Review of the RHOMOLO model

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1. Introductory remarks

The RHOMOLO model has been developed since 2010 and has been used to analyse European regional policies. The development of a spatial economic model encompassing 267 EU regions is a challenging task. Therefore, this review starts by emphasizing that the pioneering work of the RHOMOLO team expands the toolbox for ex ante quantitative assessments of regional policies in the EU with a unique economic model. The Board also holds the opinion that the core of RHOMOLO is well-founded in economic theory and incorporates important spatial mechanisms such as interregional trade. The research team has put much effort in collecting geographically disaggregated statistics from various sources and constructing a regional data base. The Board very much appreciates that this data base will shortly be openly accessible because this will both enhance legitimacy in the Member States and the credibility among the scientific community. The focus of this report is on identifying the most promising and valuable improvements for future editions of RHOMOLO – many of which have been acknowledged by the RHOMOLO team members beforehand.

RHOMOLO is one of the few spatial computable general equilibrium (CGE) models that cover a large number of EU regions. The earliest European large scale spatial CGE model is CGEurope (Bröcker 1998, Bröcker and Schneider 2002) (covering 1373 EU NUTS 3 regions), which is used for transport policy simulations. The GMR-Europe (Varga 2017) (with 181 NUTS 2 regions) model is most frequently applied for the estimation of regional and macroeconomic impacts of regional innovation policy interventions. As a model constructed for Cohesion policy impact assessment, RHOMOLO is less specialized in its policy focus, but covers a broad set of instruments, ranging from investment support to transportation, human capital or R&D promotion.

Economic models designed to support policy face the challenge to be complex enough to be relevant for assessments of detailed real-world policy proposals on the one hand, and to remain tractable on the other hand. The trade-off between complexity and tractability needs a careful consideration, strategy and planning supported by explicit decision criteria. In addition, a considerate use of the model and a clear presentation of results are advisable in order to enhance the model’s flexibility (e.g. adding features to address a broader range of policy questions) while avoiding that the model is regarded as a black box.

The RHOMOLO model development is a continuous process. However, this review concentrates on one version of the model at one point in time (presented to the Review Board in April 2016). The RHOMOLO core model is capable of incorporating a number of add-on modules, and not all these modules are covered in this review. In particular, the extensions on migration, Bertrand/Cournot imperfect competition, the social module with households disaggregated in quintiles and process and product innovation are not covered here. As a general rule, that seemed particularly relevant for the Bertrand/Cournot imperfect competition module, the added value and the implications of additional modules to the core model should be made clear. Moreover, this review does not include a discussion of the interregional trade data and the web interface.

The Board members agree that the development of an economic model should be driven by the particular policy questions at hand. Therefore, we first summarize the policy issues that RHOMOLO intends to address. The remainder of the report discusses the extent to which RHOMOLO is equipped to provide answers to these policy questions.
2. Identify the key policy questions to direct model enhancements

Place-based policies and the spatial distribution of economic activity have become central elements in EU policy debates. The general objective of social cohesion in the EU is achieved through specific policy measures. This general-to-specific perspective challenges economic models such as RHOMOLO to reconcile an economy-wide framework with a high degree of regional disaggregation and substantial detail to address particular questions in crucial policy domains such as employment, R&D, education and poverty. The key policy questions for the future should drive the choices for further model improvements and extensions.

The RHOMOLO model aims to meet policy-makers expectations regarding its use for simulating policy scenarios related to the EU cohesion policy and for the analysis of its impact on 267 NUTS regions and the Member States of the European Union. It has the unique feature, not available in other existing CGE models, to extend its analytical capacities to the regional level and inform on impact of EU investment support through cohesion policy on growth in six macro sectors (agriculture; manufacturing and construction; business services; financial services; public services; R&D). Additionally, RHOMOLO has been recently applied to evaluate the macroeconomic impact of the European Investment Bank (EIB) activities, confirming its methodological flexibility.

The model has a potential, if further developed, to enhance its value for policy makers and programme managers in the following three areas.

Supporting policy mix choices for geographical programme managers while interacting with Member States and regions, using level of intervention codes as widely used in structural funds;

Informing on the impact of structural reforms within and across EU NUTS regions through changing the incentives on the use of the available resources, reallocation of factors across and within sectors, with a more disaggregated level of sectors than currently developed;

Aiding Impact Assessment practice of the EU helping policy desk officers in responding to evaluation criteria:

- Effectiveness: how successful has EU intervention been? What factors and to what extent have different factors influenced the achievements?
- Efficiency: to what extent are the costs involved justified given the associated effects?
- Coherence: are interventions coherent with wider EU policy?
- Relevance: to what extent is the intervention still responding to the needs?
- EU value added: what are the most likely consequences of stopping EU intervention?

It is important to manage the expectations of potential users. The RHOMOLO description and manual should clearly identify the target group of users and inform them as to how they can best use the model at the present stage of development. A user driven analysis, using the existing model could identify potential developments and their technical and financial feasibility.
As a background for the reader of this document, Box 1 provides a more general context by summarising the priorities in the Territorial Agenda of the European Union.

