Critical Mathematical Economics and the Model-theoretic Foundations of Controversies in Economic Policy

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Abstract

The aim of this article is to present elements and discuss the potential of a research program at the intersection between mathematics and heterodox economics, which we call Criticial Mathematical Economics (CME). We propose to focus on the mathematical and model-theoretic foundations of controversies in economic policy, and aim at providing an entrance to the literature and an invitation to mathematicians that are potentially interested in such a project.

From our point of view, mathematics has been partly misused in mainstream economics to justify 'unregulated markets' before the crisis. We thus identify two key parts of CME, which leads to a natural structure of this article: The first focusses on an analysis and critique of mathematical models used in mainstream economics, like e.g. the Dynamic Stochastic General Equilibrium (DSGE) in Macroeconomics and the so-called "Sonnenschein-Mantel-Debreu"-Theorems.

The aim of the second part is to improve and extend heterodox models using ingredients from modern mathematics and computer science, a method with strong relation to Complexity Economics. We exemplify this idea by describing how methods from Non-Linear Dynamics have been used in what could be called "The Dynamical Systems approach to Post-Keynesian Macroeconomics", and also discuss (Pseudo-) Goodwin cycles and possible Micro- and Mesofoundations.

We conclude by giving an outlook in which areas a collaboration between mathematicians and heterodox economists could be most promising. The focus lies on the mathematical and model-theoretic foundations of controversies in economic policy, and we discuss both existing projects in such a direction as well as areas where new models for policy advice are most needed from the perspective of the progressive political left.

Contents

1 Introduction

The Financial Crisis 2008-2009 has been associated with a crisis in economic theory, or even a "systematic failure of academic economics" ([20]). Although there had been critical voices before that time (e.g. [16], calling economics the "Naked Emperor of the Social Sciences"), the financial crisis was a turning point with even the general public and journalists asking questions about the unability of the economics profession to foresee such a major crisis. Some even noted "the unfortunate uselessness of most 'state of the art' academic monetary economics" ([23]).

From our point of view, mathematics has been partly misused in mainstream economics to justify 'unregulated markets' before the crisis. This can be illustrated by a quote from [13]: "Prior to the financial crisis, mathematicians helped to develop the Neoclassical paradigm simply because, to them, it was synonymous with economics. Since then, awareness of non-Neoclassical approaches has spread amongst mathematicians."

As one of the responses to the Financial Crisis, the "Institute for New Economic Thinking" (INET [21]) emerged, and it has called for a major change in "Economics after the Crisis" ([24]). It explicitly supports interdisciplinary perspectives (taken from [22]):

"'The 2008 Crisis demonstrated the need for more diverse approaches to math and economics. Using complexity economics, mathematical physics, and modern dynamical systems theory, we can reach beyond the traditional models ubiquitous in business schools and economics departments today."

One example is the workshop "Mathematics for New Economics Thinking" ([10]), which was an attempt to gather both mathematicians and heterodox economists, organized by Matheus Grasselli at the Fields Institute for Research in Mathematical Sciences at the University of Toronto.

Recently, there has been a "Workshop on Complexity and Economics" ([57]) at the Fields Institute, which was organized in collaboration with the "Young Scholars Initiative" (YSI) of INET ([55]) and especially the "YSI Complexity Economics Working Group" ([56]. The aim of this article is to describe some of the research is this direction - in order to see what mathematics and mathematicians can contribute to the development of a competitive alternative to the neoclassical paradigm in economics.

2 The Use of Mathematics in Standard Macroeconomics

2.1 DSGE models in macroeconomics

Mainstream macroeconomics is relying heavily on Dynamic Stochastic General Equilibrium (DSGE)-models, partly because of their microfoundation based on neo-classical General Equilibrium Theory. Also, these are the type of models that are mostly used in central banks and for policy advice (see e.g. [5]). That's why we discuss them here - for a recent survey of their major drawbacks, see e.g. [51], where it is stated that "DSGE models still fail to recognize the complex adaptive nature of economic systems, and the implications of money endogeneity. " ([51], p.1)

In the paper [34], Grasselli and Ismail articulate two main points of critique of DSGE models and their microfoundation - they state that "both 'rational expectations' are an inherently inappropriate way to make forecasts under frequent unanticipated changes in the environment and that models based on 'representative agents' merely assume away the solution of the aggregation problem, entirely disregarding the powerful negative results on stability and uniqueness of equilibrium provided by the Sonnenschein-Mantel-Debreu theorems" ([34] p. 2, also see [36, 38, 39] and section 2.2 of this paper).

