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Methodology Does Matter: About Implicit Assumptions in Applied Formal Modelling

The case of Dynamic Stochastic General Equilibrium Models vs Agent-Based Models

Claudius Gräbner*

This article uses the functional decomposition approach to modeling (Mäki, 2009b) to discuss the importance of methodological considerations before choosing a modeling framework in applied research. It considers the case of agent-based models and dynamic stochastic general equilibrium models to illustrate the implicit epistemological and ontological statements related to the choice of the corresponding modeling framework and highlights the important role of the purpose and audience of a model. Special focus is put on the limited capacity for model exploration of equilibrium models and their difficulty to model mechanisms explicitly. To model mechanisms that have interaction effects with other mechanisms is identified as a particular challenge that sometimes makes the explanation of phenomena by isolating the underlying mechanisms a difficult task. Therefore I argue for a more extensive use of agent-based models as they provide a formal tool to address this challenge. The overall conclusion is that a plurality of models is required: single models are simply pushed to their limits if one wishes to identify the right degree of isolation required to understand reality.

Keywords: Functional decomposition approach, general equilibrium, agent-based models, methodology, epistemology, ontology, formal modeling, isolation

1. Introduction

In 1977 the then president of the Royal Economic Society stated that "methodology does not matter" (Hahn, 1977). And indeed, until today, methodological considerations have been largely absent in the majority of applied economics research papers. It seems that most researchers focus on the application of their models and prefer to develop and explore these models - not to justify them. According to a widespread belief methodology would indeed not matter too much as long as models as such were good:

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Models based on bad methodological considerations would turn out to be bad models in any case, no matter if one considers economic methodology explicitly or not - and if a model would be a good model, methodological consideration could not turn it into a bad one.

I will argue in this article that this point of view, widely accepted as it may be, is wrong. It is wrong in a very unpleasant way, because its failure does not come up as a false derivation of a proof that can be clearly identified as such. It is implicitly present in many state-of-the-art economic models and it does not invalidate the models as models. But it has important consequences for the inferences from the models to the real world and for the discourse within the scientific community about (and through) the models. These consequences do not come clear immediately if the model is discussed in isolation, but require the consideration of the whole modeling framework in which the model has been developed, and of the purpose for which the model is designed and finally used.

I build upon the functional decomposition approach of models (FDM) developed by Mäki (2009b) and use two formal modeling frameworks as an example to illustrate the usefulness of the approach: Dynamic stochastic general equilibrium (DSGE) models, that dominate the landscape of macroeconomic research, and models from the framework of agent-based computational economics (ACE), that increase in popularity especially in fields dealing with economic complexity, but are a peripheral approach in economics still. I use these two frameworks because they are similar enough to be compared easily and DSGE models are representative for a wider range of economic models. This article does not argue for a *general* superiority of one approach over the other, but to illustrate the consequences of the choice regarding the one modeling approach or the other, and how this choice depends on purpose and audience of the model.

DSGE models are said to have brought a consensus about the correct way of macroeconomic modeling and are the natural way to model macroeconomic phenomena for the vast majority of economists (Mishkin, 2007; Goodfriend, 2007). They are not chosen because of methodological considerations but because they are the standard in their realm of application. In practice, their use does not require any further justification any more. Comparing these models with ACE models reveals many of the implicit assumption inherit in the technical foundations of the models. These hidden assumptions, while generally not being discussed, are crucial if one wishes to infer from the models to reality. In this article I will illustrate how the praxis of how DSGE models are used blurs potential pitfalls inherent to this attempt of inference and the important epistemological and ontological consequences inherent to the use of DSGE models .

In particular, the latter have serious difficulties in modeling mechanisms explicitly, but are well suited to simulate their consequences. This is very important from an epistemological point of view and an advantage of ACE models that has not been discussed in the literature so far. I think that even a large part of the discussion about the (artificial) distinction between *explanatory* and *predictive* modelling is at its very core a discussion about whether one should model mechanisms explicitly or only replicate their consequences. While I think that there are situations in which either of the two options is to be preferred, a clarification of this distinction will not only proof valuable to compare GE modelling with ACE models but necessarily leads to the conclusion that depending what purpose the modeller attaches to its model, either of the two approaches might be the adequate choice.

This means that ACE models are not automatically superior to GE models. In particular, the existing ACE models represent countless different approaches to economic modeling, and range from simple, qualitative models, to extremely complex models whose parameters become estimated. Some of them are used for prediction purposes, others to illustrate certain mechanisms. Some are very similar to certain GE models, others represent a contrary approach. while GE models are implicitly bounded to an instrumentalist epistemology, the ACE community has not yet developed a common approach to give epistemic meaning to their models. This is a serious shortcoming. I argue that the FDM as developed by Mäki (2009a,b) and interpreted in this article is able to fill this gap.

The rest of the paper is structured as follows: I start by providing a verbal sketch about the nature of DSGE and ACE models in section 2. I then argue that both modeling frameworks are subject to a reasonable comparison because both constitute formal systems in which conclusions are reached deductively and both are in principle computationally equivalent (section 3). In section 4 I introduce the FDM in more depth and discuss the distinction of modeling mechanisms or facts and interpret the methodological consequences in the context of ACE vs. DSGE modeling. I then point to difficulties attached to the isolation of mechanisms in the course of modeling (section 5) and discuss two intuitive examples and possible solutions in section 6. After a discussion of the results in section 7 I conclude in section 8.

