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JAKUB BORATYŃSKI

ROBUSTNESS OF CGE SIMULATION RESULTS IN THE CONTEXT OF STRUCTURAL CHANGES – THE CASE OF POLAND [1]

1. INTRODUCTION

Sensitivity analysis is a common way to address the problem of uncertainty of results in simulations based on computable general equilibrium (CGE) models. Different studies have considered the consequences of both using alternative model specifications and varying parameter values. Limiting ourselves to the latter case only, the most prominent approach in the recent literature is the systematic sensitivity analysis (SSA) – a technique in which parameter values are drawn from assumed distributions and the variances of simulation outcomes are next analyzed (Arndt, 1996; DeVuyst, Preckel, 1997; Hermeling, Mennel, 2008). SSA is usually applied to various elasticity parameters, i.e. the ones that are not derived from the CGE model's database and thus usually taken from external empirical sources (examples are Hertel et al., 2007; Domingues et al., 2008; Narayanan et al., 2010; Elliott et al., 2012). Less frequently sensitivity analysis concerns parameters obtained from calibration to benchmark equilibrium data. Using SSA in that case is more difficult, as parameter errors typically cannot be treated as independent (Dawkins, 2005). Examples of the use of SSA in this context are Dawkins (2005) and Elliott et al. (2012). Otherwise sensitivity analysis might boil down to calibrating the model to alternative benchmark equilibrium databases, e.g. data for different years (Roberts, 1994) or different estimates of data for the same year (Cardenete, Sancho, 2004).

In recent years a number of studies were published, presenting applications of various CGE models developed for Poland. For example, the ORANI-type model POLGEM was developed to study fiscal policies (Honkatukia et al., 2003). Based on another model, originally developed by the World Bank and the National Bank of Poland (Gradzewicz et al., 2006), Hagemejer et al. (2011) analyzed different strategies to reduce general government deficit, and Hagemejer, Żółkiewski (2013) estimated the impact of the EU 2020 climate and energy package on the Polish economy. Hagemejer

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et al. (2014) use a global CGE GTAP model (with Poland as one of the regions) in an analysis of liberalization of trade in services under the EU Services Directive. Zawalińska (2009) and Zawalińska et al. (2013) are examples of the use of regionally-disaggregated CGE models for Poland to study the consequences of agricultural policies. Energy and climate policies were analyzed using a model with extended treatment of energy inputs to production (Kiuila, Peszko 2006), as well as using a global economy model ROCA, with Poland as a distinguished region (World Bank 2011; see also Böhringer, Rutherford 2013). Borowski et al. (2011, 2013) assessed the impact of the preparations and organization of 2012 European Football Championships in Poland, based on a dynamic CGE model of the Polish economy. Finally, Boratyński, Borowski (2012) adopted the CGE framework to simulate the effects of a possible introduction of flat income tax. Sensitivity analysis (with respect to crucial modeling assumptions) in the cited studies is rather limited. In Hagemejer et al. (2011), Boratyński, Borowski (2012), as well as Hagemejer, Żółkiewski (2013) it amounts to performing simulations under alternative model closures. However, none of the papers has addressed the problem of uncertainty of the calibrated (share) parameters.

The present study is a follow-up to an earlier paper (Boratyński, 2011), in which systematic sensitivity analysis with respect to elasticity parameters was undertaken. These studies share the same model and simulation scenarios, but refer to distinct sources of uncertainty. The former paper analyzed consequences of uncertainty connected with unobserved behavioral (elasticity) parameters; therefore it indirectly referred to uncertainties inherent in econometric work; in terms of methodology, the cited study adopted the Gaussian Quadrature approach, as a replacement for a more computationally intensive Monte Carlo simulation. Whereas the present paper relates to the problem of uncertainty of information concerning the structure of the economy (e.g. industry/commodity composition of output/demand, technologies – including proportions of intermediate inputs, import intensities of different industries/commodities, structure of taxes etc.). These data give rise to a number of the so called “share” (or “structural” or “calibrated”) parameters of a CGE model, which – along with elasticity (behavioral) parameters – drive simulation results.[2]

The topic of uncertainties related to these calibrated share parameters is less frequently met in the CGE literature (compared to studies concerning elasticity parameters). This paper contributes to that research, firstly, by using an extensive database – a time series of annual supply and use tables for the Polish economy spanning the years 1996–2005[3] (a previous study of that type for Poland, by Roberts, 1994,

[2] In the CGE framework, the calibrated parameters are those which are derived from benchmark equilibrium data; the non-calibrated ones (e.g. elasticities) are taken from external sources, e.g. literature reporting results of econometric estimation.