They propose to use an "agent-based computational model instead, which does not rely on any free-floating notion of equilibrium either, with the possible outcomes being the result of the interactive dynamics for agents, as is the case with most complex adaptive systems". In the paper, they develop such a model in the context of banking systems. They are confident that "agent-based computational models constitute an important new weapon in the arsenal of statistical, mathematical and economic methods deployed to understand and mitigate systemic risk in modern banking systems" ([34], p. 25).

To our knowledge, there is no explicitly "mathematical critique of DSGE models", maybe with the exception of [59], which "draws attention to the problems inherent in the technique of local linearisation and concludes by proposing the use of nonlinear models, analysed globally.".

But there is a considerable literature with critical reflections on DSGE models (see e.g. [7]), which is growing after the financial crisis (for further references see [8]). While some mathematicians have focussed on criticizing DSGE-models from a statistical/forecasting point of view ([8]), we choose to focus on a theoretical problem here and elaborate on the aggregation problem in the next section.

2.2 Theorem of Sonnenschein-Mantel-Debreu on Stability and Uniqueness of Market Equilibria

The theorem of Sonnenschein-Mantel-Debreu has tremendous consequences and could be seen as the "endpoint" of the neoclassical attempt to show that a market economy is stable and necessarily maximizes social welfare. Also, it undermines a key feature of the neoclassical approach to economics: that "everything happens in equilibrium". For this idea to work out, it would be essential to prove existence, uniqueness and dynamic stability of a market equilibrium - but this fails already in the simplest interesting example, a pure exchange economy. While the existence of a market equilibrium can be proved without further assumptions (by using fixed-point theorems), the theorem of Sonnenschein-Mantel-Debreu is a "negative result" in the way that it shows the complete arbitrariness of the excess demand functions under the standard assumptions in microeconomics.

The structure of this section is as follows: We first refer to the original papers but then state and explain a modern version of the theorem. In the final part, we give an outlook how methods from symplectic topology can be used to adress the aggregation problem.

2.2.1 Original Papers and Recent References

The now so-called "Sonnenschein-Mantel-Debreu-theorem" or "Sonnenschein-Mantel-Debreu-conditions" have their origin in a few papers from the seventies ([36, 37, 38, 39]). They use methods from differential topology and global analysis and are demanding to read from a technical point of view. A more accessible treatment can be found in [6], where the question "whom or what does the representative individual represent" is asked. For a recent discussion and further references, see [4].

2.2.2 A Simplified Modern Version of the Theorem

The aim of the next section is to present a simplified modern version of the theorem, and explain its mathematical formulation. The theorem and description below is taken (with some simplifications) from chapter 5 on exchange economies from [33]:

Theorem. *Let $f : S \to \mathbb{R}^l$ be a C^3- vector field satisfying some boundary conditions. Then for any $\epsilon > 0$ we can find an economy E such that the excess demand function of E coincides with f on S_ϵ and p is an equilibrium for E if and only if $f(p) = 0$, i.e. no new equilibrium is added.*

In his book ([33]), Andreu Mas-Colell proves a version of the Sonnenschein-Mantel-Debreu-theorem using topological index theory. For a regular economy, it turns out that to every equilibrium one can associate in a natural manner an index equal to plus one or minus one, in such a way that the sum of these indicies is one. In particular, this implies that an equilibrium exists because the number of equilibria must be odd. The key insight is, however, that it is not possible to derive any stronger theorem from the general hypotheses describing an exchange economy. To get restrictions on the equilibrium set beyond the ones yielded by the index theorem (like dynamic stability, for example), it is necessary to consider special classes of economies.

The central result is the theorem above: It tells us that, except at the boundary, we are dealing with an arbitrary vector field $f(p)$, and in general, even for a unique equilibrium, it is possible for the dynamics not to approach this equilibrium from any initial point, e.g. because of the existence of a stable periodic orbit surrounding the (unstable) equilibrium.

