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The digital twin of the economy: proposed tool for policy design and evaluation

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Abstract
The macroeconomic models of the ‘mainstream’ are hardly useful as expert support tools for policymakers. There is a need for an adequate instrument which does more realistically replicate the real-life economy and, thus, would provide better (unbiased) advise to politicians. The concept of the *digital twin of the economy* introduces an economic tool and platform which allows the dynamic-experimental development as well as objective-transparent evaluation of macroeconomic policies and is constructed on two consecutive methods: Firstly, the building plan of the underlying economic model is established by an *economic architecture*, that is an investigative approach to uncover hidden contexts for more transparency, and, secondly, the complex nature of the economy, as designed/created after that blueprint, is then dynamically as well as realistically simulated by *agent-based modelling*. The purpose of this tool and its respective platform, apart from the provision of reliable recommendations for political decision-making, is the promotion of interdisciplinary innovative research to enhance the state of knowledge in economics and to facilitate the transformation to a much more economically/ecologically sustainable as well as socially fairer economy/society.

1. Introduction

The complexity of the economy is steadily increasing due to the growing interconnectedness (e.g. global value chains) as well as rising product variety (e.g. intertwined financial services). Macroeconomic models, such as *dynamically stochastic general equilibrium models* (DSGE), miss much of the real life complexity because of – among others – unrealistic assumptions (cf. Romer, 2016) and due to these deficiencies, serve only to a limited extent as appropriate support for political decision-making (cf. Mankiw, 2006). As an example for its insufficiency,

> “the DSGE model ignored issues that turned out to be key in the 2008 crisis; not surprisingly, the model neither predicted the most important macroeconomic event in the past three-quarters of a century nor provided good guidance as to the appropriate policy responses” (Stiglitz, 2018, p. 90).

An objective economic-political tool for the development as well as evaluation of economic policy initiatives and measures [over a longer period] requires a more reliable basis which need to be much closer to reality than currently used models, especially those DSGE ones.

In a vibrant world with a tremendous variety of actors, who do not only pursue heterogeneous preferences or objectives, but also differ significantly in their characteristics, no representative agent, household or firm reflects this diversity adequately – contrary to what currently used models with their aggregation as well as simplification endeavours suggest. Models of so-called ‘mainstream economics’ have at least at this point reached their limits – namely to support the provision of reliable real-world policy advices since they cannot, for example, represent the vital essence of the economy as a *complex system,* in which a multitude of interacting individuals “constantly change their actions and strategies in response to the outcome they mutually create” (Arthur 2015, p. X). A realistic representation of economic participants like firms with their usually intricate processes, various dependencies as well as numerous interactions can, therefore, not be achieved within the limitations of mathematical (deterministic) models that are widely used (cf. Gahlen, 1972). Assumptions made in those 'mainstream models' hardly reflect the economy properly because "as soon as one considers the economy as a complex adaptive system in which the aggregate behaviour emerges from the interaction between its components, no simple relation between the individual participant and the aggregate can be established" (Kirman, 2017, p. 37). Moreover, in today's globalized and thus highly connected world, it is getting increasingly difficult to adequately predict the impact of economic policies – both the desired results as well as the undesirable side effects, when the model just replicates a tiny as well as separated slice of the respective economy.

In contrast to many other sciences like biology or physics, macroeconomics is confronted with the restriction that large-scale experiments on a macro level with real market participants just as firms or social groups are barely feasible due to financial as well as legal reasons and hardly acceptable from an ethical point of view. Though, as Mankiw and Taylor state,

> "there are two major fields of experimentation in economics that are worthy of note. Experiments in economics can be conducted in [1] a 'laboratory' where data can be collected via observations on individual or group behaviour, through questionnaires and surveys, interviews and so on, or [2] through the collection and analysis of data that exists such as wages, prices, stock prices and volumes of trades, unemployment levels, inflation and so on [whereby this second one also includes so-called *natural experiments*]" (2017, p. 21).

However, neither can one cover all research questions by these two types of experiments, nor are they sufficient for a holistic policy advice. The collection of data only illuminates the past but does not represent the future in a sufficient way. Only models allow to predict the future, even if the past might give some highly considerable indications about the future course.

