THE CGE MODELS PARAMETERS ESTIMATIONS TECHNIQUES[1]

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Techniky odhadov parametrov CGE modelov

Abstract: *The paper presents four different techniques of the computable general equilibrium model parameters estimations: calibration, an econometric approach, a maximum entropy approach, and the Bayesian cross-entropy approach. Each method is shortly introduced, and the advantages and disadvantages of each of them are discussed. It is shown that it is possible to work on with the CGE models in situations with scarce or noisy data, which is the case of developing countries.*

Keywords: *computable general equilibrium model, calibration, econometric estimation*

JEL Classification: C 68, C 82

1 Introduction

A Computable General Equilibrium (CGE) model is a macroeconomic model based on the microeconomic principles used mainly to simulate economic policies, international trade or environmental changes. The model consists of behavioural equations and identities and makes up together a system of simultaneous equations model with some equations non-linear even non-linear in parameters. An analytical structure of the model is based on the economic fundamentals identifying the variables and their casual relations. A functional structure is therefore a mathematical representation of the analytical structure; it consists of the algebraic equations of the model. Finally, the numerical structure means the parameters signs and magnitudes in the functional form of the model [11]. The aim of this paper is to describe almost all accessible methods of parameters estimation in the manner of same notation,

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discuss them and show the positives and negatives of each of them.

The commonly used approach to get the values of the model parameters is the procedure of calibration that is based on the one-year dataset represented by the Social Accounting Matrix (SAM). In this method, some values of the parameters are set according to the literature and previous survey; some are set according to the economic theory or economic policy in the modelled country and the rest of the parameters are set such that the values used in the model replicate the data of the benchmark year [15].

In the nineties, most economists argued that the parameters of CGE models are almost impossible to estimate by econometric methods, and that this method deprives the economic structure of the model. Mansur and Whalley [10] in 1981 stated: "Available data do not typically allow one to estimate CGE models econometrically, and so calibration procedures are used to obtain models that can be simulated." Despite that, Jorgenson [7] in 1984 was the most eager critic of the calibration and used the econometric estimation. Also in works of Lau [8], Diewert and Lawrence [4] the calibration has been criticized on several grounds. In 1998 McKitrick [11] proves that many years after the initial literature the calibration method is still almost always used. Later, in 2001 Arndt, Robinson and Tarp [1] quote that with the rising popularity of the CGE models they are criticized for weak empirical foundations, particularly for estimates of behavioural parameters. Braker [2] in 2004 blames the CGE calibration for ignoring the availability of rich sources of time-series data, if available, and do not model the long-term processes, adjustment to price changes or technological change. Scrieciu [14] names the calibration as mathematical manipulation and his econometric critique is based on the fact that the calibration year, typically the latest with available data, may misrepresent the modelled economy in invalidate even short term forecast since the information about the historical trends is ignored. On the other hand, the calibration, expert estimates of parameter values taken from other sources of literature enable abundant structure of the model with stochastic and non-linear equations incorporated. Some authors concerned to demonstrate that a particular method is the best way to obtain the values of the parameters; some compared the traditional calibration with econometric estimation or newer methods as the maximum entropy approach by Arndt, Robinson and Tarp [1] and the Bayesian cross-entropy approach by Go, Lofgren, Ramos and Robinson [6].

The work of Benčík [3] was the first in the field of Slovak economy CGE modelling. The calibration was used to estimate the whole set of parameters. Mlynarovič [12] describes the calibration procedure as the base for the CGE modelling. The methodology described in [12] was used in [13] in the CGE model application used to quantify assets and costs of Slovak Republic's admission to the European Union. The econometric approach used for the CGE model parameters estimation was used in [9]. Authors estimated the values of the CES production function of the Slovak economy by the OLS method.

2 Calibration

McKitrick [11] in his research focused on question whether "the Walrasian general equilibrium framework imposes enough constraints on the range of possible results from a CGE policy experiment to render the choice of functional forms and parameter values irrelevant." He concluded that the calibration approach is dependent on non-flexible functional forms. The functional forms in the CES class impose restrictions, which are frequently rejected in formal tests. According his results the use of flexible functional forms is preferred in the empirical modelling.