<table>
<thead>
<tr>
<th>Box 1: Territorial priorities for the development of the European Union</th>
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<tr>
<td>1. Promote polycentric and balanced territorial development</td>
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<tr>
<td>2. Encouraging integrated development in cities, rural and specific regions</td>
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<tr>
<td>3. Territorial integration in cross-border and transnational functional regions</td>
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<tr>
<td>4. Ensuring global competitiveness of the regions based on strong local economies</td>
</tr>
<tr>
<td>5. Improving territorial connectivity for individuals, communities and enterprises</td>
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<tr>
<td>6. Managing and connecting ecological, landscape and cultural values of regions</td>
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*Source: Territorial Agenda of the European Union 2020 (European Commission, 2011)*
3. Prioritise specific improvements to the methodological framework

This section zooms in on the specifics of the model and is organised in three categories: the labour market, research and development (R&D) and dynamics.

3.1. Labour market

The Board understood from the presentation of the structured sensitivity analysis that the labour market specification (and the wage curve elasticity in particular) is of crucial importance for the simulation results, not only for the order of magnitude, but also for the sign of the impacts. A revision of the labour market module of RHOMOLO is high on the agenda of the modelling team anyway. The Board encourages the team to put special effort in this module, both conceptually and through its own estimation efforts. In addition to the wage curve elasticity, the other assumptions about the labour market, such as the composition of the labour stock, the elasticity of labour productivity with respect to additional years of training and the treatment of labour in the R&D sector, seem to be important. The following considerations may form part of the search for an appropriate specification, even if the ultimate choice will require a transparent form of weighting of the different aspects.

In the current set-up of RHOMOLO any labour market effect of regional policy is channelled through labour productivity. If labour productivity is increased in one way or other, this will produce an upward pressure on wages. The wage curve specification then essentially says that any increase in the wages is accompanied by some reduction in the unemployment rate. On the one hand, this is a desired effect, because according to Okun’s law, productivity increases help to reduce unemployment. On the other hand, it seems less plausible that any productivity increase – regardless of its cause – will lead to a permanent reduction in unemployment. After all, if there are forces that have led to a discrepancy between the wage and marginal productivity of labour in the initial situation, these are not likely to be permanently removed by regional policy. There is a strong case for wages following labour productivity one-to-one in the long run. This clash of intuitions might be softened in several ways. Only if labour supply is exogenous (as in the current core version of RHOMOLO), changes in employment are directly reciprocal to changes in the unemployment rate. With endogenous labour supply (either by a labour-leisure choice or by migration), labour productivity increases can be combined both with a constant unemployment rate in the long run and with increased employment.

Second, to the extent that centralised (national) wage formation is a realistic feature of the country/region considered, changes in relative regional unemployment rates can be linked to changes in relative regional productivity levels, even if in the national average, the wage is in line with productivity. This is another modelling route that should be explored. After all, the seminal wage curve estimations were meant to explain regional wage dispersion rather than the inter-temporal co-movement of wages and unemployment.

The option of running RHOMOLO with a Phillips curve instead of a wage curve as labour market closure is inspired by the desire of generating a more realistic pattern of wage adjustment, namely a delayed response of wages to changes in productivity. This aspiration to a more realistic adjustment pattern is understandable; however, it does not fit well with the general modelling approach of RHOMOLO, which starts from the assumptions of sequential perfect equilibria. If the dynamics of price adjustments is part of the ambition of the modelling approach, this should rather be spelled
out explicitly and consistently applied to all markets, not only to the labour market in isolation. Given that there are other model types (most prominently, DSGE) which are better suited for capturing this type of price dynamics, the board is sceptical about making this a target for the further development of RHOMOLO.

3.2. R&D

Innovation is the main driver of growth, so that the way it is modelled crucially affects the calculated Cohesion Policy impacts. Therefore, the Board appreciates the effort to model explicitly research and development activities. Innovation modelling is a difficult task and modellers are usually forced to introduce simplifying assumptions to come up with reasonable model structures. However, it is always important to provide careful argumentations for the introduction of all the simplifications. The aspects of innovation modelling in RHOMOLO where the Board believes additional argumentation is desirable are highlighted below.

Though R&D is an important input to innovation it is not the only one. Thus the present model recognises that R&D is typically only one input into innovation, which yields returns to output or productivity. This approach therefore uses measures of innovation as inputs to the production function rather than modelling the impact of R&D on innovation. The model further simplifies innovation modelling by ignoring any differences in the effects of R&D by type of research (fundamental and applied), by type of beneficiary (public and private), by type of intervention (direct and indirect), by the mode of intervention (grants and financial instruments), or by the code of intervention (e.g., research and innovation in large enterprises, research infrastructure in public bodies), by different lag times of research investments (e.g., private and public R&D), or by differences in rates of depreciation between private and public R&D investments. As a result, the model follows a stylized approach and considers the high-skilled labour component of R&D as the only type of research input. Caveats to this approach need to be carefully addressed.

