Effects of a terms of trade shock on the Russian economy

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Abstract

The principal interest of the paper is the quantification of terms of trade shock response of the Russian economy on a detailed computable general equilibrium (CGE) model calibrated with Russian input-output data. A number of recent theoretical studies ((Baqaee and Farhi 2019), (Atalay 2017)) stressed importance of explicit introduction of the intermediates in the models assessing effects of microeconomic and external shocks. CGE models permit introduction of rich details and complex production structures as well as optimizing behaviour of economic agents.

The results suggest a decrease of welfare of the representative consumer and real GDP with the deterioration of the terms of trade. In the Central scenario (a 10% decrease in the world price of crude oil, a 3% decrease in the world price of natural gas and an 8% decrease in the world price of petroleum products) welfare of the representative consumer decreases by -3,55% of benchmark consumption level or 1,76% of the base year GDP in the comparative static model, where factors are fixed at benchmark levels. Percentage change of the GDP in the Central scenario of the comparative static model is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,73%.

Welfare changes associated with the Central scenario of the steady-state model, where capital stock adjusts to it's long-term level, indicate a significant decrease in the welfare of the representative agent up to -5,79% of benchmark consumption level or -2,92% of the base year GDP. Percentage change of the GDP in the Central scenario of the steady-state model exceeds representative agent's decrease in welfare in terms of the benchmark GDP: -3,59%.

These results exceed welfare changes in the Central scenario of the static model, and we can refer to these values as an upper bound of possible changes in welfare in the dynamic modelling exercise (Rutherford and Tarr 2003).

The model was validated by historical simulation with observed levels of exogenous parameters, mimicking change in economic environment from 2011 to 2015. The results of the historical simulation stress the importance of fiscal parameters (i.e. export taxes) in analysis of production behaviour of Russian extraction industries.

Key words: terms of trade, oil price shock, computable general equilibrium models, input-output table, industry output; CGE model validation.

JEL classification: F17, C68, D58.

1. Introduction

The focus of this paper is on the output response on detailed industry level. The aim is to study propagation of oil price shock in the simplest general equilibrium settings possible, in a small open nested-CES economy with a representative agent, perfectly competitive cost-minimizing producers and inelastic factor supplies. This paper examines the impact of changes in world prices on the Russian economy. In particular, I am interested in the change in production as a result of changes in world prices for the main Russian export and import commodities. The model presented in the paper belongs to the class of computable general equilibrium (CGE) models, it has a detailed industry structure, which allows tracing the effect of changes in world prices on all aspects of the Russian economy.

One of my principal interests is the quantification of terms of trade shock response of the Russian economy on a detailed CGE model calibrated with Russian input-output data. A number of studies ((Baqaee and Farhi 2019), (Atalay 2017), (Acemoglu, Ozdaglar, and Tahbaz-salehi 2017) (Burstein, Kurz, and Tesar 2008)) stressed importance of explicit introduction of the intermediates in the models assessing effects of external shocks. I am interested in assessing effects of a terms of trade shock on the Russian economy with a detailed computable general equilibrium model. Models of this class permit introduction of rich details and complex production structures as well as optimizing behaviour of economic agents.

The results suggest a decrease of welfare of the representative consumer and real GDP with the deterioration of the terms of trade. In the Central scenario (a 10% decrease in the world price of crude oil, a 3% decrease in the world price of natural gas and an 8% decrease in the world price of petroleum products) welfare of the representative consumer decreases by -3,55% of benchmark consumption level or 1,76% of the base year GDP in the comparative static model. Percentage change of the GDP in the Central scenario of the comparative static model is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,73%.

Welfare changes associated with the Central scenario of the steady-state model indicate a significant decrease in the welfare of the representative agent up to -5,79% of benchmark consumption level or -2,92% of the base year GDP. Percentage change of the GDP in the Central scenario of the steady-state model exceeds representative agent's decrease in welfare in terms of the benchmark GDP: -3,59%. The GDP response in the steady-state model is in line with estimates obtained in compatible work (Полбин 2017).

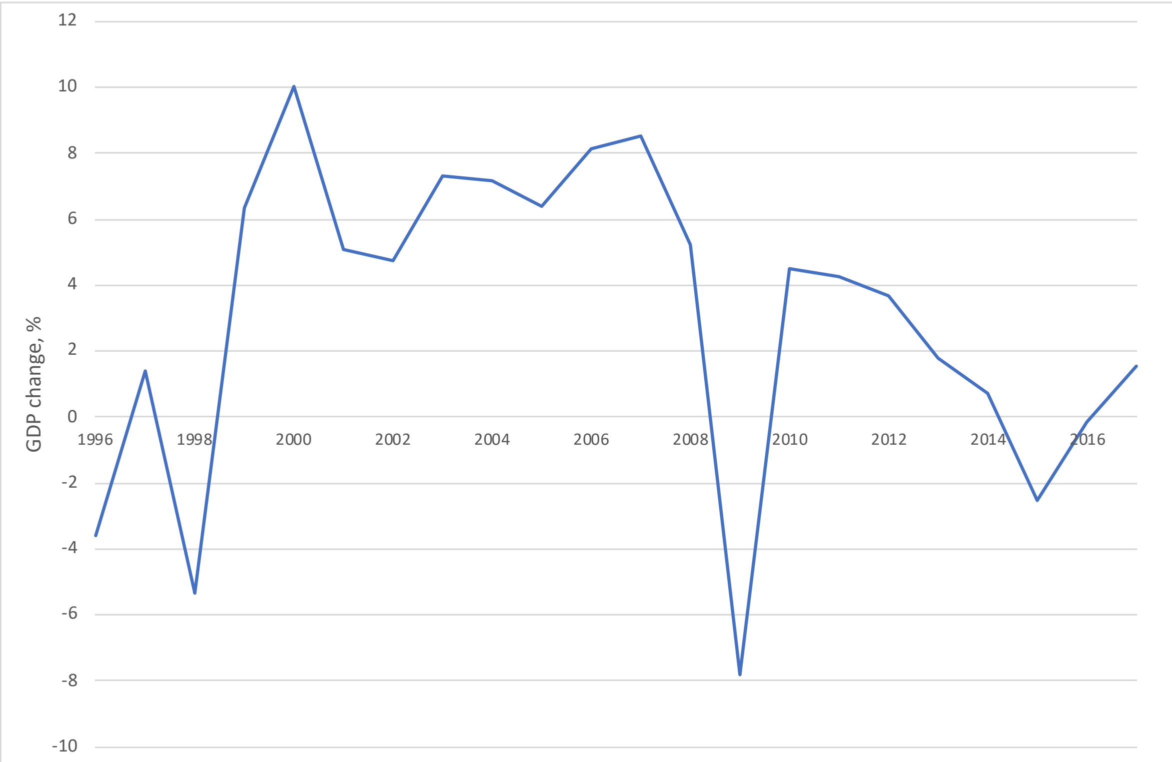
These results exceed welfare changes in the Central scenario of the static model, and we can refer to these values as upper bound of possible changes in welfare in the dynamic modelling exercise (Rutherford and Tarr 2003).

2. Literature review

The effect of the shock of the terms of trade on the output of industries

The dependence of the Russian economy on oil prices manifests itself in 2014-2015 (see Figure 1), when, following the reduction in oil prices and the restriction of access to capital markets, Russia's economy has entered a recession (World Bank Group 2015).

Figure 1. Real GDP of the Russian Federation, in % to the previous year



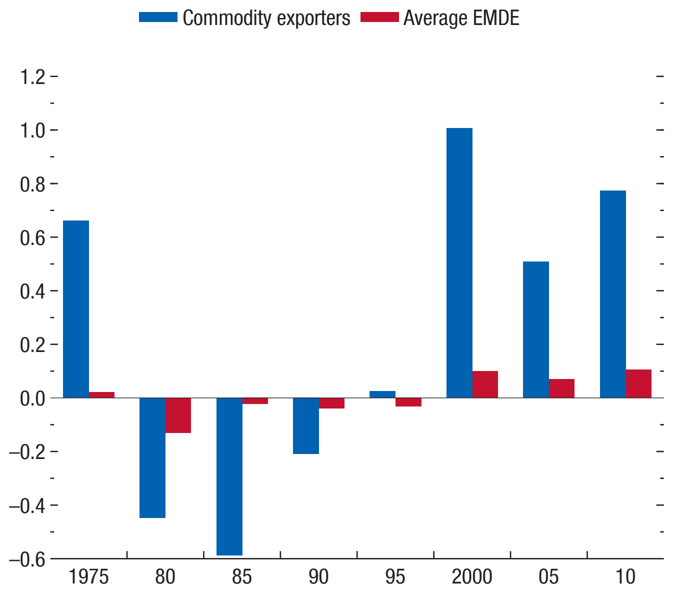
Source: Rosstat.

The main reasons for the decline in production in 2015 were a sharp drop in oil prices, a subsequent depreciation of the ruble with a corresponding increase in inflation. The situation was complicated by the loss of investor confidence resulting from economic, political and external economic circumstances.

The decline in prices for oil and oil products, which are the key Russian exports, while maintaining world prices for goods imported into Russia, led to a reduction in the ratio of prices of export goods to the prices of imported goods, or terms of trade (Reinsdorf 2010).

Numerous studies (International Monetary Fund 2017), (Cavalcanti, Mohaddes, and Raissi 2015) find that GDP growth (see Figure 2) and other macroeconomic characteristics of commodity-exporting countries, including Russia, depend to a greater extent on changing terms of trade than comparable countries, which are not commodity exporters.

Figure 2. Contribution of terms of trade to GDP per capita change, commodity-exporting countries and EMDE, in average for developing countries.



Source: International Monetary Fund, (International Monetary Fund 2017), p. 74.

There are various estimates of the extent to which the shocks of the terms of trade cause business cycles in developing countries. For a long time economists considered that up to 30% of the change in output and other macroeconomic indicators was due to changes in terms of trade (Mendoza 1995) и (Kose 2002). The latest estimates (Schmitt-Grohé and Uribe 2018) significantly reduce this estimate, referring to less than 10% of the relationship between changes in terms of trade and the movement of gross output. Despite the uncertainty about the impact of the terms of trade on the economy of developing countries on average, the mechanisms of influence are well described. Idrisov et al. (Идрисов, Пономарев, and Синельников-Мурылёв 2015) note two main channels of the impact of terms of trade on the Russian economy: a reduction in disposable income and a devaluation of the ruble.

The impact of the real ruble exchange rate on the macroeconomic parameters of the economy and aggregate output has always been in the focus of attention of economists. Let us consider below a few works devoted to this topic in general and in application to the Russian economy.

Total output and real exchange rate

There is no consensus in the theoretical literature on the impact of a change in the exchange rate of the national currency on the real output. Gylfason and Schmid (Gylfason and Schmid 1983) discuss a possible channel for the negative impact of the weakening of the national currency on aggregate output: in the case of a large share of imports in intermediate consumption, devaluation leads to an increase in the costs of domestic production, which can cause a fall in supply, as a consequence, a reduction in the equilibrium output. This channel of influence is the more important, the less the elasticity of substitution of imported intermediates by domestic in the production processes of domestic firms.

For the economy as a whole, the substitution of imported goods by domestic largely depends on the structure of the preferences of households: if imports and domestically produced goods are easily substituted in the consumption, then with the increase in import prices there will be a switch to consumption of domestic goods, and, as shown in the work of Kadochnikov et al. (Кадочников, Синельников-Мурылёв, and Четвериков 2003), this will lead to an increase in the domestic output. If domestic and imported goods are compliments and do not replace each other in consumption, the increase in import prices will be accompanied by a decrease in demand for home products, which is due to the predominance of the income effect over the substitution effect, and as a result, the demand for home products will decrease.

An important channel of propagation of exchange rate swings on the aggregate output may be the relationship of exchange rate and investment demand. As noted in a number of growth models with technology adaptation (Easterly et al. 1994), the weakening of the national currency leads to a rise in the cost of borrowing technology. This leads to a drop in investment, and, ultimately, to a decrease in the aggregate output. As Badasen and co-authors (Бадасен, Картаев, and Хазанов 2015) note, this channel of influence is especially important for developing economies in which technology import plays an important role.

In the works of Aghion and co-authors (Aghion, Bacchetta, and Banerjee 2000), Greenwald and Stiglitz (Greenwald and Stiglitz 1993), Gatti et al. (Gatti et al. 2007), it is shown that in the case of a large volume of borrowings of the private sector in foreign currency, after a devaluation, debt servicing becomes more complicated due to its growth in the national currency. This can lead to a reduction in the cumulative output.

The general direction of the change in the aggregate and industry output caused by the exchange rate changes depends on the conditions prevailing at a particular moment in the given economy, and economic theory does not give a single answer to the question of the direction of change. In part, this thesis is confirmed by the heterogeneous results obtained for the Russian economy in the studies of various authors over the past few years.

Dynnikova (Дынникова 2000), on the basis of the theoretical model, came to the conclusion that in the period from 1993 to 1997, the strengthening of the real exchange rate of the ruble was accompanied by an increase in output, presumably due to lower prices for imported components and intermediate goods.

Kontorovich's empirical findings (Конторович 2001) show that strengthening the real ruble/dollar exchange rate by 1% with a lag of several months is accompanied by a reduction in the intensity index of industrial production by approximately 0.2%.

In the work of Kadochnikov et al. (Кадочников, Синельников-Мурылёв, and Четвериков 2003), a link was made between the strengthening of the national currency and the growth in demand for imports: the strengthening of the real exchange rate by 1% leads to the replacement of domestic goods with imports by 0.77% on average in the economy.

Kartayev (Картаев 2009) concluded that the weakening of the national currency by 1% leads to an increase in real GDP of Russia by 0.66%. From the point of view of sector dynamics, it was concluded that the weakening of the ruble does not lead to changes in the production of the extractive industry, but at the same time, it leads to an increase in the output of the manufacturing industry.