2. Introducing DSGE and ACE models

I will not provide a technical exposition of the two modeling frameworks, but give an intuitive verbal description. For a good introduction into DSGE models see Canova (2007), Gali (2008) or Walsh (2010), for ACE models see Borrill and Tesfatsion (2011).

2.1. Dynamic Stochastic General Equilibrium Models

DSGE models were developed as a response to the Lucas critique that criticized Keynesian macroeconometric models for ignoring individual rationality and to have proposed policy measures that have led to the period of stagflation in the 60s and 70s: macroeconometric models have suggested a negative relationship between unemployment and interest rate (the original Phillips Curve). Therefore governments were thought of facing a trade off between unemployment and inflation. But it turned out that these models confounded correlation with causation: If people are smart and adaptive, they anticipate the effects of an expansive monetary policy of the state and adjust their consumption and investment decisions accordingly. In this case, higher inflation does not yield a stimulus for the economy and the employment rate does not change. The response of Lucas and other neoclassical economists were the real business cycle (RBC) models that assume perfectly rational agents that optimize over an infinitely long time horizon, therefore forming optimal expectations that are consistent with the model. The state of the art are now New Keynesian DSGE models that address the shortcomings of the RBC literature by including market frictions and financial markets. They generally consist of three blocks: The demand block consists of a representative household. The supply block consists of a representative firm that acts in a perfect competitive market and sells its goods to the household. Additionally there is a continuum of firms producing distinct intermediate goods that are sold in a monopolistic market to the final good firm. The intermediate goods firms are owned by the household and pay dividends to it. The third block consists of a monetary authority that pursues a certain policy, most commonly a Taylor rule. As DSGE models normally do not have a closed form solution, solutions can be obtained only approximately Aruoba et al. (2006). The models are designed in a way such that the economy has a unique and semi-stable saddle state. The functions can be linearised for the neighborhood of this steady state and one can add stochastic disturbances to the model and calibrate or estimate it using empirical data.

While more and more aspects, including financial markets, are added to DSGE models, some mechanisms must necessarily stay beyond their scope. There is, for example, no way to consider heterogeneity of agents and explicit network structures simultaneously in the same model - this is particularly severe, as will be elaborated in section 5.

2.2. Agent based computational models

The fundamental idea of agent-based modelling is to start with a number of heterogeneous agents, that can be different in many respects but usually share the same attributes, e.g. *age*, *wealth* or *health condition*. For the collection of all agents (or a subset of them), aggregate properties can be computed, such as *total wealth*. The agents interact with each other in a specified manner, i.e. according to a graph specifying whether which agent interacts potentially with which other agent, whether they meet in a deterministic or random manner and whether their interactive structure is static or dynamic. What the single agent does might depend on her own state only, the state of their neighbors or on properties of the system as a whole. All agents change their states according to their update functions which can depend on the present state of the agent, their neighbors, specific groups of some aggregate property of the system. Because the resulting system of equations is usually to complicated to allow for a closed form solution, the models are solved via numerical simulation. The resulting flexibility explains why ACE models are widely used outside economics, e.g. to forecast the weather, design traffic systems, model the mating behavior of mosquitoes or the emergence of institutions. Formally, ACE models are usually written in a computer language and represent a mixture of computer code and equations.

3. Formal similarities

From the above said it becomes clear that both modeling frameworks are formal in the sense that they represent logical systems in which any step in the model is a deductive step. The initial model configuration with the initial conditions for the parameters, the preference structure, the network structure, etc. can be interpreted as the axioms of the system. The rules of inference are the rules according to which variables in the model change. Examples are the local update functions for the agents in the ACE or the monetary policy rule of a DSGE model. Thus, in every time step from t_{n-1} to t_n the model state M_n is deduced from the previous model state M_{n-1}. This makes the two frameworks subject to a reasonable comparison. Intuitively, the above said suggests that ACE models are a richer modeling tool than DSGE models. This is because even a lay person can imagine that in an ACE many different agent trade with each other in different spaces, i.e. on a complete network where everybody can reach anybody else, or in a restricted network where some agents can trade with many others, but others have only few chances to engage in trade. But the definite assessment of such a question is more subtle:

Asking questions about the generality of two modeling frameworks means to ask a question about the computational foundations of these frameworks. "Computational" in this context must not be understood as a too technical term: What we are interested in is, whether one of the frameworks can express everything the other framework can express, or even more.