Our second set of comments is related to the way knowledge spill-overs are modelled. The allocation of all R&D activities to one region of a country could perhaps be a doable simplification for some countries where innovation spatially concentrates (i.e., in small countries) but not for countries where innovation is geographically more evenly distributed (i.e., large developed countries: UK, France, Germany). It is a strong finding in the literature that knowledge spill-overs decay with distance. The solution in RHOMOLO ignores this finding by considering spill-overs the same to each region. Our further comments relate to the measurement of inter-regional knowledge spill-overs. These externalities are modelled with a parameter borrowed from a paper where spill-overs are estimated on a data of nations and not on the data of sub-national regions. The Board encourages additional efforts in this respect. Spill-over modelling can be improved in two additional ways. In the current model version knowledge flows are assumed between regions of the same country but not between regions of neighbouring countries. However, knowledge spill-overs across (national) borders are a main reason for the EU government to intervene or subsidize innovation. Furthermore, knowledge spill-overs do not reflect regional absorptive capacities or differences in the composition of sectors and the labour force across regions.
3.3. Time patterns of adjustment and model dynamics

A general point that needs to be addressed in a comprehensive model development strategy is the treatment of the time pattern of model reactions. Does the model development team consider it essential that the model captures adequately the expected time path of the economic consequences of Regional Policy interventions, or is the main modelling focus the overall effect with timing as a secondary issue? At the moment, the priorities are not clearly formulated with the impression that the ambition is not consistent throughout the different parts of the model.

The present model has a recursive dynamic form. That is to say, it is run in period-by-period fashion with some variables updated from one period to the next. Each period is one year. If the timing of model responses is considered a priority in the further model developments, the following elements of RHOMOLO need a revision with respect to inter-temporal accuracy:

- The timing of the scenario impulses (e.g. when exactly does an investment in traffic infrastructure lead to a decrease in trade costs?). These require essentially off-model information and analysis.
- Delayed adjustment of economic variables due to nominal or real rigidities in the economic system (e.g. migration, wages).
- Depreciation of stocks (e.g. R&D, infrastructure, public capital and investment).
- Lag between R&D investment and induced productivity increases (technical change and spatial spill-over effects).

The following paragraphs go into more detail on some of the abovementioned examples.

**Calibration.** The model is calibrated in the initial period to be in static equilibrium. That is to say, if there are no exogenous changes to parameters or external variables, then the model would simply reproduce the same outcome period by period. This implies that any variation from base is the result of the exogenous change, typically introduced by policy innovation. These changes can be introduced in a dynamic fashion, changing exogenously period by period. Although there are some CGE models that are calibrated on an equilibrium growth path and others that are apparently not in long-run equilibrium in the base year, such characteristics are unusual. There are many advantages of adopting the present RHOMOLO approach. Further, given the size and complexity of the model this is probably the only practical option.

**Investment.** There are present two options in the core model. Both are “backward looking” or recursive. This simply implies that the adjustment to the capital stock is driven by current imbalances in the economy, rather than projections into the future which is when the capital will become operational. The two options are:

- Savings-based approach in which total investment is driven by total EU savings which are distributed across countries and regions, together with some degree of capital-migration between regions.
- Capital demand-based approach which allows saving to or from the rest of the world to balance saving and investment.

There are arguments in favour of both options but it must be made clear that not only the short-run dynamics, but also the long-run equilibrium will, in general, be influenced by which is chosen. In
general, dynamics are important if the time period over which policies are to be evaluated is relatively short (say less than 10 years) because the adjustment to the long-run equilibrium can be protracted. The main argument for choosing a recursive dynamic approach is the computational one, as it keeps the mathematical problem dimension smaller.

A number of members of the Board were in favour of having forward-looking investment (and presumably also consumption and where operative migration) behaviour. This has the advantage of being consistent with the optimising behaviour in production and consumption generally. Whilst such assumptions are used in other models, such as QUEST, they do depend upon extreme assumptions about foresight. There can be important differences between the dynamics with backward and forward looking models, especially where supply-side shocks are introduced. However, there are almost certain to be big differences where temporary (specifically time-bounded) shocks are introduced, especially where they are pre-announced. There are also big differences in dynamics when a temporary policy stops. However, it was accepted that there are likely to be major difficulties in running a forward-looking variant of such a big model.

**Dynamic wage adjustment.** A particular aspect of the model dynamics is the specification of the wage function. The modelling team has experimented with wage functions in which the standard Blanchflower-Oswald wage curve has been replaced by a Phillips curve formulation capturing the delayed response of wages to price inflation. This is without doubt a valid approach in macroeconomic modelling. However, in a recursively dynamic CGE setting like RHOMOLO, this forms a troublesome element. Wages may be modelled react to prices and the unemployment rate with a delay, but this raises questions as to the possibly delayed adjustment response of all prices and quantities, and whether these are treated in a consistent manner. The approach of introducing element of delayed adjustment in the wage function while in the whole rest of the model instantaneous market clearing with fully flexible prices is assumed, is not convincing. The dynamic wage curve gives the model a set of options in terms of wage setting, in that variations in the parameters can generate wage curve and short- and long-run Phillips curve options. There were reservations expressed as to the appropriateness of introducing incomplete price adjustments in one market (the labour market) whilst not in others (product markets). However, if there are such sticky price adjustments, is the appropriate reaction to be consistent but wrong, or inconsistent and partly right? The practical point is that such imperfect adjustment can be easily incorporated in the wage equation. Also from the existing sensitivity analysis the coefficient on the wage equation appeared to be a key parameter. In addition to the above, the introduction of migration introduces changes to the regional labour force (composition) and hence will affect, perhaps radically, both the dynamics and long-run equilibrium.