2.2.3 Exterior Differential Calculus and Sonnenschein's problem

In the paper [35], exterior differential calculus is used to address the problem of characterizing aggregate demand of a market economy. The authors explain that, from a mathematical standpoint, the ideas of maximization and aggregation have a natural translation in terms of combination of gradients.

Specifically, this means that for a function $X : \mathbb{R}^n_+ \to \mathbb{R}^n$ representing aggregate behavior, the question is if it can be decomposed as a linear combination of gradients $D_p V^k(p)$, where $V^k, k = 1...K$ are functions defined on $\mathbb{R}^n_+$:

$$X(p) = \sum_{k=1}^{K} \lambda_k(p) D_p V^k(p)$$

A natural question, initially raised in [36] is the following: what does the above relation imply upon the form of the function X? In particular, are there testable necessary restrictions on the aggregate function $X(p)$ that reflect its decomposability into individual maximizing behaviour? And is it possible to find sufficient conditions on $X(p)$ that guarantee the existence of a decomposition of the above type? In the paper, after giving a general introduction to exterior differential calculus, two powerful theorems due to Darboux and to Cartan/Kähler are presented, which are in the end used to address Sonnenschein's problem. More material in this direction can be found in the book [40], called "The economics and mathematics of aggregation".

3 The Dynamical Systems approach to Macroeconomics

The title of this section is taken from a thesis written under the supervision of M. Grasselli ([3]). It uses modern mathematical techniques from Dynamical Systems to analyse differential equations arising in macroeconomic models stemming from a Post-Keynesian tradition (see e.g. [18]).

3.1 Post-Keynesian Macro-Models

Stock-Flow-Consistent Macro Models, based on Post-Keynesian Economic ideas, are described in detail in [18]. In this line of reseach, supported by an INET grant ([13]), several extensions of the original Goodwin model of the buisness cycle ([1]) have been analysed. The starting point was the one proposed by S. Keen ([14]) to model Minsky's Financial Instability Hypothesis, and was analysed mathematically in [9]. An extension containing a government sector was treated in [11], while inflation and speculation was incoporated into the model and analysed in [12].

3.2 Goodwin and Pseudo-Goodwin Cycles

The paper [2] contains material in a similar spirit, studying the interaction of several types of cyclical behaviour in (simplified) Goodwin- and Minsky-models. There, also the relation between Goodwin-cycles and so-called "Pseudo-Goodwin-cycles" is discussed, but there is still room to make these concepts more mathematically precise. See [15] for a first step in this direction, including a more detailed analysis of the differential equations and studying the arising Hopf bifurcation. As an illustration, we reproduce one of the figures showing a pseudo-goodwin-cycle (see figure 3.1).

All of the works refered to until now in this section deal with the aggregated Macro level of the economy. The next part of this section will be devoted to the question of a "Micro- and Mesofoundation" of Macroeconomics. In [29], a "stochastic microfoundation framework" for Minsky's Financial Instability Hypothesis is presented. This approach will also shortly be described in the next section.

3.3 A probabilistic Micro-/Meso-foundation of Macroeconomics

In section 2.2 above, we elaborated on the (shaky) Mircofoundations of DSGE Macro-Models. This section deals with the possibilities of a probabilistic Micro-foundation of Macroeconomics.

In [19], a perspective from statistical physics and combinatorial stochastic processes towards Marcoeconomics is presented. Macroeconomic models are treated as beeing composed of large numbers