In order to make the argument clear, I make use of a theoretical model of a machine that does computations, i.e. takes steps in a model. One of the most famous examples is the Turing machine (TM): It is an imaginary machine that can in principle compute any algorithm. In fact, it is used to provide a formal definition of what an algorithm actually is. The TM consists of a writing head focused on a tape. The tape has an end on its left side but is infinitely long to its right side. It is divided into many squares. There can be only one symbol on a square and there is a finite number of different symbols. The writing head is in one out of (finitely) many possible states, reads the current symbol on the square, may override the symbol on the square and can move the tape while potentially changing its current state depending on the symbol on the tape. This theoretical machine is useful, as it can simulate every physical computer (excluding, maybe, quantum computers). There are other theoretical machine models that work in a different way than the Turing machine, e.g. the register machine which intuitively resembles the functioning of the assembler in real computers. Although the actions of the two machines are very different, they can simulate each other in polynomial time. This means they can generate the same kind of computer languages, can finish the same calculations and are therefore equally powerful. This is the famous Church-Turing thesis at the heart of modern computer science. It can be shown formally that the same is true for DSGE and ACE models: Both represent Turing-complete systems and are *computationally equivalent*.[1]

We skip the formal argumentation that has been outlined in greater detail in Gräbner (2014), but the logic is the following: DSGE models represent differential equations with more than two degrees of freedom.

[1] For more information about machine models and computability see e.g. Martin (2011).

Such systems are called *Turing-complete* because they can simulate a Turing machine. The adequate computational model for ACE models is a community protocol, as the computation of the overall system emerges from the many computations done by the individual agents. It has been shown that community protocols have the same computational power than Turing machines (at least for situations that are of interest for us, see Guerraoui and Ruppert (2007)). DSGE and ACE models are therefore computationally equivalent.

4. The functional decomposition appraoch and practical differences in the application of ACE and DSGE models

While the two modeling frameworks have theoretically the same expressive power, practically, things are more complicated. I will use the FDM to clarify the practical relationship between the two frameworks. The FDM allows one to consider the role of purpose and audience of a model. Both aspects are crucial to understand the role currently played by DSGE and ACE models in economic research, but also to understand the variety of different epistemological approaches within among ACE models (and why such a variety is smaller in the DSGE context).

While both ACE and DSGE models usually have the the purpose of either to explain an economic phenomenon or to provide policy advice, their audiences are quite different: DSGE models are especially popular in the economic mainstream, while ACE models are widely used in complexity economics. I will come back to the discussion about the role of the different audience in sections 4.2 and 7 and but first, I first need to introduce the FDM in more depth. It allows us to understand how the formal models can gain epistemological meaningfulness despite the unrealistic assumptions they carry. This meaningfulness is required to make reasonable inferences from the model to reality and is thus particularly crucial for models that aim at informing public policy.

4.1. Introducing the functional decomposition approach

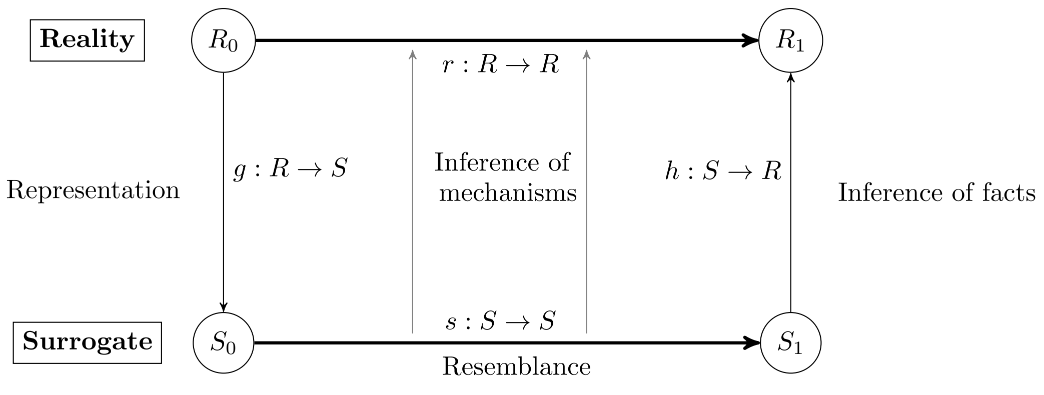

Figure 1: Modeling as a mapping process and as a mean for representation and resemblance.

According to the functional decomposition approach models are representations. They have two aspects: The representative aspect and the resemblance aspect. To be representative means to serve as a *surrogate* for the real world. This means that the model is built as an image of the real world.

To build a model that represents the real world is considered to be a *weak success*, because it is only a first step to *understand* something about the real world. It is is a success because it is also possible to study a model for its own sake - for the beauty of its math or because one likes the story associated with the model. If one does not even try to represent anything in the real world, one commits a *strong failure*. In this case the model is no surrogate, but a *substitute* that is studied instead of the real world, not as a measure to get insights into it. Many theoretical models of economics are accused to commit this failure, but ACE and DSGE models in particular are applied models that try to inform policy or public action. So there is no case of a strong failure here. I have interpreted this part of the FDM as a mapping process in figure 1 (Miller and Page, 2007; Moss, 2009; Gräbner, 2014). The process of reducing the real world R to the model can be described by a function $g : R \rightarrow S$. For the state real world at time t_0 (denoted R_0 in figure 1) it gives a corresponding model in state S_0. The surrogate (or the model) is always less complex than the real world. I call g therefore the complexity reduction function of the model. Although a model might include several factors that are not present in the real world, these additions are generally added to make the overall system easier: While real individuals have much less computational capacity than their economic counterparts, the presence of such actors makes a system simpler to handle by the modeller (Mäki, 2009a, p. 31), i.e. the *exploration* of the model gets facilitated.