**Agglomeration and dispersion forces.** Spatial computable general equilibrium models are typically rooted theoretically in the new economic geography literature. In such spatial CGE models agglomeration and dispersion forces are endogenous and play a crucial role in determining short-run (regional) and long-run (spatial) equilibriums. RHOMOLO documents introduce the specific centripetal and centrifugal effects that are at work in the model. What is missing for the reader is a clear description of the mechanisms by which these forces are integrated in the model structure to
generate short run and long run impact results. More specifically it is not clear how interregional migration of labour and capital are related to the forces of agglomeration and dispersion.

**Technical change.** The different lag times of research investments and the time pattern of knowledge diffusion will be important in the dynamics of adjustment. For a broader discussion on the topic, we refer to the Section 3.2 on R&D.

The review board is sceptical about placing a modelling focus on the inter-temporal aspects. The revision of the abovementioned aspects of the model poses enormous challenges because in any of these areas the empirical underpinnings of possible parameter choices are relatively weak. Most importantly, a convincing approach to modelling delayed adjustment of economic variables requires an inter-temporal, forward-looking set-up of the model. This has been suggested as a possible direction of future model development by the RHOMOLO team. However, the Review Board was not able to reach a consensus on this matter. A forward-looking model with that many regions is an unexplored area beyond the research frontier and was regarded as too ambitious by some of the Board Members. It is likely to require specifically tailored numerical methods, which implies an extremely high uncertainty in the model development process.

Considered all of these aspects, the Review Board recommends to focus on the overall effects of regional policy in the further development of RHOMOLO and to downplay the detailed model results about the timing of the effects. Extending the model with forward-looking agents can be a valid option if the time pattern of adjustment is an indispensable factor in the assessment of a particular policy question. However, the Board holds the opinion that priority could rather be given to exploring in detail the options that are currently included in the model, such as the savings vs. investment-driven model closures.
4. Engage in a data validation process and parameter estimation

4.1. Data validation process

The construction of the regionally disaggregated data base on which RHOMOLO operates is itself a major task. It is created by the regionalisation of national data from Eurostat and the international Input-Output accounts constructed by the World Input Output Database. The inter-regional trade data, which are central to the simulation results in the RHOMOLO model, are taken from Thissen et al. (2015).

A central issue is that, of necessity, much of the initial data base is itself constructed/modelled. That is to say, key regional input-output data and inter-regional trade and income flows are not directly observed but are generated, consistent with the existing national data, available economic information at the NUTS-2 level and certain key assumptions. The methods used to construct the regional accounts were presented in some detail. There was no specific presentation of the modelling of the inter-regional trade flows, although this has been done with the co-operation of the RHOMOLO team. However, information on the trade modelling is in the public domain.

The process whereby the data are constructed will flatten differences between different regions. RHOMOLO at present works with a very aggregated industrial structure (effectively 5-sectors). The data construction process forces individual sectors to have a similar input structure across regions of the same country. However, this is unlikely to be the case, especially as the scale of the region falls. This means that whilst the regional disaggregation to the NUTS-2 level is required for policy purposes, the data construction is likely to be missing a lot of regional heterogeneity at this spatial level.

It is not possible to validate the data base as a whole because the detailed data do not exist. However, it would be valuable to make the data available to the public and the modelling community (as already planned), and to engage actively in a validation process with stakeholders (DG REGIO, Member States, EIB) and statistical offices, and with regionalization efforts undertaken in administrations and academic research institutes in the Member States. Here more detailed local knowledge could be used to validate and, where appropriate, adjust the existing data base. The Board believes that the quality of the data is a crucial determinant for the reliability of simulation results. Hence, all efforts to improve and validate the data are to be encouraged.

4.2. Data sources

Constructing the database is always one of the most difficult tasks when developing a model, especially at the level of granularity used by RHOMOLO. Therefore, the data-collection and data-cleaning procedures applied in the model have to be well acknowledged. Since some of the data are not available on the NUTS 2 level, they have to be estimated. The estimation of interregional trade flows is one example. The Review Board emphasizes that the quality of the (interregional trade) data is important, but an assessment of the data itself is outside the scope of this report.

The data construction process should strive for and verify consistency with Eurostat (Input-Output) data, as this is an official, institutionalized data source in the EU. To provide necessary robustness
and consistency, the datasets could be also verified by external experts, as described in more detail in the previous subsection.

