are either consumed in the country or are exported. Finite elasticity is assumed between exports and domestic sale. These two types of use are expressed by a transformation aggregation function written as the following:

$$Z_t = \theta_t \cdot \left(\xi e_t \cdot E_t^{\phi_t} + \xi d_t \cdot D_t^{\phi_t} \right)^{1/\phi_t}, \quad \forall t \tag{10}$$

where the elasticity of substitution is expressed by the parameter ϕ. Domestic supply and the supply for exports can be derived from the transformation functions:

$$D_t = \left(\theta_t^{\phi_t} \cdot \xi d_t \cdot \frac{(1 + \tau_t) \cdot pz_t}{pd_t} \right)^{1/(1-\phi_t)} \cdot Z_t, \quad \forall t \tag{11}$$

$$E_t = \left(\theta_t^{\phi_t} \cdot \xi e_t \cdot \frac{(1 + \tau_t) \cdot pz_t}{pe_t} \right)^{1/(1-\phi_t)} \cdot Z_t, \quad \forall t \tag{12}$$

4.1.3 Production in the energy sector

Production in the energy sector is modelled differently than the other sectors. We assume that in the energy sector the technology is Leontief at every level of the nested structure for domestic production; therefore, supply of energy requires primary inputs and intermediate inputs in given ratios. As capital is fixed and not mobile across sectors, the supply of energy is completely determined by the available amount of capital in the sector. The demand for other inputs, like labour and intermediate inputs adjust according to the given technology parameters.

This specification makes it possible to shock the supply of energy in a very simple manner. As the available capital in the energy sectors decreases, there is a similar decrease in the supply of energy. Our simulation experiment aims at understanding how and to what size this shock is going to influence the rest of the economy.

4.1.4 Government

The incomes of the government are determined endogenously, while the expenditures are exogenous. The income of the government comes from two parts: indirect taxes (Tz) occurring due to the use of products and direct taxes (Td) levied on the primary factors of production. Expenditures of the government are governmental consumption (Xg) in sectoral level and transfers paid to households (Tr). The primary balance of the budget (Sg) is the difference of the incomes and expenditures. Thus, the equations of the governmental sector are as follows:

$$Td_L = \tau d_L wL \tag{13}$$

$$Td_K = \tau d_K \sum_j GOP_j \tag{14}$$

$$Tz_j = \tau z_j \cdot pz_j \cdot Z_j, \quad \forall j \tag{15}$$

$$Sg = \sum_h Td_h + \sum_j Tz_j - \sum_i Xg_i - Tr \tag{16}$$

4.1.5 Labour market

Although labour demand equation (??) and labour supply equation (4) determine aggregate employment, the mechanism providing labour market adjustments needs to be modelled, as well. In standard CGE models labour market as well as the other markets clear due to the adjustment of the real wage, and thus unemployment occurs only voluntarily. However, in the last decades several ways of modelling labour market rigidities were implemented in CGE framework; for an excellent summary of these methods see Boeters & Savard (2012). In the present model labour market rigidities are introduced following efficiency wages theory.

In the efficiency wages model the equilibrium wage is determined as the intersection of the labour demand curve and the wage curve. Since this wage level is not necessarily the one where labour supply and demand are equal, there is an oversupply of labour in the market; thus, there is unemployment. The wage curve is the result of an incentive situation stemming from the information asymmetry between employers and employees. The parameterization of the efficiency wages approach used here follows Boeters & Savard (2012).

First, employees during working time can make different levels of effort, for simplicity here we distinguish two discrete cases - working and shirking. There is an exogenous probability of losing job that indicates the circulating fashion of the labour market. However, employees are monitored with a frequency rate q; where shirking workers lose their jobs. There is also an exogenous rate of job finding for the unemployed. Thus, utilities of the different states can be defined as follows:

$$d \cdot J_{EN} = U_{EN} - s \cdot (J_{EN} - J_U) \tag{17}$$

$$d \cdot J_{ES} = U_{ES} - (s + q) \cdot (J_{ES} - J_U) \tag{18}$$

$$d \cdot J_U = U_U + \Upsilon \cdot \left(J^E - J^U \right) \tag{19}$$

where EN indicates working and ES indicates shirking employees, s is the job losing rate and Υ denotes the job finding rate. J variables are discrete state values with U indicating the utility levels assigned to these states.

