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ASSESSMENT OF POLICIES USING THE 'CORE' AND 'PERIPHERY' MACROECONOMIC MODELS IN THE POST-CRISIS ENVIRONMENT[1]

Prior to the financial crisis, little attention was paid to evaluating the spatial impact of public policies or to the proper inclusion of the financial sector in the models. Most of the central banks were using the computable general equilibrium models. After the emergence of the crisis, these models were widely criticized by policy-makers and academics. The recent developments in spatially disaggregated data could be a breaking-through point in the significance of alternative tools such as agent-based modelling. Making use of these models, we can learn in depth about the relations between actors, emphasizing the importance of heterogeneity, networks, location and learning. These models help us to understand the expected trend of macroeconomic variables as well as its impact on the other actors according to their characteristics. In this way, this kind of models seems to be more useful than the spatial econometric models for making forecasts. The heterodox ('periphery') models also resist the Lucas and Velupillai's critiques. Moreover, financial institutions, markets and infrastructure can be satisfactory modelled, allowing for the analysis of prudential policies and financial regulation. The goal of this paper is to compare and discuss the mainstream ('core') and heterodox ('periphery') approaches to economic modelling in the context of public and prudential policy assessment. Taking into account the importance of the recent financial crisis, the possibility of using the agent-based approach in financial modelling is also discussed.

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1. INTRODUCTION

In the literature there seems to exist a blurring of consensus on what actually the mainstream and heterodox (alternative) economics are. R. Caballero in the article "Macroeconomics after crisis. Time to deal with

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the Pretence-of-Knowledge syndrome" explains that in modern macroeconomics the difference between mainstream ('*core*') and heterodox ('*periphery*') economics is associated with the adoption of specific assumptions in macroeconomic models. According to R. Caballero: "The ultimate goal of macroeconomics is to explain and model the (simultaneous) aggregate outcomes that arise from the decisions made by multiple and heterogeneous economic agents interacting through complex relationships and markets. (…) The periphery has focused on the details of the subproblems and mechanisms but has downplayed distant and complex general equilibrium interactions. The core has focused on (extremely stylized) versions of the general equilibrium interactions and has downplayed the subproblems". In practice, 'core' economics is associated with the general equilibrium theory and the neoclassical growth model. The 'periphery' approaches are closely tied to alternative procedures of economic modelling and the complex theory. In fact, many assumptions have traditionally been shared by both of them. Nonetheless, while the mainstream always assumes the equilibrium, the 'periphery' allows for non-equilibrium in special cases. In finance, the theory of instability (Minsky, 1973, 1982, 1993) and models with self-organized criticality (Bak and Paczuski, 1987) are widely used. Due to the possibility of incorporating feedback effects and non-linearities in heterodox models, 'the periphery' approach seems to be a 'wider' approach to economic research.

After the recent financial and economic crises, a great number of researchers started to question the validity of '*core*' economics assumptions. Recently, those doubts have been voiced by many authors working in different research areas such as macroeconomics and finance (Caballero, 2010), environmental economics (Janssen, 2005) as well as regional economics (Schenk, Löffler and Rauh, 2007).

Despite the fact that 'core' and 'periphery' economics have been studied from different points of view, further research is needed on how both types of models can be used to assess the effects of public and prudential policies. The failure of conventional macroeconomic models to predict the last financial crisis has made the whole field of study particularly prone to further research.

The goal of this article is to compare and contrast agent-based models (ABM), the computable general equilibrium (CGE) approach as well as spatial econometrics (SE) in the context of the assessment of public and prudential policies. Both the spatial effects and the possibility of financial system modelling are also studied. The article is purely theoretical. The conclusions are based on the precise literature review as well as on the analysis of the structures of the CGE and ABM models that have already been used by central bankers and public institutions around the world. This research assumes a systematic study directed towards understanding the CGE and ABM approaches to economic research. This basic research is executed without specific applications or products in mind. However, as different modelling procedures in public policy assessment are studied, the insights from the analysis might be important for policy-makers and central banking modellers.

In the first section the main characteristics of the computable general equilibrium models are presented. In the second section the main shortcomings of the CGE models are discussed and a paradigm shift to agent-based modelling is emphasized. In the third section the main features of agent-based models are analysed. The application of ABMs in spatial analyses makes use of statistical matching and downscaling. Both are studied in this section. The artefacts in agent-based models are briefly described in the fourth section. In the fifth, the use of spatial econometric models as another alternative is presented. The last section concludes.