Therefore, the creation and application of models are essential. Sure, models cannot replicate the reality one by one. Simplifications as well as limitations are necessary to a certain extent. Nonetheless, models which simplify the reality with the assistance of convenient assumptions and misrepresenting aggregations lead to distortions and can scarcely contribute to address practical economic policy issues. Moreover, "the danger is that the simplifications bias the answers, sometimes in ways that we are not aware of" (Stiglitz, 2018, p. 90). Fortunately, modern IT can outgrow most of these authenticity barriers as it allows creating increasingly complex models and thus, not requires assumptions aiming at simplifying the model. Today, modern computer technology and growing IT capacities can handle models which come much closer to reality and support to prepare the foundations for objective/wise decisions. As

> "with the aid of computer-based modeling environments, we can simulate complex patterns and better understand how they arise in nature and society. Whereas in many areas of science we have relied on simplified descriptions of complexity – often using advanced mathematical techniques that are tractable and allow us to calculate answers – we can now use computation to simulate thousands of individual system elements […]. This allows new, more accessible and flexible ways to study complex phenomena – we [simply] simulate to understand" (Wilensky and Rand, 2015, pp. 13–14).

Nevertheless, an orchestrated approach is required to harness the forces and opportunities of modern computer technology with the aim to use them for the enhancement of economics.

There is a need to digitize macroeconomic models in order to adequately describe the reality and to create a tool that is capable of realizing economic policy initiatives more successfully.

2. Mastering the complexity of economics with economic architecture

Approaches from the corporate and military world evidence how complexity problems might be tackled well. The use of *enterprise architecture management* (EAM) does provide some revealing insights into corporate operations (e.g. manufacturing processes), organizational structures (e.g. consolidation potentials) or the business ecosystem (e.g. supply chains), and enhances the comprehensive understanding by, for example, shedding some light on hidden contexts. There exists a multitude of definitions about *enterprise architecture (management)*. Generally, *architecture* is in the IT defined as "the fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution" (ISO/IEC, 2011). A rather business-related description states that

> "*enterprise architecture* (EA) is a discipline [and/or sometimes also referred as a method or practice] for proactively and holistically leading enterprise responses to disruptive forces by identifying and analyzing the execution of change toward desired business vision and outcomes. EA delivers value by presenting business and IT leaders with signature-ready recommendations for adjusting policies and projects to achieve targeted business outcomes that capitalize on relevant business disruptions" (Gartner, 2020).

In other words, *enterprise architecture* investigates the properties as well as the structure of an organization's elements and the relationships between its individual components. It is therefore intended to be a rather static description of the exact nature as seen from different perspectives due to its various *views*. As an obvious analogy, one might imagine the building plan of a single-family house since it describes in detail a building with all required information for its construction. The key purpose of such plan is to provide a graphic representation of what/how is to be built. Moreover, it should be concise and coordinated to avoid, if possible, ambiguity as well as confusion. It is drawn to scale and encompasses several elevations. So, almost each craft gets its own detailed view to grasp all relevant construction specifications of that house/project, including layouts, dimensions, building materials, as well as techniques.

Apart from the creation of continuous (functional) transparency in order to cope in time with the actual state of affairs, such architectural approach supports the future-oriented alteration of business processes as well as application of technological innovations to steadily changing market conditions and evolving business purposes. Besides its primary focus on information technology, *enterprise architecture* serves as a beneficial analysis method for the entire organization. With an architectural presentation, complex problems can be examined more holistically. Moreover, different levels of granularity are feasible, whereby the depth of detail can be adapted to the respective information needs. An insightful use case which highlights the benefits of *enterprise architecture management* is given by the IT transformation at Dell.

> "In Dell's case the EA team began by establishing an enterprise vision – a blueprint to guide individual projects. This blueprint laid out the structure of the enterprise in terms of its strategy, goals, objectives, operating model, capabilities, business processes, information assets, and governance. Using the blueprint, enterprise architects can now inventory all applications and the

> underlying technology currently in use, and then map the applications to business capabilities to identify omissions and redundancies. Completing an inventory and mapping exercise has revealed overlapping and duplicate applications that are now candidates for consolidation" (Oracle, 2012, p. 3).

Another need for this holistic approach may arise when new technologies for efficiency increases are considered. As an example, one may imagine a company looking for a new industrial control software for the manufacturing process. Before, it should be known which devices must be connected and which resulting requirements the software must meet. The architectural model can provide that information, which makes the project less complicated and costly. The essence of an *enterprise architecture* is provided by purpose-related frameworks, such as *TOGAF Standard* or *NATO Architecture Framework*, which do generally include "conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders" (ISO/IEC, 2011).