Vdovichenko et al. (Вдовиченко, Дынникова, and Субботин 2003) also expressed the idea that the manufacturing industry reacts more strongly to fluctuations in exogenous factors, including the real exchange rate. From the point of view of the difference in the sectoral response to the change in the real exchange rate, the industries were divided into three groups: losers of the strengthening the real exchange rate (fuel, wood pulp and paper, chemical and petrochemical, non-ferrous metallurgy), insensitive to real exchange rate changes (food and mechanical engineering) and winners (light industry, ferrous metallurgy, construction materials industry and electric power industry).

In the work of Badasen, Kartaev, and Khazanov (Бадасен, Картаев, and Хазанов 2015), based on econometric research, it was concluded that when the exchange rate of the ruble depreciates, the most favourable effect is on export-oriented industries, as well as on industries with a low share of imports in costs.

The studies referred above generally agree with the positive influence of the relative weakening of the domestic currency on domestic output. But it should be noted, that in a case of a ToT shock, usually both channels of influence are present: income effect and exchange rate. Thus, in order to simulate effect of a ToT deterioration of the detailed industry structure of the Russian economy there is a need of a structural model. One of possible solutions is use of the computable general equilibrium model.

Estimating effects of a ToT shock with a general equilibrium model

Computable (applied) general equilibrium model is a system of equations describing behaviour of economic agents in an economy. The numerical parameters of the model equations are based on statistical data of one year or averaged data over several years. The procedure for calculating the parameters of a model is called calibration. The model is calibrated so that the base year data is obtained as the initial equilibrium.

Scenario forecasts are set by changing one or several controls, for example, by changing exogenous world prices for export or import goods. After changing the controls a new equilibrium is obtained. The new equilibrium reflects the effect of the proposed changes in the controls. Resulting changes in endogenous variables are obtained by comparing the basic data set and the new equilibrium obtained as a result of the experiment.

Models of computable general equilibrium (CGE models) have traditionally been the most effective and most widely used tool for assessing possible changes in foreign trade (Hertel 2013), taxation (Dixon and Rimmer 2016), public expenditure (Holmøy and Strøm 2013), social security (Fehr 2016), demography (Zodrow and Diamond 2013), immigration (Fehr et al. 2013), labour markets (Dixon, Koopman, and Rimmer 2013), environment (Böhringer et al. 2015), as well as assessing the effects of natural (Shibusawa et al. 2011) and man-made disasters (Rose and Liao 2005). CGE models are the only practical way to quantify these effects at the level of industries, regions (Giesecke and Madden 2013) and socio-economic groups (Horridge et al. 2013).

Even at the dawn of its existence, computable general equilibrium models were used to assess the effects of the shock of terms of trade on the welfare, changes in output and factor income (Devarajan and Robinson 2013). Subsequently, a variety of studies were conducted both at the level of one country (Dixon, Koopman, and Rimmer 2013), often in a regional breakdown (Dong et al. 2017), or in the framework of global models (Timilsina 2015).

Models of computable general equilibrium for the Russian economy

Examples of the use of computable general equilibrium models for Russia include: Makarov (Макаров 1999), Zemnitsky (Земницкий 2003), Bakhtizin (Бахтизин 2003), Alekseev, Turdyeva, Yudaeva (Alekseev, Turdyeva, and Yudaeva 2003), Alekseev, Sokolov, Turdyeva, Yudaeva (Alekseev et al. 2004), Jensen, Rutherford and Tarr (Rutherford and Tarr 2004), (D. G. Tarr and Rutherford 2004), (Helm and Rutherford 2004), Rutherford, Tarr, Shepotilo (D. G. Tarr, Shepotylo, and Kouduyarov 2005), Alekseyev et al. (Алексеев et al. 2004),, Besstremyannaya, Bakhtizin (Besstremyannaya and Bakhtizin 2006), Volchkova and others . (Волчкова et al. 2006), Rutherford and Tarr (D. Tarr 2006), Kolik, Radziwill, Turdiyeva (Kolik, Radziwill, and Turdyeva 2015), Bohringer et al. (Böhringer et al. 2015).

The effects of the shock of the terms of trade and the subsequent recession of 2014-2015 on welfare distribution in Russia are considered in the work of Bussolo and Luongo (Bussolo and Luongo 2017). The authors concluded that a 50% reduction in oil prices would lead to a significant decline in oil production and refining (-13%), a reduction in construction industry production (-5%) and transport (-1.3%). The main gain will be for the export industries of manufacturing (+ 12.7%), agriculture (+ 9.5%), other manufacturing (+ 8.2%) and other extractive industries (+ 5.1%), and the food industry (+ 2.3%). Among other consequences, the authors note a fall in the well-being of the population by 6.88% in terms of consumption.

3. Model Description

Results of two models are discussed in the present paper: the core model with inelastic factor supply (the comparative static model) and a steady-state model with variable capital stock. The steady-state model solves for time-invariant capital stock, i.e. cost of investment equals the discounted stream of rents on installed capital.

3.1. The core model: the comparative static model

The structure of the core model is close to the model used in Böhringer et al. (Böhringer et al. 2015). The model is based on optimizing behaviour of all economic agents, supply and demand balances in all markets for goods and services, and income balances for all agents.

The algebraic formulation presented below corresponds to the core model of a small open nested-CES economy with a representative agent, perfectly competitive cost-minimizing producers and inelastic factor supplies. Consumers of final and intermediate goods differentiate between domestic and imported goods, i.e. the Armington (Armington 1969) assumption is used (Figure 3).

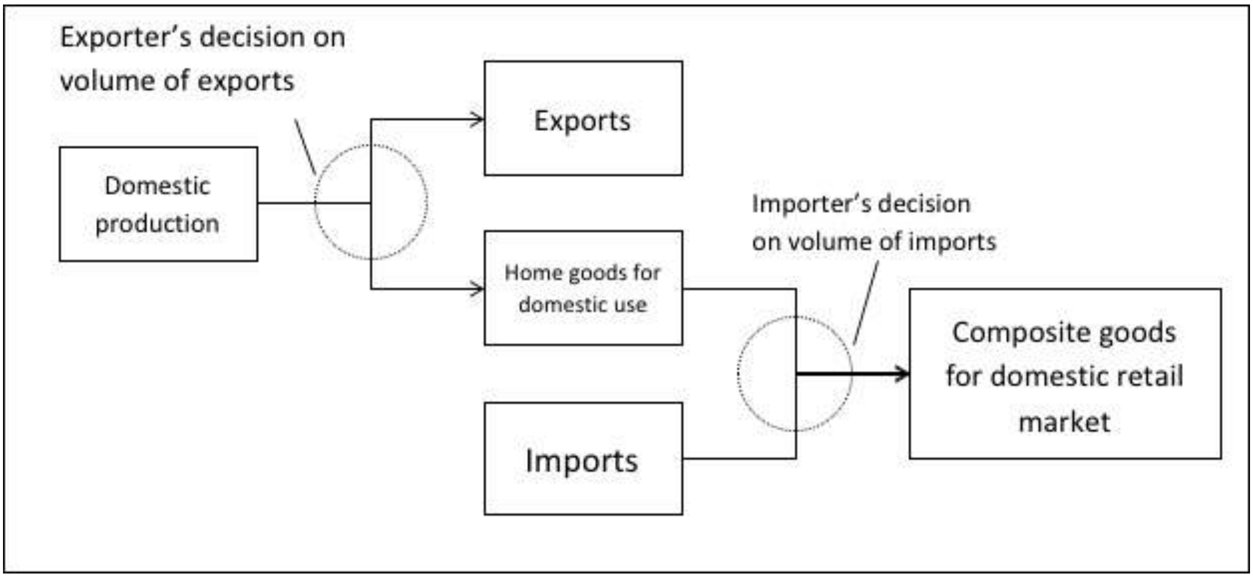


Figure 3. Structure of products differentiation in the model.
Source: author

Representative agent

Representative agent (RA) of the core model accumulates characteristics of a representative household, the government and a savings-investment bank (see Figure 4). The assumption of the core model is that government is collecting taxes with fixed ad-valorem tax rates and purchases final goods in the amount of the base year. Budget deficit or surplus, which might appear due to changes in relative prices and changes in volumes of tax revenues in a counterfactual experiment, are accommodated by the household's budget.

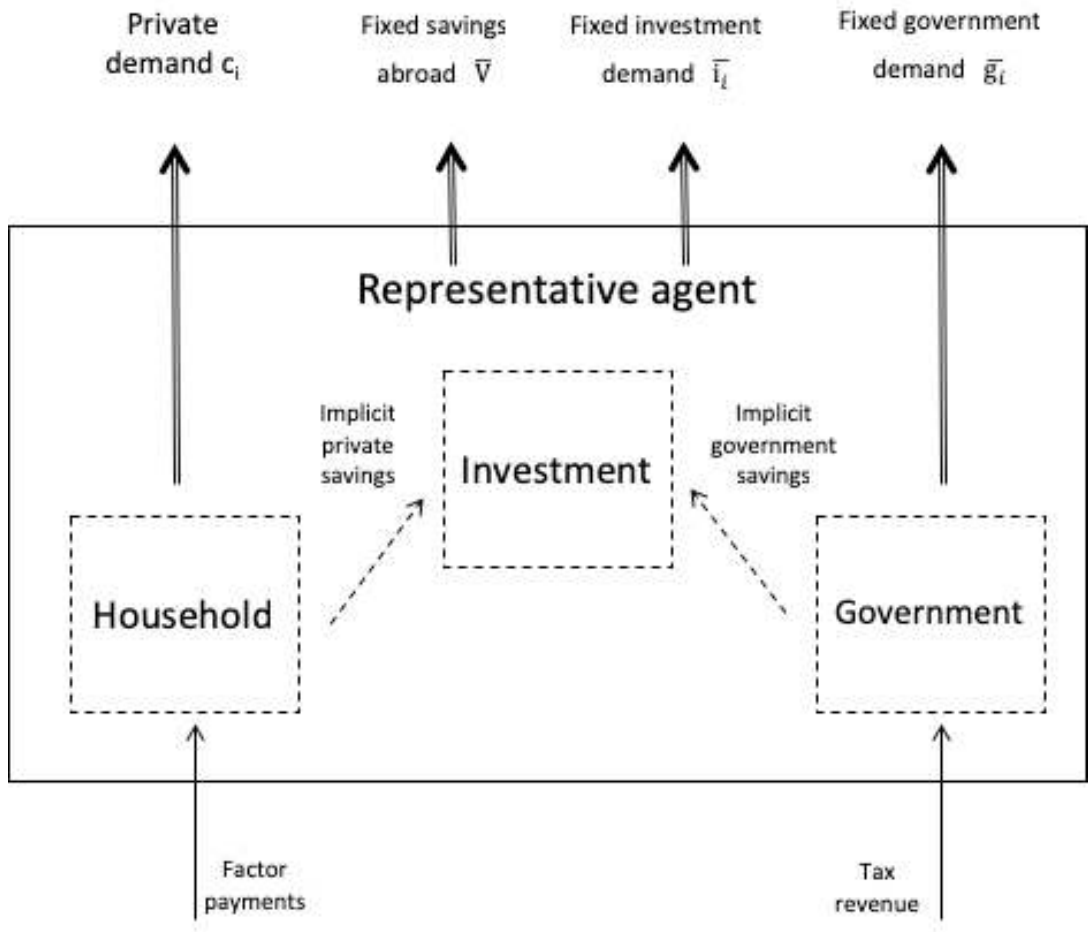


Figure 4. Structure of income and spending of the representative agent.
Source: author

In the settings of the model, all indirect tax revenues are channelled to the RA's budget. Cost of goods for implicit government's consumption are deducted from the disposable income of the representative agent, thus ensuring the priority of government over private consumption.

Private and government savings are investment-driven and implicit in the model. Total cost of purchases of investment goods is subtracted from the RA's consumption budget, i.e. it is assumed that savings cover investment demand which is fixed on the base year level.

There is no international ownership of factors, i.e. model does not account for non-zero net factor payments. Default external closure of the core model states that foreign savings of the RA is fixed and exchange rate is fully flexible. RA's foreign savings is fixed on the base year level $\overline{V}$, which equals to the current account surplus (or, in the case of NFP=0, to the trade surplus).

Industries

There are 52 industries (Table 5) producing goods and services, each described by a representative firm. Cost-minimizing firms operate in free-entry markets, which leads to zero profit, i.e. marginal returns for an individual firm equal marginal cost.

Production technologies are characterized by constant returns to scale. Output (Y) is a Leontief ($\sigma^{Y} = 0$)[1], combination of value added (VA) and intermediate goods (INT). Value added is a Cobb-Douglas ($\sigma^{VA} = 1$) aggregate of primary factors (mobile labour (L), mobile (K) and specific capital (SK)) and intermediate goods and services (INT) (see Figure 5).

Intermediate goods are a bundle of imported (m_{ij} – imports of commodity i for industry j) and domestically produced intermediates (d_{ij}). Bundling of domestic and imported intermediates is done for each industry and each type of good separately. All bundling techniques for the intermediate products are described by CES functions and share the same low (Atalay 2017) elasticity of substitution between domestic and imported goods ($\sigma^{m} = 0.4$), share parameters for each industry *i* and each good *j* are calibrated on detailed information provided by Russian input-output tables[2]. Relatively low value of elasticity of substitution between domestic and imported intermediates reflects high level of complementarity of imports in firms' intermediate consumption (Березинская and Ведев 2015).

Domestically produced goods (Y) are split between domestic (D) and export markets (X) on the basis of relative prices at home and export markets. This transformation, i.e. a decision of an exporter, is described by the constant elasticity of transformation (CET) function. Default value of elasticity of transformation η equals 0.15. This relatively low level of the elasticity of transformation corresponds to values reported in (Tokarick 2014) and (IMF 2017) and reflects problems in reallocation of resources from domestic supply to export markets that Russian economy faces.

