CGE model calibration using multi-objective evolutionary algorithms

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The research aims to expand the possibilities for country-level model calibration with the interest of speeding up and facilitating parameter choice when data to inform these values is not available while certain model responses are desirable. For this aim, we use a single-country CGE model set up in a dynamic recursive mode and embed it in multi-objective evolutionary algorithm (MOEA) framework. The framework is thus employed to search the space of possible parameter values, notably in the case of elasticities, to minimise the error between the model target- and actual responses. For illustrative purposes, the case study of aligning a country-level model to a global multi-regional model is considered.

With a usual Social Accounting Matrix containing over 200 accounts, the parametrisation of the behavioural parameters of a single-country model for applied work (elasticities regarding production, trade and consumption) requires many decisions regarding the values to be used. Given limited data available from the literature, the user needs to make assumptions about these values informed by expert judgment or use values from other more general databases (e.g., the GTAP database including trade elasticities by commodity group, but not differentiated by region). In a dynamic-recursive setting, the validation of the model parametrisation can be done using back-casting techniques against a number of desired outcomes or objectives (e.g., GDP, trade volumes, sectoral output); however, the process is laborious and not guaranteed for success given the multiple iterations involved in adjusting the parameters and the multitude of possible combinations. In addition, the calibration process is complicated by the non-linear nature of CGE models, which prevents behavioural parameters (elasticities) from being endogenised.

Furthermore, the growing complexity of studies in which the CGE models are involved requires linking to other modelling frameworks. These frameworks could be of the same nature (partial equilibrium or general equilibrium) or coming from a different field of science (e.g., biophysical models of water or land systems). In this regard, the model linking adds another level of complexity to the parametrisation work, given that the CGE setup needs to be adjusted to allow for a certain degree of convergence of its responses to those of the other models to which it is linked. This is especially relevant when a bi-directional model coupling is not possible or practical.

A case in point in this regard is the simulation at a country-level of international trade agreements. While a trade agreement is more easily included in a global multi-regional CGE model, there is an interest in running the same simulations in country-level CGEs in order to increase the level of detail of the assessment (notably on the household level where country-level SAMs are much more detailed). There has been some development of methods to link the results of the global model into the country-level model in order to facilitate a similar model response to tariff liberalization[1]. These methods imply an alignment of trade elasticities between the country-level and the continental models. However, these can provide a sub-optimal solution when linking two models that have different structures of production and consumption and different closure rules.

[1] Horridge and Zhai, 2006. Shocking a single-country CGE model with export prices/ quantities from a global model, in: Poverty and the WTO: Impacts of the Doha Development Agenda, Trade and Development Series. Palgrave Macmillan and the World Bank, Washington, DC, pp. 94–103.

Multiple Objective Evolutionary Algorithms (MOEA) could be a practical way of automating the search of simulation model parameters (these parameters are called 'decision variables' in the MOEA literature) in order to solve a problem with multiple objectives, when the optimal solution cannot be derived mathematically, or when the objectives involved cannot be given weights as part of the optimisation exercise (for example it is not straightforward to weigh GDP gains against welfare gains). They rely on metaheuristics to scan the space of possible solutions by using the so-called "genetic algorithms" through which a set of non-dominated "best achievable" solutions (for instance, a specific parameter configuration if the algorithm is used for model calibration) are iteratively selected. As a metaheuristics approach, it needs to run many iterations of the same problem in order to find the approximate Pareto-optimal solutions to cover the entire Pareto Front (defined by the multiple objectives) and for the search algorithm to meet a convergence criterion (point at which the Pareto Front can no longer be improved). The MOEA algorithms have been used in the modelling literature to calibrate biophysical models[2] but have not yet been implemented in the field of economy-wide/CGE modelling. As opposed to goal programming, applied to a very limited extent in CGE studies and which implies adding weights to conflicting objectives to offer one prevailing solution[3], the MOEA algorithms enable the user to visualise a wide spectrum of outcomes without imposing any a priori preferences for specific objectives.

For this research, the MOEA algorithm is linked to a GAMS CGE model (JRC DEMETRA) of the Kenyan economy. Developed by the Joint Research Centre of the European Commission, the Dynamic Equilibrium Model for Economic development Resources and Agriculture (DEMETRA) is a single-country computable general equilibrium (CGE) model, developed in GAMS under a Mixed Complementarity Problem (MCP) formulation. The core of the DEMETRA model is based on STAGE_DEV . STAGE DEV has been developed for the European Commission by Aragie, E., McDonald, S., and Thierfleder, K..

To illustrate the use of the framework for calibration purposes, we use as case study the alignment of model responses to trade shocks of the DEMETRA model (single-country) and the MAGNET model[4] (global model using GTAP). The trade shocks are resulting from the establishment African Continental Free Trade Area (AfCFTA) and are applied to the two models for 2021-2035 time horizon. The MAGNET responses of trade (quantities and prices), GDP and other macro-variables are used as target values for the MOEA-based calibration of the DEMETRA model. The MOEA thus aims to minimize the DEMETRA response error across a number of model responses and takes into account the possible trade-offs between these errors, which are set as objectives.

The model calibration is further complemented by an analysis of the Pareto Front results to indicate the DEMETRA model parameters that are the most impactful in reducing the differences in model responses between MAGNET and DEMETRA.

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[2] See Gonzalez et al., 2021. Frontiers in Environmental Science 9, 107. https://doi.org/10.3389/fenvs.2021.596612 or Tang et al (2006) Hydrology and Earth System Sciences 10, 289–307. https://doi.org/10.5194/hess-10-289-2006

[3] See André et al., 2009. Environmental Management 43, 888–898. https://doi.org/10.1007/s00267-009-9276-x

[4] Woltjer, G.B., Kuiper, M., Kavallari, A., van Meijl, H., Powell, J., Rutten, M., Shutes, L., Tabeau, A., 2014. The MAGNET model: Module description. LEI Wageningen UR.