2. THE COMPUTABLE GENERAL EQUILIBRIUM APPROACH IN MACROECONOMICS AND ‘MACRO-FINANCE’

Up until the mid-twentieth century, macroeconomic policy was mostly based on empirical knowledge. Macroeconomics as a field of study and the ‘guidelines’ for policy-making evolved through a long ‘trial and error’ procedure. The applications of Keynesian theory and the advances in quantitative approach changed successively the way policy decisions were made. In 1937 Hicks presented a formal macroeconomic framework: the IS-LM model. In 1980 the same author recognized the inadequacies of general equilibrium models for assessing the impact of public decisions (Hicks, 1980). During those years, the microeconomic foundations were integrated into sector models. As a consequence, most of them only apparently were based on the axiomatic approach extracted from the general equilibrium theory. This led Keynesian economics to separate from the stance of its founder who based the findings on the individual decisions of the interacting agents (Mancha and Villena, 1993). Criticism of the Keynesian approach started in 1957 with Friedman’s publication of his permanent income hypothesis. Neoclassical authors continued to criticize Keynesian models, arguing that economic instability was caused by monetary policy rather than by the animal spirits of investors (Friedman and Schwartz, 1963).

In 1976 Lucas emphasized that Keynesian models were not valid for predicting the effects of policies as they were based on the optimal decision rules of economic agents, and these rules vary when the environment changes. Hence any change in policy also alters the structure of econometric models. According to Lucas, it is naive to try to predict the effects of a change in economic policy only on the basis of the relationships observed in historical data, especially when the aggregates are used. The Lucas critique can be summarized in the following way: "Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of the series relevant to the decision-maker, it follows that any change in policy will systematically alter the structure of econometric models" (Lucas, 1976).

Other relevant theories that contributed to change the dominant view in macroeconomics were the cycle theories of Kydland and Prescott (1982) and Long and Plosser (1983). These works differed from the previous ones as they did not highlight the role of monetary policy in explaining economic cycles. These authors stressed the role of random disturbances in technology and the inter-temporal substitution of consumption and leisure.

The real business cycle (RBC) models are the prominent example of the dynamic general equilibrium theory. The main difference between the dynamic general equilibrium theory and Keynesian macroeconomics is the 'general vision or perspective'. Keynesian macroeconomics offered the vision from 'the general to the particular one', while the general equilibrium theory – 'from the particular to the general one'. The RBC theory gives a comprehensive explanation of the production, consumption and price formation in an economy with one or several markets for goods, services and factors of production.

In free market economies, the price setting of all goods is interrelated. A change in the price of one good affects other prices such as the wages of the producers of these goods as well as the price of substitute and complementary goods. Thus to compute the equilibrium price of a single product, it is required to widen the analysis. The first attempt to model the price formation of an entire economy was made by Walras (1874). His research was then continued by neoclassical economists. To ensure its existence, uniqueness and stability, certain mathematical conditions have to be met. Arrow and Debreu (1954) studied the problem of the uniqueness and stability of the state of equilibrium. However a number of authors have criticized the lack of credibility in enforcing these conditions, as most of them are implausible in reality.

Simultaneously to the neoclassical revolution, Keynesian economists started to use general equilibrium models to understand the allocation of resources and the emergence of crises (Barro and Grossman, 1971). Later, Keynesian economists continued discussing the hypothesis of perfect rationality and pricing (Mankiw, 1985; Akerlof and Yellen, 1985). Keynesian contributions were finally included in the general equilibrium theory, obtaining the Neoclassical Synthesis. The result was not satisfactory for economists such as Joan Robinson, Nicholas Kaldor and Michał Kalecki.

In the 1990s a new synthesis was established, applied especially to monetary policy (McCallum and Nelson, 1999; Clarida, Gali and Gertler, 1999). This synthesis has its roots in the neoclassical models and the general equilibrium theory. It materialized in the dynamic stochastic general equilibrium approach (DSGE). The framework of the DSGE models includes the inter-temporal optimization (OLG – overlapping generation approach). In most of the DSGE models the rigidity of prices in the short term is assumed. In fact, the DSGE models are an example of a wider class of models (Marimom and Scott, 1999; Canova, 2011; DeJong and Dave, 2011), namely computable general equilibrium models (CGE).