Model exploration denotes the study of the behavior of a model. It means to study the transition function of the model, denoted by s in the figure. This function transforms the state of the model at time t_0, denoted by S_0, to the state at t_1, denoted by S_1. The general idea is to learn something by the model exploration about the behaviour of the real world, i.e. the transformation function r, that is, in its completeness, too complicated to be understood by the scientist. In order to get the desired epistemic meaningfulness, a model must also *resemble* the real world, i.e. it must be useful to understand r. This means that we can learn something by applying the combination of functions $h \circ s : S \rightarrow R$.

This explains partly why many economists react indignantly to the reproach of making unrealistic assumptions: They want to resemble facts about the real world. They do not care too much about an adequate representation but put the match between S_1 and R_1 at center stage. This match is considered a proof that the resemblance of r through s was successful. Most audiences in and outside economics agree to this criterion: the match and a rigorous derivation of the model results, i.e. a well-specified transition function s, are often considered the most important aspect of the model and its exposition. But is this criterion without problems? The answer depends mainly on the purpose of the model, as well become clear from the next section.

4.2. Modelling facts or mechanisms?

Some immediate questions arise: Is there a difference between modeling facts or mechanisms? If yes, does the distinction matter and, if it does, which option is to be preferred? The answers are "yes", "yes", and "it depends" respectively.

Regarding the first question, is a model meant to resemble facts or mechanisms? To speak with figure 1, is it mainly the state of the world in $t + x$ that the model should predict or should it describe parts of the transition function g most precisely? Given knowledge about R_0 and a suitable surrogate S_0, there are many possible mechanisms providing the same prediction for R_1. Because equifinality is common in nature, many of these models could be "correct". The question of model selection would then be a matter of abduction, if one is interested in understanding the underlying mechanisms, or a matter of applying Ochams razor, if one is interested in getting R_1. So the distinction certainly exists. An example from the DSGE literature is the widely used Calvo pricing due to Calvo (1983): In order to incorporate Keynes idea of sticky prices and wages into DSGE models one assumes that firms can optimize prices and wages every time step only with a given probability. While this is not the mechanism Keynes had originally in mind, it has a similar effect in the model.

The distinction also matters for the process of model building: To model mechanisms explicitly, i.e. to design the transition function of the models such that it represents the transition function of reality, requires the inclusion of all aspects of reality that are relevant for the mechanisms to be explained during the representation process: If we want to consider how a distribution of links among the individuals affects the distributional effects of a specific exchange mechanism, then we need to implement a given network structure explicitly in the model. Otherwise we could not explore the model in this direction. Exploration therefore requires a certain degree of accuracy in the representation process. This requirement is not without problems: Due to their technical design, DSGE models reduce the degrees of freedom for the formulation of the complexity reduction function and thus limit the number of mechanisms to be explored in the model. The justification for the technical design is the increased clarity associated with DSGE models.

Many mechanisms are excluded from consideration systematically by the technical construction of DSGE models: All mechanisms involving downward effects and mutual interdependence of the different levels of the economy, mechanisms involving non-rational behavior of economic agents or mechanisms based on the structured interaction of heterogeneous agents cannot be implemented as such. The consequences of these mechanisms might be replicated in a sophisticated DSGE model, but within the DSGE model other mechanisms bring up the results. The results are explained in the DSGE framework, i.e. as the consequence of the choices made by rational agents and firms, acting in an environment of economic equilibrium, perpetuated by exogeneous shocks. This means that one did not represent the mechanisms, but only their consequences and the resulting states. This suggests that modeling mechanisms is substantially more difficult as to explain a fact, if explanation is considered to be the deduction of the explanans from some well defined axioms, simply because there are many potential mechanisms that bring about one fact. A mechanism, however, is by definition unique and its identification requires substantial effort.[2]

Such an approach has merits and disciplines research, but it also suffers from some serious shortcomings: To be widely applicable, insights are preferably about mechanisms: In reality, facts are always the consequence of a specific combination of mechanisms. If one wishes to transfer the insights from one model designed for a certain situation to another situation without building the model anew from scratch, one is required to posses a certain toolbox for mechanisms that can be included into and excluded from the model.[3] This requires models that have a modular structure such that some mechanisms of the model can be exchanged while the rest of the model is left unchanged. This is a feature intuitively implemented in ACE models, but very cumbersome (if not impossible) in DSGE models. In praxis, this "shortcoming" is not really problematic as the most accepted form of "explanation" in economics is the derivation of the phenomenon to be explained from well-specified micro assumptions, i.e. preference relations and the like. And DSGE models serve this purpose very well. This is another reason for their superior popularity compared to ACE models: The increased flexibility of ACE models is not so much of an advantage if one presents one's models to an audience that favors explanation via one specific form of reduction that can be implemented best in the (less flexible) DSGE framework. The increased flexibility of ACE models is not a positive asset for this kind of audience, but comes up with less clarity and much more variety of the existing models.If the audience would be a different one, that pays particular attention to the underlying mechanisms and not so much on the correct prediction of the future, then such an audience might be much more open minded to the applicatoin of ACE modes and more rejective towards DSGE modeling. The institutionalist or evolutionary communities in economics might be examples for such audiences.