[3] The database was compiled using primarily the data supplied by the Polish Central Statistical Office. As the additional sources we also used the Eurostat database and the EU KLEMS Database, March 2008 Release (see Timmer et al., 2007). An advantage over international databases such as WIOD (World Input-Output Database) is in the fact that data for *each year* are derived from official country

used aggregate, single-sector data and model). Secondly, we attempt to identify which parameter groups contribute most to variability of simulation outcomes. Thirdly, the results are reported for three different simulation exercises, comprising demand-side, supply-side and tax shocks. A practical question in the background of this paper is whether the lag between benchmark equilibrium year and the simulation period is a serious problem for the reliability of results, especially for emerging economies, such as Poland.

The paper is structured as follows. Section 2 characterizes the model and the closure used. In section 3 we examine how robust are simulation results to changes in the database used as a benchmark equilibrium for model calibration. Section 4 investigates the importance of different parameter groups for the variability of simulation results. Section 5 concludes.

2. THE MODEL AND CLOSURE

The specification of the model used in this study largely follows that of ORANI-G – a generic static single-economy, single-region computable general equilibrium model (Horridge, 2003; see also Dixon et al., 1982; for principles of CGE models, their recent developments and applications see Dixon, Jorgenson 2013). The ORANI (or MONASH) approach constitutes a long tradition in CGE modeling and has had a large number of implementations worldwide (Dixon et al., 2013). Our model represents the economy in an 18 industry/commodity breakdown. Below we characterize its key features.

– *Nested production structure*. In each industry, intermediate input composites and the primary factor bundle are combined in fixed proportions (Leontief production functions). Primary factor bundle is a CES (constant elasticity of substitution) composite of capital and labor, while intermediate inputs are CES composites of domestic and imported products.
– *Multiproduction*. Each industry produces a variety of commodities, subject to CET (constant elasticity of transformation) production frontier.
– *Household demand*. Household demand for commodities, for a single representative household, is determined in the linear expenditure system (LES) framework, which corresponds with the Klein-Rubin (or Stone-Geary) utility function.
– *Exports*. The economy faces downward sloping foreign demand schedules, so it is assumed to have some (limited) market power in international markets.
– *Sourcing of final demand*. Final demand of a given user for a given commodity is a CES composite of demand for imported and domestic commodity (as in the case of intermediate inputs in the production nest).

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supply and use tables, which is not the case of WIOD tables for Poland (and for a number of other countries); moreover in international databases original data are often subject to additional processing, in order to reach inter-country consistency.

– *Optimizing behavior*. Capital-labor substitution and product sourcing decisions are subject to the cost minimization principle. Producers adjust their product-mix to maximize revenue. Household are assumed to be utility maximizes.
– *Market structures*. We assume competitive commodity markets, and, accordingly, marginal cost pricing and zero pure profits.

However, there are some differences to the ORANI-G model. Most importantly, we assume that the composition of investment demand (e.g. the shares of demand for construction services, machinery, transport equipment etc.) are identical for all investing industries. Other differences include a more detailed, SAM-based representation of income distribution in our model, compared to ORANI-G; we do not model tariffs explicitly, but include them into the broad category of taxes on products. Finally, we also use a different notation, based on a mixed level and percentage change representation of the model equations (see e.g. Dixon, Parmenter, 1996, p. 17–21). The 18 industry/commodity breakdown was chosen as a supposedly good compromise between model detail (disaggregation) and tractability (in terms of computational burden in repeated simulations as well as presentation and analysis of the results).

In this study we adopt a long-run closure, which entails further assumptions:
– *Capital and investment*. Industry capital stocks adjust to preserve original (observed) gross rates of return, i.e. the ratios of capital rental rates to the price of new capital. Investment follows (is proportional to) capital stock in each industry. As a consequence of such a specification, capital is treated as industry-specific.
– *Labor market*. Aggregate (effective) labor supply is fixed, while labor may flow between industries, so that the wage per effective labor unit is equalized.
– *Absorption*. Aggregate consumption adjusts to facilitate a fixed (nominal) balance of trade to GDP ratio. Government and non-profit institutions' consumption follow (are proportional to) aggregate household consumption.

