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ANALYSIS OF FISCAL AND ENVIRONMENTAL POLICIES BY GENERAL EQUILIBRIUM MODELS

PH.D. THESIS

Concise English version

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1. Scope, background and the method of analysis

The thesis presents the current state of an almost twenty years old applied modelling activity in Hungary. It highlights the author's most recent contributions in the field. The selection of the topic is partly explained by the author's earlier interest and involvement in environmental modelling, partly by his conviction, that general equilibrium models provide the most practical tool for multisectoral economic policy analysis in a transition economy.

The candidate has been involved in environmental modelling already when he was still a student, he participated in an environmental modelling research team consisting of experts of economics, water management, ecology, forestry, futurology, mathematics and programming. After his graduation he took up a job in a different field (energy economics). Quite a few years later, however, the Harvard Institute for International Development (HIID) started a project in Hungary connected with environmental policy and the candidate participated in that environmental modelling work. By that time, he had been working with Professor Zalai, developing computable general equilibrium (CGE) models for Hungary, which due to their multisectoral, comprehensive and complex nature seemed suitable for incorporating gradually the various aspects of environmental policy issues. At the request of the HIID the research concentrated on the problem of air pollution. At that time the Hungarian government was considering the introduction of air load fees, partly as a consequence of the then rather intensive international negotiations which later resulted in the Kyoto-agreement. The subsequently developed environmental module and its various applications can be found in Revesz et al. 1999. This thesis presents of an extension of this model. The extension was primarily made by the generalization of the household utility (welfare) function, by the introduction of environmental quality into the traditional leisure-consumption choice framework. The policy scenarios of the thesis are also partly different from what can be found in the referred paper.

The first variants of the Hungarian CGE model, called HUMUS (Hungarian Multi-Sectoral) model, wereas developed in the early '80s, written in FORTRAN code. The generalized Newton algorithm, which was also designed in FORTRAN, however, proved to be rather restrictive in changing the model structure. The program required a block recursive structure, which was less and less possible to maintain as the model developed. Nevertheless, the FORTRAN version of the model was already capable for analysing the issues of foreign trade liberalization and reorientation, the elimination of the indirect subsidies, and the reallocation of fixed capital across sectors. This phase of the modelling is described in Revesz-Zalai, 1989b and Revesz-Zalai, 1993.

In the international CGE modelling practice the GAMS software gradually became the standard tool, which provides rather suitable and efficient solvers to find the solution of the system of nonlinear equations of the CGE models. Therefore, at the

beginning of the ‘90s, the candidate started to translate the HUMUS model to GAMS code. Naturally, this autodidactic trial and error approach required considerable amount of time, but finally a well-tested and transparent new model was developed. Due to the less restrictions on model structure and changes in the economic system the new model structure became considerably different and more flexible than the FORTRAN version used to be. The new GAMS version (subsequently called HUNGAMS or HUGE), and was applied successfully to various relevant policy issues like the impact of EU integration on the food economy, the impact of the 1995 stabilization package, and the impact of the changes in the tax system between 1991-1994. To describe the rather different impacts of economic transition on the individual social groups, the HUNGAMS model disagregated the household sector into 10 socio-economic groups. For this disagregation the authors two years research activity at the University of Cambridge served as a rather good basis (see Revesz, 1994 and Revesz, 1994b).
However, to make the model suitable for analysing economic impacts in (during transition sometimes fast) changing marcoeconomic policy regimes (exchange rate policy, budget deficit target, wage- and employment policy, etc.) the candidate developed a tool, by which the policy analyst can test the effects of different macroeconomic closures of the model. This was done in three phases: first, the theoretical-mathematical basis of the generalization was elaborated, then a convenient GAMS technique was designed to handle the problem efficiently, and finally a linear approximation technique was developed to test the behaviour of the model and to handle the even more general closure possibilities which are still not „wired-into” the GAMS program.

2. The structure of the thesis

Chapter 1 discusses the main characteristics of the CGE models and its role in economic policy analysis.
Chapter 2 presents the model structure with a special emphasis on the generalized production functions. Price formation, unusually detailed income distribution and the supply-demand determination is also discussed. The interested reader can find the complete English description of the model in Revesz et al. (1999b).
Chapter 3 begins with a survey of environmental CGE modelling literature. Then the development of the environmental module of the Hungarian CGE model is presented. As noted this also can be found in Revesz et al., 1999.
Chapter 4 deals with the generalization of the household welfare function with a special emphasis on the possible nesting structure of the three components of household utility, and on the non-optimal behavior of the households. It also discusses the possibility of the introduction of group-specific utility functions into the model.