In equilibrium the amount of workers losing job and that of unemployed finding job equals; thus, in the long run job losing rate and job finding rate are connected to each other by the following equation:

$$\Upsilon = \frac{s \cdot (1 - u)}{u}$$

The firm wants to determine a wage rate along which the employee is incentivised to work instead of shirking. Thus,

$$J_{EN} = J_{ES} \tag{20}$$

As the present utility of an employee is the difference between the wage and the effort made, while that of the unemployed comes from the unemployment benefit (b) and the utility of leisure, net wage can be derived as:

$$(1 - \tau_L)w = \frac{1}{1 - r} \left[\frac{s}{u} + d + q \right] \frac{e}{q}$$

where $r = b/(1 - \tau_L)w$ indicates the rate of substitution. Thus, unemployment rate can be expressed as follows:

$$u = \frac{s}{\left((1 - r)(1 - \tau_L)w\frac{q}{e} - d - q \right)} \tag{21}$$

Knowing the unemployment rate and the labour supply, the aggregate labour demand can be determined as the following:

$$L = H \cdot (1 - u)$$

4.1.6 Market equilibrium

As the present model has a general equilibrium framework, equilibrium must hold in all markets; therefore, total consumption of every tradable good must be equal to the sum of the supplies of the import and domestic production:

$$Q_i = Xp_i + Xg_i + Xv_i + \sum_j X_{ij}, \quad \forall i \tag{22}$$

where Xp_i is private consumption, Xg_i is governmental consumption, Xv_i is investment demand and $\left(\sum_j X_{ij} \right)$ is the use of intermediate goods. As for non-tradable goods, domestic supply must equal to domestic demand:

$$
\begin{aligned}
Z_j + Tz_j &= Q_j \quad \forall j \\
pz_j &= pq_j \quad \forall j
\end{aligned}
$$

Trade balance and the balance of the capital account add up to determine savings of the rest of the world. The investment-savings balance holds as domestic investment can only be financed from domestic savings and foreign savings:

$$I = S_p + S_g + \varepsilon \cdot S_f \tag{23}$$

where S_p is private saving, S_g is government saving and S_f is the balance of trade, thus savings of the rest of the world.

The sum of sectorial demand for labour must add up to the aggregate level of employment:

$$L = \sum_j L_j \tag{24}$$

In the labour market it means that the difference between labour demand (as is defined by the sum of sectorial labour demand) and the labour supply (from household utility maximization problem) defines unemployment. However, this unemployment rate must be consistent with the wage specified by the wage curve.

4.1.7 Closure rule

The macroeconomic aggregates of a static CGE model are not fully determined. As it is usual in this modelling environment, a so-called "closure rule" is applied. Closure rule means to identify which macroeconomic variable is considered as being exogenous in order to fully specify the macro level of the model. In our application the investment-driven closure rule is applied. We assume that the model simulations aim at measuring the impact of a short-run event without having any significant impact on future plans, including investment. Therefore, (sectorial) investment demands are taken as exogenous.

4.2 Dynamics

The characteristics of the system described above determine the static equilibrium of the model. However, for describing the time path of the economy dynamics should be added. Dynamics of a model can either be forward-looking or backward-looking. In the present model recursive dynamic relationships are used; therefore, past and present values determine the initial values of the next period.

These recursive relationships are the following:

1. Capital stock increases with investments and decreases due to depreciation:

$$K_{s+1} = (1 - \delta) \cdot K_s + I_s \qquad (25)$$

2. Net foreign debt of the country is the debt of the previous period increased by payable interests and decreased by redemption, which is expressed by the balance of trade of the country.

$$F_{s+1} = (1 + i_{s+1}) \cdot F_s + S_f \qquad (26)$$

Real interest rates are determined by the foreign real interest rate (i^*) and risk premium (Φ) related to the debt of the country. This risk premium is a nonlinear function of the indebtedness of the country, and is modelled by a so called linex function that punishes high indebtedness strongly. Formally, if dr_s indicates the debt-to-GDP ratio at period s and $target$ is the target value of this ratio, real interest rate and the risk premium can be defined as follows:

$$
\begin{aligned}
i_s &= i^* + \Phi(dr_s) \\
\Phi(dr_s) &= \exp\left(\mu_r \frac{exp(\xi_r(dr_s - target)) - \xi_r(dr_s - target) - 1}{\xi_r^2}\right) - 1
\end{aligned}
$$

The savings rate of the household is exogenous; however, it may change in time due to the changes in the real interest rate. In this model it is assumed that the lagged value of the real interest rate affects the savings rate of the household:

$$ssp_s = coeff_1 + coeff_2 \cdot i_{s-1}.$$

5 Case description and Data

5.1 Data

The parameterization of any CGE model requires enormous effort from the model builder. The core data source of the parameterization is the published input-output tables that are estimated by the Central Statistical Office of Hungary. These tables are published for every fifth year, the last available has been published for 2010. Thus, we based our estimation experiment on this table and collected other statistical information of 2010 to finalize parameterization. In some cases missing information were utilized from other sources; however, in each cases we aimed to avoid using data of different years. The input-output data has been completed with data on income flows between different agents of the economy by creating a consistent social accounting matrix (SAM). The SAM in our application follows the standard structure (see Table 4). There are 62 different sectors of the economy that are distinguished in the application. The energy sector is one of these, so there are 61 sectors that are influenced indirectly in our application, and the energy sector is shocked directly.

The "upper right" and "bottom left" blocks of the SAM (as denoted by different shading) are also part of the published input-output tables; however, we needed to make small data corrections (these are described in detail below). The "bottom right" block of the SAM contains some non-market income flows (transfers and taxes) between the different agents that are not part of the input-output tables, so these cells have been filled with additional information from the national account statistics that are published by the CSO. From these statistics we utilized information on how much tax has been paid by the households, these were interpreted as taxes on labour. The taxes paid by the firms were interpreted as taxes on gross operating profit. The transfers from government to households have been added to the model. By the addition of these statistics we could model the change in the primary budget balance of the government and the overall sum of private savings, which now has been assigned to the household sector.