In the comparative static framework, simulations do not show the distribution of the analyzed effects in time (which is accomplished in either recursive-dynamic, or "fully" dynamic models with expectations). The results represent (percentage) deviations from a hypothetical baseline growth path, but without giving an explicit account of time needed by the economy to fully accommodate to the analyzed shocks. Under the long-run assumption, the length of the accommodation period is interpreted as the time necessary for the capital stock in each industry to reach its new optimum level, which is in turn related to the specificity of investment process and depreciation rates in different industries.

To avoid confusion related to interpretation, we should strongly stress that the results presented further are not the *effects for consecutive years* in the usual sense (i.e. they are not analogous to the results of a dynamic model). Rather the *data for consecutive years* are used to calibrate the model which is then solved in static long-run experiments, as described above. Calibrating the static model to data from year t entails an implicit assumption that these data – at least approximately – describe the economy's structure in year $t+s+d$, in which the effects of the shocks under consideration are expected to materialize ($t+s$ is the period in which the simulated shock is actually expected to take place, and d is the time necessary to accommodate to the shock). Given that in practice $s+d$ can often be as long as several years, this raises a question whether such obsolete structural data can reasonably approximate the future picture of the economy. This is especially an issue for emerging economies, for which it is not likely that period t structural data represent (or are close to) steady state. By calibrating the model to data from subsequent years (spanning the transition period in Poland) we test how much of a problem the structural changes are for the robustness of simulation results.

3. SIMULATION RESULTS FOR ALTERNATIVE CALIBRATION DATABASES

To perform this specific robustness analysis we repeat the same set of three simulation experiments using the same model calibrated to 10 different datasets (for the Polish economy), for subsequent years between 1996 and 2005. The results are presented as *average* responses (percentage changes) of endogenous variables to the imposed exogenous shocks, along with variation coefficients as measures of dispersion of those responses (see tables 1–3). Non-calibrated parameters, such as substitution elasticities, were held constant across simulations. The simulation scenarios where chosen arbitrarily, but they represent three distinct type of shocks – supply-side, demand-side and tax shocks. Below we briefly analyze the main mechanisms “at work” and the macroeconomic outcomes in the three experiments. Next we move to the results of sensitivity analysis itself.

Simulation 1 assumes a 20% decrease of the joint capital and labor productivity in the energy sector (electricity, gas and water supply). Such a shock might for example relate to the need of conforming with higher environmental protection standards. From the macro perspective, the shock immediately reduces the amount of *effective* primary factor inputs available in the economy – more for capital than labor, as the energy sector is capital-intensive. This makes labor relatively cheaper and induces substitution of capital for labor, which decreases capital stock even further. On the other hand, keeping the balance of trade to GDP ratio unchanged (lower activity level diminishes demand for imports, which must be followed by exports decrease) requires real appreciation of the local currency. This effect will mitigate the fall of capital stocks – by lowering the cost of investment (which is characterized by a relatively high import-intensity in Poland). Negative productivity shock and the decrease of aggregate capital stock make the real GDP fall by – on average – 0.80%. Energy prices increase by 9.47% (GDP deflator being constant, as a numeraire), while energy sector output falls by 2.04%, on average.

Simulation 2 shows the impact of decreasing the effective rates of taxes on products by 10%, while keeping government expenditure unchanged. The increased household demand stimulates output growth, requiring capital expansion (aggregate labor input is held fixed). The expansion is mitigated by the increase in production costs and terms of trade deterioration (real depreciation), making investment costs rise. The mean response of aggregate capital stock is 0.88%, and the resulting GDP increase equals 0.50%. The analyzed policy change would diminish government revenues from taxes on products by 8.62%, on average, and the total tax revenues – by 4.17%.

In *simulation 3* we assume a vertical downward shift in foreign demand schedules, such that the pre-shock quantity of goods would be exported only if the prices decreased by 5%. Such an effect can be attributed for example to an increase in import taxes paid abroad. An immediate result is the terms of trade deterioration, and real depreciation (by 6.53%, on average), necessary to preserve the original (nominal) balance of payments to GDP ratio. The increased costs dampen investment, which reduces capital stocks (by 2.80%, on average), and, as a consequence, the GDP (by 1.67%, on average). On the absorption side, it is mainly consumption and fixed capital formation that decline (by 3.21% and 2.94%, respectively), while exports volume decrease is moderate (1.5%, on average). Import volume drops by as much as 6.16% (on average), both due to constrained activity and substitution towards cheaper domestic products.