Chapter 5 accounts the process of data compilation. It describes the considerations in choosing the benchmark-year, the transformation of the Input-Output table, the reconstruction of the income distribution and the household group specific income and expenditure data. This chapter also presents the various methods for adjusting the inconsistent data or estimating the missing data.

Chapter 6 illustrates the applicability of the environmental module and the generalized welfare function in economic policy analysis. The designed five scenarios contain different assumptions on macroeconomic closure (labor market, final demand determination, etc.) and different schemes for recycling emission or energy taxes. The chapter concludes that significant, but not necessarily of the EU-level, air load fees seem to be beneficial and highlights the trade-off possibilities between economic policy goals and the limits of the approach. It also points out in which area is more information essential for a reliable analysis.

Last but not least, Chapter 7 presents the linearization of the model closure and its application for Hungary. Within that section 7.4. discusses the characteristics of nine possible closures which were obtained by this approximation method.

3. The author's contribution

In an applied economic research it is rather difficult to separate out the new contribution of the author. Nevertheless, the linearization and generalization of the macroeconomic closure of the CGE model may well be a new approach even in thoretical sense. Other new elements in the thesis are the various first applications in Hungary, the systematized and full documentation of the model, the compilation of new databases, the original data-estimating methods, and the new economic policy applications.

In particular, the following novelties can be enumerated:

Although the HUNGAMS model is mostly based on the standard neoclassical CGE modelling approach, to address the special phenomena of the economic transition, it allows for the incorporation of various non-standard or non-equilibrium features.

INCORPORATION OF NON-EQUILIBRIUM MECHANISMS

CGE models usually assume profit-maximization or cost-minimization behavior. In certain cases, however, we allow for the non-optimality of the benchmark data. Concretely, we distinguish the (technical) elasticity of substitution and the (behavioral) price elasticity of the isoelastic demand function. In addition, the scaling parameter of the demand function can be determined independently from the share parameters and the technical elasticity of the CES-utility functions.

ELABORATION OF THE ENVIRONMENTAL MODULE

By adapting the environmental module used in a Greek model, emission of air pollutants was determined proportionately to combustion of fuels. We also assumed that the potential emission can be abated by various end-of pipe technologies. For the English reader, the construction and a standard application of the environmental module of the HUNGAMS model is properly described in Révész-Morris-Zalai-Fucskó (1999).
The own contribution of the candidate was the introduction of various recycling schemes of the environmental taxes, the introduction of emission limits, the endogenization of the emission tax rates, the introduction of endogenous energy tax rates and the incorporation of the environmental quality into the household welfare function.

EXTENSION OF THE HOUSEHOLD WELFARE FUNCTION

The neoclassical welfare function has two components: consumption and leisure. Aggregate consumption in turn is also a CES-aggregate of the individual consumption goods. Inclusion of environmental quality into this framework requires decisions about the assumed nesting structure of the 3 components in determining overall welfare. Based on the opinion of prominent environmental economists it was concluded that environmental quality is closely related to leisure, the quality of the latter depend heavily on the former and the length of the leisure time determines how important the residential environmental quality is. So in the first stage environmental quality and leisure is nested together, then their composite is aggregated with consumption to get the overall welfare level. However, some part of the consumption was accounted not as part of the aggregate consumption but as one of the components which determine environmental quality. The explanation for this approach is that these are goods (medicines, travel, etc.) directly, that substitute or compensate for worsening environmental quality.
The model can deal with the non-optimal behaviour of the households too. It means that of the 3 components 1, 2 or 3 may not satisfy its first order condition of optimality.

ELABORATION OF DETAILED INCOME-DISTRIBUTION MECHANISMS

The model’s income distribution block tracks down the process of income distribution by sectors and beyond the operating surplus. In Hungary it was especially important to achieve, since there are many sectoral differences in the rules and an unusually large part of the redistribution takes the form of capital transfers (investment subsidies, revaluations, write-offs, debt undertaking, etc.). The model also takes into account appropriately the various in-kind and earmarked transfers which are also very frequent in Hungary. Further innovations by the

candidate are as follows:
Unlike in standard CGE models many tax rates can be determined endogenously. Profit tax is determined as the sum of a sector specific base level and marginal tax. This was also necessary to be dealt with, since in Hungary there are many profit tax exemptions and preferential rates (mainly for the foreign direct investment and for promoting fixed capital investments). The SNA routing through technique is used in a such a way that many transfers (of which we do not know who pays whom) are routed through the government. Interest payments are routed through the banking sector.
Depending on the selected closure option, sector specific behavioural functions are specified either for the fixed capital investments or the net credits (net changes in financial claims and liabilities).