[1] σ^{Y} – is the elasticity of substitution between value added (VA) and intermediate consumption (INT) in the upper-level production function. Notational convention: σ (sigma) - denotes elasticity of substitution in various production and bundling functions; η (eta)- elasticity of transformation between domestic goods for domestic market and exports. Please note, that limit case of a CES function with elasticity of substitution $\sigma = 0$ is the Leontief function, and $\sigma = 1$ is the Cobb-Douglas function.

[2] Base input-output tables for the Russian Federation were estimated for year 2011 (http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/accounts/#), more on data sources in the relevant chapter. Information on the composition of intermediate consumption is provided by use tables for domestic and imported goods.

Domestically produced goods for the domestic market (D), are bundled with imports (M). The composite good (A) is supplied to the domestic market where it serves final demand by the representative agent (Figure 4). The bundling of domestic and imported goods is described by constant elasticity of substitution (CES) function with elasticity ($\sigma^A = 4$). This value is close to the average of Armington substitution elasticities between domestic and imported goods in GTAP 9 database (Aguiar, Narayanan, and McDougall 2016).

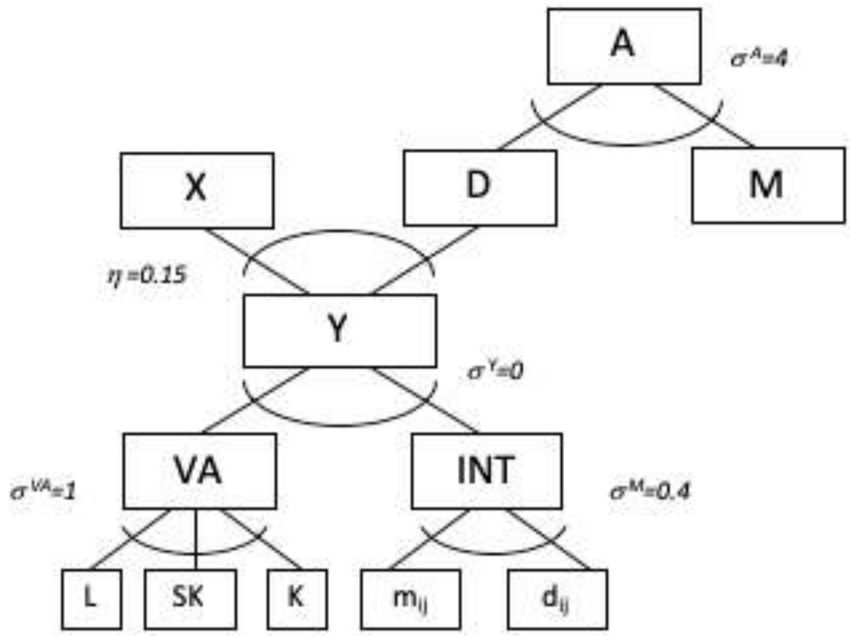


Figure 5. Structure of industrial production and supply of composite goods for the final market.

Source: Author

Intermediate goods and services are treated differently in the model. Services used for intermediate consumption by firms are supplied as a bundle of domestic and foreign services (with a CES bundling technology). The bundling of domestic and imported services for intermediate consumption is done on the aggregate level – there is a single bundle of each service of type *i* supplied for intermediate consumption for all firms in the economy. The service bundling technology shares the same elasticity value as the bundling of goods for the final market ($\sigma^A = 4$).

Analytical structure of the core model is presented in Appendix.

3.2. Steady-state model

The steady-state model is an extension of the core comparative static model. The goal of the steady-state calculation is to evaluate the upper bound (Rutherford and Tarr 2003) on welfare changes associated with terms of trade change for the Russian economy.

In the comparative static model the price of capital varies, while total supply of capital is fixed. In the steady-state model the mobile capital stock and investment demand are endogenously determined while the price of capital is constant. In other words, the steady-state model solves for time-invariant capital stock. In the steady-state model optimal capital stock is such that cost of investment equals the discounted stream of rents on installed capital[3]. “This can be viewed as a multi-sector version of the “golden rule” equilibrium” (Rutherford and Tarr 2003).

4. Benchmark dataset

4.1. Social accounting matrix

The social accounting matrix (SAM) describes the economic activities of a single country for a certain period of time. The matrix is square and consists of accounts in rows and columns that represent production activities, goods, economic agents, economic policy instruments and production factors. Instruments of economic policy include taxes, subsidies, import tariffs and export duties.

In the rows income receipts are presented, and the columns represent payments. A balanced SAM is a matrix where for all rows, the sum of the row and the corresponding column is equal. The economy of the country is represented by industries that produce goods and services.

For the calibration of the model, the data of the "Input-Output" tables of 2011 contained in the official publication of Rosstat were used. The basic " Input-Output " tables for 2011 consist of a resource table, usage tables for buyers' prices and basic prices, tables for the use of home and imported products, and tables for transport and trade margins and a table of taxes. Due to the great detail of the basic tables, the sectoral and commodity details of the data were consolidated. The types of activities and goods

[3] In the present version of the model depreciation is set to zero.

presented in the general equilibrium model are presented in the table below (see Table 5).

4.2. Elasticities

Notational convention: σ (sigma) - denotes elasticity of substitution in various production and bundling functions; η (eta)- elasticity of transformation between domestic goods for domestic market and exports. Please note, that limit case of a CES function with elasticity of substitution $\sigma = 0$ is the Leontief function, and $\sigma = 1$ is the Cobb-Douglas function.

Output in each industry is produced with a nested production function. The upper nest is a Leontief combination of value added (VA) and intermediate goods (INT), $\sigma^{Y} = 0$ – is the elasticity of substitution between value added (VA) and intermediate consumption (INT) in the upper-level production function. This type of nested production function was used in several models of the Russian economy, see (Böhringer et al. 2015).

Value added is a Cobb-Douglas aggregate of primary factors (mobile labour (L), mobile (K) and specific capital (SK)) and intermediate goods and services (INT) (see Figure 5). $\sigma^{VA} = 1$ is the elasticity of substitution between different factors in production of value added.

Bundling of domestic and imported intermediates is done for each industry and each type of good separately. All bundling techniques for the intermediate products are described by CES functions and share the same low (Atalay 2017) elasticity of substitution between domestic and imported goods ($\sigma^{m} = 0.4$), share parameters for each industry *i* and each good *j* are calibrated on detailed information provided by Russian input-output tables[4]. Relatively low value of elasticity of substitution between domestic and imported intermediates reflects high level of complementarity of imports in firms' intermediate consumption (Березинская and Ведев 2015).

Transformation of domestically produced goods (Y) between domestic (D) and export markets (X) is described by the constant elasticity of transformation (CET) function. Default value of elasticity of transformation η equals 0.15. This relatively low level of the elasticity of transformation corresponds to values reported in (Tokarick 2014)

[4] Base input-output tables for the Russian Federation were estimated for year 2011 (http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/accounts/#), more on data sources in the relevant chapter. Information on the composition of intermediate consumption is provided by use tables for domestic and imported goods.

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The bundling of domestic and imported goods is described by constant elasticity of substitution (CES) function with elasticity ($\sigma^A = 4$). This value is close to the average of Armington substitution elasticities between domestic and imported goods in GTAP 9 database (Aguiar, Narayanan, and McDougall 2016).

Table 1. Central values of elasticities in the model

	Elasticity	Description	Value	Reference
1	η	elasticity of transformation between supply to domestic and export markets	0.15	(Tokarick 2014) (IMF 2017)
2	σ^m	elasticity of substitution between domestic and imported goods in intermediate consumption	0.4	(Atalay 2017)
3	σ^Y	elasticity of substitution between value added and intermediate goods in the production function	0	(Böhringer et al. 2015)
4	σ^{VA}	elasticity of substitution between different factors in production of value added	1	(Böhringer et al. 2015)
5	σ^A	elasticity of substitution between domestic and imported goods in the Armington aggregation function for production of final goods	4	(Aguiar, Narayanan, and McDougall 2016).

5. Results: Terms of trade decrease

One of my principal interests is the quantification of terms of trade shock response of the Russian economy on a detailed CGE model calibrated with Russian input-output data. A number of studies ((Atalay 2017), (Acemoglu, Ozdaglar, and Tahbaz-salehi 2017) (Burstein, Kurz, and Tesar 2008)) stressed importance of implicit introduction of the intermediates in the models assessing effects of external shocks. The assessment of effects of a terms of trade shock on the macro and industry level is completed with a help of a detailed computable general equilibrium model. Models of this class permit introduction of rich details and complexity of production structures as well as optimizing behaviour of economic agents.

5.1. Scenario definition

The central scenario is a 10% decrease in world prices of crude oil, accompanied by a 3% decrease in the world price of natural gas, and an 8% decrease in the world price of petrochemical products.

Relationship between the world oil and gas prices

There is a growing literature on long-term relationship between global crude oil and natural gas prices (Nick and Thoenes 2014). Recently, the long-run oil–gas price relationship has been challenged quite often, as these two prices have shown evidence of decoupling from each other (Ramberg et al. 2017). Based on (Zhang and Ji 2018), we adopt factor of 0.3, describing relationship between change in the world price of oil and change of the world price of natural gas. Thus, in our central scenario a 10% decrease in the world price of oil is accompanied with a 3% change in the world price of natural gas.

Relationship between the world oil and oil products' prices

Strong technological connections (Ramberg et al. 2017) between crude oil and oil products dictates relatively high factor of 0,8, describing relationship between crude oil and oil products world prices for Russian exports (Polanco Martínez, Abadie, and Fernández-Macho 2018). In our central scenario, a 10% decrease in the world price of crude oil is accompanied by an 8% decrease in the world price of oil products.

We cap present Central scenario as a composition of three scenarios: “Oil”, “Natural gas” and “Petroleum products”. Each of these scenarios model decrease in the world prices of one separate good. Thus, the Central scenario is summarized as a simultaneous decrease in three world prices for Russian exports:

- Crude oil (scenario “Oil”: decrease of the world price for crude oil by 10%);
- Natural gas (scenario “Natural gas”: decrease of the world price for Natural gas by 3%);
- Petroleum products (scenario “Petroleum products”: decrease of the world price for Petroleum products by 8%).

5.2. Simulations results: comparative static model

Overall economic impacts: static model, Central scenario

Overall economic impact for the Central scenario in the settings of the static model are shown in the table below (Table 1). The results are presented for the Central scenario and it's components. Welfare changes associated with the Central scenario indicate a significant decrease in the welfare of the representative agent up to -3,55% of benchmark consumption level or -1,76% of the base year GDP.

Percentage change of the GDP in the Central scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,73%.

The decline in the GDP is driven by decrease in private consumption. By the assumptions of the static model real government consumption is fixed, as well as real investment demand and trade balance in real terms. This leads to the only variable component of the GDP – private consumption.

The external closure of the model fixes trade balance in real terms and lets the exchange rate to adjust to changes in relative prices of exported and imported goods. The exchange rate is defined in unites of local currency to units of foreign currency, thus an increase in the value of the exchange rate means depreciation of the local (domestic) currency. A decrease in the exchange rate means that domestic currency strengthens.

The Central scenario is associated with a 3,92% increase in the exchange rate. This means that all imported goods are 3,92% more expensive than in the base year.

Numeraire of the static model is consumer price index, thus CPI change in all scenarios equal to zero. Since only relative prices matters in the computable general equilibrium models, all other prices are quoted in terms of the numeraire (CPI in our case). Given that CPI is fixed, changes in the exchange rate reflect changes in the real exchange rate. In the Oil scenario wages change by -0,2% and return to mobile capital by -1,25%.

Return to specific capital in extracting industries or natural rent, decreases for crude oil production (-4,93%), indicating reduction of production activities.

All other extracting sectors feel much better with increase in return to specific capital in the Central scenario. The resource rent in production of natural gas rises (3,77%), as well as the resource rent in production of coal (3,24%), and other mining activities (4,84%).

Aggregated production index rises by 0,42%. Agriculture production index doesn't change. Extraction production index decreases by -0,05%. Manufacturing production index rises by 0,64%. This indicates shift of the resources to manufacturing sector.

Services production index decreases by -0,18%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is not significant: 0,87% of mobile capital changes sectors in the Central scenario, and 0,8% of workers.

Overall economic impacts: static model, Oil scenario

Overall economic impacts for the Oil scenario (a 10% decrease in the world price of crude oil only) in the settings of the static model are shown in the table below (Table 1).

Welfare changes associated with the Oil scenario indicate a significant decrease in the welfare of the representative agent up to -2,26% of benchmark consumption level or -1,11% of the base year GDP.

Percentage change of the GDP in the Oil scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,1%. The Oil scenario is associated with a 3,92% increase in the exchange rate.

Representative agent's income comes from primary factors. Thus, a decrease in remuneration and return to mobile capital is a significant reduction of income. In the central scenario wages change by -0,05% and return to mobile capital by -0,71%.

Return to specific capital in extracting industries or natural rent, decreases for crude oil production (-3,87%), indicating reduction of production activities. All other extracting sectors feel much better with increase in return to specific capital in the Oil scenario. The resource rent in production of natural gas rises (6,21%), as well as the resource rent in production of coal (2,03%), and other mining activities (2,85%).

Aggregated production index rises by 0,26%. Agriculture production index slightly decreases (-0,01%). Extraction production index decreases by -0,04%. Manufacturing production index rises by 0,39%. This indicates shift of the resources to manufacturing sector. Services production index decreases by -0,08%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is not significant: 0,54% of mobile capital changes sectors in the Oil scenario, and 0,48% of workers.

Overall economic impacts: static model, Natural gas scenario

Overall economic impacts for the Natural gas in the settings of the static model are shown in the table below (Table 1).