The published data needed some small corrections as it had to fit to the model requirements. We made three important changes to the data. First, we had to eliminate re-export from the sectoral international trade data. The symmetric input-output tables for import (published by CSO) contain information on how large part of the import is used directly for export. These data have been extracted from the original export and import values for each sector. This modification had no implication on the sum of the net export. At the same time it is rather crucial from our application's point of view. As it turned out, there are three sectors of the economy with extraordinary degree of openness. In the "26: Computer, electronic and optical products", "27: Electrical equipment" and the "29: Motor vehicles, trailers and semi-trailers" sectors the

Table 4: Social Accounting Matrix

| | Sectors | Factors | | Taxes | | Final consumption | | | |
		CAP	LAB	DTX	IDT	HOH	GOV	S-I	RoW
Sectors	X_{ij}					Xp_i	Xg_i	Xv_i	E_i
CAP	GOP_j								
LAB	$w \cdot L_j$								
DTX						Td			
IDT	Tz_j								
HOH		GOP	$w \cdot L$				Tr		
GOV				Td	Tz				
S-I						S_f	S_g		$\varepsilon \cdot S_f$
RoW	M_j								

The accounts of the SAM are indicated as follows: CAP = capital, LAB = labour, DTX = direct taxes, IDT = indirect taxes, HOH = households, GOV = government, S-I = savings-investment balance, RoW = rest of the world. Income flows are indicated in the cells of the tables. Any cell without a variable in it indicates zero income flows. The notations are the following: X: intermediate and final consumption, GOP = gross operating profit, w: real wage, L: employment, Tz: indirect taxes, Td: direct taxes, M: import, E: export, S: savings, e: real exchange rate. Sectors are indicated by i and j.

value of export is higher than the value of domestic production. Similarly, the value of import exceeds the value of domestic (intermediate and final) consumption. A situation like this can only be reached if there is some re-export in the industry. The key difficulty in this situation is that without the extraction of the re-export the domestic supply of the goods will be inevitably negative (according to the model equations), which is highly implausible (and makes the model numerically intreatable). After extracting the value of re-export, the situation could be solved.

Second, the income flows in the published symmetric input-output tables are at basic prices, do not involve the value of indirect taxes. The overall sum of the indirect taxes in Hungary adds up to approx. 15% of the GDP, which is far from negligible. Most importantly, indirect tax rates play an important role in forming consumption and production behaviour; therefore, its importance cannot be overlooked. Because of these reasons we added net indirect taxes to the elements of final consumption as it is published by CSO and also added the sectoral sum of these taxes to the IDT row of the SAM matrix. Finally, we added the indirect taxes of intermediate consumption to the IO block of the SAM. Unfortunately this final step has broken up the symmetry of the SAM and the balance of the rows and column sum has been lost. Therefore, we applied RAS algorithm to the IO block for restoring the symmetry of the IO table.

Third, we used a cut-off point approach to identify non-tradeable sectors of the economy. Sectors, where the ratio of the export to domestic production and the ratio of import to final domestic consumption were lower than 5%, and the sum of export and import was less than 6% of domestic production, were classified as non-tradeable. As we applied three different criteria for data between 2008 and 2011, in some cases they led to different conclusions. In these cases we made individual decisions based on the nature of the sector. For example, the "55-56: Accommodation and food services" sector was almost always tradeable while in two years it seemed as non-tradeable based on the export criteria. No doubt, tourism is a tradeable service, so it was classified finally as a tradeable.

Even though based on these information the energy production sector is tradeable, we decided to classify it as a non-tradeable. This analysis is focusing on understanding what the possible costs of an electricity outage are. In case there is import available, by shocking the domestic supply system, import could overtake its role. By assuming that some unexpected event destroys the electricity system, import electricity will not be available, either. Therefore, we considered energy sector as non-tradable only for the present analysis.

After all these considerations there are 16 industries that are classified as non-tradeables, including all sectors of public services, some domestic service industry, like "78: Employment services" or "41-43: Construction and construction works" and the energy sector itself. The remaining 46 sectors are considered as tradeable.

5.2 Elasticity parameters

The elasticity parameters of CES utility and production functions are usually free parameters in a CGE model. Even though it is possible to calibrate the share parameters based on flow data, we needed additional information to specify the values of the elasticity parameters. The elasticity parameters describe the substitution in consumption and factors of production; therefore, their values have a huge influence on the direction and size of the impacts.