In this section there is described the calibration procedure of the CGE model parameters according Mansur and Whalley [10][3]. The CGE model may be written as

$$\mathbf{f}\left(\mathbf{X}_t, \mathbf{Z}_t, \boldsymbol{\beta}\right) = \mathbf{q}_t \quad t = 1,2,\ldots,T \tag{1}$$

where $\mathbf{X}_t$ is a vector of endogenous variables, $\mathbf{Z}_t$ a vector of exogenous data, $\boldsymbol{\beta}$ a vector of unknown parameters and $\mathbf{q}_t$ the net demand for quantity at time *t*. The procedure may be shortly summarized in five steps: 1) At the beginning choose a base year (denoted *t*'). 2). Adjust the demand for quantity using a numerical algorithm (such as row-and column scaling – RAS method, described in [17]), if needed. 3) Separate the vector $\boldsymbol{\beta}$ into vector of observed parameters $\boldsymbol{\beta}^o$ which usually contains the elasticity values and vector of unobserved parameters $\boldsymbol{\beta}^u$ which contains remaining scale or shift parameters. 4) Use the literature sources and other a priori methods to set the values of $\boldsymbol{\beta}^o$ and determine each element of $\boldsymbol{\beta}^u$ to yield

$$\boldsymbol{\beta}^u = \mathbf{f}^{-1}\left(\mathbf{X}_t, \mathbf{Z}_t, \boldsymbol{\beta}^o, \mathbf{q}_t\right) \quad t = 1,2,\ldots,T \tag{2}$$

5) The solution of the model is then

$$\mathbf{f}\left(\mathbf{X}_t, \mathbf{Z}_t, \boldsymbol{\beta}^o\right) = \mathbf{q}_{t'} \tag{3}$$

According to a Walras' law the system ensures the valid CGE general equilibrium [10].The main advantage of this method is that it uses spot data of one year which is independently selected by the model user. The base year is usually chosen for the time period with the most available data and moreover to ensure the stability requirement. From the technical point of view, the use of the method is modest.

The values of the elasticities are often used for commodity or industry classifications inconsistent with those in the model in sense of they are often only distantly related to the case studied, coming from different countries or time periods than the object of the research. There may be used obsolete estimates from past literature even outright guesses when no published figures are available. McKitrick [11]quotes that "These expediencies detract from the ability of the model to represent the tech-

3 The notation was changed towards the original to achieve consistency with the other methods of estimation in this paper.

nology and tastes of the economy under study."

It is a well-known fact that the quality of the model is dependent on the quality of the data. This is especially true for the CGE model if a benchmark year is arbitrarily chosen. There may be found stochastic anomalies or uncommon economic situations in any one year used for a calibration. In addition, almost always there is a need to go through various scaling processes to force consistency of the SAM, which introduces sometimes untraceable biases into the rows and columns [11].

McKitrick [11] states that "The calibration approach tends to limit the researcher to the use of first-order functional forms (those in the constant elasticity of substitution class). Those functions embody restrictive assumptions about the structure of the modelled economy. Lau [8] suggests determining in average only one parameter per equation by the calibrated model. Despite these facts, the calibration is the most commonly used approach in the CGE modelling.

3 The Econometric Approach

In the econometric approach the benchmark data are computed by the general equilibrium model itself. The method treats the entire time series data as the benchmark, rather than one arbitrarily chosen year. The econometric approach by Jorgenson [7][4] may be simply summarised as

$$\mathbf{f}\left(\mathbf{X}_t, \mathbf{Z}_t, \boldsymbol{\beta}\right) + \boldsymbol{\varepsilon}_t = \mathbf{q}_t \quad t = 1,2,\ldots,T \tag{4}$$

The full time series of T observations are needed. The statistical estimation gives $\hat{\boldsymbol{\beta}}$. The base-case solution for some time period consists of the price vector **X**' at which is satisfied, yielding

$$\mathbf{f}\left(\mathbf{X}_t', \mathbf{Z}_t, \hat{\boldsymbol{\beta}}\right) = \mathbf{q}_t \quad t = 1,2,\ldots,T \tag{5}$$

Although the econometric approach has many positives it is difficult to carry them out. Here are suggestions how to carry them out: General equilibrium constraints: Even there are special econometric methods designed to feed parameter estimates in the CGE models [7] and the estimated parameters may describe the behaviour of agents well; they are not fully compatible with the general equilibrium system since the full set of general equilibrium constraints are often not imposed [1]. As an alternative approach may be used simple "validation" procedure – the model run forward over a historical period and the results for some variables are compared. They provide a basis for revising selected parameters and recalibrating the model, see [5]. However, the approach provides no statistical basis for evaluation of robustness of parameters.