The application of the *architecture method* might also be suitable and useful with regard to the (macro)economic domain. Similar to the above-mentioned frameworks, it would first be necessary to establish an *economic architecture framework*, by which economies or individual sectors (e.g. industrial clusters) could be described in detail to ensure the connectivity of the models even on a broader level. Due to such modelling conformity and compliance, scientific collaboration would be easily conceivable across different institutes or research projects. In parallel to the formal-mathematical methodology, another scientific language would be created, which could facilitate a more illustrative and comprehensible communication. Thus, even people non-trained in economics could participate in such projects and interdisciplinary research would be promoted. *Economic architecture* may not only substantially increase transparency, it also enables the execution of deep analyses and the raising of optimization potentials. Besides, there is an overarching aspect of *economic architecture* as it may open the path to a comprehensive as well as continuous coordination between requirements of the economic sphere and those of human beings. For it must not be forgotten that the economy should serve humankind while preserving its natural habitat and not the other way around.

3. Close-to-reality simulation of the economy by agent-based modelling

Based on *economic architectures*, so to speak the building plans or blueprints for the next step, industrial clusters or, as a result of intensive modelling endeavours, an entire economy could be even artificially replicated in a quite realistic manner (by assembling all necessary sub models into one large one). *Agent-based modelling* (ABM) or *simulations* (ABS), which so far have delivered impressive results in social scientific research, can serve as simulation software to bring the artificial/replicated economy to life. Briefly, "agent-based modeling is a computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within the environment" (Gilbert, 2020, p. 1). In other words, *ABM* facilitates the creation of scalable models with a variety of heterogeneous agents in an adaptive nature. Thus, complex systems can be built in which agents dynamically coexist or cooperate with each other and their surroundings while making situational-adapted decisions based on their individual-programmable characteristics and preferences. From this bottom-up perspective, emergent phenomena can be examined in a vivid way. Also, future-oriented experiments can be carried out in different settings and the outcomes, among others, can be displayed graphically in real time. There are various ways of analysing the results with the existing macroeconomic toolkit in the aftermath, too. *ABM* can therefore be used to address economic decision-making problems as well as research questions that can hardly be solved with, for example, the classical (regression) analysis and optimization techniques.

A remarkable (practical) example of the insightful application of *ABM* can be found in the modelling of financial markets. *Agent-based financial market models* have thus already proven to be valuable as artificial laboratories to help, for instance, improving the institutional framework by testing regulatory policies (e.g. transaction tax), as these models can mimic well the market dynamics (Westerhoff, 2008). Due to the individually programmable features of modelling very dissimilar/numerous intricated matters and simulating complex systems, the *ABM method* has experienced growing occurrence across various disciplines, just as from biology over physics to traffic science (cf. Wilensky and Rand, 2015). Moreover, *agent-based modelling* is also considered as an appreciated tool for economic policy analysis (cf. Fagiolo and Roventini, 2017) as well as economic policy design (cf. Dawid and Neugart, 2011).

In terms of building such models, one is quite unbound in its modelling opportunities and has therefore a huge variety of options. However, Railsback and Grimm (2019, 7ff.) suggest, for example, to start with a simple model and enhance it, just as the *Scrum Framework* proposes for software development or project management. This iterative and incremental approach is rational because in the beginning, there is barely sufficient understanding of the system and thus, it is hard to decide which elements and contexts, among others, are actually relevant. If prepared properly, *economic architecture* could at this point deliver the model's specifications as well as that required understanding of the respective system. Moreover, this building plan would bring essential transparency as well as conformity into the *ABM* creation process.

A vital tool for *agent-based modelling,* that is successfully used in many fields, is *NetLogo;* an open source and freely available software provided by the Northwestern University. This programming language and integrated modelling environment allows for an easy introduction to *agent-based modelling* as well as *simulation* of complex systems but is also broadly used in academia. It has already been applied to economic problems and could hence showcase its value (cf. Hamill and Gilbert, 2016). In addition, this software (package) provides an extensive model library with many suggestions and comes along with the support from a large community. However, there do also exist several other suitable tools (cf. Abar et al., 2017).