The elasticity of substitution between all (but the electricity) goods in consumption are estimated from aggregated, cross sectional consumption quantity and price indices data. As the demand for consumption goods is a constant elasticity type function of the price indices, and its coefficient depends on the elasticity of substitution parameter of the utility function, from the observed changes in prices and quantities we

made a first attempt to estimate it. We used household consumption data from the 2008 and 2009 use tables valued at constant prices and at previous years' prices; and from the relative changes in quantities and prices we made a cross-sectional regression. As it is often the case with aggregate variables, the changes in both variables may reflect other influences; therefore, the explanation power of the regression is quite low. Nonetheless, the coefficient is significant and shows a relatively high willingness of substitution between goods; thus, the elasticity of substitution in consumption has been set to $\sigma_c = 1.33$.

$$log\_price = \begin{array}{cc} -0.0197351 & -1.32918 log\_cons \\ (0.026981) & (0.67681) \\ T = 50 & R^2 = 0.0551 \end{array}$$

The consumption from energy has been set at a different nesting level. Its substitution with all the other goods can therefore be separately parameterized. We do not model the technical dependencies directly but it seems quite reasonable to assume that electricity is rather complementary than substitute to other goods' consumption. As we found no direct estimation on the substitution parameter between electricity and all the other goods, we simply assume that they are quite close but not perfect complements and used $\sigma_{EN} = 0,168$ as a parameter.

The elasticity of substitution between capital and labour is less understood. Therefore, there is a sensitivity analysis for understanding what different values could cause in the model. There are two different values that are used for simulation. In the base case it is assumed that $\sigma = 0.5$, which means that labour and capital are complements rather than substitutes to each other. However, it is also simulated what the impacts would have been if the elasticity of substitution is higher, namely it is $\sigma = 1$.

The elasticity parameters of the Armington and transformation functions are taken from Imbs-Méjean (2010) study. The export elasticity (1,782) and import elasticities (1,878) have been estimated for the Hungarian economy based on data of years 2001-2006. These can be considered as moderate values and are very close the usual trade elasticities used in CGE models.

5.3   Case description

As CGE models are best used to understand the indirect, economic impacts of sectorial shocks of moderate size, it is more reasonable to assume that there are regular bottleneck capacities in the economy, which lead to regular but not very long-lasting electricity outages. As an approximation let us assume that due to some unexpected event (like a natural disaster) shortage of electricity occurs, which needs time to fully recover. Therefore, electricity is not available for two hours every day for three months (outside heating season). This is basically a 1/48 size decrease in the supply of electricity. Therefore, we build our application to measure the economic costs of a 1/48 decrease in the supply of electricity.[5]

The results depend more or less on the parametrization of the model. We used as many statistics and other informational sources to calibrate model to the Hungarian economy as possible. However, the substitutability of primary factors in the production of goods remained a less convincingly solved issue. Therefore, we made two different scenarios based on the value of substitution between labour and capital. In the base case we assume that $\sigma_L = 0.5$, which means that labour and capital are complements rather than substitutes to each other. In the other scenario we assume that $\sigma_L = 1$, which means that labour and capital is more close substitute to each other.

Finally, we simulated how the results change if the household and government sector faces a maximised price for the energy in a form of price support. The energy firms may use price discrimination in the sense that their price can differ in different segments of the economy. The revenue of the energy sectors' firms therefore adds up from the sales revenue to households and government valued at the original price and from intermediate consumption of energy valued at market price.

6   Simulation results

The simulation experiment aims at understanding what the major macroeconomic impacts of an electricity outage are in Hungary. For this goal we summarised the main impacts in the year of the shock on main macroeconomic variables as GDP, employment, etc. These results are discussed in section 5.1. Probably the most interesting feature of a CGE application is its main sectoral disaggregation that makes it possible to understand how the structure of the economy changes when some sectoral shock occurs. Our experiment shows that the changes in the overall output of the sectors have a negative sign; however, its magnitude varies to a large extent. In section 5.2 we addressed the issue why and how these responses differ across sectors.

---

[5]For the simulations to be calculated it is necessary to solve the model equations. As there are actually a large number of nonlinear equations to be solved, usually it is done numerically. In our case we programmed the model equations in OCTAVE and used the built-in solver ('fsolve') for this purpose. This function uses a version of Newton methods to solve the system of nonlinear equations. By substituting equations into each other, the OCTAVE code reduced the dimensionality of the problem to 2*n+3, where n is the number of sectors (in this application it is 62). This meant that fsolve had to find the root of a system of 127 nonlinear equations.

6.1 Macroeconomic effects

The effects of a 2.08 percent decline in the supply of energy are shown in Table 6. We present the results of four different scenarios. The results of the base scenarios are presented in the first two columns; in this case there is no price discrimination in the market for energy, while in the last two columns households and government pay a different price for energy than firms do. In both cases two different substitution parameterizations are simulated. We take $\sigma = 0.5$ as the base case, as in this case labour and capital are more complements than substitutes to each other. We also calculated the results if primary factors of production are closer substitutes to each other, which is shown in columns $\sigma = 1$. However, in all four scenarios, energy is a close complement to other sectors' output both in production and consumption.