Tables 1–3 report absolute values of coefficients of variation (*V*) for percentage changes of endogenous variables invoked by exogenous shocks (different responses being a result of using different calibration databases). The main finding is that the results *may* be significantly sensitive to the calibration data set in use. At the same time, this need not always be the case.

In further considerations we use a coefficient of variation value of 25% as a convenient cut-off point between the ”low” and the ”high” dispersion of simulation results. In our specific sample of results a coefficient of variation greater than 25% implies that the strongest response found for a given variable is more than twice the magnitude of the weakest response.

One cannot identify variables with inherently large or small uncertainty. The scale of uncertainty crucially depends on the type of simulation experiment. The relatively highest variation of results is found in simulation 3 (the decrease in foreign demand). For 5 out of 8 reported variables, representing aggregate volumes, the coefficient of variation exceeded 25%, thus marking a considerable degree of dispersion. In the case of real tax revenues, the direction of response to the shift in foreign demand schedules is ambiguous (variation coefficients for revenues from taxes on products and total tax revenues are 182.6% and 86.6%, respectively). On the contrary, in the tax cut simulation the response of tax revenues is among the most robust results – for total tax revenues the coefficient of variation is 9.0%, while for the revenues from taxes on products – only 1.7%. In simulation 1 the sign change was found for aggregate investment reaction. Also the change in aggregate capital – although unequivocally positive – is quite sensitive to the choice of calibration database. However, in the case of 5 out of 8 aggregate volumes distinguished, the dispersion is well below 25%. Responses of aggregate prices in general appear slightly more robust than those of volumes.

Table 1.

Results for aggregates*

Variable	Simulation 1			Simulation 2			Simulation 3		
	M	*V*	*V'*	*M*	*V*	*V'*	*M*	*V*	*V'*
VOLUMES:									
GDP	-0.80	11.9	6.9	0.50	16.8	8.8	-1.67	32.3	7.4
Consumption	-0.97	5.4	5.2	0.25	45.0	23.8	-3.21	19.4	6.5
Fixed capital formation	0.20	131.3	38.5	0.92	10.2	9.5	-2.94	23.7	7.1
Exports	-0.69	15.0	7.8	0.92	7.2	6.1	-1.50	35.6	18.0
Imports	-0.46	14.5	7.4	0.49	18.5	11.1	-6.16	5.2	1.9
Capital	-0.24	41.8	21.7	0.88	10.3	9.2	-2.80	26.0	6.4
Total tax revenues	-0.51	12.7	7.2	-4.17	9.0	6.1	-0.56	86.6	20.2
Revenues from taxes on products	-0.57	30.3	12.1	-8.62	1.7	0.4	-0.33	182.6	43.0
PRICES:									
GNE	-0.06	19.6	4.9	0.10	17.9	17.4	1.54	9.6	7.1
Household consumption	0.14	12.0	10.8	-0.37	11.6	8.0	1.82	9.1	6.5
Consumption of non-profit institutions	-0.25	24.5	11.7	1.10	14.2	11.8	-0.08	190.7	184.6
Government consumption	-0.52	9.2	9.1	1.42	10.7	7.4	-1.12	17.4	17.4
Fixed capital formation	-0.27	14.6	11.2	0.38	12.1	11.9	2.86	14.3	6.5
Exports	-0.17	15.8	12.4	0.75	5.4	4.5	1.58	26.2	6.6
Imports	-0.34	13.9	8.5	0.98	4.7	4.5	6.53	4.8	1.6
Capital	-0.27	14.6	11.2	0.38	12.1	11.9	2.86	14.3	6.5
Labour	-1.22	16.9	9.7	2.30	7.1	6.7	-3.94	27.4	8.4
Real exchange rate	-0.34	13.9	8.5	0.98	4.7	4.5	6.53	4.8	1.6
Terms of trade	0.17	14.7	7.8	-0.23	7.1	6.1	-4.65	2.7	1.4

* *M* – mean response to a shock (in %), *V* – coefficient of variation (absolute value, in percentage points), *V′* – coefficient of variation after excluding trend (absolute value, in percentage points).

Table 2.