Computable general equilibrium models provide the optimal solution in response to an exogenous shock. CGE models contain explicit supply constraints, usually embedded in a neoclassical framework. The theoretical basis of CGE is the complete Arrow-Debreu equilibrium under perfect competition. The specification restricts the number of parameters allowing for a calibration relying on a database (Bröcker, 1998). The CGE approach has micro-foundations. The economy is assumed to be in a state of equilibrium even after being affected by the external shock. The effects of such external shocks can be temporal or permanent. In the first case, the initial equilibrium is preserved while in the second case, after a short period of adjustment the economy achieves a new state of equilibrium. In both cases, the mechanism of the adjustment process remains unexplained.

A very important feature of general equilibrium models is the market clearing condition (Walras, 1874). In the 'social planner approach', the set of prices is given by the 'central authority' and market forces determine their adjustment to the equilibrium values. The market clearing condition is preserved in all general equilibrium models (especially DSGE as an example of CGE models).

Nonetheless, as Fisher (1983) and Saari (1985) proved, the process of price-setting in an exchange economy is rather unstable or even ‘chaotic’. Furthermore, the mechanism has no counterpart in the ‘*real’* market economy and violates the *spirit* of a decentralized exchange that lies at the root of general equilibrium models. This is only one of the criticisms of the CGE approach.

In July 2010, a special meeting on CGE models was held in the House of Representatives of the United States. During this meeting the researchers criticized the use of just a single methodology in economic policy (Solow, 2010). The opinion shared by researchers was that simplistic assumptions such as the efficiency of financial markets and rational expectations does not allow for analyses of the complexity of socio-economic processes (Kirman, 2010). However, Chari (2010) tried to defend the CGE approach in the following way: “By construction, a model is an abstraction which incorporates features of the real world thought important to answer the policy question at hand and leaves out details unlikely to affect the answer much. Abstracting from irrelevant detail is essential given computational scarce resources, not to mention the limits of the human mind in absorbing details! Criticizing the model just because it leaves out some details is not just silly, it is a sure indicator of a critic who has never actually written down a model”.

Indeed, any model is an abstraction of reality and as Box (1987) once stated “essentially, all models are wrong, but some are useful.”. However, the main problem of the CGE models has been its predictive and explanatory weakness in the context of the recent financial crisis. Nowadays the argument of the scarcity of computational resources is also rather controversial. The development of computers in recent years has enabled to build complex models with high ‘predictive and explanatory power’. Moreover, the complex models enable users to obtain information of their interest without focusing on the side effects.

Despite the criticism, the computable general equilibrium models provide a coherent framework for analysis and policy evaluation. Using these models we can identify the sources of fluctuations and predict the effects of changes in policies. However, even if the overall result obtained with CGE models is accurate, from the perspective of policy-makers information provided to them could not be sufficient because public policies affect differently the heterogeneous agents. Hence, a model that adds the agents into an aggregate (assumes the representative agent paradigm) cannot report the characteristics of the agents who are affected by a policy. Therefore, it is not possible to report which economic agents change their labour status as a result of a labour policy variation. This should be the ultimate goal of macroeconomic analysis in addition to assessing the total effect on the economy (on aggregate).

There are particular factors in the real world such as subsistence needs, incomplete markets, imperfect competition and strategic behaviour interactions, which cause difficulties in the analytical formulations. Therefore, these elements were hardly ever incorporated into CGE models.

Moreover, a reasonable approach would recognize that the behaviour of the aggregate does not have to correspond to the behaviour of the addition of its components. A theoretically well-founded model shall analyse not only the characteristics of individuals, but also the structure of their interactions. This view is widespread in other disciplines such as biology, physics and sociology. These sciences recognize that the aggregate behaviour of systems of particles or molecules, neurons or society cannot be deduced from the characteristics of a representative sample of the population. The same is true for economic systems. The fallacy of composition exists and should be treated in the model (Howitt, 2006). The macroeconomic variables arise from the aggregation of the activities of the agents that perform economic actions. To get the best possible results it would be useful to understand these actions individually. Hence, in addition to aggregated data at national level, it is necessary to analyse disaggregate data and spatial effects.

As early as the mid-1980s, researchers were already aware of the limitations of general equilibrium models and they started to develop agent-based tools in the area of computational economics. These tools were able to capture part of the complexity of real-world economic phenomena.

Three decades later, due to the great improvement in technology and the proliferation of micro-data sources, it seems to be the right time to overcome the drawbacks of CGE models and study new methodologies that would help us to assess the spatial distribution of economic activity.