COMPILATION OF THE DATA BASE

In Hungary the statistical system has gone through its transition too. The conversion to more-less SNA like methods required much efforts, but as of now still there are many unsolved problems. For example, the accounts of the rest of the world and the state household are not fully compiled and the capital accounts are almost completely missing. In addition, data on the input-output structure of the sectors and data on factors (employment, amortization, fixed-capital) and national wealth have almost completely ceased to exist. For seven years, even detailed and observation-based I-O tables were not compiled.
However, the candidate has more than a decade long expertise (methodological information, personal acquaintances, developed own methods and softwares, etc.) in the compilation of CGE data bases, which made it possible for him to compile the 1994 data base for the model. Since the 1994 I-O table was published only at the end of 1997, the compilation took place in 1998.
Some of the steps in which a somewhat original approach was used are as follows:
The 21 sector „small" I-O table was not suitable for energy-environmental policy analyses. Therefore some sectors had to be dis-aggregated, during which the RAS-method, the rooking technique of operational research, was extensively utilized and the previous, 1991 data base was used as (structural) reference.
The model distinguishes 10 socio-economic groups within the household sector. For these groups the 1991 Household Budget Survey based income and expenditure data were updated by using a so called „additive" RAS method, developed by the candidate. Since expenditures are displayed as negative numbers in the matrix of the household budgets (where a rows represent the items, and columns represent the groups) the column-totals - by definition - add up to zero. This makes the RAS method inappropriate. Instead, the modified iteration method is the following:

$$H_{i,j} = H0_{i,j} + \left(HTOT_j - \sum_k H0_{k,j} \right) \cdot SH_{i,j}$$

where $H_{i,j}$ is the new cell-value, $HO_{i,j}$ is the previous cell-value, $HTOT_j$ is the desired column-total (in our case 0), and $SH_{i,j}$ is the original *absolute* value share. This method adjusts the individual cells proportionately to their absolute value, but the direction of the change depends not on the sign of the cell, but rather on the sign of the total discrepancy, which has to be eliminated. By this method one can estimate the change in the income distribution too. In applying it to the 1991-1994 period in Hungary it was found, for example, that relative income position of the rural and larger households (i.e. those with children) deteriorated.

ANALYSIS OF THE IMPACTS OF ENVIRONMENTAL TAXES

The results of 5 scenarios are reported and analysed in the thesis. The common assumptions in them are that the level of social consumption and capital utilization are fixed exogenously, and in the first 4 scenarios the level of trade deficit and investment are fixed too, to be able to compare easier the (long-run) welfare effects of the different runs.
The further characteristics of the scenarios are the following:

Scenario 1: Introduction of air-emission taxes is assumed. The tax revenue is not recycled.

Scenario 2: It differs from the first only in that respect, that by holding constant the budget deficit the emission tax revenue is recycled by the reduction of the employers' social security contribution (SSC) rate.

Scenario 3: It differs from the previous one only in that respect, that instead of emission taxes a uniform 5 % ad valorem additional energy tax is levied.

Scenario 4: It differs from the 2nd only in that respect, that labour supply is not optimal, but is determined only by an isoelastic function of the real-wage level (with an elasticity of 0.5).

Scenario 5: It presents those possibly relevant options which did not fit to the previous scenarios. Here, the abatement ratios, the real exchange rate and the households savings rate are fixed, and the emission tax rates are set at the level of the marginal damage. Apart from a 5 % monitoring cost, emission taxes are recycled to the households in a form of lump-sum transfers.

The main results of the model runs are the following:

The emission tax reduces the demand for coal by 13 % (28 % in the last run). In the last run even the demand for refinery products decreases by 10 %. Substitution

takes place toward natural gas. The tax is built into the price of the energy-intensive sectors. Energy demand falls by up to 2-5.3 %.
The run specific results are the following:

Run 1: Household welfare increases by 0.12 %. Energy demand and emission decreases and by the linkages (twin products) the non-taxed carbon-dioxide emission also decreases (even more than that of the nitrogen-oxides). Although households (can) decrease their environmental expenditures, environmental welfare increases somewhat.