Results for commodity outputs*

Products and services	Simulation 1			Simulation 2			Simulation 3		
	M	*V*	*V’*	*M*	*V*	*V’*	*M*	*V*	*V’*
Agriculture, forestry and fishing products	-0.83	5.7	4.7	0.46	12.6	12.0	-1.24	43.4	15.3
Coal and peat	-1.34	31.6	15.1	0.13	112.7	51.9	0.63	35.6	35.2
Oil, gas and ores	-1.56	61.4	29.9	0.38	94.2	57.5	6.79	37.7	16.4
Food and tobacco	-0.42	14.5	9.4	0.61	15.4	8.8	0.10	127.5	89.3
Textiles and wearing	-0.58	16.1	12.9	0.49	16.3	11.0	-1.30	64.5	30.0
Refined petroleum products	-0.88	10.4	8.7	1.68	7.4	5.9	-2.41	21.7	13.1
Chemicals and metals, metal products	-0.97	24.7	10.8	0.79	13.4	12.9	0.17	366.9	157.5
Machinery and equipment	-0.37	21.2	12.3	0.58	11.6	11.2	0.39	203.0	80.4
Transport equipment	-0.53	16.4	15.7	1.04	13.7	13.3	-0.81	189.3	56.8
Other products	-0.59	15.5	13.6	0.67	15.9	8.2	-0.17	102.3	69.6
Electricity, gas and water supply	-2.04	14.3	4.0	0.39	33.2	13.0	-1.13	28.1	10.8
Construction services	-0.31	82.8	22.4	0.67	14.5	13.7	-2.67	24.0	8.1
Trade services	-0.64	12.0	5.2	0.56	15.7	7.7	-1.93	35.6	7.7
Transport and telecommunication	-1.08	9.4	9.4	0.63	41.9	15.3	-1.94	40.9	16.3
Financial, real-estate and business services	-0.83	8.2	7.8	0.34	13.4	11.9	-1.35	26.6	10.5
Public administration and defense	-0.95	5.7	5.1	0.26	46.0	23.6	-3.04	17.4	8.3
Education and health services	-1.07	7.1	4.7	0.02	555.1	413.3	-3.19	16.5	7.0
Other services	-0.74	8.7	8.5	0.20	71.4	10.8	-1.76	31.3	11.0

* *M* – mean response to a shock (in %), *V* – coefficient of variation (absolute value, in percentage points), *V′* – coefficient of variation after excluding trend (absolute value, in percentage points).

Table 3.

Results for commodity prices*

Products and services	Simulation 1			Simulation 2			Simulation 3		
	M	*V*	V’	M	V	V’	M	V	V’
Agriculture, forestry and fishing products	-0.14	34.9	26.6	0.48	6.9	6.7	1.88	11.3	8.4
Coal and peat	-0.55	20.6	15.8	1.43	6.6	5.2	-0.98	35.6	29.6
Oil, gas and ores	0.11	438.7	260.1	1.37	9.9	7.6	-0.91	180.3	68.8
Food and tobacco	-0.22	25.6	24.6	0.56	6.2	6.1	1.29	11.6	9.4
Textiles and wearing	-0.28	13.5	10.3	1.06	5.9	5.1	1.01	44.1	14.2
Refined petroleum products	-0.32	33.6	24.5	0.52	36.3	26.8	3.35	10.5	9.8
Chemicals and metals, metal products	-0.03	188.7	109.5	0.79	8.9	8.3	1.60	24.6	7.6
Machinery and equipment	-0.28	21.0	14.6	0.94	6.2	5.9	1.43	28.1	7.0
Transport equipment	-0.17	47.5	27.7	0.79	2.8	2.7	2.23	23.4	9.3
Other products	-0.21	31.5	25.7	0.82	7.4	6.4	1.31	18.1	6.8
Electricity, gas and water supply	9.47	3.4	3.3	0.85	9.7	9.6	0.84	19.1	9.4
Construction services	-0.32	13.5	11.4	0.77	7.1	4.6	1.32	19.0	7.6
Trade services	-0.25	29.4	10.5	0.63	5.3	5.3	1.40	7.0	6.8
Transport and telecommunication	-0.25	16.4	8.5	0.67	26.1	9.1	0.85	34.3	12.8
Financial, real-estate and business services	0.18	70.4	45.7	0.77	13.4	5.9	1.00	25.8	7.6
Public administration and defense	-0.61	17.4	9.6	1.48	9.0	7.5	-1.30	19.4	15.8
Education and health services	-0.60	11.6	11.4	1.63	7.4	6.1	-1.76	15.9	10.4
Other services	-0.12	42.3	17.0	0.84	17.2	11.0	0.61	39.7	28.3

* *M* – mean response to a shock (in %), *V* – coefficient of variation (absolute value, in percentage points), *V′* – coefficient of variation after excluding trend (absolute value, in percentage points).