Welfare changes associated with the Natural gas scenario indicate a significant decrease in the welfare of the representative agent up to -0,21% of benchmark consumption level or -0,1% of the base year GDP.

Percentage change of the GDP in the Natural gas scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -0,1%. The Natural gas scenario is associated with a 3,92% increase in the exchange rate. In the Natural gas scenario wages change by -0,06% and return to mobile capital by -0,1%.

Return to specific capital in extracting industries or natural rent, decreases for crude oil production (0,49%), indicating reduction of production activities.

All other extracting sectors feel much better with increase in return to specific capital in the Natural gas scenario. The resource rent in production of natural gas decreases (-4,55%), and the resource rent in production of coal slightly increase (0,41%), as well as return to the other mining activities (0,51%).

Aggregated production index rises by 0,06%, agriculture production index slightly increases (0,01%), extraction production index decreases by 0,01%, manufacturing production index rises by 0,1%, and services production index decreases by -0,06%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is not significant: 0,15% of mobile capital changes sectors in the Natural gas scenario, and 0,11% of workers.

Overall economic impacts: static model, Petroleum products scenario

Overall economic impacts for the Petroleum products scenario in the settings of the static model are shown in the table below (Table 1).

Welfare changes associated with the Petroleum products scenario indicate a significant decrease in the welfare of the representative agent up to -1,03% of benchmark consumption level or -0,5% of the base year GDP.

Percentage change of the GDP in the Petroleum products scenario is of the same magnitude as representative agent’s decrease in welfare in terms of the benchmark GDP: -0,5%. The Petroleum products scenario is associated with a 3,92% increase in the exchange rate.

In the Petroleum products scenario wages change by -0,1% and return to mobile capital by -0,43%. Return to specific capital in extracting industries or natural rent, decreases for crude oil production (-1,52%), indicating reduction of production activities.

The resource rent in production of natural gas rises (2,75%), as well as the resource rent in production of coal (0,63%), and other mining activities (1,32%).

Aggregated production index rises by 0,09%. Agriculture production index doesn’t change. Extraction production index decreases by -0,01%. Manufacturing production index rises by 0,12%. This indicates shift of the resources to manufacturing sector. Services production index decreases by -0,03%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is not significant: 0,26% of mobile capital changes sectors in the Petroleum products scenario, and 0,23% of workers.

5.3. Simulations results: steady-state model

The steady-state model is an extension of the comparative static model. The goal of the steady-state calculation is to evaluate the upper bound (Rutherford and Tarr 2003) on welfare changes associated with terms of trade deterioration for the Russian economy.

In the comparative static model the price of capital varies, while total supply of capital is fixed. In the steady-state model the mobile capital stock and investment demand are endogenously determined while the price of capital is constant. In other words, the steady-state model solves for time-invariant capital stock. In the steady-state model optimal capital stock is such that cost of investment equals the discounted stream of rents on installed capital[5]. “This can be viewed as a multi-sector version of the “golden rule” equilibrium” (Rutherford and Tarr 2003).

Major difference between the results of comparative static and steady-state models is captured in the changes of investment demand. As a result of deterioration of the terms of trade optimal capital stock for the economy decreases, causing investment demand to go down. There is a 3% decrease in the total investment demand in the Central scenario of the steady-state model.

The effects induced by the ToT deterioration on the capital stock echoes in total production index decreases. Thus, a decrease in the terms of trade pushes economy to an inferior steady state, characterized by decrease in the welfare of a representative consumer, lower level of production and consumption.

Overall economic impacts: steady-state model, Central scenario

Overall economic impacts for the Central scenario in the settings of the steady-state model are shown in the table below (Table 2). The results are presented for the Central scenario and its components.

Welfare changes associated with the Central scenario indicate a significant decrease in the welfare of the representative agent up to -5,79% of benchmark consumption level or -2,92% of the base year GDP. These results exceed welfare

[5] In the present version of the model depreciation is set to zero.

changes in the Central scenario of the static model, and we can refer to these values as upper bound of possible changes in welfare in the dynamic modeling exercise (Rutherford and Tarr 2003).

Percentage change of the GDP in the Central scenario of the steady-state model is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -3,59%.

The decline in the GDP is driven by decrease in private consumption by the assumptions that the steady-state model shares with the static model: real government consumption and trade balance are fixed in real terms.

The external closure of the steady-state model is the same as in the static model, i.e. trade balance is fixed in real terms and the exchange rate adjusts to changes in relative prices of exported and imported goods. The exchange rate is defined in unites of local currency to units of foreign currency, thus an increase in the value of the exchange rate means depreciation of the local (domestic) currency. A decrease in the exchange rate means that domestic currency strengthens.

The Central scenario of the steady-state model is associated with a 4,02% increase in the exchange rate. This means that all imported goods are 4,02% more expensive than in the base year.

Numeraire of the static model is consumer price index, thus CPI change in all scenarios equal to zero. Since only relative prices matters in the computable general equilibrium models, all other prices are quoted in terms of the numeraire (CPI in our case). Given that CPI is fixed, changes in the exchange rate reflect changes in the real exchange rate.

Representative agent's income comes from primary factors. In the central scenario of the static model wages change by -2,38% and return to mobile capital by -0,12%.

Return to specific capital in extracting industries or natural rent, decreases for crude oil production (-6,93%), indicating reduction of production activities. All other extracting sectors feel much better with increase in return to specific capital in the Central scenario: the resource rent in production of natural gas rises (1,86%), as well as the resource rent in production of coal (0,67%), and other mining activities (1,77%).

Aggregated production index decreases by -1,48%. Agriculture production index decrease insignificantly (by -0,09%), extraction production index decreases by -0,2%, manufacturing production index rises by 0,15%. This indicates shift of the resources to manufacturing sector. Though, increase in production of manufacturing doesn't outweigh decrease in all other parts of the economy, contrary to the result in the static model. Services production index decreases by -1,33%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. The magnitude of reallocation in the steady-state model is more significant than in the static one: 3,43% of mobile capital changes sectors in the Central scenario, and 0,86% of workers.

As in the scenarios run with the static model, we can clearly see that the main driving force of the results in the Central scenario is the change in the world oil price.

Overall economic impacts: steady-state model, Oil scenario

Overall economic impacts for the Oil scenario in the settings of the steady-state model are shown in the table below (Table 2). Welfare changes associated with the Oil scenario indicate a significant decrease in the welfare of the representative agent up to -3,62% of benchmark consumption level or -1,8% of the base year GDP. Percentage change of the GDP in the Oil scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -2,23%. The Oil scenario is associated with a 4,02% increase in the exchange rate.

In the Oil scenario wages change by -1,36% and return to mobile capital by -0,03%.

Return to specific capital in extracting industries decreases for crude oil production (-5,1%), indicating reduction of production activities. The resource rent in production of natural gas rises (5,04%), as well as the resource rent in production of coal (0,5%), and other mining activities (1,02%).

Aggregated production index decreases by -0,88%, agriculture production index slightly decreases (-0,06%), extraction production index decreases by -0,14%, manufacturing production index rises by 0,1%. This indicates a slight shift of the resources to manufacturing sector. Services production index decreases by -0,77%. Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is rather significant only for mobile capital: 2,09% of mobile capital changes sectors in the Oil scenario, and 0,51% of workers.

Overall economic impacts: steady-state model, Natural gas scenario

Overall economic impacts for the Natural gas scenario in the settings of the steady-state model are shown in the table below (Table 2). Welfare changes associated with the

Natural gas scenario indicate a significant decrease in the welfare of the representative agent up to -0,39% of benchmark consumption level or -0,19% of the base year GDP.

Percentage change of the GDP in the Natural gas scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -0,25%.

The Natural gas scenario is associated with a 4,02% increase in the exchange rate. In the Natural gas scenario wages change by -0,22% and return to mobile capital by -0,01%.

Return to specific capital in extracting industries increases for crude oil production (0,33%), indicating increase of production activities, due to fuel substitution.

The resource rent in production of natural gas decreases with drop in the world prices of this commodity (-4,69%). The resource rent in production of coal increases (0,22%), as well as in the other mining activities (0,28%).

Aggregated production index decreases by -0,09%. Agriculture production index and extraction production indices do not change. Manufacturing production index rises by 0,07%. Services production index decreases by -0,15%.

The magnitude of reallocation of factors between industries is quite small: 0,31% of mobile capital changes sectors in the Natural gas scenario, and 0,11% of workers.

Overall economic impacts: steady-state model, Petroleum products scenario

Overall economic impacts for the Petroleum products scenario in the settings of the steady-state model are shown in the table below (Table 2).

Welfare changes associated with the Petroleum products scenario indicate a significant decrease in the welfare of the representative agent up to -1,79% of benchmark consumption level or -0,88% of the base year GDP. Percentage change of the GDP in the Petroleum products scenario is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,13%.

The Petroleum products scenario is associated with a 4,02% increase in the exchange rate. In the Petroleum products scenario wages change by -0,83% and return to mobile capital by -0,06%. Return to specific capital in extracting industries decreases for crude oil production (-2,21%), indicating reduction of production activities. The resource rent rises in production of natural gas (2,12%), and other mining activities (0,32%), but in slightly decreases production of coal (-0,21%),

Aggregated production index rises by -0,54%. Agriculture production index slightly decreases (by 0,09%), extraction production index decreases by -0,06%. Manufacturing production index decreases by -0,04%. Services production index decreases by -0,42%.

Structural changes induced by deterioration of the terms of trade lead to reallocation of mobile factors: workers change industries, as well as mobile capital. Though, the magnitude of reallocation is rather small: 1,13% of mobile capital changes sectors in the Petroleum products scenario, and 0,26% of workers.

5.4. Changes on the industry level

Output changes

Changes on the industry level are presented in the Appendix (Table 8-Table 9). On the industry level we can trace the same tendencies that were obvious on the macro level: decrease in private consumption, decrease in imports, relative increase in exports and associated with export dynamics changes in production. Exporting becomes a profitable alternative to stagnating domestic market. Though, this doesn't lead to an export-led growth.

Industrial changes in the comparative static (Table 8) and steady-state (Table 9) models describe similar pictures but have important differences. Industrial output change induced by the terms of trade deterioration depend on the cost structure of the industries, and changes in domestic demand. Magnitude of changes industry output are much bigger in the steady-state version of the model, and in the static one. Partially this reflects a much deeper restructuring of the economy under assumption of the steady-state model: reduction of installed capital, induced by the ToT change, and a much deeper decrease in imports lead to a bigger reallocation of factors, which was discussed above.

Price changes

Changes in prices on the industry level are presented in the Appendix (Table 11). Changes in prices of output, industry revenues, costs of manufactured intermediates and intermediates services in production are presented for the Central scenario of the static model. As it is evident in case of output changes on the industry level, we can trace the same tendencies that manifest themselves on the macro level: resulting prices on the industry level is a result of two main forces, decrease of domestic demand due to decrease of disposable income of the representative agent and increase in prices due to depreciation of the national currency.

The propagation of the exchange rate devaluation into production costs goes along the lines of the structure of the use of imported intermediates, as presented in the figure below (Figure 6).

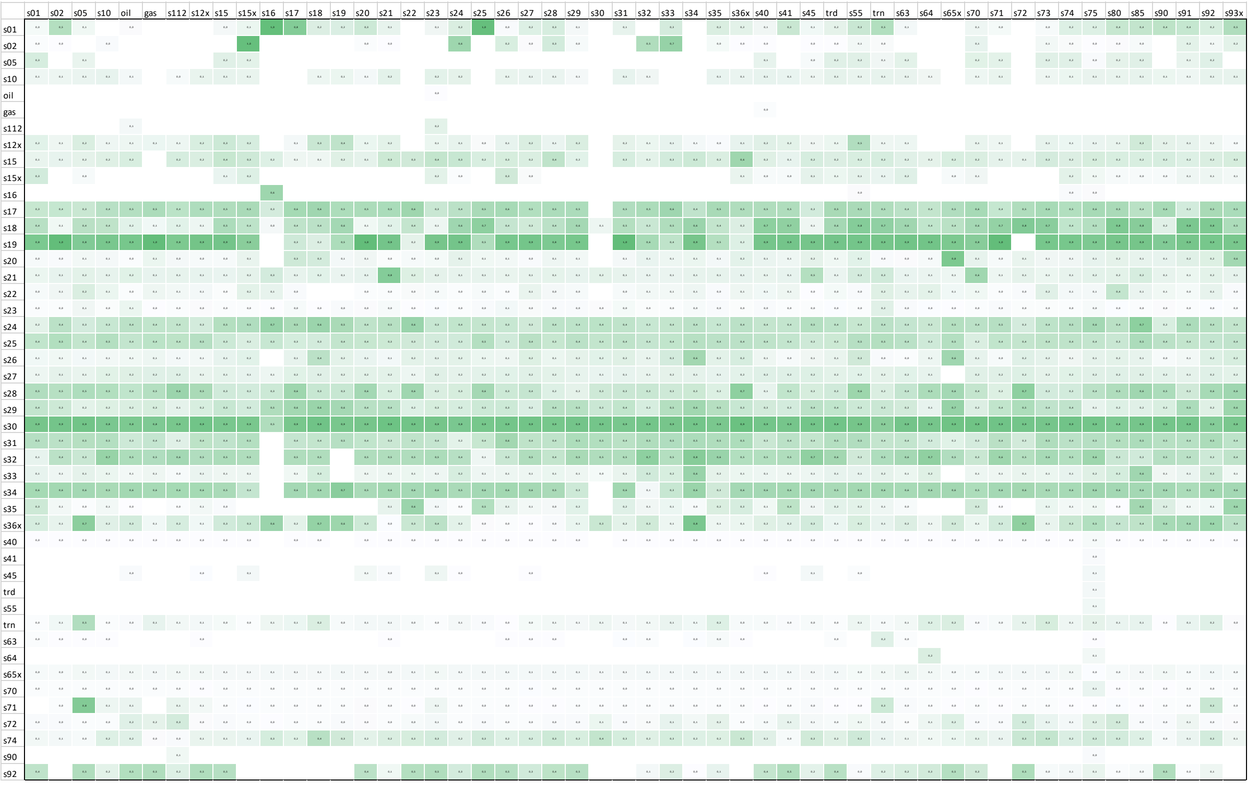

Figure 6. Imports in intermediate consumption: darker cells correspond to higher share of imports in intermediate use by industry and by intermediate commodity group, benchmark dataset, 2011.