This brings us to the third question, namely whether it is better to model facts or mechanisms. The answer depends on the purpose and the audience of the model, i.e. the pragmatic constraints of the model.

In this context it is important to emphasize again that both DSGE and ACE models are always unrealistic in the sense the some of their assumptions are false. They share this property with all economic models. The FDM allows to justify the falseness of some of the assumptions by referring to the concept of isolation. The isolation of a mechanism and the proof that the existence of this mechanisms together with some (maybe arbitrary) initial conditions leads certain results, can be a powerful way to understand this particular mechanisms. But isolation can be misleading if in reality it is the *combination* of different mechanisms that brings about the relevant consequences, i.e. the function r in figure 1 is in fact a composed function where its parts represent different mechanisms.

[2]Therefore, to test whether certain mechanisms in a model resemble mechanisms in the real world is always a stronger test for the realism of a model than the test for the prediction alone.

[3]Alternatively one assumes that the mechanism at work in the model is ubiquitous and unconditioned, but this has been shown to be false for the vast majority of mechanisms discussed in economics.

5. Where isolation of mechanisms gets problematic

The common justification for the isolation of mechanisms is in the spirit of the following logic: To be clear about the mechanism at work, one isolates it entirely from other mechanisms. One then argues that if the mechanisms is strong enough to lead to similarities to the real world even in isolation, it will certainly do so in the presence of other mechanism as well.[4]

Formally:

$$(H_1 \wedge M_1 \rightarrow C_1) \rightarrow (H_1 \wedge M_1 \wedge M_2 \rightarrow C_1) \tag{5.1}$$

with H_1 denoting the initial configuration, M_1 the mechanism under consideration, M_2 another mechanism and C_1 the consequences, assuming that M_2 does not work into the reversed direction than M_1.

Another way to state this is that there are no relevant interaction effects between the mechanisms M_1 and M_2.

But how can one be sure that such interactive effects do not exist? Empirical studies can only be of limited help, because no mechanism operates in isolation. If the purpose of modeling is to search for such interaction effects, then the use of ACE models can be very useful. This is because of their increased flexibility and their modular structure: as one can add or change mechanisms to the same model, one can elaborate on the consequences of the isolation in the original model. To study the isolation of a mechanism is of particular importance because it can have an important ontological dimension, namely if the isolation of a mechanism changes its functioning: If a mechanism, M_1, generally occurs together with another mechanism, M_2, and their joint appearance changes the character and the consequences of both of them, then isolating one of the other and making inferences from the models including the single mechanisms can be interpreted as a violation of the ontological constraints of the model, at least if we interpret the joint operation of the two mechanisms as a new mechanism. Formally:

$$(H_1 \wedge M_1 \rightarrow C_1) \wedge (H_1 \wedge M_1 \wedge M_2 \rightarrow C_2) \tag{5.2}$$

Interpreting $(M_1 \wedge M_2)$ as a new mechanism is the only way to make the system coherent. They must be understood as a new mechanism itself, M_3, otherwise a contradiction within the model would result. See the appendix for a proof. But if M_3 is a new, and thus different, mechanism, isolation of M_1 or M_2 means to exchange M_3 - a choice with important ontological implications. Then, if the aim of the model was to represent mechanisms, it gets into the danger of becoming a *substitute* model.

To identify such issues is possible in the agent-based framework because of the modular structure of most ACE models.[5]. This modular structure is the source for the superior exploration capacity of ACE models. Through rigorous model exploration, isolations can be tested and enfold epistemic content. This

[4] Only if the other mechanisms are working into a different direction, the consequences of the mechanisms might not be observable. But this does not mean that the mechanisms does not work at all: In its entire absence, the effect of the opposite effects would have been larger.

[5] This is because the object-oriented programming paradigm, that is used for most ACE models.

also suggests a certain complementary among the two modeling frameworks:

In place of most common economics models, DSGE models do not support such a rigorous model exploration. ACE models do. This means that if one considers the task to explain mechanisms the choice to model a situation with a DSGE model, one implicitly states that interaction effects do not exist and there is no other level in the economy which deserves consideration other than an independent micro structure. This means that the choice of using DSGE models in the context of modeling mechanisms often comes with an at best frivolous ontological statement. A common reaction is to retreats to the area of modeling mere facts retrenching to the area of predictions. But one could also test the assumption for the context of explaining mechanisms if one has the the absence of interaction effects using an ACE model. Or if one has understood the nature of the interaction and then interprets the DSGE model accordingly.

I will illustrate this point by discussing two examples where the interaction effects of different mechanisms matter, and models focusing on explaining these mechanisms provide important guidelines for the interpretation of all models involving these mechanisms.

6. Examples for interaction of mechanisms and the limited model exploration in DSGE models

DSGE models explain by deducing their resulting time series from the behavior of utility maximizing agents and profit maximizing firms. The central concept is economic equilibrium. The model is designed in a way such that a stable saddle path results, of which neighborhood the model gets linearized before stochastic shocks are added, exists. Because of this technical construction they cannot be explored in all the dimensions which might be desirable as adding a new mechanism would require a reconsideration of all other specifications made in the model such that the equilibrium path results anew.