Data accessibility: For an econometric estimation is needed a time series dataset,

4 The notation was again changed towards the original to achieve consistency with the other methods of estimation in this paper.

usually collected in a series of social accounting matrices. There is a problem with poorly constructed SAMs in the developing countries with missing, incomplete, uncertain data. Those working with on developed countries may face problems too because of carrying out more data-demanding analysis. On the other hand, a new dataset for previous years provides new information and it improves the estimation of parameters of a CGE model, which were based on scattered data and theoretical properties. Of course, the more data, the more reliable the estimates for structural parameters are. Moreover, the econometric estimates are almost based on annual data, thus the elasticities obtained are short run and may understate the responsiveness of agents in the model over longer time period (usually three or five years in the CGE model) [1].

The stability of the parameters: Working with the time series one can notice the changing values of the aggregates and hence changing shares of some parameters during the selected time period due to structural chances, which in fact leads to instability of estimated parameters. Go, Lofgren, Ramos and Robinson [6] propose a solution: Based on the data of one-year SAM, a priori parameters (i.e. trade elasticities) used in the structure of the economy (such as trade shares) are replicated. With more SAMs it not only the posterior estimates of the parameters (i.e. trade elasticities) may be improved but it also may be checked if the trade structure is changing (may be seen in rising elasticities or trade shares). For the econometric estimation numerous behavioural parameters are needed of long term data series to achieve sufficient degree of freedom.

Real values: SAMs are usually expressed in nominal values and information about relative prices may be limited. According to [6] the scattered information on relative prices and factor accumulation quantities are used to get the real SAMs. With each new real SAM, it is checked whether the estimates of the parameters converge to new values and if they are stable, with no trends.

4 The Maximum Entropy Method

The maximum entropy approach is another available method used for the CGE model parameters estimation. This principle together with the minimum cross-entropy is used to estimate and make inferences in cases the data is incomplete, noisy or inconsistent. It uses all available information on the one hand and does not assume any information we do not have, on the other hand.

The method needs to be specified prior distributions of parameters, than the objective function has two terms: the "precision" which accounts for deviations of the parameters from the prior and the "prediction" which accounts for differences between predicted and real values of variables. This clearly leads to two goals: estimate a parameter values such that closely fit the data and such that are close to their priors. It is possible to weight between the two terms in the objective function and finally we get "an estimation framework that supports the use of information in many forms and with varying degrees of confidence."[1]

Let's start with a static CGE model as was originally formulated in Arndt, Robinson and Tarp [1]:

$$\mathbf{f}(\mathbf{X},\mathbf{Z},\mathbf{B},\boldsymbol{\delta}) = 0 \tag{6}$$

where **f** is a vector valued function with parameters, **X** is a vector of endogenous variables, **Z** is a vector of exogenous variables ($Z^0$for observable, Z^u for unobservable from the historical data), **B** isa vector of behavioural parameters and **δ** is second vector of behavioural parameters whose values are uniquely implied by choice of **B**, the exact form of **f** and data for the base year. In the entropy formulation the static model follows the time period t = 1, 2, ..., T, the model is calibrated to a base year noted as t'. The estimated CGE model can be written as

$$\mathbf{f}\left(\mathbf{X}_t, \mathbf{Z}_t^o, \mathbf{Z}_t^u, \mathbf{B}, \boldsymbol{\delta}\right) = 0 \quad t = 1,2,\dots,T \tag{7}$$

A solution is a “series of solves” tracing a time path which can be compared with a historic time path for key variables:

$$\mathbf{Y}_t = \mathbf{g}\left(\mathbf{X}_t, \mathbf{Z}_t^o, \mathbf{Z}_t^u, \mathbf{B}, \boldsymbol{\delta}\right) + \mathbf{e}_t \quad t = 1,2,\dots,T \tag{8}$$

where $\mathbf{Y}_t$ is a vector of historical targets, **g** is a function producing the vector of model predicted values for the targets, and $\mathbf{e}_t$ is a vector of discrepancy between historical targets and predicted values. Let $\mathbf{B}_k$ (k = 1, …, K) be a discrete random variable with compact support and 2 ≤ J ≤ ∞ possible outcomes:

$$\mathbf{B}_k = \sum_{m=1}^{M} p_{km} v_{km} \quad k = 1,2,\dots,K \tag{9}$$

where $p_{km}$is the probability of outcome v_{km}. Each element of $\mathbf{e}_t$ as a finite and discrete random variable with compact support and 2 ≤ J ≤ ∞ possible outcomes:

$$e_{tn} = \sum_{j=1}^{J} r_{tnj} w_{tnj} \quad t = 1,2,\dots,T, n = 1,2,\dots,N \tag{10}$$

where r_{tnj} is the probability of outcome w_{tnj}. The objective function in the cross-entropy is as follows with the non-uniform weights q and s. Each term (precision and prediction) may be weighted by a_1 and a_2.