As expected, the problem of sensitivity of results is more serious for sectoral than for aggregate variables. Especially the results of simulation 3 are a concern – the direction of output response to the foreign demand shock is ambiguous for 5 out of 18 sectors. In total, for 14 sectors the coefficient of variation exceeds 25%. In simulation 2 the number of sectoral output reactions with ambiguous direction is four, while in simulation 1 – two (the number of coefficients of variation exceeding 25% equals 7 and 3, respectively). Only in simulation 1 the dispersion of commodity prices' reactions is larger than that of outputs – with sign ambiguities for 3 sectors, and variation coefficient exceeding 25% for 10 sectors. In simulation 2 and 3 price responses are more robust than output responses.

A more optimistic picture of results' robustness emerges when we notice that for most variables the responses to exogenous shocks change systematically when the model is calibrated to data for subsequent years. These data carry information about the changing structure of the economy (section 4 explains more closely what aspects of this structure are taken into account), reflected in the model's calibrated – share – parameters. Therefore, systematic changes in the reported results indicate that the underlying structural change is also in some way (partly) systematic, and – to that extent – it can perhaps be subject to formalized description and prediction. Contrary to that, irregular changes in simulation results (over subsequent datasets used to calibrate share parameters) point to the more erratic part of structural changes. In order to roughly assess contributions of the systematic and the irregular components of structural change, we estimate linear "trend" for each variable's responses to the analyzed shocks[4].

In tables 1–3 *V'* represents coefficients of variation of simulation results after excluding the linear "trend" component. In most cases there is a substantial reduction of response variation after "trend" removal. Coefficients of variation for aggregate variables decrease, on average, by 39%, 22% and 55% in simulations 1, 2 and 3, respectively. The respective reductions for sectoral variables (including both output and prices) are 31%, 26%, and 49% (worth noticing, the largest variation reduction concerns the simulation with the largest volatility of endogenous variable responses – simulation 3). The above outcome shows that much part of the changes in the structure of the economy, as represented by calibration databases, can be considered in a way systematic. This implies that to improve reliability of simulation results, based on a static CGE model, one should consider updating (forecasting) calibration

[4] This can be formalized as follows: $y_i^{(t)} = \alpha_i + \beta_i \cdot t + \varepsilon_i$, where $y_i^{(t)}$ is the response (percentage change) of the i^{th} variable (i iterates over a set of all variables reported in this study) in a simulation experiment, in which the share parameters were calibrated to data from year t; α and β are the parameters (estimated using OLS), and ε is the error term. The "trend" removal amounts to the following calculation $\hat{\varepsilon}_i = y_i^{(t)} - \hat{\alpha}_i - \hat{\beta}_i \cdot t$, where $\hat{\varepsilon}$ is interpreted as the (estimated) non-systematic part of simulation results variation across alternative parametrizations of the CGE model. The term "trend" is put in quotation marks here, since it does not refer to any observable quantity, but to modeling outcomes.

databases, in order to account for changes in the economy's structure (this is in line with the findings of Dixon, Rimmer, 2002, p. 4, that in dynamic CGE modeling the baseline forecasts can significantly affect policy simulation results). Such a conclusion at least holds for Poland – an emerging economy. "Trends" in simulation results may suggest that even the use of simple techniques is potentially beneficial.

4. CONTRIBUTIONS TO RESULTS VARIATION

As a next step, we assessed relative importance of different parameter groups in generating the variation of results. The following groups of calibrated (share) parameters were separated:

(A) Macro structure of final demand (shares of final demand aggregates in total final demand);
(B) Commodity structure of final demand;
(C) Import intensities of supply of commodities (import shares);
(D) Capital and labor cost shares in value added;
(E) Value added shares in gross output;
(F) Structures of intermediate inputs (produced inputs' cost shares);
(G) Trade and transport margin rates;
(H) Rates of taxes on products;
(I) Income distribution structures;
(J) Frisch coefficient;
(K) Structure of the make matrix.

The term "income distribution structures" refers to parameters of the equations showing how value added is transformed into disposable income of institutional sectors (incl. households and government). Those parameters are mostly ratios or shares – for example the households' share in total gross operating surplus in the economy. The Frisch parameter is the negative of the reciprocal of the share of discretionary expenditure in total household consumption (Dixon, Rimmer, 2002, p. 171–173). By the "structure of the make matrix" we mean shares of various products in a given industry's output. All of the parameters (shares and ratios) listed above are based on nominal values.