As a result of this complementarity, the consumption and production fall in each scenario. With the decline in energy supply, the production decreases; therefore, gross value added also decreases, as it is measured by GDP. As production declines, firms employ fewer people, and employment declines, too. The decline in employment goes hand-in-hand with an increase in unemployment. The latter is associated with a decrease in the real wage. Aggregate consumption falls, as well, partly because of the fall in income. The overall decline in economic activity influences foreign trade, too. The decline in domestic output is associated with a small real appreciation that harms export. Though less in amount, import falls, as well, probably because the decline in income overwrites the impact of the real appreciation.

In the base case, the decline in GDP is 0.53%, which is approximately one fourth of the decline in the energy supply. This seems quite a large impact considering that the overall size of the sector is only about 3%. If the impact would be proportional to the size of the sector, it should be around 0.06%. One could make an upper estimation on the impact by assuming that all economic activity should go proportional to energy consumption, in which case the decline in GDP should be equal to the decline in energy production. These natural estimates give us a natural starting point that the impact of a 1% decline in energy production on GDP should be in the [0.03%, 1%] (actually quite large) interval. Our approach makes it possible to give a point estimate in this interval that is based on scientific argument and a structural description of the indirect, economic relationships in the economy. Our model suggests that the size of the impact could be around a 0.25% decline.

However, in understanding how these results could happen we need to go beyond these macroeconomic aggregates. The decline in overall production is less than the decline in energy production, which needs an answer, as energy is – by assumption – a perfect complement to all other materials in production. The answer lies in the different reactions of the different agents in the economy. First, as energy is not used for investment and is considered as non-tradeable, (only for the purpose of this investigation) only households, government and firms buy energy. It is shown in the last rows of Table 6 that households' consumption of energy declines 3.61% whereas firms' intermediate consumption of energy declines only with 1.37%. The adjustment is largely driven by households' consumption. Second, different sectors react differently, as is shown in the next subsection (see section 5.2).

Finally, we need to emphasise that in our approach we used a flexible price model, where adjustment is always a reaction to changes in prices. Due to the decline in energy supply, its price increases and agents react to the increase in the price of energy. We presented the calculated change in the price of energy in Table 6, too. The presented results should be interpreted as a relative price change as the consumption price index has played the role of the numeraire. Energy prices grow strongly; and therefore, total energy consumption falls. However, as the demand for energy is highly inelastic, an 18-60 percent energy price growth will result in a consumption fall by only 2 percent.

The elasticity parameter of the primary factors had been chosen freely; therefore, we made simulations for two different values to check how the results changes. As the table shows, there are no considerable differences between the two specifications of the substitutability of primary factors of production. This is not the case if there is price discrimination in the market for energy.

In the price discrimination scenario, households and government do not face with the shock of higher energy prices; they pay the same price as before the shock. Therefore, they do not decrease their consumption as much as in the base case. The decline turned out to be about 0.4 percent in our application. Thus, firms will be "forced" to decrease their consumption of energy much more, which will result in a higher decrease in production and employment. This basically means that the required decrease in the demand for energy can only be reached by a much larger increase in the price of energy, as it can be seen from the simulation results. It is important to note that the energy price change shown in the results table is the price that firms pay in this scenario. Households' price does not change – by assumption – in these scenarios. Therefore, the average energy price what energy producing firms face is a weighted average. We have shown earlier that intermediate consumption of energy is approximately two thirds of all energy consumption; therefore, the average price of energy will increase by two-thirds of the price change we presented in the table (40% and 31%, respectively).

In the case of price discrimination, the adjustment in the demand for energy is largely absorbed by firms. This is resulted in a larger decrease in production, and thus a larger decrease in employment. The real wage's fall and the increase in the unemployment rate are larger in this specification. The contraction of the economy is larger when firms are forced to decrease their energy consumption since it limits their production possibilities.

Table 5: Effects of a 2.08% decrease in the supply of energy in the year of the shock

| | | base case | | price discr. | |
	unit	$\sigma = 0.5$	$\sigma = 1$	$\sigma = 0.5$	$\sigma = 1$
Macroeconomic variables					
GDP	%	-0.53	-0.57	-0.9	-0.86
Employment	%	-0.84	-0.9	-1.4	-1.33
Unemployment rate	%points	0.61	0.66	1.02	0.96
Real wage	%	-1.19	-1.27	-1.9	-1.81
Primary balance of government	%points	-0.29	-0.32	-0.46	-0.46
Consumption	%	-0.43	-0.4	-0.43	-0.38
Export	%	-1.02	-1.23	-2.11	-2.16
Import	%	-0.64	-0.77	-1.24	-1.3
Real exchange rate	%	-1.02	-0.84	-0.29	-0.13
Energy price and consumption					
Real price of energy	%	21.25	18.42	59.92*	46.52*
Households' consumption of energy	%	-3.61	-3.2	-0.44	-0.38
Firms' consumption of energy	%	-1.37	-1.57	-2.88	-2.9
Total consumption of energy	%	-2.08	-2.08	-2.08	-2.08

*: change in the market price of energy that is paid by firms only.