Run 2: Possible reduction of SSC (Social Security Contribution) rate turned out to be. Welfare increases further.

Run 3: Increase of welfare (relative to the base) is minimal, although the SSC rate decreases by 4 %. Uniform taxation of energy does not stimulate inter-fuel substitution from the „dirty” fuels to the „clean” ones. Therefore, emission decreases only slightly.

Run 4: Non-optimal (non-selfish or non short-sighted) labour supply makes possible the further increase of the household welfare.

Run 5: The excessive abatement requirements (equal to 1.2 % of the GDP) decrease the social welfare.
From the runs one may conclude, that the reduction of the SSC rate alone can not guarantee so much higher employment and wage level that SSC revenue increase. Therefore, it is better to cut them simultaneously with the introduction of (not excessive) emission tax rates. Introduction of uniform energy taxes is not recommended.

GENERALIZATION OF THE MACROECONOMIC CLOSURE

Based on the sensitivity runs of a model with a given macroeconomic closure, a linearized "reduced form" was estimated to describe the mutual interdependencies among the key macroeconomic variables. The resulting matrix of the reduced coefficients shows the unit impacts of the partial changes in the macroeconomic closure variables or parameters (constraints). This technique helps in clarifying the relationship of models with different macroeconomic closure, and in testing the stability of various effects in changing macroeconomic regimes. The following procedure was used:
The most general form of the CGE model can be expressed in the

$$F(\underline{x}, \underline{y}) = \underline{0} \tag{4}$$

$$G(\underline{x}) = \underline{0} \qquad (5)$$

form, where (4) is the core model and (5) contains the equations of the macroeconomic closure, where $\underline{x}$ denotes those variables which appear in the closure (too), and $\underline{y}$ denotes those variables which appear only in the core of the model.

Let us assume that the G function's g_i coordinate-functions are twice differentiable. Then, within a small range of a given $\underline{x}$ vector, the function can be approximated by its tangent (hyper-plane). From this follows, that the closure can be approximated by a $M \cdot \underline{x} = \underline{d}$ linear equation system. If the M matrix is invertible (practically when the number of equations is equal to the number of variables), then by introducing the $\underline{k} = \underline{d} \cdot M^{-1}$ notation, we can get the $\underline{x} = \underline{k}$ relationship. This may be called „self-determining" closure. Its simplest case is when the closure variables are exogenous. In the subsequent part of the section we will investigate, how the change of the $\underline{k}$ explicit or implicit „constraint" modifies the solution of the model.

If the core model's f_i coordinate-functions are also twice differentiable - usually this is the case - then the function can be linearized around each point, i.e. by accepting a slight error we can replace the function by its tangent (hyper-plane). In this case the core model can be expressed in the

$$A \cdot \Delta\underline{y} + B \cdot \Delta\underline{x} = \underline{0} \qquad (6)$$

form of linear equation system. Fortunately, we will not need to quantify this full form of the linearized model. By using the well-known formula for the general solution of the linear equation systems, $\Delta\underline{y}$ can be expressed as a particular solution, in function of $\Delta\underline{x}$:

$$\underline{v}_b = A^{-1} \cdot B \cdot \underline{v}_k = D \cdot \underline{v}_k \qquad (7)$$

where $\underline{v}_b = \Delta\underline{y}$, $\underline{v}_k = \Delta\underline{x}$, $D = A^{-1} \cdot B$. Note, that if we take the benchmark values of the variables, i.e. $\underline{v}_b = \underline{v}_k = \underline{0}$, then we get a base solution in both (benchmark and linear algebraic) senses. Subsequently, D matrix will be referred to as the „reduced coefficient matrix" of the model.

Note, that although it does not show the direct effects of the changes in the standard parameters of the model (i.e. which appear in the core), they influence the value of the $\underline{D}$ matrix. Therefore, $\underline{D}$ matrix can be regarded as the „compressed" description of the model parameters and makes it easier to compare nature of two models with different parameter values.