Source: author’s calculations based on 2011 Russian input-output tables

From the figure above it is evident, that according to the data in the system of national accounts, the dependence of the Russian economy on imports is not industry-based, but can be described as product-based. There is evident tendency of all industries to consume more imported leather products (s019) and imported office electronics (s30) then domestic ones. As a consequence, pass through of exchange rate depreciation associated with terms of trade shock would be more in costs of those industries which use those intermediate goods relatively more than others.

An evidence of this tendency can be traced in changes of cost indices of production presented in Appendix (Table 11). Average change in costs of manufactured intermediates and intermediate services in production across all industries is 0,2 for goods and -0,08 for services. Imported services are almost absent from the intermediate consumption, there is no influence of exchange rate deterioration on the cost of intermediate services. On the contrary, 3,9% increase in the real[6] exchange rate corresponds to average increase of 0,2% in cost index of intermediate goods consumption.

5.5. Validation of the model: historical simulations

Validation of computable general equilibrium model is important and time-consuming process. There are different ways to assure validity of a computational models, and a CGE in particular. A computational model (Dixon and Rimmer 2013):

(i) should be computationally sound. Computational quality of the present model is ensured by numerous checks, including replication of the benchmark dataset.

(ii) should use accurate up-to-date data. As discussed earlier, the most up-to-date available data is used for the creation of the benchmark dataset.

(iii) should adequately captures behavioural and institutional characteristics of the relevant part of the economy. A range of behavioural and institutional characteristics is used in the presented model based on the latest research on Russian economy.

(iv) should be consistent with history. In order to validate model's consistency historical experiments were conducted. The setting of the experiments and results are discussed below.

A historical scenario is defined as changes in exogenous parameters of the model that were observed in the data. Validation of the model is done on the basis of goodness of fit of the detailed results to the historical values of endogenous variables of the model.

One of many possible measures of the goodness of fit is the "average error" measure proposed by (Dixon and Rimmer 2013):

$$AE = \left(\frac{1}{N}\right) * \sum_{c} \left|f_c - a_c\right| / \left(1 + \frac{a_c}{100}\right),$$

Where f_c - model forecast of the percentage change in the output of goods c;
a_c — statistics on change in output;
N - the number of product groups in the model.

[6] Please note, that CPI is fixed as a numeraire in the Central scenario of the static model, thus real and nominal values of the exchange rate coincide.

As a benchmark value for the average error of a detailed industrial historical scenario results (Dixon and Rimmer 2013) used average error calculated for the USAGE model, a detailed computable general equilibrium model for the American economy[7]. Benchmark value equals AE = 19% (Dixon and Rimmer 2013).

The most important element of the historical simulation is correct assessment of changes in exogenous parameters of the model. In our case the most important exogenous parameters are world prices of exports and imports. The importance of these parameters for validation of the present model is based on the primary use of the model in estimation of the effect of the change in terms of trade for the Russian economy.

In order to calculate changes in export and import prices on the level of commodity groups, presented in the model, several datasets were used:

1) CEPII TUV dataset (Gaulier et al. 2010);
2) UN COMTRADE;
3) EAEU detailed trade data on 10-digit HS code level;
4) IMF Commodity price database;
5) IMF Commodity Terms of Trade (Gruss and Kebhaj 2019);
6) CBR database of main export prices of Russian exports.

Price data for exports and imports is highly volatile, and the most time-consuming effort is to exclude outliers from the data. The results of this process for the export price data are presented in table below (Table 2). Changes in import prices are presented in the Appendix (Table 6-Table 7).

[7] Detailed description of the USAGE model is available at https://www.copsmodels.com/usage.htm

Table 2. Changes in export prices to 2011 by commodity group

	Change in export prices to 2011				
	2012	2013	2014	**2015**	2016
01 Agriculture	101%	143%	-11%	**-22%**	-36%
02 Forestry	-2%	1%	-2%	**-19%**	-24%
05 Fishing	29%	49%	80%	**84%**	80%
10 Mining of coal	-5%	-19%	-27%	**-41%**	-50%
11101 Crude petroleum	5%	2%	-5%	**-50%**	-61%
11102 Natural gas	18%	10%	32%	**9%**	-35%
12 Mining of metal ores	50%	35%	38%	**35%**	26%
15 Food	54%	48%	42%	**19%**	18%
15 -9 Beverages	19%	14%	10%	**-19%**	-21%
16 Tobacco products	40%	45%	55%	**39%**	16%
17 Textiles	66%	62%	53%	**32%**	23%
18 Wearing apparel	19%	72%	-75%	**-90%**	-91%
19 Leather	49%	59%	65%	**20%**	23%
20 Wood products	3%	6%	35%	**-24%**	-19%
21 Paper products	55%	49%	52%	**17%**	8%
22 Publishing	93%	59%	100%	**46%**	39%
23 Refined petroleum	14%	-74%	-74%	**-78%**	-77%
24 Chemicals	-10%	-10%	-13%	**-20%**	-95%
25 Plastic products	24%	7%	-11%	**-29%**	-31%
26 Non-metallic products	40%	37%	66%	**3%**	-6%
27 Basic metals	16%	7%	0%	**-19%**	-17%

Source: author's estimates, UN COMTRADE, CEPII TUV databases

One of important characteristics of the historical response of the Russian economy on the changes in terms of trade that occurred in 2014-2015 was stable real output of the extraction sector. As we saw earlier this contradicts predictions of both static and steady-state models.

The simulations results presented in the table below (Table 3) suggest that behaviour of Russian oil and gas extraction sector is explained by changes in export taxes, which were almost cut by half at the same time when world prices fall, thus leaving the perceived dollar price of oil exports for firms in the industry almost unchanged. This situation is depicted in scenario "val04". In a medium term time span, mimicked by 30% of all capital in the economy being specific, difference between model's forecast of output of oil and gas sector and historical values, reported by Rosstat, equal to 1,31%. Further alternation of the model, including changes in the import prices, distort the results.

Table 3. Design and results of historical simulations.

	val01	val02	val03	val04	val05	val06	val07	val08
Change in export prices	*	*	*	*	*	*	*	*
Change in import prices	*		*		*			
Change in export taxes	*	*		*	*	*	*	*
GTAP elasticities							*	*
Share of specific capital in all industries	0	0	0	30%	30%	50%	50%	50%
Share of specific capital in extraction	30%	30%	30%	30%	60%	50%	50%	70%
AE	14,102	15,447	15,919	13,314	15,058	13,784	14,953	17,367
AE* weighted	19,813	19,887	19,464	19,108	20,243	19,094	18,689	20,912
% error oil and gas real output	-3,95	-1,56	-9,32	-1,31	-7,00	-3,79	-3,32	-3,83

Source: author's estimates

The results of the historical scenarios suggest that the presented computable general equilibrium model is valid for use of scenario estimation for the Russian economy. It could picture adequately diverse industrial response on terms of trade shocks.

Historical scenarios stress importance of fiscal changes in estimating changes in industry output at the time of terms of trade shocks, especially changes in export taxes in extraction industries.

6. Conclusion

This article examines the impact of changes in world prices on the Russian economy. In particular, I am interested in the change in production as a result of changes in world prices for the main Russian export and import commodities. The model presented in the paper belongs to the class of computable general equilibrium (CGE) models, it has a detailed industry structure, which allows tracing the effect of changes in world prices on all aspects of the Russian economy.

One of my principal interests is the quantification of terms of trade shock response of the Russian economy on a detailed CGE model calibrated with Russian input-output data. A number of studies ((Atalay 2017), (Acemoglu, Ozdaglar, and Tahbaz-salehi 2017)

(Burstein, Kurz, and Tesar 2008)) stressed importance of explicit introduction of the intermediates in the models assessing effects of external shocks. I am interested in assessing effects of a terms of trade shock on the Russian economy with a detailed computable general equilibrium model. Models of this class permit introduction of rich details and complex production structures as well as optimizing behaviour of economic agents.

The results suggest a decrease of welfare of the representative consumer and real GDP with the deterioration of the terms of trade. In the Central scenario (a 10% decrease in the world price of crude oil, a 3% decrease in the world price of natural gas and an 8% decrease in the world price of petroleum products) welfare of the representative consumer decreases by -3,55% of benchmark consumption level or 1,76% of the base year GDP in the comparative static model. Percentage change of the GDP in the Central scenario of the comparative static model is of the same magnitude as representative agent's decrease in welfare in terms of the benchmark GDP: -1,73%.

Welfare changes associated with the Central scenario of the steady-state model indicate a significant decrease in the welfare of the representative agent up to -5,79% of benchmark consumption level or -2,92% of the base year GDP. Percentage change of the GDP in the Central scenario of the steady-state model exceeds representative agent's decrease in welfare in terms of the benchmark GDP: -3,59%. The GDP response in the steady-state model is in line with estimates obtained in compatible work (Полбин 2017).

These results exceed welfare changes in the Central scenario of the static model, and we can refer to these values as upper bound of possible changes in welfare in the dynamic modelling exercise (Rutherford and Tarr 2003).

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Appendix I. Analytical structure of the model

Equations

Household's problem

The representative household is maximizing Cobb-Douglas utility (1) subject to budget constraint (2).

$U(C) = \sum_i \theta_i log(c_i)$	(1)

Where c_i - good i consumption by a representative agent, i=1,n;

C = (c_1, …, c_i, …. c_n) – consumption basket i=1,n of the representative household;

θ_i – Cobb-Douglas function exponent coefficient, calibrated to the cost share of the product i in the total cost of consumption of basket C;

U(C) – utility function of a representative household.

Representative household's budget accounts for sales taxes t_i^C and fixed trade and transport margins ($\boldsymbol{\tau_{ki} p_k}$):

$\boldsymbol{(1 + t_i^c) p_i c_i + \sum_k \tau_{ki} p_k = N}$	(2)

Where, N - representative agent's disposable budget;

$\boldsymbol{\tau_{ki}}$ – share of mark-ups of type k in costs of supplying Armington mix of good i to a market, $\boldsymbol{k \in (transport, trade)}$.

Representative agent's income is defined as the sum of factor returns less direct taxes:

$N = wL + r_K K + \sum r_i^s K_i^s - \boldsymbol{T_{LS}}$	(3)

where w - wage;

L – labour supply;

r_K- mobile capital rent;

K – mobile capital supply;

r_i^s – specific capital rent in extraction industries coal, oil, natural gas, other extraction industries;

K_i^s- stock of specific factor in industry i ,

$\boldsymbol{T_{LS}}$. – direct taxes.

Government and investment demands in the core model assumed to be fixed on the base year level.

Government budget

The state collects a number of indirect and direct taxes. These taxes and related ad-valorem rates include taxes on production (t_i^y), taxes on intermediate consumption (t_{ij}^a), taxes on imports (t_i^M), taxes on government procurement (t_i^G), taxes on investment demand (t_i^I), taxes on exports (t_i^X) and taxes on household's consumption (t_i^C). The state budget:

$\sum_i (1+t_i^G) p_i a_i^G = T_Y + T_a + T_M + T_G + T_I + T_X + T_C + T_{FS} + T_{LS}$	(4)

Where

T_k – *revenue from a tax k;*

T_{FS} – revenue from taxes on factors of production;

T_{LS}. – revenue from direct taxes.

It is assumed in the core model that government consumption is fixed in real terms in the core government sector's demand is fixed on the base year level: $a_i^G = \overline{G_i}$. Adjustment of the implicit savings of a representative agent compensates for changes in cost of government consumption due to changes in prices and tax revenues.

Supply for domestic and export markets

Domestically produced goods and services supplied to domestic and international markets. A constant elasticity of transformation (CET) function describes transformation possibilities between domestic (d_i) and export (e_i) supplies of domestic output (Y_i). Sales shares in the country and abroad are determined by relative prices, provided that firms produce final goods in order to minimize cost subject to CET production function:

$Y_i = \bar{Y}_i \left[\theta_D \left(\frac{d_i}{\overline{D}_i} \right)^{\frac{1+\eta}{\eta}} + (1-\theta_D) \left(\frac{e_i}{\overline{E}_i} \right)^{\frac{1+\eta}{\eta}} \right]^{\frac{\eta}{1+\eta}}$	(5)

In this equation, the parameters are:

base year supply for domestic market ($\overline{D}_i$)

and export ($\overline{E}_i$) markets,

level of the base year production $\bar{Y}$,

θ_D – the share parameter of the CET function, calibrated to domestic sales in total sales of the base year,

and η – elasticity of transformation between supply to domestic and export markets.

Associated cost function, i.e. the cost of supply of sector *i* in the domestic and export market is denoted by $CET \ (p_i^D, p_i^X)$.

Production technology is described by the nested Leontief production function: output depends on the volume of consumption of intermediate goods, a_{mi}, (where m=1,n) and primary factors of production, mobile labor L_i and capital K_i , and specific K_i^s capital.

Producers demand intermediate goods and factors in order to minimize production costs for a given volume of products under the technological constraint (production function):

$Y_i = \bar{Y}_i \min\,[a_{mi}, VA_i(L_i, K_i, K_i^s)]$	(6)

where $a_{mi} = (a_{m1,i}, a_{m2,i}, \dots)$ – *intermediate goods* used in production of good *i*.

$VA_i(L_i, K_i, K_i^s)$ – value added, a Cobb-Douglas mixture of primary factors.