6.2 Sectorial effects

The changes in the sectors' production are quite different from each other. It is reasonable to assume that production will decline more in the energy-intensive industries. However, the adjustment in different sectors might be influenced by other – but simultaneous – changes, as well. We have made a small analysis to find out how the model specification (and the applied simplifications) and the nature of different sectors are mutually responsible for the different reactions. The results are based on the simulation of the base case (no price discrimination and labour and capital are not perfect complements in production).

The energy-intensity of the sectors is measured either by the share of energy in the total costs of production (see Figure 3) or by the share of energy in the costs of intermediate inputs (see Figure 4). As these are technological parameters, they are not influenced by the shock and are calculated from the symmetric input-output tables. The figures show how these shares and the change in the sectors' output are related to each other in the simulation. As our results suggest, there are small differences in the reactions of the tradeable and the non-tradeable sectors of the economy. We used different markers in the graphs to illustrate that there are no differences in their energy-intensities on the average. The data of the energy sector is not included in the figures as it is directly influenced by the shock.

The figures suggest that there is a negative relationship between the share of energy costs and the change in output: the higher the share of energy in the costs is, the higher the fall in output of the sector is. It is also salient that in non-tradable sectors the relationship is less strong. The relationship between energy-intensity and the change in output is analysed using a simple econometric model, in which the 61 sectors' responses and its characteristics are related.

The role of foreign trade in the responses is not quite trivial. On one hand, the small real appreciation suggests that tradeable sectors might be influenced more strongly than non-tradeables. On the other hand, as investment demand and government expenditure are set exogenously, some sectors' demand decrease less just by assumption. As almost all public service sectors are non-tradeable and much part of their demand stems from the government it is not trivial if the difference between tradeable and non-tradeable comes from our assumption about investment and government demand being exogenous. However, if we compare tradeable and non-tradeable sectors on the average, there does not seem to be any systematic differences in the structure of their demand (see Figure 5).

The different responses of sectors' production is analysed in a simple econometric framework, whose results are shown in Table 7. The table presents the results of four different model specifications. In each case we used one measure of energy-dependence (share of energy in either total or intermediate input costs). As it is shown in the figures, two sectors produced "outlier" responses in the sense that their decline is much higher than their energy-intensity can explain. These outliers are the "20: Chemicals and chemical products" and "24: Basic metals" manufacturing. The variable called "outlier" is a dummy which takes value 1 only in the case of these sectors. It is important to emphasise that this "outlier" behaviour is much likely to be the corollary of the nonlinearity of the model. As we apply a linear estimation now, the exact relationship between the share of energy costs and the decline of sectorial output cannot be applied directly. As a consequence, we used these dummy variables to make a better fit without suggesting that some unexpected happened in these industries.

For understanding the role of foreign trade and demand in the responses, dummy and interaction variables

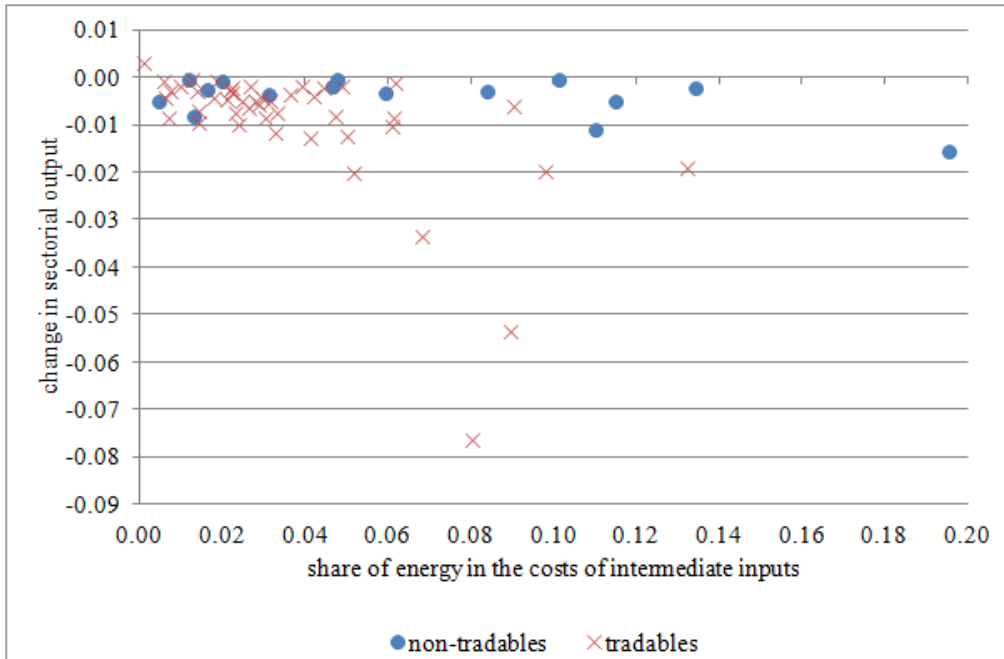Figure 4: Share of energy in intermediate consumption versus the change in sectorial output