As the best-practice, in future developments or with forthcoming data updates, it seems reasonable to keep the model in line with the most recent data specifications. For instance, should the classifications be further updated in the next years, RHOMOLO classification could be adjusted to meet the most recent standards. In such a way the model results could be better benchmarked against other analyses, and therefore better targeted from the policy point of view.

4.3. Parameter estimation

The operation of the RHOMOLO model depends upon a wide range of imposed behavioural and technical parameters. These cover elasticity measures of the extent of substitution between commodities in consumption and inputs in production but also parameters concerning the wage curve, migration function and the investment function. Typically in CGE models these parameters are informed by econometric analysis. The discussion in the model documentation of the values adopted is very limited and is a mixture of appeals to the literature and values used by other similar models. The Board encourages efforts to estimate crucial model parameters and advocates clear documentation related to the estimation procedures.

Sensitivity analysis should continue to be used to identify which are the key parameters in determining the scale (or even direction) of the change in key outcome variables, and therefore suggest priorities for verifying parameters. In many cases, at present the parameter values do not vary across industries and/or regions. There are advantages to this approach in that it makes simulation results more straightforward to understand and explain. However, in so far as it masks real differences between industries and regions, there is a clear trade-off. Existing sensitivity analysis identifies the coefficient on the unemployment rate in the wage curve as a key parameter in determining the policy impacts. This is motivating further econometric work on the labour market. Sensitivity analysis could be applied on a wider range of parameters, as will be discussed in a later section.
5. Better exploit the model's strengths, while acknowledging caveats

5.1. Use the RHOMOLO model in a wider policy assessment toolbox
A model is better than no model, but we should refrain from a one-model-fits-all-questions ideology. Caveats should be clearly mentioned and the Board recommends the use of RHOMOLO in a wider modelling toolbox. The Board suggest the use of complementary models to shed light on policy assessments from different angles, with more technological detail and addressing aspects that well-covered by the RHOMOLO model. Furthermore, we encourage the harmonization of data across models and believe that a soft-link with other models can enhance the realism of the simulations.

One example is the assessment of transport policies. The RHOMOLO model is not designed to test the effects of transport infrastructure investments in a detailed way, as the model does not include modes of transport, mobility choices, congestion or transport network. Hence, this type of assessment can be done only in a very rough way, as demonstrated by the modelling team. From the current standpoint, there is also no need to introduce these features into the model. The availability of transport models in the European Commission, which are designed for those types of tasks, is an opportunity. In the past, the TRANS-TOOLS model has been used in this context, while in the future the use of the TNET (Transport NETwork) platform (Ibáñez et al. 2017) could be considered. Using RHOMOLO for tasks it cannot plausibly deal with might undermine the credibility of the model, which would really be an undesirable development. Therefore it is essential to use the model in combination with complementary or specialized models, such as QUEST, LUISA, TNET and others.

If the calibration of the different models of the European Commission could be coordinated to some extent (e.g. same raw data sources, same base year), then different models could potentially deliver complementary evidence to study the overall effects of the policy interventions.

5.2. Provide results independently from stakeholders to build a solid reputation
Computable General Equilibrium models typically have to be used, either explicitly or implicitly, as part of a more extended approach that includes other model types and discusses aspects that go beyond what can be modelled. In ex ante appraisal or ex post evaluation of policy initiatives, conceptually there are at least three steps:

1. The modeller needs to specify the **direct effects** of policy, excluding behavioural reactions and interregional and intersectoral interactions (e.g. how a policy translates into a particular investment flow into a region). This will often involve using the output of more narrowly focussed models or micro-orientated or econometric research. Of course, the accuracy of any simulated outcomes depends on the accuracy of the initial determination of the direct effects. Simulations with the RHOMOLO model do, in many cases, incorporate the results from other models. It should be made clear that the accuracy of the CGE system-wide simulations will depend critically, amongst other things, on the accuracy of this prior analysis.

2. The direct impacts have then to be **translated into the exogenous policy shock**, and into appropriate changes in exogenous variables, model parameters or even structure/closure rules. It is often the case that flexibility is required when approaching a new issue/analysing a new policy. It is important that even though RHOMOLO is a large model that it retains this flexibility. An example of
this second step is the translation of additional investment in a region to the productivity (parameter) of the capital stock in that region.

3. The CGE analysis then provides the system-wide economic perspective and impacts. It is strongly based on economic theory and provides a micro to macro approach allowing the EU wide impact of a stimulus to individual sectors in individual regions to be tracked. Also the separate effects of different elements of the policy-induced stimulus can be identified. The model operates primarily through competitiveness, trade and subsequent induced demand effects. It is a powerful tool for understanding and quantifying the aggregate impact of policy, and the associated spatial distribution, on a range of key economic variables.

The Board views challenges in each of the steps in this procedure, discussed separately in the paragraphs below. However, it is important to stress that the problems encountered in the first two steps do not derive from the model itself, but rather the specific way in which it is activated. In that sense, it is best not to think of the RHOMOLO model as a monolithic model that goes from policy initiative to economic outcomes in a seamless manner. On the other hand, it is at least partly the responsibility of the modeller to verify the accuracy and propriety of the initial (non-model) steps. As such, this comment is closely related to the previous subsection 5.1.