3. AGENT-BASED MODELLING FEATURES

The social sciences are aimed at understanding the behaviour of individuals, but also explaining how their interactions lead to the observed aggregate outcomes. Understanding the economic system requires more information and knowledge, than only understanding the behaviour of the individuals who are components of the system. The overall effect of modelling interactions shows that the results can be more than the simple sum of its parts.

The ABM are adequate for studying macroeconomic and regional effects as it works on methods that assume the complex interactions between agents. Using this method, we describe emergent properties of simpler interactions between agents that cannot be deduced only from the aggregation of the properties or characteristics of all individuals. When the agents adapt permanently to new scenarios on the basis of previous experience, expectations and imitation, the ABM approach may be the only one existing practical method of analysis.

3.1. Agent-based computational economics

As explained in Epstein and Axtell (1996) and extended in Tesfatsion (2007), Agent-Based Computational Economics (ABCE) is the calculation of economic processes modelled as dynamic systems of interacting agents. The term "agent" refers to a collection of individualized data and the methods of representation of an entity defined in the virtual system. These agents may be living beings, social groups, institutions or companies.

ABCE is a relatively unexplored approach that tends to study the economic system holistically. Once the behavioural rules are specified by the researcher, all subsequent events are driven by the interactions between the agents. These interactions are determined dynamically by the internal structures of behaviour, the level of information, beliefs, motivations and methods of data-processing. A crucial point of agent-based modelling is that there are no prior conditions that could limit interactions between agents and which usually are subjective, there is no 'fine-tuning'. Agents in the ABM world tend to be completely free to act and interact within their virtual realities that represent the economic reality.

In order to create an agent-based model to facilitate understanding of economic processes, three criteria have to be followed. Firstly, the agent-based model should include the correct classification of agents in the 'virtual replication' of the empirical reality. Secondly, the scale of model should be appropriate to the objectives that it is to achieve. Finally, the specification of the model will be subjected to empirical validation to ensure that intermediate and final causal mechanisms will be modelled adequately.

3.2. Classification of agents

The classification of phenomena is mandatory to ensure for the scientific research process to be carried out correctly. It allows for the detection and correction of errors as well as for the comparison of results. The classification should be performed paying attention to the empirical findings. Before proceeding to the classification, the researcher should know the answer to the following questions:

- Types of human needs which are relevant for understanding the economic phenomena of interest.
- Types of goods and services that satisfy these needs.
- Types of facilities that exist or may exist to produce and distribute these goods and services, and that participate in production activities.
- Possible presence of agents that supervise the design and operation of institutions, and where applicable, their motivations.

The ABM approach provides a systematic way of incorporating any classification that is relevant in the study of economic phenomena. There is no need to focus on assumptions of the general equilibrium theory. Any artificial classification derived from different scientific areas should be rejected. In fact, the ABMs allow the researcher to include all the wide spectrum of decision functions, from the simplest ones to the specific and sophisticated cognitive abilities. These decisions are made by agents who collect and process data actively. For instance, agent-based models can include structural agents (e.g. land, buildings), institutional agents (e.g. legal system, public sector, companies and markets) and cognitive agents (e.g. employers, consumers and financial intermediaries).

Those agents may have an extensive list of characteristics but the widely accepted synthesis is the one described by Wooldridge and Jennings (1995). According to the authors, those main characteristics are:

- *autonomy* to interact independently,
- *social skills* to interact through some communication system,
- *reactivity* to perceive changes in the environment,
- *proactivity* as a capacity of making decisions on their own,
- *degree of rationality* described by the probability of making the optimal decision, taking into account the information available.

Once the classification of agents is specified, the data and relationships between each type can be defined using the available evidence from the empirical studies, results of econometric analyses, as well as surveys and interviews.

ABMs are typically implemented using object-oriented programming (Nguyen, 2008) to develop the skills of each agent and their relations. Hence, the model is firstly initiated and then further changes can be introduced in order to match the model to the economic reality under study.

3.3. Number of agents and consistency

The model scale is another critical feature of the agent-based model. This approach does not make use of the assumptions of standard economic theory such as agents' aggregation and the representative agent paradigm to simplify the specification and to find the underlying processes. Prior to making the choice of the appropriate model scale, a number of issues shall be considered in order to obtain consistent results. First of all, we should answer the question of how the different needs and desires of individuals should be represented. Then, the procedure of fulfilling those needs and desires by goods and services shall be explained. Finally, the institutional aspects of production and distribution will be explicitly incorporated into the analyses.