Balance of payments

In the main version of the model, the current account balance is fixed in real terms on the level of the base year. Current account is the difference between value of exports and imports

$\bar{p}_i^X$ – exogenous world export prices;

$\boldsymbol{e_i}$ – volume of exports (in real terms);

$\bar{p}_i^M$ – exogenous world prices for imported goods;

$\boldsymbol{m_i}$ – volume of imports (in real terms).

The increase (decrease) in imports should be compensated by a corresponding reduction (increase) in exports, while maintaining a fixed surplus of the current account at the level of the base year ($\bar{V}$)

$\sum \bar{p}_i^X \boldsymbol{e_i} = \sum \bar{p}_i^M \boldsymbol{m_i} + \bar{V} \perp \boldsymbol{\rho}$	(7)

Following work of Lars Mathiesen (Mathiesen 1985), which show that the Arrow – Debreu equilibrium can be formulated and solved as a sequence of complementary problems, the arbitrage and market clearing conditions are presented in the complementary slackness format.

The balance of payments constrains is the market equilibrium constraint that has exchange rate as a complimentary variable ($\boldsymbol{\rho}$**)**.

Arbitrage conditions

Production of a good *i* would take place if equation (8) holds, or in terms of complementary slackness formulation: (8) $\perp \boldsymbol{Y_i}$.

The cost of supply of sector *i* in the domestic and export market $\boldsymbol{CET}\ (\boldsymbol{p_i^D}, \boldsymbol{p_i^X})$ is equal to the cost of production $\boldsymbol{COST}^Y(p_{ij}^m, p_i\ , w, r_K, \boldsymbol{r_i^S})$. Primary factors of production and intermediates are connected in a nested production function with a constant elasticity of substitution (CES) $\boldsymbol{COST}^Y(p_{ij}^m, p_i\ , w, r_K, \boldsymbol{r_i^S})$ which includes:

- intermediate goods (price of intermediate goods j used in the production of good i (p_{ij}^m);
- price of bundled services for intermediate and final consumption $\boldsymbol{p_i^S}$

- labour (wage - w);
- mobile capital (mobile capital rent - r_K)
- and specific capital (specific capital rent - $\boldsymbol{r_i^S}$):

$\boldsymbol{Y_i}.\perp\ \boldsymbol{CET^y}(\boldsymbol{p_i^D},\boldsymbol{p_i^X}) = \boldsymbol{COSTS^y}(p_{ij}^m, p_i\ , w, r_K, \boldsymbol{r_i^S})$	(8)

Where $\boldsymbol{p_i^D}$ – price of a domestically produced good i for domestic market ;

$\boldsymbol{p_i^X}$ – domestic price of a good i for the export market.

$\perp \boldsymbol{a_i}$ Bundling of domestic and imported goods for different markets:

Price of goods ($\boldsymbol{p_i}$) reflects the cost $\boldsymbol{CES^A}(\boldsymbol{p_i^D},\boldsymbol{p_i^M})$ of domestic ($\boldsymbol{p_i^D}$) and imported resources ($\boldsymbol{p_i^M}$), as well as the associated trade and transport margins ($\boldsymbol{p_k}$):

$\boldsymbol{a_i} \perp \boldsymbol{p_i} = \boldsymbol{CES^A}(\boldsymbol{p_i^D},\boldsymbol{p_i^M}) + \sum_k \boldsymbol{\tau_{ki} p_k}$	(9)

Where $\boldsymbol{\tau_{ki}}$ - share of mark-ups of type k in costs of supplying Armington mix (a bundle of domestic and imported goods) of good i to a market (differs for each separate market: for final consumption of households, government, investment, and intermediate goods' markets).

Two bundling processes are described by (9): aggregation on the industry and product level of intermediate goods, and bundling of intermediate services and goods for final consumption by households, government and investment sector.

Intermediate consumption of goods ($\boldsymbol{a_{ij}^m}$) priced ($\boldsymbol{p_{ij}^m}$), for intermediate consumption of industry i of good j. Note that services are not aggregated this way – firms in the industry demand services for intermediate consumption on the final market. The equation below is presented with an associated complementarity condition:

$\boldsymbol{a_{ij}^m} \perp\ \boldsymbol{p_{ij}^m} = \boldsymbol{CE}\mathrm{S}_{ij}^m(\boldsymbol{p_j^D},\boldsymbol{p_j^M}) + \sum_k \boldsymbol{\tau_{ki} p_k};$	(9-a)

Where $\boldsymbol{CE}\mathrm{S}_{ij}^m(\boldsymbol{p_j^D},\boldsymbol{p_j^M})$ – cost of supplying a bundle of domestic and imported intermediate goods.

Intermediate consumption of services ($\boldsymbol{a_i^S}$) priced ($\boldsymbol{p_i}$), with an associated complementarity condition:

$\boldsymbol{a_i^S} \perp\ \boldsymbol{p_i}\ = \boldsymbol{CES^A}(\boldsymbol{p_i^D},\boldsymbol{p_i^M}) + \sum_k \boldsymbol{\tau_{ki} p_k}, \qquad for\ i \in \{services\}$	(9-b)

$\perp \boldsymbol{e_i}$ Domestic price of exports is equal to the exogenous (FOB) price of the world market (expressed in the world currency) ($\boldsymbol{\bar{p}_i^X}$), multiplied by the exchange rate ($\boldsymbol{\rho}$):

$\boldsymbol{e_i} \perp\ \boldsymbol{p_i^X} = \boldsymbol{\bar{p}_i^X} \cdot \boldsymbol{\rho}$	(10)

$\perp\ \boldsymbol{m_i}$ Domestic price of imports is equal to the exogenous (CIF) price of the world market (expressed in foreign currency) $\boldsymbol{\bar{p}_i^M}$, multiplied by the exchange rate ($\boldsymbol{\rho}$):

$\boldsymbol{m_i} \perp \quad \boldsymbol{p_i^M} = \boldsymbol{\overline{p}_i^M} \cdot \boldsymbol{\rho}$	(11)

Free entry guarantees zero profit in all industries. This means that gross income is equal to the sum of all production costs.

Market equilibrium conditions

$\perp p_i$ Commodity markets: aggregate supply is equal to aggregate demand on each market:

$\boldsymbol{a_i} = \boldsymbol{c_i} + \boldsymbol{a_i^I} + \boldsymbol{a_i^G} + \sum_j \boldsymbol{a_{ij}^S} \perp p_i,$ $\boldsymbol{a_{ij}^S} = \boldsymbol{Y_i}. \frac{\partial \boldsymbol{COST_i^y}}{\partial \boldsymbol{p_j}}, j \in \{services\}$	(12)

in the core model investment sector's demand is fixed on the base year level: $\boldsymbol{a_i^I} = \overline{I_i}$; government sector's demand is fixed on the base year level: $\boldsymbol{a_i^G} = \overline{G_i}$; This formulation of demand utilizes Shephard's lemma, stating that conditional factor demand for each input factor is the derivative of the cost function.

$\perp \boldsymbol{p_{ij}^m}$ Supply of intermediate goods equals demand

$\boldsymbol{a_{ij}^m} = \boldsymbol{Y_i}. \frac{\partial \boldsymbol{COST_i^y}}{\partial \boldsymbol{p_{ij}^m}} \perp \boldsymbol{p_{ij}^m}$	(13)

$\perp \boldsymbol{p_i^D}$ Domestic goods markets: the supply of domestic goods equals to the demand for domestically produced goods and services from all markets:

$\boldsymbol{d_i} = \sum_j \ \boldsymbol{a_{ij}^m} \frac{\partial \boldsymbol{CES_{ij}^m}(\boldsymbol{p_j^D}, \boldsymbol{p_j^M})}{\partial \boldsymbol{p_j^D}} + \boldsymbol{a_i} \ \frac{\partial \boldsymbol{CES^A}(\boldsymbol{p_i^D}, \boldsymbol{p_i^M})}{\partial \boldsymbol{p_i^D}}$	(14)

$\perp \boldsymbol{p_i^M}$ Import markets: total imports include sales of aggregate demand plus sales to firms for intermediate consumption:

$\boldsymbol{m_i} = \sum_j \ \boldsymbol{a_{ij}^m} \frac{\partial \boldsymbol{CES_{ij}^m}(\boldsymbol{p_j^D}, \boldsymbol{p_j^M})}{\partial \boldsymbol{p_j^M}} + \boldsymbol{a_i} \ \frac{\partial \boldsymbol{CES^A}(\boldsymbol{p_i^D}, \boldsymbol{p_i^M})}{\partial \boldsymbol{p_i^M}}$	(15)

$\perp \boldsymbol{w_\ell}$ The supply of labor is equal to the demand for labor:

$\boldsymbol{\overline{L}} = \sum_i \boldsymbol{y_i} \frac{\partial \boldsymbol{COST_i^y}}{\partial \boldsymbol{w_\ell}}$	(16)

Where $\boldsymbol{\overline{L}}$ - total supply of labour, fixed on the level of the base year;

$\perp \boldsymbol{r_K}$ Capital supply equals demand for capital:

$\boldsymbol{\overline{K}} = \sum_i \boldsymbol{y_i} \frac{\partial \boldsymbol{COST_i^y}}{\partial \boldsymbol{r_K}}$	(17)

Where $\overline{\boldsymbol{K}}$ – total supply of mobile capital, fixed on the level of the base year (core model formulation);

$\perp r_i^s$ The supply of firm-specific capital equals the demand for specific capital by the firm *i*:

$K_i^s = \boldsymbol{a_i} \frac{\boldsymbol{\partial CES_i^A}}{\boldsymbol{\partial r_i^s}}$	(18)

Where K_i^s – fixed supply of specific capital in industry i .

Symbol map

Table 4. Symbols used in the analytical description of the model

	Symbol	Definition (in the order of appearance in the Appendix I)
1	$\overline{D}_i$	benchmark production for domestic market of good i, where i=1,n
2	$\overline{E}_i$	benchmark exports of good i, where i=1,n
3	$\overline{G}_i$	the base year government demand
4	$\overline{I}_i$;	the base year investment demand
5	$\overline{p}_i^M$	exogenous world prices for imported goods
6	$\overline{p}_i^X$	exogenous world export prices
7	$\overline{Y}_i$	domestic output of good i in the benchmark equilibrium of the base year, where i=1,n
8	$\boldsymbol{a_i^G}$	government consumption of good i
9	$\boldsymbol{a_i^S}$	Armington mix of services (domestic and import bundle) for final and intermediate consumption
10	$\boldsymbol{a_i}$	supply of an Armington mix (a bundle of domestic and imported goods) for final markets (household, government and investment)
11	$\boldsymbol{a_{ij}^m}$	Armington mix of goods (domestic and import bundle) for intermediate consumption
12	$\boldsymbol{c_i}$	good i consumption by a representative agent, i=1,n;
13	$\boldsymbol{CES}_{ij}^m(\boldsymbol{p_j^D}, \boldsymbol{p_j^M})$	cost of supplying a bundle of domestic and imported intermediate goods j to industry i
14	$\boldsymbol{COST}^Y(p_{ij}^m, p_i^S, w, r_K, \boldsymbol{r_i^S})$	cost of production of good $\mathbf{Y_i}$ with a nested production function
15	$\boldsymbol{d_i}$	supplies of good i for the domestic market, where i=1,n
16	$\boldsymbol{e_i}$	exports of good i, where i=1,n
17	K_i^S	stock of specific factor in industry i
18	$\overline{\boldsymbol{K}}$	mobile capital supply
19	$\overline{\boldsymbol{L}}$	labour supply
20	$\boldsymbol{m_i}$	volume of imports (in real terms)
21	$\boldsymbol{p^G}$	price index on government procurement
22	$\boldsymbol{p_i^D}$	price of a domestically produced good i for domestic market
23	$\boldsymbol{p_i^M}$	domestic price of imports
24	$\boldsymbol{p_i^X}$	domestic price of a good i for the export market

	Symbol	Definition (in the order of appearance in the Appendix I)
25	p_i	price of a good (Armington bundle of domestic and imported goods) i on the final goods' market (final goods and services are consumed by households, government and investment sector), where i=1,n
26	p_{ij}^m	price of intermediate goods
27	$\boldsymbol{p_k}$	Price of service k, used for supplying goods to markets (transport or trade services)
28	r_i^s	specific capital rent in extraction industries coal (s10), oil, natural gas, other extraction industries (s12x);
29	r_K	rent
30	$\boldsymbol{T_a}$	revenue from taxes on intermediate consumption $\mathbf{t_{ij}^a}$
31	$\boldsymbol{T_C}$	revenue from taxes on household's consumption t_i^C
32	$\boldsymbol{T_{FS}}$	revenue from taxes on factors of production
33	$\boldsymbol{T_G}$	revenue from taxes on government procurement $\mathbf{t_i^G}$
34	t_i^C	sales tax rates on good i, where i=1,n
35	$\boldsymbol{T_I}$	revenue from taxes on investment demand $\mathbf{t_i^I}$
36	$\boldsymbol{T_{LS}}$	direct taxes
37	$\boldsymbol{T_M}$	revenue from taxes on imports $\mathbf{t_i^M}$
38	$\boldsymbol{T_X}$	revenue from taxes on exports $\mathbf{t_i^X}$
39	$\boldsymbol{T_Y}$	revenue from taxes on production $\mathbf{t_i^y}$
40	$\boldsymbol{\bar{V}}$	fixed surplus of the current account at the level of the base year a
41	Y_i	domestic output of good i, where i=1,n
42	θ_D	the share parameter of the CET function, calibrated to domestic sales in total sales of the base year
43	θ_i	Cobb-Douglas function exponent coefficient, equal to the cost share of the product i in the total cost of consumption of basket C;
44	$\boldsymbol{\tau_{ki}}$	share of mark-ups of type k in costs of supplying Armington mix of good i to a market
45	$\boldsymbol{C = (c_1, \ldots, c_n)}$	consumption basket i=1,n of the representative household;
46	$\boldsymbol{CES^A(p_i^D, p_i^M)}$	cost of producing an Armington mix of domestic and imported goods for final (household, government and investment consumption) and intermediate markets
47	$\boldsymbol{CET\ (p_i^D, p_i^X)}$	cost of production of good $\mathbf{d_i}$ for domestic market and good $\mathbf{e_i}$ for the export market with a CET production function
48	N	representative agent's income
49	$U(C)$	utility function of a representative household
50	VA_i	$VA_i(L_i, K_i, K_i^s)$ – value added, a Cobb-Douglas mixture of primary factors
51	w	wage
52	η	elasticity of transformation between supply to domestic and export markets
53	$\boldsymbol{\rho}$	exchange rate (in terms of units of local currency to a unit of foreign currency used for pricing of the country's exports and imports)
54	η	elasticity of transformation between supply to domestic and export markets