1. The direct effects of policy: A general concern is that the current policy simulations undertaken using RHOMOLO will overestimate the positive effects of EU Regional Policy due to the choices made when translating policy measures into model impulses. For example, the effects would generally be much less positive if a certain slack in policy implementation were introduced: a certain fraction of EU funds is, for whatever reason, not brought to productive use at all.

2. The translation to exogenous shocks in the model: It was felt that in a number of simulations, the direct productivity improvements that would be associated with the policy were overestimated. For example, the productivity of education measures (with an internal rate of return of 7%) could easily be lower for the target groups of EU measures and the productivity effect of publicly financed R&D measures could easily be lower than indicated by the elasticities estimated by Kancs and Siliverstovs (2016). Similarly, it was argued that the model can overestimate the short-term demand impacts of innovative projects for smaller and less developed regions. In such projects one would expect the leakage of investment funds to be much larger than in case of more standard projects as the technology and capital transfers from abroad would be higher than dictated by the regional SAM. Also the argument that the structural impact, or the long-term impact, of a given investment project materializes in the same year the money is spent seems to be convincing for piece-by-piece projects only. The impact of larger investments, whose impact materializes only upon completion, can be unrealistically large in the initial years of the project. Again, it should not be thought that these are inherent weaknesses of the model, but simply that the actual shock that is transferred to the model should be delivered with care.

3. The CGE analysis: with regards to the RHOMOLO model itself, there are two key issues. These relate to (1) the validity of the model and (2) the influence of customers of the model on the choice of key parameter values and model closures. These concerns point to the desirability of identifying a core model whose characteristics are very well known and whose behaviour is rigorously tested, and a set of additional modules and ad hoc adjustments, which increase the flexibility of the model.
However, it needs to be very clear where variants of the RHOMOLO model are being used, what has been changed and why. This point is discussed in more detail in the Section 5.3.

1) Model validity: It would be standard to test the model using simulations and model set-ups where the qualitative nature of the outcomes is known. For example, all the supply constraints in the model could be turned off so that the model should exhibit extended IO/SAM modelling characteristics. This is useful for testing the model and also for isolating particular effects. We did not see any simulation results of this, or similar, types.

2) Ad hoc adjustments: The Board was not convinced about the ex-post adjustment of model parameters to bring the RHOMOLO results in line with results of other models or user demands. It is certainly useful to compare simulation outcomes from different models, to ask about the reasons for differences in these outcomes and to think about model adjustments that reduce deviations. However, this should be organised as an open, two-way discussion process rather than the imposition of inappropriate procedures or parameter values in the operation of one model simply for compatibility with a second model. The apparent adjustment to simulations so that temporary shocks generated permanent outcomes, supposedly in order to satisfy the requirements of the customer, is unsatisfactory for and discouraged by the Board. To guarantee scientific credibility, more attention should be paid to the explicit mentioning and motivation of particular choices and to the appropriate framing of the simulation results.

5.3. Provide clarity on model specifics for each simulation

As it stands, RHOMOLO consists of several versions with modules that can be added or not and several options that can be switched on or off. This creates an unnecessary reduction in clarity in the communication of model results, both for members of the Review Board and for readers of documents based on RHOMOLO simulations. In the work of the Review Panel, the following modules have been discussed:

- Migration module (currently not used because it is set up for two, rather than three, skill groups).
- Spatial module with Cournot/Bertrand competition instead of the standard Dixit/Stiglitz set-up (not normally used because of the large computational burden).
- Further modules under development: Social module (distribution) and R&D module (process vs. product innovations).
- Using results from intermediate runs of other models (e.g. TRANS-TOOLS to determine trade-cost-reducing effects of investment in infrastructure) can also be considered as “modules” in a loose sense.

In additions, the following options have been demonstrated by the modelling team:

- Switch between wage curve and Phillips curve formulation in the wage function.
- Switch between saving-driven investment and a Keynesian investment function as inter-temporal closure of the static model.
Given this extended menu of options, the Review Board considers it as crucial that in any communication about the model it is always clear which model version is used. At the very least this includes the three aspects discussed in the following paragraphs.

First, there is a need for a clear specification of the core version of the model. The different optional modules that have been presented to the board have not always been specified in this way in the RHOMOLO documents.

Second, clear default choices should be made for the options in the model. Modelling flexibility certainly increases where the user has access to a range of options concerning key characteristics of the model. However, simulation results become confusing if options can be combined at will. A structured presentation of model results in the form of alternative model formulations as compared to the default option helps to keep the overview.

Model modules and options should be introduced and explained using standardised, simple shocks, i.e. shocks in one dimension, in one region and of a standard size. This way, one can identify, for instance, the difference made to the GDP impact of an infrastructure investment of size x in region y if the migration module is switched on or off. The following subsection builds further on this suggestion.