I will now give two examples for mechanisms that are very likely to exhibit strong interaction effects with other mechanisms and therefore pose a particular challenge for DSGE models. While one of the mechanisms here might be dealt with in DSGE models of the future, the other is definitely beyond the scope of such models. The former concerns the social interaction structure of an economy, the second the process of how prices form in markets. But not only do these mechanisms pose a very high challenge for DSGE modeling, they also illustrate the difficulties that sometimes come up when isolating mechanisms in general. Both mechanisms can be assessed through ACE models and thus also serve as examples for potential complementarities between models focused on mechanisms and those focused on predicting facts: The latter can then designed in a way they efficiently mimic the factors identified in the mechanism based model, hopefully leading to better and more robust predictions.

6.1. Networks

The standard Arrow-Debreu model, still one of *the* cornerstones of modern economics, does not consider an explicit network structure. So how would the model outcome change if edges between the vertices were distributed in a certain manner? While the original model is not suited to address this question, an ACE model modeling the original model might help to answer the question and thus to specify and qualify the results of the original model. This has been done for the general equilibrium framework by Albin and Foley (1992), Axtell (2005) and Gintis (2007) who replicated the results of analytical models via agent based simulations and then added additional features such as an explicit network structure. They were then able to explore the model in the dimension of different network structures. The motivation therefore is straightforward: In reality, networks are ubiquitous: In every system involving any kind of interaction, there is a certain structure of the local interactions, which can be illustrated via a network. While the field of network science is comparatively young, it has already provided a large number of concepts through which interaction networks can be described and has described several key features of empirical networks.

Although the very details depend on the case considered, social networks in general were identified to have heavy-tailed degree distributions, show high clustering and small average path lengths. It would be a logical next step to include these information into basic economic models to consider how the introduction of these features affects the outcomes of the model. This has been done, at least for a very simple ring structure, for the Arrow-Debreu GE model (Albin and Foley, 1992). The authors concluded that considering the network structure (and the absence of a central price setting mechanism, see below) affects the distributional properties of the market. This is not only an important finding in itself, it also increases the value of the original model as a heuristic, as we know how the results change if the situation to which the model is applied, changes.

How did Albin and Foley (1992) reach their conclusion? They implemented an ACE version of the Arrow-Debreu model, replicating the behavior of the original model and exploiting the modular structure of ACE models and varied the underlying network structure *everything else left equal.* Such studies are particularly important as introducing networks alone has already important effects on the model outcome, but introducing it jointly with additional heterogeneity of the agents affects this outcome even more (Page, 2012).

6.2. Central control vs. self organization

Most analytical models in economics rely on comparative statics. This means that they prove the existence (and sometimes the stability) of equilibria, but do not consider the process of how these equilibria will be reached. Consider the canonical general equilibrium model: While the existence of an efficient equilibrium was shown to exist, it comes about only through the help of the imaginary Walrasian auctioneer. In reality, markets consist of people interacting with each other. Prices form because of offers being made, accepted, rejected and adjusted, not because everybody consults a central price authority. However, the auctioneer is still at the heart of most modern economic models, including the most sophisticated DSGE models, even if the models as such are dynamic: As was explained above, the praxis in DSGE models is to linearise the models *along their steady state*, then to add the shocks and to conduct a policy analysis. The areas far from economic equilibrium are not considered. This is why even for these dynamic models, the same criticism than for static models applies, simply because the way the equilibrium is reached in the first place is not considered. Additionally, DSGE models often assume other markets not considered explicitly in the model to be in equilibrium, e.g. the labor market. The process of how this market reaches equilibrium is left out of the argumentation.

This means that although we can calibrate a purely equation based model to produce an output more or less similar to that of the real world, but we do not know *how exactly* it resembles reality because we know that there is not Walrasian auctioneer. ACE models, on the other hand, are *generative* models (Epstein, 1999) in this respect: In the agent-based version of the Arrow-Debreu model, prices form because of the interactions among the agents, because of the offers rejected, accepted and adjusted by them. One clearly knows *how*, i.e. following which mechanism, the model resembles the reality. This has important implications: The first welfare theorem, for example, states that all outcomes from perfect markets are Pareto efficient. It is a mathematical theorem that is derived from the assumptions about the market and the preference relations of the individuals, but *how exactly* these artificial markets produce efficiency is not entirely clear. This is particularly severe if we want to infer from the model to a situation where the assumptions are not fully met: In what direction does a lack of rationality affects the efficiency of the market? There is a (mathematical) result according to which the second best result can be obtained by changing all other parameters instead of trying to meet all assumptions to the best possible degree (Lipsey and Lancaster, 1957) but this is not a constructive contribution. It would be much more attractive to simulate the different trajectories and to compare them directly.

This is particularly important because mechanisms that were identified to have certain effects in an environment with a Walrasian auctioneer might have very different effects in an environment without such a central control.Again, the problems outlined here become explicit only if one tries to represent mechanisms. If one wished to model mere states of the world, the considerations come up only implicitly, e.g. when interpreting the result of a perfect market or when motivating a certain design for the model. Furthermore, the systematic neglection of a certain class of mechanisms in prediction based models, e.g. reconstitutive downward effects, can partly explain wrong prediction of these models.