	Symbol	Definition (in the order of appearance in the Appendix I)
55	σ^m	elasticity of substitution between domestic and imported goods in intermediate consumption
56	σ^Y	elasticity of substitution between value added and intermediate goods in the production function
57	σ^{VA}	elasticity of substitution between different factors in production of value added
58	σ^A	elasticity of substitution between domestic and imported goods in the Armington aggregation function for production of final goods

Appendix II Data and parametrization

Industry list

Table 5. **Activities and commodity groups presented in the model**

#	Code	Short name of activity / commodity group
1	s01	Agriculture
2	s02	Logging
3	s05	Fishery
4	s10	Coal and peat
5	oil	Crude oil
6	gas	Natural gas
7	s112	Services related to oil and gas prod.
8	s12x	Other minerals
9	s15	Food products
10	s15x	Beverages
11	s16	Tobacco products
12	s17	Textile products
13	s18	Clothes and fur
14	s19	Leather products
15	s20	Wood
16	s21	Paper
17	s22	Publishing and printing
18	s23	Coke and petrochemical products
19	s24	Chemical products
20	s25	Rubber and plastic products
21	s26	Other non-metallic mineral products
22	s27	Metals
23	s28	Finished metal products
24	s29	Machinery and equipment
25	s30	Office equipment and computers
26	s31	Electrical machinery
27	s32	Radio, television and communication equipment
28	s33	Precision and optical instruments
29	s34	Motor vehicles
30	s35	Other transport equipment

#	Code	Short name of activity / commodity group
31	s36x	Furniture, recycling
32	s40	Power supply, steam and hot water
33	s41	Collection and distribution of water
34	s45	Construction
35	trd	Trade
36	s55	Hotels and restaurants
37	trn	Transport
38	s63	Auxiliary modes of transport
39	s64	Post and telecommunications
40	s65x	Financial intermediation and insurance
41	s70	Real estate activities
42	s71	Rent of machinery and equipment
43	s72	Computer and related activities
44	s73	Research and development
45	s74	Other business services
46	s75	Public administration and defense
47	s80	Education
48	s85	Health and social work
49	s90	Sanitation and waste management
50	s91	Activities of membership organizations
51	s92	Recreational cultural and sporting events
52	s93x	Other activities, domestic work

Source: author

Appendix III Simulations design

Table 6. Changes in import prices to 2011 by commodity group, part 1

	Change in import prices to 2011				
	2012	2013	2014	**2015**	2016
01 Agriculture	-9%	-25%	-6%	**-21%**	-18%
02 Forestry	2%	13%	-2%	**3%**	-11%
05 Fishing	-1%	12%	17%	**-68%**	-66%
10 Mining of coal	37%	33%	-44%	**-53%**	-63%
15 Food	9%	12%	11%	**-20%**	-24%
15 -9 Beverages	0%	8%	-3%	**-24%**	-25%
16 Tobacco products	-6%	1%	-7%	**-12%**	-20%
17 Textiles	17%	16%	19%	**9%**	12%
18 Wearing apparel	23%	32%	34%	**22%**	21%
19 Leather	4%	11%	21%	**23%**	36%
20 Wood products	56%	60%	76%	**34%**	24%
21 Paper products	11%	4%	-1%	**-16%**	-17%

Source: author's estimates, COMTRADE, CEPII TUV databases

Table 7. Changes in import prices to 2011 by commodity group, part 2

	Change in import prices to 2011				
	2012	2013	2014	**2015**	2016
22 Publishing	2%	8%	-10%	**2%**	11%
23 Refined petroleum	55%	87%	37%	**50%**	48%
24 Chemicals	-4%	-1%	-8%	**-33%**	-30%
25 Plastic products	8%	0%	2%	**-9%**	-6%
26 Non-metallic products	22%	33%	19%	**16%**	22%
28 Metal products	54%	51%	26%	**12%**	13%
29 Machinery	6%	8%	8%	**0%**	2%
30 Office machinery	-6%	15%	21%	**22%**	27%
31 Electrical machinery	14%	14%	10%	**3%**	0%
32 Radio television	0%	0%	0%	**0%**	0%
33 Medical instruments	1%	6%	4%	**-15%**	-13%
34 Motor vehicles	0%	4%	-3%	**-22%**	-17%

Source: author's estimates, COMTRADE, CEPII TUV databases

Appendix IV Simulation results

Table 8 Impact of the terms of trade shock in the Central scenario and it's components, static model, results are percentage changes from the base year

	Central scenario	Oil scenario	Natural gas scenario	Petroleum products scenario
World price change				
Crude oil	-10%	-10%		
Natural gas	-3%		-3%	
Petroleum products	-8%			-8%
Aggregate welfare				
Welfare (EV as % of consumption)	-3,552	-2,265	-0,213	-1,033
Welfare (EV as % of GDP)	-1,757	-1,113	-0,104	-0,505
GDP decomposition				
GDP (% change)	-1,727	-1,101	-0,104	-0,502
Real private consumption (C % change)	-3,552	-2,265	-0,213	-1,033
Real government consumption (G % change)	0,000	0,000	0,000	0,000
Real investment demand (I % change)	0,000	0,000	0,000	0,000
Real aggregated exports (E % change)	-4,265	-2,598	-0,419	-1,286
Real aggregated imports (M % change)	-6,357	-3,871	-0,625	-1,917
RER and CPI				
Real exchage rate (% change)	3,917	2,297	0,375	1,124
Consumer price index (% change)	0,000	0,000	0,000	0,000
Return to primary factors				
Labor (w % change)	-0,202	-0,052	-0,061	-0,097
Mobile capital (r % change)	-1,247	-0,707	-0,096	-0,434
Crude oil resources (% change)	-4,925	-3,874	0,489	-1,517
Natural gas resources (% change)	3,769	6,211	-4,552	2,754
Coal resources (% change)	3,236	2,035	0,414	0,635
Other mining resources (% change)	4,841	2,845	0,507	1,322
Aggregated production				
Aggregated production index (% change)	0,416	0,262	0,056	0,086
Argiculture production index (% change)	0,000	-0,005	0,007	0,001
Extraction production index (% change)	-0,046	-0,045	0,011	-0,010
Manufacturing production index (% change)	0,640	0,390	0,103	0,125
Services production index (% change)	-0,178	-0,078	-0,065	-0,029
Factor adjustment				
Mobile capital (% changing sectors)	0,870	0,536	0,153	0,264
Labor (% changing sectors)	0,801	0,480	0,110	0,234

Source: Author's estimates

Table 9. Changes in production, exports, imports and household's consumption in the Central scenario, comparative static model

Code	Short name of activity / commodity group	Change in production	Change in exports	Change in imports	Change in RA consumption
s01	Agriculture	-0,043	0,959	-10,689	-3,447
s02	Logging	1,503	2,548	-0,434	-2,818
s05	Fishery	-0,809	-0,311	-4,851	-4,494
s10	Coal and peat	3,248	4,154	-0,265	-1,912
oil	Crude oil	-2,755	-3,458	-1,439	0,000
gas	Natural gas	3,631	2,706	-1,876	0,000
s112	Services related to oil and gas prod.	0,524	1,122	-8,841	-7,187
s12x	Other minerals	4,559	5,088	3,037	-3,526
s15	Food products	-0,690	0,259	-10,387	-3,403
s15x	Beverages	-0,955	-0,034	-14,576	-3,303
s16	Tobacco products	-2,738	-1,886	-11,435	-3,267
s17	Textile products	4,394	5,157	-4,522	-4,402
s18	Clothes and fur	5,771	6,614	-6,433	-4,163
s19	Leather products	14,407	14,942	-6,335	-4,575
s20	Wood	2,688	3,687	-3,808	-2,660
s21	Paper	1,494	2,370	-2,580	-3,884
s22	Publishing and printing	-0,077	1,145	-8,799	-3,399
s23	Coke and petrochemical products	-1,429	-2,869	1,056	-7,725
s24	Chemical products	5,820	5,706	-2,918	-4,025
s25	Rubber and plastic products	1,887	2,826	-1,364	-4,001
s26	Other non-metallic mineral products	0,857	1,812	-1,916	-3,670
s27	Metals	4,924	5,962	-1,742	-1,671
s28	Finished metal products	2,979	4,295	-2,372	-4,026
s29	Machinery and equipment	7,347	8,066	-4,248	-4,411
s30	Office equipment and computers	9,649	8,990	-1,448	-5,222
s31	Electrical machinery	5,014	6,001	-2,048	-4,105
s32	Radio, television and communication	6,441	6,348	-2,644	-4,365
s33	Precision and optical instruments	7,578	6,726	-6,154	-4,293
s34	Motor vehicles	3,313	4,083	-5,278	-5,033
s35	Other transport equipment	9,044	9,227	-11,281	-4,024
s36x	Furniture, recycling	5,692	6,562	-12,678	-3,731
s40	Power supply, steam and hot water	0,105	1,138	-0,886	-2,535
s41	Collection and distribution of water	-1,652	-0,220	-0,863	-2,938
s45	Construction	0,341	1,239	-12,120	-3,036
trd	Trade	-1,317	-0,090	-17,539	-2,853
s55	Hotels and restaurants	-2,657	-1,554	-15,082	-3,155
trn	Transport	0,098	0,689	-16,522	-3,462
s63	Auxiliary modes of transport	0,511	1,293	-15,722	-2,976
s64	Post and telecommunications	-1,099	-0,178	-15,070	-2,923
s65x	Financial intermediation and insurance	0,256	1,151	-15,312	-2,890
s70	Real estate activities	-1,548	-0,478	-18,015	-2,488
s71	Rent of machinery and equipment	3,525	3,793	-15,782	-2,487
s72	Computer and related activities	3,248	3,668	-14,338	-2,788
s73	Research and development	-0,260	0,884	-15,367	0,000
s74	Other business services	4,331	4,372	-14,439	-2,438
s75	Public administration and defense	0,002	0,839	0,000	-3,239
s80	Education	-0,386	0,451	-17,936	-3,300
s85	Health and social work	-0,589	0,191	-17,295	-3,551
s90	Sanitation and waste management	-0,885	-0,109	-14,400	-3,493
s91	Activities of membership organizations	-0,284	0,000	0,000	-3,357
s92	Recreational cultural and sporting	0,831	1,684	-13,035	-3,154
s93x	Other activities, domestic work	-3,280	0,000	0,000	-3,288

Source: Author's estimates

Table 10. Changes in production, exports, imports and household's consumption in the Central scenario, steady-state model

Code	Short name of activity / commodity group	Change in production	Change in exports	Change in imports	Change in RA consumption
s01	Agriculture	-2,392	-1,447	-12,425	-5,865
s02	Logging	-0,839	0,277	-2,760	-4,910
s05	Fishery	-2,807	-2,282	-7,143	-6,604
s10	Coal and peat	1,367	2,399	-2,538	-3,657
oil	Crude oil	-4,814	-5,466	-3,590	0,000
gas	Natural gas	2,045	1,044	-3,741	0,000
s112	Services related to oil and gas prod.	-2,179	-1,415	-12,187	-9,432
s12x	Other minerals	2,380	3,055	0,530	-5,488
s15	Food products	-2,829	-1,883	-12,560	-5,632
s15x	Beverages	-3,067	-2,114	-17,155	-5,485
s16	Tobacco products	-5,166	-4,364	-13,248	-5,637
s17	Textile products	3,012	3,832	-6,844	-6,583
s18	Clothes and fur	4,364	5,255	-8,790	-6,387
s19	Leather products	14,016	14,596	-8,747	-6,792
s20	Wood	0,323	1,405	-6,533	-4,690
s21	Paper	-0,387	0,521	-4,667	-6,083
s22	Publishing and printing	-1,528	-0,248	-11,320	-5,449
s23	Coke and petrochemical products	-3,506	-4,920	-0,883	-9,968
s24	Chemical products	4,015	3,889	-4,763	-6,238
s25	Rubber and plastic products	-0,373	0,648	-3,822	-6,130
s26	Other non-metallic mineral products	-1,734	-0,681	-4,646	-5,741
s27	Metals	2,650	3,746	-4,276	-3,729
s28	Finished metal products	0,785	2,247	-5,032	-6,105
s29	Machinery and equipment	5,760	6,603	-7,616	-6,528
s30	Office equipment and computers	8,228	7,509	-4,004	-7,442
s31	Electrical machinery	3,043	4,166	-4,844	-6,221
s32	Radio, television and communication	5,078	4,857	-5,474	-6,478
s33	Precision and optical instruments	6,496	5,339	-9,723	-6,323
s34	Motor vehicles	1,140	1,983	-8,202	-7,157
s35	Other transport equipment	8,261	8,429	-16,039	-5,981
s36x	Furniture, recycling	3,649	4,604	-15,602	-5,845
s40	Power supply, steam and hot water	-1,631	-0,534	-1,536	-4,473
s41	Collection and distribution of water	-3,039	-1,479	-1,195	-4,283
s45	Construction	-2,477	-1,516	-15,194	-5,107
trd	Trade	-3,445	-2,102	-19,544	-5,105
s55	Hotels and restaurants	-4,574	-3,447	-16,705	-5,306
trn	Transport	-1,804	-1,120	-19,578	-5,410
s63	Auxiliary modes of transport	-1,258	-0,414	-19,182	-4,758
s64	Post and telecommunications	-2,989	-2,048	-16,988	-5,101
s65x	Financial intermediation and insurance	-1,590	-0,611	-18,577	-4,745
s70	Real estate activities	-4,173	-3,211	-17,503	-5,480
s71	Rent of machinery and equipment	1,082	1,301	-15,744	-5,398
s72	Computer and related activities	2,246	2,459	-16,960	-4,724
s73	Research and development	-3,488	-2,059	-21,642	0,000
s74	Other business services	2,748	2,738	-17,688	-4,214
s75	Public administration and defense	-0,129	0,903	0,000	-4,656
s80	Education	-0,486	0,633	-23,643	-4,129
s85	Health and social work	-0,777	0,256	-22,466	-4,617
s90	Sanitation and waste management	-1,877	-1,222	-17,605	-5,181
s91	Activities of membership organizations	-0,378	0,000	0,000	-4,465
s92	Recreational cultural and sporting	0,089	1,083	-17,206	-4,751
s93x	Other activities, domestic work	-3,905	0,000	0,000	-3,985