5.4. Decompose results to illustrate the driving mechanisms

A clear description and presentation of the results is fundamental to understand how the model works, how different modules interact and what the main drivers behind the results are. Moreover, an intuitive presentation of numerical results can offer a way out of the trade-off between ease of understanding and model complexity. Hence, clarity in reporting can play an essential role in conveying the main messages and bridging the gap between the technical perspective of modellers and the practical viewpoints of policymakers. Since economic geography is an important aspect in a spatial model such as RHOMOLO, maps are an attractive way to visualize results. The RHOMOLO team has well understood this and has produced an enlightening set of maps to illustrate the results from different policy simulations. In addition to maps, the Board encourages the RHOMOLO team to continue to explore alternative ways to analyse and present the outcome of model simulations. The best way to report results may depend on the (results and conclusions of) specific scenarios. Nevertheless, two concrete examples are given below.

The first suggestion relates to the build-up of scenarios. The power of a CGE model such as RHOMOLO is not only that it can provide quantified answers to policy questions, but also that the model can be informative on the channels through which policy impacts arise and spread to other sectors and regions in the EU. To disentangle the impact of different modules and mechanisms captured by the model, a careful build-up of scenarios with incremental increases in complexity should be considered. This could involve scenarios ranging from a back-of-the-envelope analysis or a close look at the initial shocks introduced, to a 'naive simulation' with the simplest version of the model to a scenario with a model version that incorporates the full-blown set of functionality. By adding complexity stepwise, one can disentangle the relative importance of different mechanisms present in the model in determining the final assessment of a policy measure. To identify spill-overs,
the RHOMOLO team could consider a comparison of the sum of single-region model runs (if not too time-consuming with the present level of geographic disaggregation) with a model run in which policy measures are implemented in all regions simultaneously. To quantify policy interactions, different policy measures could first be assessed separately, and then jointly. The RHOMOLO team could think about how a stepwise scenario building approach could best be used to illustrate the importance of different mechanisms in the model, such as spatial effects, interregional trade connections and tax recycling schemes, by activating/deactivating the migration, R&D, Bertrand/Cournot imperfect competition modules and by adjusting parameter values (e.g. start with fixed unemployment and Leontief trade structure and gradually move to more realistic assumptions).

The second example is simply an illustration of a type of visual output that could be useful to illustrate the informational value of the RHOMOLO model. This and alternative ways to report results can be used in combination with the stepwise scenario build-up mentioned above. Figure 1 plots (fictitious) simulation results against (fictitious) data used as an input in the scenario for 267 regions of 6 countries (or country groups). In cases where both axes can be expressed in the same units (e.g. % of GDP), the 45° line is what would be obtained without incorporating behavioural responses, economy-wide feedback mechanisms, etc. – in short, without the use of a model (e.g. net receipts from Cohesion Funds). The position relative to this 45° line provides a first estimate of economic interactions, spill-overs and competitiveness effects, which can be used to further analyse the results.

One of the strengths of the model lies in the interregional interactions and spill-overs. In addition, interregional spill-overs are an important reason for EU government action. Therefore, the model could be used to illustrate which shocks, in which regions and through which mechanisms, generate the most substantial spatial spill-overs.

![Figure 1: Alternative way to present simulation results; each circle represents a NUTS2 region (n=267)](image-url)
5.5. Set up realistic scenarios including real-world financing instruments

RHOMOLO is a simulation, not a forecasting model. Such CGE models are ideal for identifying the system-wide impacts of specific exogenous shocks (particularly policy shocks) to the economy. The model is parameterised to be initially in long-run static equilibrium, so that if it is run forward with no changes in the exogenous variables (population, external EU economic conditions, technology for example), the endogenous EU regional economies will similarly remain unchanged. Whilst this is unrealistic, it is a conceptual strength because it provides an automatic (no change) counterfactual.

However, there is then a requirement that the full direct implications of introducing a policy change in the model need to be properly identified. On this score, the topic that raised most concern was the financing of policy changes which involved increased EU expenditure. At present the assumption that was adopted was that these were financed by neutral, lump-sum taxes on household income. Whilst this is a procedure often invoked in CGE simulation, the reason is to separate the impact of the policy from the supply-side impact of its financing. However, this actual supply-side financing impact is probably going to have a negative impact on measured economic activity, so that the simulations at present will tend to overestimate the impact of EU regional policy.

There is no easy answer to this issue but investigation of the impact of introducing non-neutral financing options would be a useful exercise to attempt to get a ball-park measure of the size of the problem.

5.6. Continue with further sensitivity analysis

The data construction process, the parameterisation of the model as well as each of the three steps described in section 5.2 involve a degree of uncertainty. The Board feels that it is important to acknowledge this in the communication of simulation results. In some cases, presenting a range of results may be appropriate. In their presentation of the results of structured sensitivity analysis to the Review Board (not published yet), the RHOMOLO modelling team has introduced important procedures to systematically check crucial elements of the model. The Review Board encourages the modelling team to continue these types of experiment. The following comments may help to guide the process.