$$\min_{p,r,Z_t^u} \left\{ \alpha_1 \sum_{k=1}^{K} \sum_{m=1}^{M} p_{km} \log \frac{p_{km}}{q_{km}} + \alpha_2 \sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{j=1}^{J} r_{tnj} \log \frac{r_{tnj}}{s_{tnj}} \right\} \tag{11}$$

subject to constraints stated in the original work of Arndt, Robinson and Tarp [1]. If the priors have unitary weights, the minimum cross-entropy becomes to the maximum entropy. In case where q_{km}=q and s_{tnj}=s we get

$$\max_{p,r,Z_t^u} \left\{ -\alpha_1 \sum_{k=1}^{K} \sum_{m=1}^{M} p_{km} \log p_{km} - \alpha_2 \sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{j=1}^{J} r_{tnj} \log r_{tnj} + K\alpha_1 \log g + T\alpha_2 \log s \right\} \tag{12}$$

The cross-entropy formulation in (12) minimizes the Kullback – Liebler measure of deviation of weights from the prior.

According to authors [1] this method combines the positives of the econometric approach and the calibration / validation process. From the point of view of econometrics, it uses the full historical data-set and provides statistical tests for estimated parameters. On the other side, the full model tracks the historical data and the maximum entropy can be applied in the absence of copious data. It “takes into account all relevant constraints, employs prior information about parameter values, and applies variable weights to alternative historical targets. Available information does not need to be complete or even internally consistent.”

As a complication may be the fact that the estimation problem is highly non-linear in parameters and a number of locally optimal solutions may exist. Founders of this approach state that in their empirical experiences the model converges to the same point over a range of initial values. Also, as the number of observations increases, the prediction term increasingly dominates pre precision term in the objective function such that the prediction becomes irrelevant. In case the information is scarce, the prior distributions on parameters are the only relevant ones. This approach targets only a subset of endogenous variables of the CGE model and was criticized by [6].

5 The Bayesian Cross-entropy Method

The cross-entropy method is defined as a three-step procedure according to Go, Lofgren, Ramos and Robinson [6]: a data step, a parameter estimation step, a statistical and validation step. It is appropriate for use in developing countries or those with noisy and scarce data. The parameters are treated as fixed but not observed, represented as prior mean values with prior error mass functions. The information-theoretic Bayesian approach is used for parameter values estimation. It uses a series of social accounting matrices to exploit additional information. The special attribute of this method is that uses all available information and makes no assumptions about unavailable data.

In the data step, the nominal SAMs from different years are deflated by price indices so that they are measured by the same base year prices. The nominal magnitudes are separated into their respective prices and quantities, than each cell is adjusted by the corresponding relative price index. After that, all individual SAM cells are expressed in equivalent real terms. The data step implements four practical procedures depending on the availability of data (relative prices, price indices, national accounts). For first, all cells in the historical SAMs are deflated by a single GDP deflator, so they are expressed in the base year prices. Afterwards, the cross-entropy estimation is applied to target known aggregates in constant prices (from the previous procedure) to rebalance the SAM to preserve these critical economic aggregates. The result of this step is a series of real SAMs that are consistent with the aggregates of national income accounts in constant prices.

The second one, parameter estimation step, uses the cross-entropy method to estimate the unseen parameters subject to the outputs (i.e. the real SAMs).The main idea of this method is that value of each parameter θ_i is not observed but can be expressed by its prior and an error term $\theta_i = \theta_i^o$. The error term has a prior error probability mass distribution. The estimation concerns on the posterior parameter values

$$\mathbf{\Theta} = f\left(\mathbf{f}(\cdot) = \mathbf{0}, \mathbf{Y}, \mathbf{V}, \mathbf{\Pi}(\varepsilon|\cdot)\right) \qquad (13)$$

Where $\mathbf{f}\left(\mathbf{X}_t, \mathbf{Z}_t^o, \mathbf{Z}_t^u, \mathbf{B}_t, \mathbf{\delta}_t\right) = \mathbf{0} \quad t = 1,2,\ldots,T$ are the specifications of the CGE model ($\mathbf{X}_t$ is a vector of endogenous variables, $\mathbf{Z}_t^o$ is the vector of observed exogenous variables, $\mathbf{Z}_t^u$ is the vector of unobserved exogenous variables; $\mathbf{B}_t$ is the vector of behavioural parameters and $\mathbf{\delta}_\mathbf{t}$ the vector of calibration parameters);$\mathbf{Y}$ are the SAM targets; $\mathbf{V}$ are the SAM data and $\mathbf{\Pi}(\varepsilon|\cdot)$ is the posterior error distribution, which is a conditional joint distribution of all error parameters. Again in this method, similarly as in [1], the precision and the prediction terms are used. The precision refers to the first two parts of the equation (14) and the prediction to the third one. In this concept, precision means the difference between the posterior and prior values of behavioural and structural parameters; the prediction is the difference between the estimated values of the targeted SAM cells and their prior values. "The objective function minimizes the sum of the Kullback – Leibler divergence of the prior and estimated probabilities, for all the discrete error distributions that characterize unobserved parameters and SAM targets." [6]