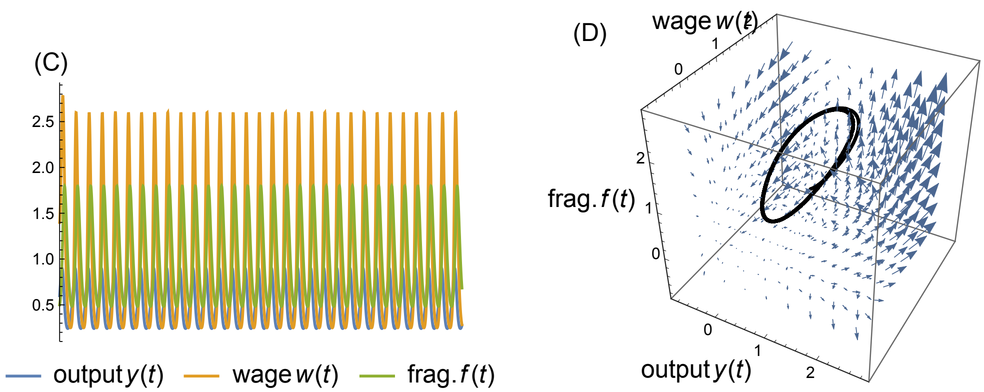

Figure 3.1: Orbit for $s = 0$. The cycle in y and f drives cyclical behavior in the enslaved variable w (f stands for financial fragility). A pseudo-goodwin-cycle can be observed. This case corresponds to the Minsky model with a reserve army effect. See [15] for a more detailed description and explaination.

of micro-units or agents of several types, and stochastic dynamic and combinatorial aspects of interactions among them are discussed explicitly. For the microeconomic foundations of Macroeconomics by interacting agents, it is stated that 'The point is that precise behavior of each agent is irrelevant. Rather we need to recognize that microeconomic behavior is fundamentally stochastic.' ([19]).

In [29], more specifically, the aim is construct such a stochastic microfoundation for Minsky's Financial Instability Hypothesis. The idea ist to identify homogeneous sub-populations of agents, and then to compute mean-field variables and study their interaction. Mathematically, this leads to a master equation: It allows the study of the dynamics of the number of agents in each cluster, i.e. the transition probabilities between the sub-populations.

Such a mean-field approximation represents economic interaction at an intermediate 'Meso-level', and is a promising addition to the toolbox. Ultimately, the aim is to combine ingredients from Agent Based Modelling, Statistical Physics and Non-Linear Dynamics in oder to create a unified model of the Micro-, Meso- and Macro-Level of the economy. A first step in this direction can be found in [28], where a dynamic aggregation of heterogeneous interacting agents leads to what can be called an "analytical solution for agent based models". But coupling this to truly non-linear differential equations at the Macro-Level (e.g. of Goodwin-/Keen-type) remains to be done.

4 Conclusion

We have discussed how mathematics is used in the standard model of Macroeconomics and presented some examples of non-mainstream approaches that use tools from advanced mathematics. For a wider discussion how heterodox economics can profit from interations with the mathematical community see [17], a project S. Keen called “Mathematics for pluralist economics”.

As there has been an enormous progress and breadth of mathematical research in the past decades, those interactions are still at the beginning. Possible interesting topics to look at for a co-operation between heterodox economists and mathematicians include:

- Systemic Risk in Financial Networks, Contagion and Financial Crises ([25, 26, 27])
- Mean Field Games and applications in economics ([30, 31, 32])
- Non-Ergodicity, Entropy and and Ecological Economics ([41, 42, 43])
- Path Dependency, Hysteresis and Macrodynamics ([48])

A particularly promising example can be found in [46], where (stochastically modified) Keen-type macroeconomic differential equation are integrated with a model of an interlinked banking system in a dynamic way. This combines ideas from the modelling of systemic risk in banking systems (where a recent reference is [45]) with the methods described in section 3.

From a Dynamical Systems point of view, other promising topics to look at include Hysteresis, e.g. with relation to Keynesian modelling of the labour market ([49]). In the future maybe even advanced topics like Spatio-Temporal Patterns, Turing instability or Delayed Feedback Control could be part of the mathematics used for new economic thinking - for a panorama of recent advances in dynamical systems theory and their interplay with a wide range of applications see e.g. ([58]).

5 Outlook: Foundations of Controversies in Economic Policy

Recently, there has been a growing interest in the relation between Complexity Economics and Policy (see e.g. [44]), and Wolfram Elsner described the “Policy Implications of Economic Complexity and Complexity Economics” ([47]). In this direction, we propose to clarify the mathematical and model-theoretic foundations of controversies in economic policy. The idea is to check the political demands in debates on economic policy and in how far they (explicitly or implicitly) relate to mathematical models. This can illuminate the controversies in and the debates about economic policy by showing in detail which modelling assumption leads to which policy outcome.