It should always be made clear in the communication about the sensitivity analysis, and the model results in general, that a validation of RHOMOLO in the narrow sense (i.e. a direct comparison of model results with real-world developments) is not possible. As with other macroeconomic models, the absence of the possibility to perform experiments in the real world economy puts close limits on the options of model validation. This is self-evident for economists, but needs to be clearly communicated to an audience without a background in academic economics. Sensitivity analysis should therefore be framed as a means to identify the parts of the model that are crucial for the quantitative model outcomes. The main effort in the empirical foundation of model parameters must be directed to those parameters that are identified as drivers in the sensitivity analysis.

As presented during the meeting with the Review Board, in the current version of the RHOMOLO model sensitivity analysis has been mainly focused on the deep parameters, in particular the elasticities of substitution in the various CES functions throughout the model. With respect to these
parameters, the results are reassuring: most parameter value changes have only a limited effect on the overall model outcomes. A notable exception is the wage curve elasticity, which deserves closer scrutiny.

A number of rather “shallow” parameters of the model have not been included in the sensitivity analysis yet. These parameters control the translation of policy shocks into economic variables and potentially have a large effect on the model outcomes. Examples are the Mincer parameter, which translates education expenditures into productivity increases, the elasticity of the R&D function, which does the same with R&D expenditure and the parameters that govern the spatial spill-overs on R&D.

In any case, an encompassing sensitivity analysis of the model should stress that the main uncertainty in the results is generated in the step that determines the initial impulses (in terms of productivity increases or cost reductions) that enter the economic system, rather than in the parameters that govern the details of the economic mechanisms. The former type of parameters contains also the parameters that are the most important candidates for further empirical work.
6. Further considerations
The Board recommends that the team develops a strategy for further work on RHOMOLO. This strategy could inter alia be based on priorities from the policy DGs of the Commission and other model users. The results of the sensitivity analysis are another source for establishing research priorities, as are the recommendations of the review Board.

It is well known that place-based models have a tendency to become more and more detailed because the real world is very heterogeneous and stakeholders and fellow modellers come up with numerous requests to accommodate the heterogeneity. It is important that the team makes deliberate choices every time it is faced with such advice.

The presentations during the review meeting did not touch upon Quality Control and issues like model version management. Nevertheless, the Board wants to stress the importance of these topics. The size of the team, the number of customers of the model and the political relevance of the model results are all growing in size and importance. This makes the Quality Control in all its aspects a high priority.

The Board encourages attempts to try and link to existing national inter-regional modelling teams to test and compare data, model properties and simulation results. A broad involvement of stakeholders will be beneficial for the model development in the long run.

References


Biography of the members of the Review Board

**Stefan Boeters** works as a researcher in the Netherlands Bureau for Economic Policy Analysis (CPB). He completed his PhD at the University of Dortmund on general equilibrium effects of tax policy. In his subsequent work at the Centre for European Economic Research and the CPB, he has focused on applications of CGE models in climate policy, international trade and tax policy. His special expertise is in labour market modelling in a general equilibrium context.

**Leen Hordijk** led the Review Board in conducting this model review. He has obtained his doctoral degree at the Vrije Universiteit Amsterdam, after which has worked, among others, as the Director of the International Institute for Applied Systems Analysis (IIASA) and of the Institute for Environment and Sustainability, the Joint Research Centre of the European Commission (IES-JRC).

**Artem Korzhenevych** is the head of a research area at the Leibniz Institute for Ecological Urban and Regional Development (Dresden, Germany) and a professor of regional, urban and environmental economics at the Technical University of Dresden. He is a specialist in CGE modelling, in particular in the areas of transport and regional economics, environmental and climate policies, and has implemented a number of projects in these areas for the European Commission and the German Federal Ministries.

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**Kim Swales** is Emeritus Professor at, and past Director of, the Fraser of Allander Institute at the Strathclyde Business School, Glasgow, UK. He has a long-standing interest in regional economics, modelling and policy. He is a member of the team involved in the development of the AMOS suite of regional/national Computable General Equilibrium (CGE) models of Scotland and the UK and has worked on the GEM-E3 model.

**Toon Vandyck** completed his PhD at the University of Leuven (KU Leuven) in 2013. In his dissertation, he developed regional CGE models to study the efficiency and equity of energy taxes and road pricing. In his current position at the European Commission (DG JRC), he is responsible for assessing climate and energy policies in a global and European context with the GEM-E3 model.

**Attila Varga** earned his PhD at West Virginia University (USA) in 1997. He is professor of Economics and Director of the Regional Innovation and Entrepreneurship Research Center (RIERC) at the Faculty of Business and Economics of the University of Pécs. With his collaborators he has developed the GMR (Geographic Macro and Regional) model system for policy impact analysis of various interventions supporting knowledge-based regional economic development.

**Janos Varga** is part of the unit working on 'Model based economic analysis' in the Directorate-General for Economic and Financial Affairs (DG ECFIN) of the European Commission. He is an expert in endogenous growth and regional policy modelling.

**Marcin Wolski** is an economist at the European Investment Bank (EIB), specialising in the fields of monetary and fiscal policies as well as banking and financial econometrics.