7. Discussion

I have used the case of ACE and DSGE models to clarify the epistemological and ontological dimension of implicit assumptions in much of economic theory.

I have chosen this example because ACE models and DSGE models are theoretically equivalent from a computational perspective, both frameworks are formal and purely deductive, and both models are applied, both try to represent and resemble reality. Therefore, a clear comparison was possible.

Because the assumptions of all economic models are naturally false to a certain degree, many strategies have been developed to give epistemological meaning to these models and to study their "falseness". The FDM as interpreted here is particular useful because it helps to show how DSGE models prescribe a certain form of representing reality, but also to understand and structure the huge variety of existing ACE models (regarding their ontological and epistemological orientations). But most importantly, it puts the concepts of "purpose" and "audience" of a model at center state, and both categories have been shown to be of crucial importance for understanding how the two modeling frameworks currently are used, and how their application can be improved.

and used it to show that the DSGE models prescribe a particular form of complexity reduction and that they are not able to model many mechanisms explicitly - which can be particularly problematic if mechanisms show important interaction effects with other mechanisms. In this case, the choice of which mechanisms to include into one's representation of reality has a strong ontological dimension. This is particularly true for the cases of networks and the price building mechanisms.

Here, the choice of the modeling framework inhibits an ontological conviction, and the associated isolation can come with an ontological reduction and carries the danger of breaking the ontological constraints of the model. But whether this is considered a problem depends on the pragmatic constraints of the model: Most economists use a set of pragmatic constraints for their models according to which a too detailed representation of mechanisms would be rather harmful and confusing rather than adding additional explanatory power to the model. As mentioned above, DSGE models perfectly fit to what is currently most widely accepted as an economic explanation of phenomena, namely the deduction of the the explanans from "well-specified" micro assumptions. This is exactly what DSGE models do. Furthermore, in periods where there are no major changes in the business environment, they are a good choice to make predictions.

To consider mechanisms involving a mutual interdependence of different levels in the economy such as reconstitutive downward effects (Hodgson, 2002, 2011), the consideration of the meso level of the economy, or the use of a more realistic conception of economic agents, as it is demanded by e.g. institutional economists, is not an issue for the DSGE community. The common commentaries, another important aspect of modeling (Mäki, 2009a), during the model expositions seem to provide evidence for this claim: methodological considerations do not seem to have too much importance during the model exposition in most journals and conference presentations today. This is bad, because even if the focus of the model is mere prediction, the interpretation of and the commentaries on the models should be clear about what kind of inference to the real world can be made or not. Such qualifications are often imprecise, as a match of predicted facts is too often interpreted as a proof for the complete resemblance of the real world through the model (i.e. including the mechanisms).

Are the results obtained here also valid for other models, that try to make direct statements about reality or is the case of ACE and DSGE models a rather special one? The praxis of explaining facts by deducing them from the behavior of utility maximizing individuals and profit maximizing firms via the concept of economic equilibrium is shared by most analytical models in economics. This is the main limit for the explorative capabilities of DSGE models, and so it limits much of current models in this tradition.[6] It represents a sharp reduction of mechanisms that can be considered in the associated models and is as such a strong, but seldomly discussed, ontological, and epistemological statement, which is - implicitly or explicitly - shared by most of the economics audience.

Does the above said mean that all models that do not potentially include any potential mechanism are useless? Not at all. Much of the usefulness of a model always depends on its purpose and audience. From a pluralistic perspective the coexistence of models from different frameworks is desirable. If a modeling framework serves a good purpose for very specialized task, but excludes explorations beyond this task by its technical construction, it must not be the only framework under use, as it is currently the case for DSGE models in current macroeconomics. We have also seen that the question whether one should model mechanisms instead of facts is also answered by purpose and audience of the model at hand. Sometimes, the additional effort of modeling mechanisms explicitly might be too high. But the above said illustrated particularly how the systematic exclusion of mechanisms can lead to misleading results concerning mere facts as well: If markets have other distributional effects if they worked in a decentral manner than in a centralized manner, the predictions derived from the two models differ in a very substantial sense and only a focus on the mechanisms of the model reveal the reason for this difference. And only the focus on mechanisms reveals the degree to which the dominant equilibrium framework creates uncertainty through limiting the ability for model exploration.

A rather natural question to arise is whether the comparison can be extended to verbal models. The attractive thing about the comparison between ACE and DSGE models is that they both are purely deductive and can be be compared quite easily. Many verbal models are not entirely deductive, but include deductive elements. But they also have inductive and abductive elements which makes it difficult to compare them directly with ACE and DSGE models. Still, any verbal model involves a complexity reduction of the real world that can be questioned and is to be justified, so similar arguments might be made in this regard and the elaborations can be of some use when one considers verbal models.

The above said also illustrated the importance of what Mäki (2009a) calls the pragmatic constraints for modeling: A modeler always build a model for a given purpose and a given audience and frames her work accordingly using specific comments. DSGE models fit very well the demands of most mainstream economic journals.