One important pillar of such a project is a didactic presentation of the results, both for the general public as well as for potential "multipliers" like students, journalists and policy makers. A first step in this direction is tackled in the Project "Model-theoretic Foundations of Controversies in Economic Policy - a Computer-based Didactic Presentation" ([72]) at the Institute for Political Economy of the Berlin School of Economics and Law ([71]). The aim of the project is "to create a didactic tool with elements of a computer game which makes those controversies explicit by presenting competing paradigms in economics and their economic policy conclusions in an interactive way. This should contribute to pluralism in the education and teaching of economics, as well as to a democratization of economic knowledge in the society as a whole." (see [72]).

But a didactic presentation of the foundations of controversies in economic policy would also be very helpful to illuminate debates among progressive forces - let us take the Euro-Crisis and the question of the common currency as one example. Many conferences were held concerning the Plan B, which was introduced first by Jean-Luc Mélenchon in September 2015 ([60]). This Plan B would be implemented in case the Plan A for a fundamental democratization of the European Union was not feasible. The Plan B proposes that countries of the EU should have the possibility to leave the Euro-Zone and to return to their own national currencies. Others claim that the focus on the currency question is connected to substantial problems. In their view, on the one hand, the risks of leaving the common currency are underestimated, while, on the other hand, the leeway that is to be gained is overestimated (see e.g. [61]) For a panorama of the different positions discussed in the German Left, see e.g. [62] - we propose to base these discussions on a common framework of mathematical models of the (political) economy of Europe, in order to illuminate the debates and maybe even to find new roads for reconciling different political positions. This might become of crucial importance when the parties in the spectrum of social democrats, greens and democratic socialists will try to form progressive governments in the future. And such a question is obvoiusly related to complexity economics, given the complexity of the political economy of the euro-crisis. One recent attempt to combine agent-based macroeconomic modeling and policy analysis in Europe can be found in [50].

We also suggest to develop new models for policy advice in areas which are discussed in the general public and in politics, but currently are non-existent or extremely underrepresented in academic economics. Examples include debates about Post-/De-Growth, basic income or gender relations. The latter would require a project we propose to call "Gender-Aware Economics", and is discussed e.g. at the Young Scholars Initiative of INET ([53]), amoung other places. Although there is a community of "feminist economics" (see e.g. [54]), it is virtually absent in most mainstream economics departments or let alone macroeconomic models used for policy advice. There has also not yet been an attempt to model the economic impact of traditional and progressive male role models (see e.g. in [64])[1].

So the goal of the project we describe is to go beyond the traditional scope of economics, and we suggest to build a model for what has been called "Solidaric Modern Times" (in reference to the German think tank "Institut Solidarische Moderne" [52]). This could include trying to model the concept of "resonance" from psychology (see [63], p. 71, where the question is asked why we accept to live in collective structures that make it very difficult for many if not most people to have a meaningful and good life). Ultimately, the aim would be to reconcile political reform strategies and more fundamental approaches in a transformative agenda, in order to tackle three important and related questions: Given the power structures that currently exist in the society and the economy, what could and should a progressive government do policywise? Or is it even not advisable to participate in a government and preferable to stay in opposition for left parties in order to shift the balance of power? And, given a majority in the society, how should we organize our collective and economic structures in order to allow "resonance" for the highest number if not all people?

As an example of concrete political demands that we propose to include in such a model is to tackle the question how an "income corridor" with minimum and maximum income could be implemented (e.g. by modelling near 100% taxation or by putting limits to the amount of money companies can deduct from their tax bills as executive pay). Also, existing (mathematical) models for Macro- and Meso-co-ordination in the economy should be reviewed, and potentially included, in order to build a model of an alternative way to organize the economy, in relation to what is discussed under the headings "Democratic Socialism" or "Economic Democracy" (see e.g. [68]).

Questions like this are discussed intensively in the political left (see e.g. [65, 66, 67]), but it is not even on the agenda of academic economics departments to think about economic models to answer them (with only a few exceptions, among them e.g. [71, 70, 69]). In this sense, we agree that there is a "systematic failure of academic economics" ([20]), and we suggest that heterodox economists and critical mathematicians join forces in order to change this situation.

[1] On p. 71 of [64], it is e.g. mentioned that the life expectancy of a low-income male member of the (German) society is 15 years lower than of a high-income women. Probably there is a bunch of very different reasons for this fact - the question is: Why is there no economic model for that, which gives a policy advice how to change it?

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