Crucially, *ABM* allows to include insights from modern approaches, as set out in *Prospect Theory* (Kahneman and Tversky, 1979) and *Behavioral Economics* (Thaler, 2016), by giving agents realistic human behaviours and characteristics. This might be done, for example, by implementing relevant cognitive biases and thus bounded rationality. Additionally, *economic field experiments* (cf. Banerjee and Duflo, 2017) could be carried out to identify regional peculiarities. Reasonable microfoundations are required, but not in form of "macroeconomics built on foundations that center on optimizing decisions by households and firms [because] for such an approach to be tractable too much needs to be abstracted from" (Summers, 2018). Consequently, microfoundations must be built on realistic terms to further the understanding of the mechanisms behind economic events aiming at the ability to influence them. This can probably not be achieved with formal-mathematical methods or equation-based modelling and their required unrealistic assumptions (to make mathematics tractable), as mentioned before, like those of rational expectations, as introduced by Lucas (1976). It is crucial to allow a certain level of diversity in economic models which corresponds to the fact that human beings are, among others, quite different from each other and that they are not pure rational utility maximisers. As an enormous advantage, ABM – in comparison to those restrictive, traditional methods – can handle this easily as it is not constrained by such mathematical tractability.

The required data to equip agents and their environment with realistic properties are already largely available through well-established statistical authorities and commercial market research institutes. *Big data* further improves data availability in quality as well as quantity. Of course, it is mandatory that people's privacy rights are observed. Furthermore, as a wide range of jurisdictions today disallow an abuse of data, the same should apply to the models. It must be prevented that this concept is misused to create dangerous dependencies and (quasi-)monopolies, aimed at empowering detrimental market concentration or rent-seeking by misappropriation of this proposed *research tool* and its underlying *collaborative platform*. Henceforth, a balance must be achieved between the required transparency and desirable data protection (keyword *transparent citizen)* in order to generate individual prosperity, global sustainability, and far-reaching equality of opportunity with support of this approach.

4. Interdisciplinary modelling platform for policy analysis and design

The amalgamation of *economic architecture* and *agent-based modelling* could thus establish a *digital twin of the economy,* by which real-world economic activities and phenomenon are realistically simulated and represented, respectively. A technical definition states that a

> "digital twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its digital twin" (Grieves and Vickers, 2017, p. 94).

A rather business-oriented explanation generally claims that "a digital twin can be defined, fundamentally, as an evolving digital profile of the historical and current behavior of a physical object or process that helps optimize business performance" (Deloitte, 2017, p. 3). Hence, economic policy initiatives, like measures to endorse or facilitate key industrial clusters, could be experimentally designed and objectively evaluated as well as effectively and efficiently implemented. Various policy alternatives could be run through on such tool/platform and only those that have proven to be fruitful in the test phase may go into the realization phase. This procedure allows an appropriate cost-benefit analysis at an early stage. Additionally, it helps to face subjectivity or fact distortion in political and economic debates. Political initiatives like measures combating the climate crisis or actions furthering the maintenance of infrastructure could be advanced by that rather straightforward set of methods. Hence, governments or citizens' movements could be allowed to apply that *digital twin* to let objectively evaluate their concepts while being able to improve the details. The use of taxpayers' money and the overall benefits of such proposed initiatives for society could be thus easily evaluated against alternatives. Yet, this approach would not only be suitable, among others, for optimizing existing structures and regulations but could also help to design innovative scenarios for less developed regions: Development aid as well as subsidies could be much more beneficially deployed. The current economic crisis due to the coronavirus does provide a good use case for that idea: with the *digital economic twin*, governments could experimentally test different rescue packages for upkeeping and recovery of the economy to see which measures might be the most effective and less costly ones. More specifically, by modelling, for example, the consumer buying behaviour of an entire heterogenous population, one could figure out which (e.g. income or social) groups should be financially supported to realize the highest GDP as well as welfare gains from those endeavours. As a tremendous and pretty unique advantage, reliable and unbiased quantitative advices/recommendations would arise as final results.

