

# Gender-Aware Critical Mathematical Economics - Modelling the Social Cost of Traditional Male Role Models

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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 Critical Mathematical Economics (CME). We emphasize the need to include a 'gender-aware' discussion of care work and male role models as a key pillar of (critical) economics and provide an entrance to the literature as an invitation to mathematicians and economists interested in such a project.

The first part 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 Post-Keynesian Macroeconomics', and also discuss (Pseudo-) Goodwin cycles and possible Micro- and Mesofoundations.

In the third part, we present some ideas how to include the discussion about male role models into what we propose to call 'gender-aware economics'. Recently, there has been research on compiling the 'costs of traditional male role models'. There are also proposals how to achieve progressive male role models. The challenge is how to include these findings into (macro)economic models, and we develop some first ideas in this direction.

Finally, we outline in which areas a collaboration between mathematicians and heterodox economists could be most promising, and discuss both existing projects in such a direction as well as areas where new models for policy advice are most needed. In an outlook, we discuss the role of (ecological) data, and the need for what we call Progressive Data Science, with relation to recent discussions on Circular Economy and Democratic Ecological Economic Planning.

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# 1 Introduction

The Financial Crisis 2008-2009 has been associated with a crisis in economic theory, or even a “systematic failure of academic economics” ([22]). 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 inability 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” ([25]).

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 [23]) emerged, and it has called for a major change in “Economics after the Crisis” ([26]). It explicitly supports interdisciplinary perspectives (taken from [24]):

“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.

Also, there has been a “Workshop on Complexity and Economics” ([59]) at the Fields Institute, which was organized in collaboration with the “Young Scholars Initiative” (YSI) of INET ([57]) and especially the “YSI Complexity Economics Working Group” ([58]). The aim of this article is to describe some of the research in 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 Economics

### 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. [53], where it is stated that "DSGE models still fail to recognize the complex adaptive nature of economic systems, and the implications of money endogeneity. " ([53], p.1)

In the paper [36], 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" ([36] p. 2, also see [38, 40, 41] 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" ([36], p. 25).

To our knowledge, there is no explicitly "mathematical critique of DSGE models", maybe with the exception of [61], 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 address 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 ([38, 39, 40, 41]). 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 [35]:

**Theorem.** *Let  $f : S \rightarrow \mathbb{R}^l$  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  $S_\epsilon$  and  $p$  is an equilibrium for  $E$  if and only if  $f(p) = 0$ , i.e. no new equilibrium is added.*

In his book ([35]), 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 indices 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 [37], 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  $X : \mathbb{R}_+^n \rightarrow \mathbb{R}^n$  representing aggregate behavior, the question is if it can be decomposed as a linear combination of gradients  $D_p V^k(p)$ , where  $V^k, k = 1 \dots K$  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 [38] 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 [42], 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]). For an introduction to "Post-Keynesian Foundations" see [19], a recent treatment of "Macroeconomics after Kalecki and Keynes" can be found in [20].

#### 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 research, supported by an INET grant ([13]), several extensions of the original Goodwin model of the business 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 incorporated 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 referred 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 [31], 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) Microfoundations of DSGE Macro-Models. This section deals with the possibilities of a probabilistic Micro-foundation of Macroeconomics.

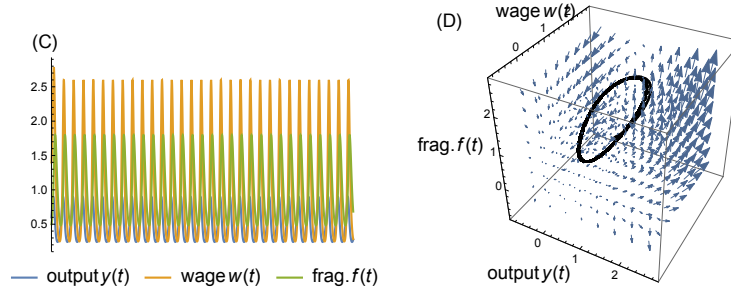


Figure 3.1: Orbit for  $s = 0$ . The cycle in  $y$  and  $f$  drives cyclical behavior in the enslaved variable  $w$  ( $f$  stands for financial fragility). A pseudo-goodwin-cycle can be observed. This case corresponds to the Minsky model with a reserve army effect. See [15] for a more detailed description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

In [21], a perspective from statistical physics and combinatorial stochastic processes towards Macroeconomics is presented. Macroeconomic models are treated as being composed of large numbers 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.’ ([21]).

In [31], more specifically, the aim is construct such a stochastic microfoundation for Minsky’s Financial Instability Hypothesis. The idea is 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 order 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 [30], 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.



### 3.4 Collaboration between Mathematicians and Heterodox Economists

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 interactions 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 ([27, 28, 29])
- Mean Field Games and applications in economics ([32, 33, 34])
- Non-Ergodicity, Entropy and Ecological Economics ([43, 44, 45])
- Path Dependency, Hysteresis and Macrodynamics ([50])

A particularly promising example can be found in [48], 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 [47]) 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 ([51]). 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 advanced methods in dynamical systems theory and their interplay with a wide range of applications see e.g. ([60]).