The choice of the number of agents is critical to capture their impact on the economic activity. On the one hand, there can be a perfect competition among buyers and sellers, if we assume that the market participants are sufficiently numerous in the model. On the other hand, when a market consists of a seller facing many buyers, a monopoly emerges. In that case the only seller sets the market price to obtain maximum profit. However, there can be plenty of intermediate positions that lead to imperfect competition. Modern economic modelling is largely based on the assumptions of perfect competition. This strategy has been used because of its convenience in analytical terms rather than its empirical foundations. In fact it is easier to incorporate the imperfect competition setting to the agent-based model than to the CGE models.

One of the greatest contributions of the ABM approach to economic theory is the exploration of the effects of scale without the external imposition of artificial coordination devices. In the ABM approach it is possible to simulate what would occur if the economy was composed from even several million participants. To obtain the results, it is not necessary to pre-define the behaviour ('decisions') of agents in the setting of prices and quantities. One should also analyse whether the different economic effects on the regions (or another spatial unit) are satisfactorily met by small-scale models or whether a scale closer to empirical reality is needed. Increasing computing abilities enables this kind of simulations to be carried out.

4. AGENT-BASED MODELLING IN PUBLIC POLICY ASSESSMENT

Recently, an increasing number of agent-based models have been used to predict and simulate the impact of public policies. In 2006, Gintis questioned the functioning of the markets assumed in the general equilibrium theory and in the 'core' paradigm in public policy assessment. The first methodology presented by the author was deficient in many aspects, nonetheless, it assumed a remarkable advance in the right direction. Some of the pitfalls were subsequently rectified in the *Lagom* group of models. Since then, many articles about the ABM methodology were published and huge advances in the prediction methods have been made (Wolf et al., 2013). Further research on the potential use of ABM was also initiated by the publication of the article "Schumpeter meeting Keynes: a policy-friendly model of endogenous growth and business cycle" (Dosi, Fagiolo and Roventini, 2010) that unifies the theories of these two authors and studies the dynamic properties of economic aggregates and the way public policies can affect different components of economies.

Nowadays, this approach is becoming even more attractive as current advances in computation capacity permits modelling a great number of agents and relations between them. Noteworthy examples of robust models are:

- Eurace@Unibi (Deissenberg, Van der Hoog and Dawid, 2008, Cincontti, Raberto and Teglio, 2010; Dawid et al., 2011);
- MOSIPS (Pablo et al., 2014).

In macrofinance, the most important models are the following:

- Financial networks and Systemic Risk: SNF Partnership at Dept. Banking and Finance, UZH;
- EU-FET SIMPOL 2013-2016;
- INET – Financial Stability Program directed by J. Stiglitz;
- EU-FET DOLFINS 2015-2018.

The EURACE model was the first attempt to simulate the European markets, including the financial market from the 'balance sheet view' perspective. In fact this model was the first one to be developed for the whole EU economy using the disaggregated data. Nonetheless, this model has never been used to assess the effectiveness of macroprudential regulation and policies or to study financial stability. This problem has been studied by Hałaj (2014), Hałaj and Kok (2014), and Kaszowska and Santos (2014, 2015, 2017), as well as in so-called 'macrofinance' models. The SIMPOL model was focused on financial stability and policy modelling. It was elaborated in collaboration with the central banks, ECB and DG-Market. The four main areas of research were: complex derivatives, rehypothecation, climate-finance and big-data research. The INET model was composed of two 'building blocks'. The first one was focused on macroeconomic modelling, the second was aimed to study financial stability. The last model is EU-FED DOLFINS elaborated between 2015 and 2018. In the project, the relations between financial stability and sustainable investments were studied. The goals were then to design incentives for sustainable investing and civic engagement as well as to evaluate this kind of policies.

Finally, the aim of the second aforementioned 'macroeconomic' project – MOSIPS - was to model regional economies in a more realistic way and to evaluate the impact of public policies on SMEs. In the MOSIPS model the emphasis has been put on relations between agents that are determined through the spatial variables. Not only the main characteristics of the agents were defined but also their locations, the possibility of sharing information and exchanging products, services, inputs and financial assets.

The ABM used in prediction and simulation (counterfactual analysis) of the impact of policies focused on the regional impact, will be developed in parallel to the elaboration of an adequate data base or designed to use an available big data source. The main characteristic of the data base to feed the model should be the assignation of the values to any agent and any relevant variable of the model, including the agents' precise location and the definition of the relationship between the agents, in order to create realistic networks. If the data do not accomplish the requirements it will not be possible to classify the potential inaccuracies between the model and data errors. Unfortunately, at present there is no public data base that can meet those requirements. For this reason, such a data base has to be constructed using the two procedures presented in the following section of the article. Those two procedures are still uncommon in social sciences. The first one includes statistical matching and it allows for joining micro data from various sources, such as the population census or labour force survey. While in the second one, downscaling allows us to understand how the spatial dimension of the model is designed.