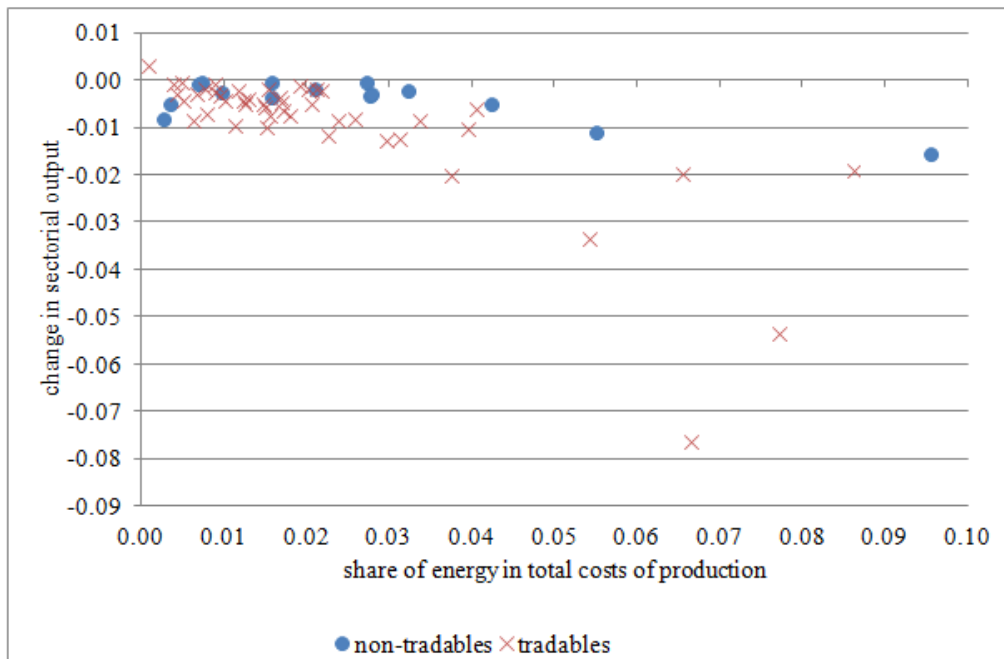Figure 5: The share of energy in total costs of production versus the change in sectorial output
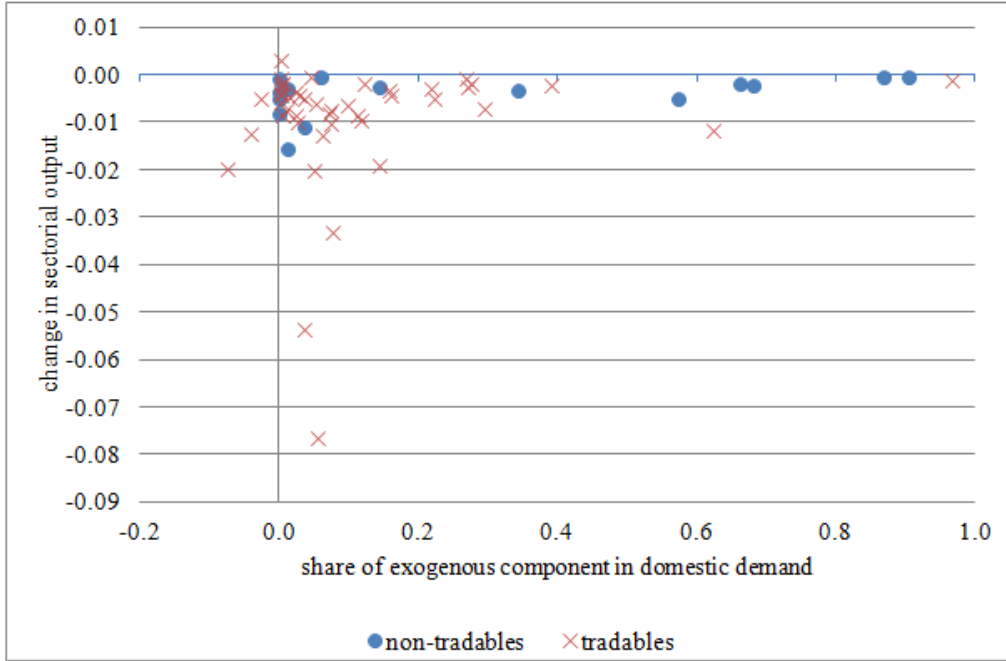
Figure 6: Share of exogenous demand versus the change in sectorial output

are used in the regression. The variable "non-tradable" is a dummy variable that takes value of 1 only for the non-tradable sectors. The share of exogenous demand component variable shows how much part of domestic demand comes from completely exogenous sources (that is, from investment and government expenditure). In this latter case it is possible to measure non-linear effects by applying a threshold method and creating a dummy variable having value of 1 if this share exceeds a certain threshold. In the present application this threshold takes the value of 50%, which can only be considered as a first trial.

In the first two model specifications, the focus is on the share of energy in costs and the difference between tradeables and non-tradeables. It can be seen that the higher the energy share of a sector is, the higher the fall in output is, but for non-tradable sectors this negative effect is smaller.