We adopted the following procedure for the calculations. First, a series of simulations is performed with parameters from group (A) varying (derived from databases for subsequent years between 1996 and 2005), all other parameters being constant (derived from the 2000 database). After that we are able to calculate the variance of endogenous variables' responses to a given shock, *due to variation of parameters belonging to the (A) group*. The same is next repeated for the remaining parameter groups. In this way we obtain variances of simulation results attributed to the variation of different parameter categories. The whole procedure is repeated for each of the three simulation experiments considered.

Table 4.

Ranks of parameter groups as sources of results variation

Sources		Simulation					
		1		2		3	
		macro	sectoral	macro	sectoral	macro	sectoral
(A)	Macro structure of final demand	4	2	27	13	4	3
(B)	Commodity structure of final demand	17	15	16	18	14	8
(C)	Import shares	2	1	1	1	29	18
(D)	Capital/labour cost shares	15	9	22	26	39	46
(E)	Value added shares in gross output	14	16	2	5	6	11
(F)	Intermediate input structures	30	40	2	8	5	10
(G)	Margin rates	0	1	2	2	1	2
(H)	Rates of taxes on products	8	1	22	24	1	0
(I)	Income distribution structures	2	0	4	0	0	0
(J)	Frisch coefficient	0	1	2	1	0	0
(K)	Make matrix structure	7	13	0	1	1	2

It is noteworthy that modifying a single group of share parameters leads to an imbalance in the benchmark equilibrium data (e.g. if we impose 1996 shares of final demand aggregates on 2000 input-output flows table). Therefore at each step original flow data are re-balanced such that consistency with the desired full set of share parameters is achieved.

Partial variances resulting from the procedure described above do not sum up to the ones reported in section 3, i.e. those obtained when all parameters vary jointly. One reason is that the CGE model is non-linear. Another one is that parameter changes in time might be correlated between parameter groups. Thus, what we perform is not literally a decomposition (which is the case in global sensitivity analysis – see Saltelli et al., 2008). Nevertheless, we find it useful to rank the importance of different parameters in generating the variation of the results by adding up variances related to individual parameter groups and calculating their shares in that total. This is done for each endogenous variable of interest (i.e. for all variables listed in tables

1–3). Averages of the shares described above, calculated separately for aggregate and sectoral variables, are reported in table 4.

Looking at the results, there are only two parameter groups – namely the commodity structures of final demand (B) and the shares of capital and labor compensation in the value added (D) – which play important (although not necessarily dominant) roles in all simulation experiments, as factors contributing to the results variation. There are also parameters – including margin rates (G), income distribution structures (I), and the Frisch coefficient (J) – that proved irrelevant from the same point of view. Most importantly, however, the relevance of a given parameter group as an uncertainty source crucially depends on the shock being simulated.

For example, in simulation 1 (negative supply shock in the energy sector) the dispersion of results is driven mainly by the changing structures of intermediate inputs (F). These relate to changes in both the energy-intensity of production, as well as changes in the input composition in the energy sector itself.[5] These changes are of much smaller importance for the results of the other two experiments. In simulation 2 (tax cut), there are four parameter groups with similar contributions to the dispersion of the results – the (initial) rates of indirect taxes (H), capital and labor cost shares (D), as well as macro and micro composition of final demand (A & B). The first of the mentioned factors plays practically no role in simulations 1 & 3. The main sources of uncertainty in simulation 3 relate mainly to capital and labor cost shares (D) and import intensities of supply (C). Dispersion of sectoral and aggregate results is largely driven by the same factors, although there are certain differences in the actual contributions.

We can conclude that in order to improve the reliability of simulation results for a given policy (or other) question, one could focus on a narrow set of parameters only. Sensitivity analysis of the kind presented above could help identify those parameters (and model mechanisms) that generate a significant part of uncertainty about the simulation outcomes.

5. CONCLUDING REMARKS

It is a typical situation that a (static) CGE model is calibrated to a database that represents structural information which is not quite up-to-date. We have asked, to what extent the changes in an economy's structure, as represented by the input-output data, affect CGE simulation results. The analysis involved model calibration to the Polish data for subsequent years of the period 1996–2005, and running three distinct simulation experiments under the different parameterizations (under a long run-closure).

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[5] Since what we can derive from our database is changes in cost shares only (i.e. changes in input structures in nominal terms), the dispersion of outcomes might as well be related to changes in relative prices of different inputs – e.g. being a consequence of changes in the world prices of energy resources.