What will be of particular interest in the future is how the two modeling frameworks are perceived

[6] This is particularly true for computable general equilibrium models.

outside the mainstream economics journals, especially by practitioners. For the last decades, DSGE models were the dominant modeling framework also for central banks and other important policy institutions such as the IMF, the World Bank and government departments. But especially since the financial crisis, ACE models are getting more and more popular for this kind of audience as well. To see whether economists react to this trend by widening their portfolio of modeling tools is an exciting question and it is not clear how it will be answered.

8. Summary and Conclusion

This article has shown the importance of explicit methodological considerations when using formal models for applied economic research. I used the illustrative case of ACE and DSGE models to show how certain modeling frameworks constrain the possibility of exploring models in different dimensions and to represent real world mechanisms explicitly. This results in important epistemological end ontological statements that should be discussed explicitly, rather then being disregarded implicitly.

To clarify these statements I have used the FDM of Mäki (2009a,b) which is well suited to give epistemological meaning to models whose assumptions are not entirely realistic. The FDM furthermore helps to identify implicit differences in methodologically similar models.

It also helps to illustrate the question of whether to model mechanisms or facts. In particular, this question renders the imprecise discussion about explanatory vs. predictive modeling superfluous.

Finally, we were able to discuss the usefulness, but also the potential difficulties associated with the concept of isolating mechanisms, especially if mechanisms have important interaction effects with each other.

The overall conclusion is that a plurality of models is required: if one wishes to identify the right degree of isolation, single models are simply pushed to their limits. Only the comparison of different models and their mutual qualification can then bring about a deeper understanding of reality. The task is, in the spirit of Keynes, to choose the right model with the combination of mechanisms that is most relevant to the contemporary problem at hand, and to justify and qualify it in comparison to alternative models.

In this sense, the paper also argued that both approaches to modeling can be useful and can profit from each other: If one wishes to make mere quantitative predictions for a more or less stable system, a focus on modeling facts is probably a good choice. But if one wished to motivate certain designs for such models more generally, or if one wishes to derive more general statements about how the economy works, a focus on modeling mechanisms should be the preferred option. In this case, modeling frameworks that allow for a flexible specification of the complexity reduction function and can be explored in more dimensions are often necessary.

The paper furthermore illustrated the usefulness of the FDM when talking about the epistemological meaningfulness of models because it provides the necessary vocabulary to assess the methodological foundations of models and to clarify the problems such as the limited capacity for model exploration. It also highlights the important role of the purpose and the audience of the models.

Because of this, the approach also helps to explain the dominance of DSGE models: they best fit the current expectations of the biggest audience for economic models, the economic mainstream. Whether the expectations of economic practitioners will be met by DSGE models in the future is an important question and cannot be answered yet as alternatives such as ACE models are not yet developed to the same degree as DSGE models. For economists in academia, a more extensive use of ACE models in the spirit of Albin and Foley (1992), Axtell (2005) and Gintis (2007) in order to broaden the assessment of existing analytical models and to consider the combination of mechanisms explicitly seems to be an important and fruitful area of future research. In this context, the FDM can help to classify the huge variety of existing ACE models and to reveal the enormous variety of different (and sometimes contradictory) approaches to economic modeling within this community: a purely formal comparison of the models is not sufficient. But interpreting an ACE model in the FDM framework helps one to carve the theoretical content out of the models.

While there are some open questions that deserve future research, such as the question whether the technical necessity in DSGE models to isolate and explain mechanisms through the deduction of their consequences in the environment of economic equilibrium should be considered to be a mere pragmatic constraint, or this in fact means a violation of the ontological constraints to models, the the abovementioned conclusions are already sufficient to confidently contradict Prof. Hahn: Methodology matters for economists, and its neglect brings about much confusion and serious problems if our models are confronted with reality.

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A. Proof that combinations of mechanisms must be interpreted as new mechanisms

We consider the situation in which there is

1. a given initial condition, H_1
2. two potential mechanisms, M_1 and M_2
3. two potential results, C_1 and C_2

We assume that if M_1 operates in isolation, C_1 will result:

1	$H_1 \wedge M_1 \rightarrow C_1$	$A(1)$

Because we are considering a closed model we can also say that:

1*	$H_1 \wedge M_1 \leftrightarrow C_1$	$A(1)$

We further assume that if M_1 and M_2 both operate, C_2 will result:

2	$H_1 \wedge M_1 \wedge M_2 \leftrightarrow C_2$	$A(2)$

Thus

3	$(H_1 \wedge M_1 \leftrightarrow C_1) \wedge (H_1 \wedge M_1 \wedge M_2 \leftrightarrow C_2)$	$\wedge E(1, 2)$

Not considering $(M_1 \wedge M_2)$ as a new mechanism in itself, M_3, would result in the following:

4	$C_1 \vee C_2$	A(4)
5(3,4)	$\neg((H_1 \wedge M_1 \leftrightarrow C_1) \wedge (H_1 \wedge M_1 \wedge M_2 \leftrightarrow C_2))$	$\neg((3, 4)$
6(5)	$(H_1 \wedge M_1 \leftrightarrow C_1) \vee (H_1 \wedge M_1 \wedge M_2 \leftrightarrow C_2)$	$\vee E(3, 4)$

which is a contradiction to A1 and A2. Thus, the joint appearance of M_1 and M_2 should be considered to constitute a new mechanism.