Source: Author's estimates

Table 11. Changes in prices of output, industry revenues, costs of intermediates in production of manufactured goods and services, in the Central scenario, static model

Code	Short name of activity / commodity group	Change in output price (py), %	Change in industry revenue, %	Change in manufactured goods intermediate cost index, %	Change in services intermediate cost index, %
s01	Agriculture	-0,31320	-0,29452	0,06848	-0,03622
s02	Logging	0,24278	0,16936	0,94850	-0,07735
s05	Fishery	1,12206	0,73011	1,98669	-0,05547
s10	Coal and peat	-0,00061	-0,01352	-0,02772	-0,06470
oil	Crude oil	-1,75778	-1,24604	-0,07836	-0,12359
gas	Natural gas	0,42658	0,51798	-0,09346	-0,32809
s112	Services related to oil and gas production	-0,22457	-0,24185	-0,11198	-0,11654
s12x	Other minerals	0,31129	0,22480	0,33567	-0,06373
s15	Food products	-0,07622	-0,08451	0,04286	-0,02607
s15x	Beverages	-0,14977	-0,15751	0,08987	-0,04747
s16	Tobacco products	0,26607	0,25849	1,14600	-0,02890
s17	Textile products	0,39264	0,34670	0,77051	-0,03995
s18	Clothes and fur	0,22812	0,19036	0,88371	-0,06359
s19	Leather products	0,14882	0,11531	0,47766	-0,03449
s20	Wood	-0,34907	-0,34096	-0,28101	-0,04862
s21	Paper	0,08647	0,03006	0,38833	-0,03701
s22	Publishing and printing	-0,15386	-0,15770	0,01033	-0,07282
s23	Coke and petrochemical products	3,55086	2,56584	4,18186	-0,04340
s24	Chemical products	0,28095	0,27082	0,77260	-0,04118
s25	Rubber and plastic products	0,04519	0,01865	0,15314	-0,03020
s26	Other non-metallic mineral products	-0,20795	-0,21233	-0,10295	-0,04565
s27	Metals	-0,56686	-0,54671	-0,57044	-0,02272
s28	Finished metal products	-0,72145	-0,67576	-0,88033	-0,03932
s29	Machinery and equipment	-0,22170	-0,24342	-0,17499	-0,04342
s30	Office equipment and computers	0,63554	0,48811	1,13661	-0,03997
s31	Electrical machinery	-0,43613	-0,42012	-0,48742	-0,03216
s32	Radio, television and communication equipment	0,44439	0,37341	0,90810	-0,03022
s33	Precision and optical instruments	-0,04239	-0,07483	0,15813	-0,03803
s34	Motor vehicles	0,56514	0,51726	0,85362	-0,02510
s35	Other transport equipment	-0,36995	-0,36677	-0,43111	-0,02939
s36x	Furniture, recycling	-0,59984	-0,58638	-0,65975	-0,04587
s40	Power supply, steam and hot water	-1,18262	-1,15487	-1,68757	-0,02133
s41	Collection and distribution of water	-0,51012	-0,34769	-0,44633	-0,03897
s45	Construction	-0,24672	-0,24905	0,05194	-0,04121
trd	Trade	-0,42735	-0,35691	0,12708	-0,23495
s55	Hotels and restaurants	-0,22781	-0,23434	0,13538	-0,12286
trn	Transport	-0,01769	-0,03227	0,40167	-0,15646
s63	Auxiliary modes of transport	-0,08837	-0,10198	0,23941	-0,19763
s64	Post and telecommunications	-0,27763	-0,27736	0,09286	-0,11388
s65x	Financial intermediation and insurance	-0,31789	-0,31853	0,03116	-0,21853
s70	Real estate activities	-0,61704	-0,61244	-0,18563	-0,19724
s71	Rent of machinery and equipment	-0,56868	-0,56350	0,20486	-0,17315
s72	Computer and related activities	-0,18876	-0,19688	0,23588	-0,14161
s73	Research and development	-0,13898	-0,16623	-0,00667	-0,05549
s74	Other business services	-0,26155	-0,26577	0,10475	-0,12100
s75	Public administration and defense	-0,15953	-0,16036	0,03939	-0,08165
s80	Education	-0,16823	-0,16848	-0,27612	-0,06337
s85	Health and social work	0,00998	0,00902	0,31170	-0,04670
s90	Sanitation and waste management	0,05642	-0,01410	0,42018	-0,07080
s91	Activities of membership organizations	-0,08759	-0,10243	0,01163	-0,13663
s92	Recreational cultural and sporting events	-0,21939	-0,22024	-0,01265	-0,10842
s93x	Other activities, domestic work	-0,11008	-0,11382	0,15405	-0,20272

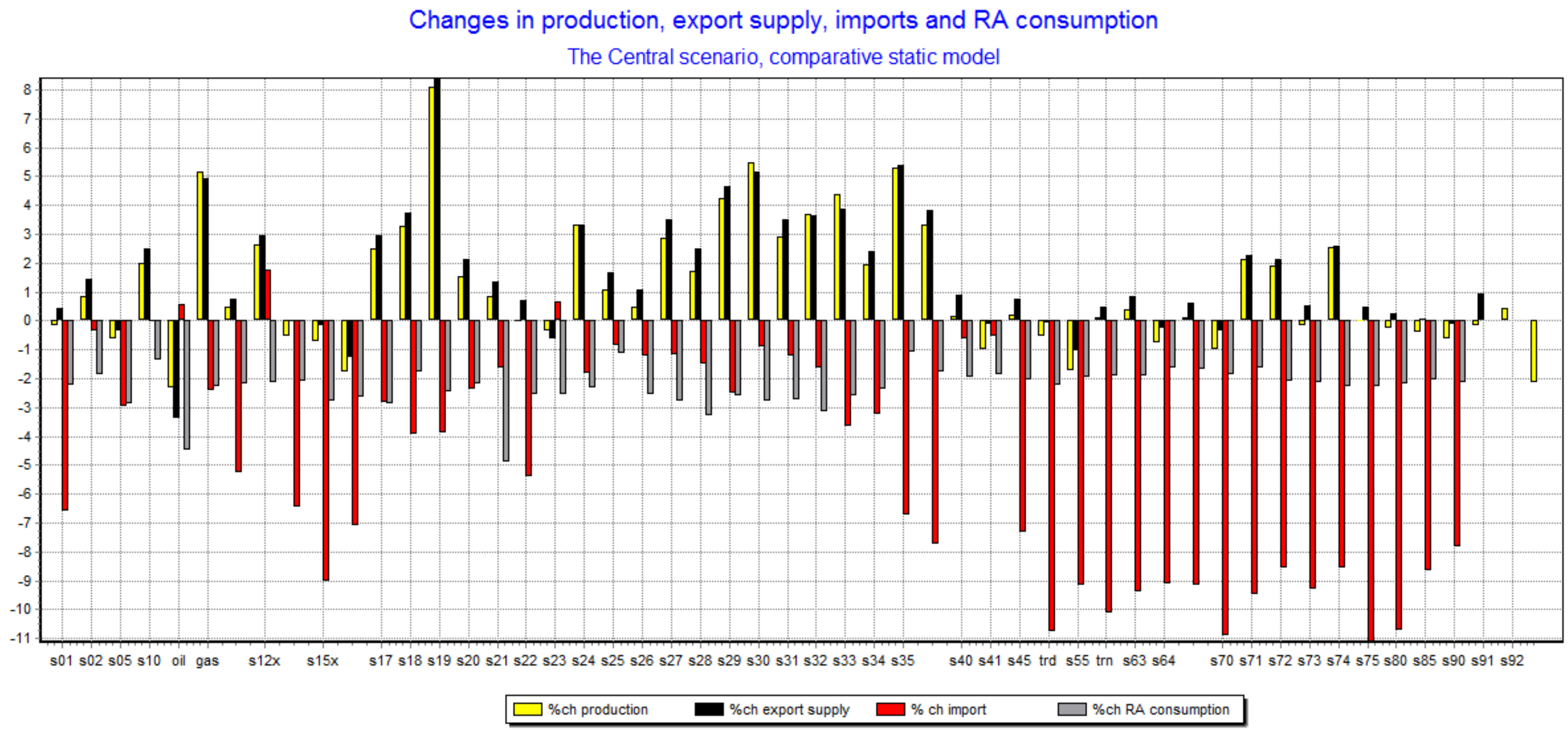

Figure 7. Changes in production, export supply, imports and representative agent's consumption in the Central scenario, comparative static model

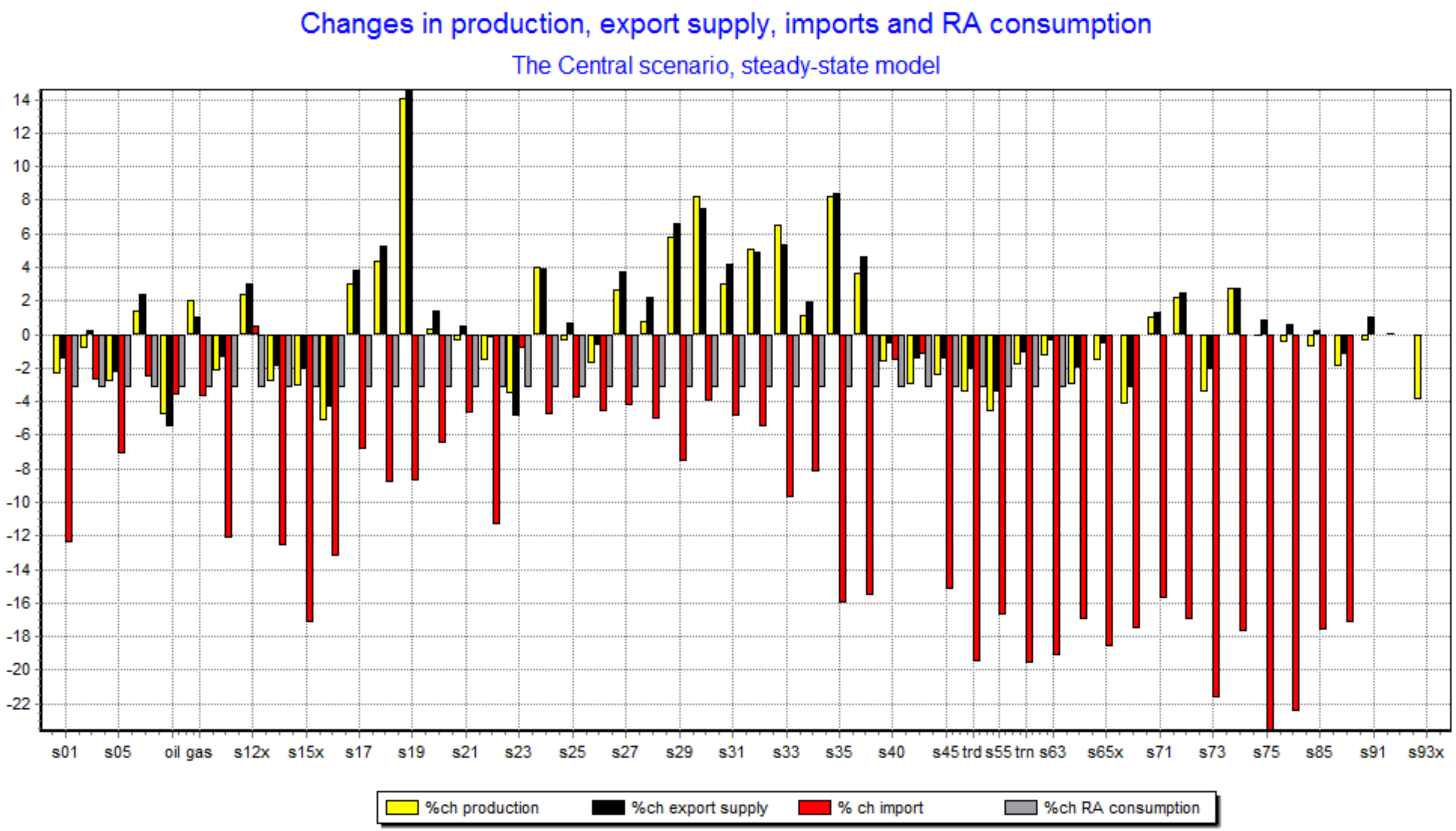

Figure 8. Changes in production, export supply, imports and representative agent's consumption in the Central scenario, steady-state model