## 4 Gender-Aware Economics

Here, we present some ideas how to include the discussion about male role models into what we propose to call 'gender-aware economics'. Recently, a book (in German language) has dealt in detail with the 'costs of traditional male role models' (see [76]). There are also sophisticated proposals how to achieve progressive male role models, see e.g. [77]. The challenge is how to include these findings into (macro)economic models, and we develop some first ideas in this direction, it is still work in progress.

### 4.1 Patriarchy and Progressive Male Role Models

In 2023, the Swiss psychologist Markus Theunert wrote a book entitled »Boys, we can do it« ([78]) that deals with masculinity and progressive male role models.

In the introduction, he reflects on patriarchy and capitalism. He starts by naming current political threats to democracy, i.e. the "revival of authoritarianism — not only to the authoritarian rulers themselves (Putin, Xi Jinping, Erdoğan, Orbán, etc.), but also to their social consequences (war, destruction, exclusion, polarization, radicalization, hatred, moral decay, and so forth)". He continues to analyse that "the ecological and political threats are closely intertwined. Their common root is patriarchy, which in Western democracies is inseparably linked to the capitalist ideology of growth and domination. By patriarchy, I do not mean simply the rule of men, but a system shaped by male-defined rules yet upheld jointly by both men and women. [...] The patriarchal and capitalist logics merge insofar as, first, both portray exploitation—of oneself, of others, and of natural resources—as something entirely normal, even natural; and second, both do everything possible to ensure that this assumption of normality appears fundamentally and eternally without alternative."

In a recent interview ([79]), he explains that he was motivated to write the book because in the past "neither society as a whole nor men reflected on the harmfulness of common masculinity requirements. The motto seemed to be: We'll sit it out. We'll just play dumb and pretend we have no idea what we're talking about".

And when it comes to masculinity, it is not the case that things have changed vastly - he elaborates that "let's say something has changed a little. There is a discourse about toxic masculinity in the mainstream. However, for my taste, it focuses too much on toxic male behavior rather than on the structures and norms that suggest and demand it. These remain far too often unexamined. Patriarchy is extremely clever at disguising itself".

He further elaborates that "it is the compulsion to develop a masculine self-relationship, i.e. to have to behave in accordance with social masculinity requirements. These requirements exist, even if they are not explicitly laid down anywhere. And all those men or people identifying as male, who wish to find recognition, to relate as a real man, are forced to refer to these masculinity requirements in such a way that they fulfill enough of them. In this way, they avoid the risk of being devalued as unmanly". And those "masculinity requirements" still relate a lot to traditional male role models - and have very high social costs, which is the topic of the next section.

## 4.2 Modelling the Social Cost of Traditional Male Role Models

In his book "Was Männer kosten - Der hohe Preis des Patriarchats" (in German language, the title roughly translates to English as "The cost of men - the high price of patriarchy"), Boris von Heesen has dealt in detail with the costs of traditional male role models (see [76]). In a recent interview [80], he emphasizes that "the patriarchy is a burden for everyone, including men", and that "men also suffer from unhealthy stereotypes". He explains that the idea behind his book was the observation that men are socialized differently from women in our society. This has various consequences [...] For example, in the areas of traffic accidents, domestic violence, white-collar crime, theft, unhealthy eating, football hooliganism, and incarceration. My intention is not to badmouth men, but to highlight the imbalances caused by patriarchy. Ultimately, everyone suffers from this: men, women, and children."

He continues to explain that he "examined social areas for which publicly available data exists and from which the gender imbalance can be measured in terms of cost". He emphasizes that his approach was to "always use reliable cost indicators", such that does not have to estimate anything by himself. He also gives some examples how he compiled the numbers in practice, e.g. the Federal Highway Research Institute "calculates the societal cost of traffic accidents, which is 12 billion euros, and breaks down the data by gender". Based on that, he looked at who causes most of the damage. It turns out that men cause twice as many traffic accidents compared to women. The most serious accidents are largely caused by men.

Likewise, he went looked at other sectors of society in a similar way: "For instance, 94 percent of people in prison are men, and only 6 percent are women. The average daily cost of imprisonment in Germany is 130 euros". So he was able "to calculate the additional costs caused by male incarceration, which amount to 3 billion euros per year". In addition, according to the official statistics, 75

As a summary, he compiles a table on the "Social Cost of Traditional Male Role Models" ([76], p. 116). All statistics taken together, men cost the German state 63 billion euros more than women – per year:

Table 1: Total Economic Costs

| <b>Category</b>         | <b>Economic Costs</b>      |
|-------------------------|----------------------------|
| Prisons                 | 3,02 billion euros         |
| Domestic violence       | 2,75 billion euros         |
| Addiction               | 49,93 billion euros        |
| Theft                   | 1,34 billion euros         |
| White-collar crime      | 1,57 billion euros         |
| Nutrition               | 5,00 billion euros         |
| Youth welfare           | 1,96 billion euros         |
| Hooligans               | 0,17 billion euros         |
| Traffic accidents       | 2,51 billion euros         |
| Environment and climate | 1,25 billion euros         |
| <b>Total costs</b>      | <b>63,50 billion euros</b> |

One research idea could be to see in how far such social costs of traditional male role models can be put together for other countries than Germany. Then one can use concept e.g. like the "Patriarchy Index" (see [81]), a measure of gender-related inequalities in different countries, to test in how far there is a correlation between this index and the social costs caused by men.