Well-maintained and steadily enhanced models of the most relevant economic systems could contribute, among others, to carry out those high-qualitative as well as time-critical analyses, particular, in times of crisis where quick responses are needed. Hence, such model(s) might help to develop internationally coordinated policy recommendations as previously stated. Notably, the interoperability and connectivity between these modelling methods – *economic architecture* and *agent-based modelling* – is of key importance just as it is important that each of this method has its own framework and standards. Yet, “there is a real and major problem with the use of ABM in economics and that is the lack of standardisation” (Hamill and Gilbert 2016, 239). However, if basic modelling conventions and principles were observed, a holistic picture could be created by various contributors over time. In other words, models which are representing different sectors could be combined to create a bigger picture of the economy. This requires a wide range of *standard elements*, or to put it differently, reusable *building blocks*, which specify, among others, certain market participants and market structures. Consequently, such *building blocks* require a broad approval in the research community. Those elements could, for example, represent a group of agents whose psychological or financial characteristics are specified so that they correspond to the current state of research. Hence, for realistic modelling, interdisciplinary cooperation would be vital. Furthermore, widely agreed *standard elements* allow for a high degree of transparency, thereby making it more manageable to evaluate the quality of a model’s methodology and the (empirical) relevance of the results obtained. Additionally, the full disclosure of how these single elements are set up and composed is vibrant in order to make them widely usable in the respective community.

Though, it is obvious that such large model could not be created at once. Therefore, it is not proposed to instantly build a *super model* with all real-world elements and relationships, but the idea is about initializing a database with sub models contributed by different originalities, which can then be merged for analysis purposes, research projects or to some extent also for commercial matters. Decisively, the overall quality and consistency of those models as well as control processes are crucial. So, it is central to establish a starting point in form of a *modelling platform*, which means the development of widely accepted modelling conventions, both in *economic architecture* and a*gent-based modelling*, as well as the creation of a *web portal* with underlying *repository* to facilitate the assembly of those different kinds of models.

With that *modelling platform* or *web database*, respectively, in combination with a (distributed) version-control system, the audit-proof administration and editing of models could be handled by many authorized institutes/users. Different levels of confidentiality and access rights would ensure that sensitive data, concerning, for example, critical supply chains, are not publicly available. Moreover, that proposed *centre of excellence* for the *digital economic twin* could also accommodate the evolution of modelling conventions and progress-driven exchange of information. For management and security purposes, that research platform should probably be associated with an independent research organization such as the Max Planck Society.

5. Concluding remarks

New technologies do not just allow innovative business models but also enable economics to overcome its deficiencies (e.g. unrealistic assumptions). Thus, modelling in economics should take advantage of the opportunities in the wake of increased data availability and computer performance because the “unreality of premises is not a virtue in scientific theory; it is a necessary evil – a concession to the finite computing capacity of the scientist […]” (Simon, 1963, 231). Additionally, due to its descriptive, empirical character, such *digital twin* and its single parts (e.g. program modules or statistical foundations) would satisfy the *Criterion of Falsifiability* (Popper, 1959) and does further prevent *Model Platonism*, which refers to the "immunization against experience as a neoclassical tendency" (Albert et al., 2012, p. 300).

The experimental possibilities as well as knowledge gained from such application would be immense. But the related effort and required IT resources (e.g. access to *high performance computing*) are immense, too. It must be stressed that this concept of the *digital twin of the economy* is by far not intended to promote any kind of *planned economy*. The aim of this proposed tool is to achieve a better understanding of our globalized and complex reality in order to design proper economic policies and successfully implement them. Additionally, hidden optimization potentials or synergy effects could be explored, which empowers a more resource-efficient as well as sustainable economy. Global value chains could be rendered more apparent for public authorities to support them in investigating infringements (e.g. illegal logging or labor law violations). In times of a severe crisis, important supply chains would be analysable in a timely manner and then widely maintainable through appropriate measures.

Finally, the guiding principle of this concept states that the complexity of economics requires a comprehensible modelling approach without mathematical rigor and unrealistic assumptions for practical policy advice. Just as Albert Einstein noted, *you should make things as simple as possible, but no simpler*. With that proposed macroeconomic tool which is based on detailed and realistic microfoundations, even the challenging path to a *Circular Economy (EU, 2020)* could be guided properly. This concept endorses the individual perspective and puts human beings at its centre, so that *humanity in economics* (Pobuda, 2017) might come to prevail. For the purpose of the *social-ecological market economy*, it could further enhance its regulatory framework to promote individual prosperity and global progress amid a liberal society.

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