The robustness of results to changes of calibration database (i.e. to the underlying structural changes) has shown to be dependent on the analyzed shock. Also, the responses of different endogenous variables to the shocks are characterized by quite different scales of dispersion within a given experiment. Hardly any regularity can be identified when analyzing the ”distribution” of uncertainty among the variables. In general, sectoral results are more sensitive than aggregate results, and volumes are usually more sensitive than prices.

Although in a majority of cases (under the three analyzed experiments) the dispersion of simulation outcomes was in an acceptable range, there was also a number of cases where robust inference was not possible, including the cases of ambiguity of the direction of a variable's response (especially with respect to sectoral variables). Thus, presuming that lagged data provide a good proxy for the current or near-future economic structure might be a potentially risky practice, at least for emerging economies, which undergo substantial restructuring. A proposed approach is to perform a thorough sensitivity analysis in order to identify uncertainty sources. As our analysis suggests, these sources confine to a subset of parameters – what subset, however, being again strictly dependent on the shock in question.

A promising finding is that when calibrating the model subsequently to the databases for consecutive years, the results – responses of endogenous variables to the imposed shocks – reveal pronounced trends. This indicates that the changes in the economic structures are in a way systematic, and thus utilizing the information inherent in the time series of calibration (benchmark equilibrium) datasets is likely to bring parameter updates improving the reliability of results.

University of Lodz

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ODPORNOŚĆ WYNIKÓW SYMULACJI NA PODSTAWIE MODELU CGE W WARUNKACH ZMIAN STRUKTURALNYCH W GOSPODARCE – PRZYPADEK POLSKI

Streszczenie

Typowym sposobem odniesienia się do problemu niepewności wyników symulacji na podstawie modeli CGE (*Computable General Equilibrium*) jest analiza wrażliwości. Większość prac poświęconych temu zagadnieniu koncentruje się na kwestii wyboru wartości różnego rodzaju elastyczności. W niniejszej pracy podejmujemy analizę wrażliwości dotyczącą parametrów opisujących strukturę gospodarki, uzyskiwanych w drodze kalibracji. Do kalibracji modelu używamy zestawów danych za kolejne lata z okresu 1996-2005, a następnie analizujemy rozrzut wyników dla trzech różnych eksperymentów symulacyjnych.

Wyniki dla części – choć nie większości – zmiennych charakteryzują się znaczącą wrażliwością na wybór bazy danych wykorzystanej do kalibracji (włączając niepewność co do kierunku reakcji). Stopień rozrzutu wyników i jego źródła istotnie zależą od rodzaju analizowanego scenariusza symulacyjnego. Skala niepewności dotyczącej poszczególnych zmiennych jest również zróżnicowana. Zaleca się zatem, aby gruntowna analiza wrażliwości była standardową częścią badania symulacyjnego. Ponadto zastosowanie nawet prostych (np. opartych na analizie trendów) metod aktualizacji bazy danych mogłoby najprawdopodobniej zwiększyć wiarygodność wyników, biorąc pod uwagę, że reakcje zmiennych endogenicznych na zadawane w symulacjach impulsy podlegają systematycznym zmianom, gdy model kalibrowany jest do danych z kolejnych lat.

Słowa kluczowe: modele CGE (*Computable General Equilibrium*), analiza wrażliwości, kalibracja

ROBUSTNESS OF CGE SIMULATION RESULTS IN THE CONTEXT OF STRUCTURAL CHANGES – THE CASE OF POLAND

Abstract

It is common to address the problem of uncertainty in computable general equilibrium modeling by sensitivity analysis. The relevant studies of the effects of parameter uncertainty usually focus on various elasticity parameters. In this paper we undertake sensitivity analysis with respect to the parameters derived from calibration to a benchmark data set, describing the structure of the economy. We use a time series of benchmark databases for the years 1996-2005 for Poland to sequentially calibrate a static CGE model, and examine the dispersion of endogenous variables' responses in three distinct simulation experiments.

We find a part – though not the most – of the results to be significantly sensitive to the choice of calibration database (including ambiguities about the direction of response). The dispersion of the results and its sources clearly depend on the shock in question. Uncertainty is also quite diverse between variables. It is thus recommended that a thorough parametric sensitivity analysis be a conventional part of a simulation study. Also, the reliability of results would likely benefit even from simple, trend-based updates of the benchmark data, as the responses of endogenous variables exhibit systematic changes, observed when the model is calibrated to the data for consecutive years.

Keywords: computable general equilibrium (CGE) modeling, sensitivity analysis, calibration