In the third and fourth model specification we controlled for the fact that non-tradeable sectors are often related to a high exogenous demand component. Therefore, the share of exogenous demand component (a continuous variable) is used in interaction with the energy-intensity in the model. It can be seen that this effect is significant and positive: sectors whose demand were – by assumption – less sensitive to the shock, responded less. However, after controlling for exogenous demand component, non-tradeable dummy is still significant – even if its coefficient is much smaller than in the first model. The fourth model is a variant of the third, where instead of the continuous variable a dummy variable used to measure the role of exogenous demand component. Whether the sector is non-tradable has again small, statistically significant additional explanatory power.

The analysis has shown that there are rather large differences in the responses of the different sectors. These differences largely related to the energy-intensity of the given sectors. However, the role of demand is crucial, and will influence the responses to a large extent. Finally, it seems that non-tradeable sectors are a bit less intensively influenced by this negative shock as they do not need to overcome the impacts of the real appreciation.

Conclusions

No doubt, energy, and especially electricity plays crucial role in the modern economies. Neither production, nor consumption can be done without access to electricity. And even though it is hard to imagine how to live without continuous access to electricity, regular or irregular outages could happen – as it is actually the case sometimes. The damages and costs it may cause to the economies are hard to measure; however, it is worth a try to understand how large these costs might be.

The advantage of a CGE application stems from the fact that – even though it is a highly abstract approach without too many technological specifications – it makes it possible to understand how large those indirect economic impacts can be. Indirect economic impacts exert their effects through the alteration of prices, which also provides information about scarceness of goods. This application could not aim to go into the very details of the micro environment, as how big part of a certain good can be consumed or produced without access to energy. However, we assumed that energy is a close complement in both production and consumption to other goods – moreover, it is a perfect complement to other intermediate inputs and the primary inputs in production.

Table 6: Regression results on the decline in sectorial output

	(1)	(2)	(3)	(4)
share of energy in intermediate consumption	-0.143***		-0.106***	-0.102***
	(0.0286)		(0.0217)	(0.0216)
share of energy in intermediate consumption*non-tradable	0.102***			
	(0.0273)			
outlier	-0.0510***	-0.0434***	-0.0528***	-0.0529***
	(0.0042)	(0.00393)	(0.00405)	(0.00409)
share of energy in costs		-0.286***		
		(0.0384)		
share of energy in costs*non-tradable		0.155***		
		(0.0441)		
share of energy in intermediate consumption*share exogenous demand component			0.113***	
			(0.0417)	
non-tradable			0.00366**	0.00363*
			(0.00179)	(0.00182)
share of energy in intermediate consumption*exogenous demand component > 50%				0.0743**
				(0.0302)
Constant	-0.00153	-0.00081	-0.00330***	-0.00315***
	(0.00116)	(0.00093)	(0.00107)	(0.0011)
Observations	61	61	61	61
R-squared	0.816	0.866	0.821	0.817

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As a result of the complementarity assumption, we showed that a decline in the supply of energy leads to a contraction of the economy that is much higher than the size of the sector would suggest – however, it is not as much as it would be if all economy activities would be done in proportional to energy consumption. This latter reasoning gives us a natural estimation that a 1% decline in the energy production should result a decline of GDP somewhere in the [0.03%; 1%] interval (as the size of the energy producing sector is about 3% in Hungary). The simulation results showed that the size of the impact could be around a 0.25% decline.

It is important to understand what the adjustment mechanisms are behind this result. The decline in overall production is less than the decline in energy production, which needs an answer, as energy is – by assumption – a perfect complement to all other materials in production. The answer lies in the different reactions of the different agents in the economy. As it turned out, the adjustment is largely driven by households' consumption. Also, we have shown that sectors with higher energy-intensive production technologies decline more. Thus, the overall change of production is less than the change in the energy supply. This is a kind of compound effect.

The different scenarios revealed that the size of the decline in GDP highly depends on which agents react more drastically to the shock. In the base case, when prices are flexible and there are no limits to adjustments, agents with the highest motivation to do so react more: either because their price-elasticity is higher or because their energy intensity is higher or because they still need to compete with foreign competitors. Therefore, this estimation must be considered as a lower bound on actual costs of electricity outages: if there are limitations to adjustments of any kind, the GDP costs of the outage can be even higher.

This is illustrated with the scenario, when there is a special form of price discrimination in the market for energy. When prices are distorted and do not reflect the actual scarceness of the goods, the adjustment will cost more because it is not actors, who can do it at the lowest price, who respond more. We wish to emphasise that the results come from a numerical simulation, which are to some extent sensitive to the values of the parameters. Therefore, all numerical results should be interpreted conditional on the parameters that had been chosen correctly. To our best knowledge these parameters fit to the available statistics of the Hungarian economy; however, further improvement in the data background of any CGE model can never be an over-researched area.

Finally, we wish to point out that CGE models with their rich details about the industrial structure of the economy are valuable tools to understand and measure how sectorial shocks will influence the economy, how large the costs are related to certain sectorial specific shocks, and last but not least, how different institutional arrangements could influence the impacts that these shocks unfold on the economy.

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