## 5 Conclusion: Foundations of Controversies in Economic Policy

We observe a growing interest in the relation between Complexity Economics and Policy (see e.g. [46]), also Wolfram Elsner described the “Policy Implications of Economic Complexity and Complexity Economics” ([49]). 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” ([71]) at the Institute for Political Economy of the Berlin School of Economics and Law ([70]). 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 [71]).

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 ([55]), among other places. Although there is a community of “feminist economics” (see e.g. [56]), 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 [63]).

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” [54]). This could include trying to model the concept of “resonance” from psychology (see [62], 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. [67]).

Questions like this are discussed intensively in the political left (see e.g. [64, 65, 66]), 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. [70, 69, 68]). In this sense, we agree that there is a “systematic failure of academic economics” ([22]), and we suggest that heterodox economists and critical mathematicians join forces in order to change this situation.

## 6 Outlook: Progressive Data Science

We are deeply convinced that the ecological crisis necessarily demands research on post-capitalist economic systems, to which the 'STEM subjects' science, technology, engineering, mathematics (as well as many other fields) urgently need to contribute in order to achieve social progress. So in addition to critical mathematical economics, we propose to do research in what we call 'progressive data science', with strong connections to (progressive) computer science and artificial intelligence. In this last section of this paper, we elaborate a bit more on this promising research area.

The aim for such an ambitious project is e.g. to look at the European economy from an overall, ecological perspective. We propose to evaluate in how far new technologies and AI-methods allow for a new organization of an ecological economy at a European level: Can we move beyond the traditional way of doing business that all private companies plan only for themselves and achieve a more comprehensive ecological economic planning at the level of more aggregated entities? Recent developments in Data Science and AI (e.g. in the field of reinforcement learning) have enabled economic planning at large scales e.g. in multinational companies in a way that was unthinkable a decade ago, as it was published in the book "The people's republic of Walmart" [75]. We propose to use such state of the art methods from AI, reinforcement learning and game tree search to evaluate the material flows in the European Economy, and to discuss the potential for ecological economic planning on a European level on that basis. In the EU, a "Circular economy Action Plan" [73] was adopted, and one central part of it is to improve the availability of digital product data. The "EU digital product passport" (see e.g. [72] or [74]) is designed to provide information about each product's origin, materials, environmental impact, and disposal recommendations. With this European-wide product data infrastructure for all products sold and used in the EU, new forms of ecological economic planning will become possible. The discussion about the requirements and design of digital product passes has just started in recent years, and we propose to define requirements for a digital product passport to enable European ecological economic planning.

So in the future, a lot of (ecological) data will become available, including ecological data e.g. for so-called "lifecycle assessment". This creates the need for "Progressive Data Science", i.e. to use methods from data science (and AI) for a progressive change of the economic system. Since a few years, there is a hype around „Artificial Intelligence“ (AI), and we propose to have a closer look on the role that digital product data and AI (in a broad definition, see below) can play for a democratic economic system that respects planetary boundaries. One focus lies naturally on ecological questions, such as

those arising in order to „close the loops“ of material flows and achieving a „circular economy“, while also the role of care work and “male role models” is very important and should be considered from the start (see [87] or [85]). The current hype of AI was fuelled by the introduction of large language models (“LLMs”) like ChatGPT, and nowadays “AI” and “LLMs” are often used interchangeably. However, for our purpose, AI can and should be defined much more broadly: A classic definition by Marvin Minsky from the 1960s defined AI as “the science of making machines do things that would require intelligence if done by humans”, and in a recent article on artificial intelligence and modern planned economies [84], Spyros Samothrakis noted that historic debates and proposals on "Computerised Economic Planning" (CEP, also see [82]) “have been inspired by and/or have touched upon other numerate disciplines like cybernetics, game theory, optimisation, complex systems, machine learning, and statistics. Arguably, the applied cutting edge of the fields that have partially contributed to the debate is currently being studied under the broad umbrella of artificial intelligence (AI)".

Recently, there has been an application of data from "Life cycle sustainability assessment" to planning purposes. A starting point for the project of "Progressive Data Science" could e.g. be openLCA (see [openlca.org](https://openlca.org)), a free and open source software for modelling the life cycle of products and sustainability. For more context on LCA, see e.g. [83]. Ultimately, we believe a combination of Critical Mathematical Economics and Progressive Data Science is necessary in order to achieve economic democracy within planetary boundaries, as outlined e.g. in [86] or in the final section of [88].



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