The method employed, can be summarized in the following way:

If we change the closure, i.e. if $\underline{v} = \{ \underline{v}_b , \underline{v}_k \}$ vector's other elements will be set exogenously in the closure than $\underline{v}_k$, then the new model's reduced coefficient matrix can be derived from the original D matrix by the well known basis transformation (pivot) method.

Concretely: $\underline{v}_b$ and $\underline{v}_k$ vector's can be split to two parts. One part represents those variables which change role in the new model (becomes or ceases to be exogenous closure variable), while the other part includes those variables which do not change their role. Without loss of generality, we can assume that $\underline{v}_b$ and $\underline{v}_k$ vectors were defined so that the variables which change role were grouped in their lower part according to the

$$v_b = \begin{bmatrix} v_{by} \\ v_{bc} \end{bmatrix} \quad \text{és} \quad v_k = \begin{bmatrix} v_{km} \\ v_{kc} \end{bmatrix}$$

formulas, where the c second index refers to the group of the variables which change role, the y and m second indices refer to the variables which do not change role (y as usual symbolizes the dependent variables, while m refers to those variables which remain among the exogenous closure variables).
Then, the solution of the original (5) model can be written in the

$$\begin{bmatrix} v_{by} \\ v_{bc} \end{bmatrix} = \begin{bmatrix} D_{ym} & D_{yc} \\ D_{cm} & D_{cc} \end{bmatrix} \cdot \begin{bmatrix} v_{km} \\ v_{kc} \end{bmatrix} \tag{8}$$

form, where the second indices of the blocks of the D matrix show, that the effects of which group of the exogenous closure variables is in question. Similarly, the first index shows, that which group of the other variables are affected.

By expressing $\underline{v}_{kc}$ from the second block of the above equation system we get:

$$\underline{v}_{kc} = D_{cc}^{-1} \cdot \underline{v}_{bc} - D_{cc}^{-1} \cdot D_{cm} \cdot \underline{v}_{km} \tag{9}$$

By substituting it into the first block, we get:

$$\underline{v}_{by} = D_{yc} \cdot D_{cc}^{-1} \cdot \underline{v}_{bc} + (D_{ym} - D_{yc} \cdot D_{cc}^{-1} \cdot D_{cm}) \cdot \underline{v}_{km} \tag{10}$$

These two formulas show, how one can compute the variables in terms of the new closure variables. Let us introduce the

$$u=\begin{bmatrix} v_{by} \\ v_{bc} \end{bmatrix}, D_m=\begin{bmatrix} D_{ym} \\ D_{cm} \\ D_{yc} \\ D_{cc} \end{bmatrix}, D_c=\begin{bmatrix} D_{yc} \\ D_{cc} \\ 0 \\ E \end{bmatrix} \tag{11}$$

„extended” notations, where $\underline{u}$ is the vector of the new closure variables, while D_m and D_c matrices contain the reduced coefficients of the original closure (augmented by the $\underline{E}$ and $\underline{0}$ matrices, which stand for the unit and zero matrices). Then, the transformed form of the core model can be expressed by the

$$\underline{v} = [\, D_{ym} - D_c \cdot D_{cc}^{-1} \cdot D_m \;;\; D_c \cdot D_{cc}^{-1} \,] \cdot \underline{u} \tag{12}$$

formula.

Finally, we get the new model, if the above core model is supplemented with the $\underline{u} = \underline{h}$ assignments. Therefore, the solution of the model appears as a particular solution of a linear equation system.

By this method one can get a new model (i.e. which are different in their closure) by each elementary basis tranformation step. In this way one can generate systematically the reduced coefficient matrices of different models. From these matrices then one can analyse the ‘distance’ of various macroeconomic regimes and can discover meaningful or select desired closure possibilities.

Indeed, the thesis contains such an experimental exercise. However, it required the numerical estimate of the D matrix and $\underline{k}$ vector, which was provided by the following method. First, an arbitrarily initial closure and the corresponding $\underline{k}$ vector were selected. Then, each elements of $\underline{k}$ were changed one by one by one unit and after every such change the model was solved. From the results obtained the approximate value of the elements of the D reduced coefficient matrix could be seen.

This method was tested by comparing the results of the linear approximation with the results obtained by running the actually modified model. The stability of the elements of D (over time) was also tested. The test results were quite satisfactory. Finally, nine models were selected of the generated D matrices (i.e. models), which were especially worth for discussion and comparison. Some of these models have rather interesting non-traditional closure, which offered useful lessons for macroeconomic policy analysis.

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