$$\min_{\{w,X_t\}} \left\{ \alpha_1 \sum_{t=1}^{T} \sum_{m=1}^{M} \sum_{k_m=1}^{K_m} w_{B,t,k_m} \ln\left(\frac{w_{B,t,k_m}}{\overline{w}_{B,t,k_m}}\right) + \alpha_2 \sum_{t=1}^{T} \sum_{s=1}^{S} \sum_{k_s=1}^{K_s} w_{Z,t,k_{sm}} \ln\left(\frac{w_{Z,t,k_s}}{\overline{w}_{Z,t,k_s}}\right) + \alpha_3 \sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{k_n=1}^{K_n} w_{Y,t,k_n} \ln\left(\frac{w_{Z,t,k_n}}{\overline{w}_{Y,t,k_n}}\right) \right\} \qquad (14)$$

subject to the constraints given by the model, which consists of the CGE block, the calibration block, the behavioural parameter (precision) block, the unobserved non-behavioural parameter (precision) block and the SAMs target (prediction) block. The vector of posterior error probabilities $\mathbf{w} = \left\{\mathbf{w_B}, \mathbf{w_Y}, \mathbf{w_Z}\right\}$ consists of the behavioural parameter, the SAM target and the non-behavioural parameters; the vector of prior probabilities is noted similarly $\overline{\mathbf{w}} = \left\{\overline{\mathbf{w}}_\mathbf{B}, \overline{\mathbf{w}}_\mathbf{Y}, \overline{\mathbf{w}}_\mathbf{Z}\right\}$. The prior values and the likelihood of probability may be taken from the theory, previous research, subjective or expert guesses. The full mathematical statement may be found in the original work of Go, Lofgren, Ramos and Robinson [6].The postulates about values are checked with the historical data in order to derive new estimates of the parameters and their likelihoods. On the basis of the model, data, initial guesses and likelihoods the method refines the calculation with posterior error distribution estimates. SAM targets are specific SAM cells selected such that adjust the system for convergence and closer represent a historical data. A maximum entropy approach by Arndt, Robinson and Tarp [1], in contrary, targets a subset of endogenous CGE variables as it was mentioned above.

The final step provides statistics measuring noise and information gains in recovered parameters as well as statistics that differentiate models through data validation measures. The pseudo R^2 statistics is calculated as

$$\hat{R}^2 = 1 - \hat{S}(\mathbf{w}) = \left(-\sum_{k=1}^{K} w_k \ln w_k\right) / \ln K \qquad (15)$$

where $\hat{S}(\mathbf{w})$ is the normalized entropy of the error terms. The statistics measures the noise generated by model: the smaller the statistics is the less noise is produced and then the best model-data fit. Since $\hat{S}(\mathbf{w}) = 0$ implies no uncertainty and $\hat{S}(\mathbf{w}) = 1$ total uncertainty, the $\hat{R}^2 = 0$ means that the system has total uncertainty while $\hat{R}^2 = 1$ total certainty on the posterior and prior error behaviour.

The cross-entropy approach in the estimation procedure uses all available information and makes no assumptions about unavailable information. Furthermore, the estimated parameters maintain consistency with microeconomic principles, the base of the general equilibrium in the CGE models. The main advantage of this method is that it seems to be ideal for CGE modelling where SAM is very limited. Since the method is developed only in the very near past, we can name the negative only as authors see it: There is a trade-off between the number of estimated parameters due to the degrees of freedom and data constraints.

6 Conclusion

Four different approaches to the estimation of the CGE model parameters were presented in the paper. The most often used and the oldest one is the calibration. It has many disputants proposing mostly econometric methods of estimation. On these principles are based also the entropy approaches presented here as maximum entropy method and the Bayesian cross entropy method. Each of the procedures has positives and negatives, and also it is not possible to state whether the use of one of them is better or not. The choice depends on the model user and data availability. In our next research, we focus on the econometric methods applied to the CGE model of the Slovak Republic.

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