4.1. Statistical matching

Statistical matching is used to join multiple data sources into a single one combining their variables whenever there is no common identifier in the data. This technique is a procedure of combining data sources containing two complementary variables such as income and family expenditure.

Notwithstanding this, in the case of more sophisticated models the elaboration of data bases for the purpose of ABM for regional and local forecasting and simulation, is much more complicated. A large number of data sources have to be joined into one. Moreover, different data sources have their own different characteristics. For all these reasons the process of statistical matching has to be carried out with precision and several issues are of prime importance (Sutherland, 2001). First of all, it is essential for the two samples to have a significant number of variables in common and also other variables that are not necessarily directly comparable. Then, the researcher should be able to distinguish between the primary sample and the complementary one. The first one gives the structure, data and sample size while from the second one, only additional information is extracted. The next step is to homogenize data to correct the heterogeneity problems in different aspects and dimensions (units, territory, population definition etc.). The appropriate linkage variable between both databases will be established to allow for matching observations. Once all the above-mentioned steps have been carried out, the merger itself can be conducted in two phases. In the first of them, cells of similar observations are created which are grouped according to predefined criteria for matching variables. In the second one, observations in the same cell are grouped using other matching variables (M-variables). ‘M-variables’ are common to both samples and they are used to match observations. The conditional independence condition has to be preserved in the matching process (D'Orazio, Di Zio and Scanu, 2006).

Joining the population census that provides data on residence with data on mobility (from additional surveys) reporting where individuals work, can help to verify buying patterns and explain how these patterns can be modified by taking into account additional information (Schenk, Löffler and Rauh, 2007). The authors discussed the change in household expenditure distribution before and after performing statistical matching between the population census and the labour force survey. After including information about the workplace, the consumption in each of the shops located nearby changes significantly.

4.2. Downscaling and location importance

Downscaling is a statistical technique that unifies spatial data at different levels to obtain the results that quality exceeds the one in any of the sources of data used in the procedure. This technique was firstly used in studies on climate, but now it has gained relevance in other fields, such as economics.

In order to represent properly in the model the relations between individuals, information about their geographical location will be included. The European Union has already noticed the importance of the implementation of geo-reference in such analyses and in future the obligation of collecting such individual data will be binding. However, as at present there is no such database, the most widely used solution consists of joining several sources by the down-scaling procedure to obtain a grid to set the location of agents (Gallego, 2010). Then, data is extracted to the model.

The agents' behaviour is mostly based on their characteristics. However, other important features can be included in the model such as their place of work, residence or mobility pattern. For instance, if an individual has a property in an exclusive area, there is a greater probability that this individual could borrow more from banks or other financial institutions. Companies differ in terms of effective demand and costs depending on location. In addition, the environment is determined by the characteristics of individuals and companies. These characteristics as well as the environment define and alter their behaviour. Data on the location of economic agents will be complemented by information about the use of roads, public facilities, as well as the price of the land.

While in conventional models all actors participate in making transactions on one market, in a well-defined agent-based model there are plenty of markets and agents. Each individual has no access to all the companies in the market, but only to those he/she knows that actually used to be the ones located close to their location and the largest ones. For this reason it is essential to define the concept of *visibility*. Normal type functions can be set depending on the locations of agents, the sizes of companies and distance to them. The visibility changes depending on distance. In the literature, this concept is illustrated with the example of retail shopping. Individuals usually know the prices of *all* the shops in the neighbourhood, but only some of the prices in the big supermarkets far from their homes. Additionally, in the second case, the cost of transport will be added to the prices according to the agents´ degree of rationality. Thus every individual does not encounter all the supply and its demand can only be positive in some establishments. The introduction of transport infrastructure alters the distances and consequently *visibility* and *purchasing patterns*. The same happens when more data sources are added with statistical matching.

Hence, in the agent-based approach, what makes it possible to establish commercial relations and exchange products in the markets is the visibility of companies together with the location of agents. In contrast to ABM, in the

CGE models all the agents trade with everybody at the same time. This assumption is unrealistic and the results extracted from the model differ substantially from the real ones.

On the other hand, if the agents were homogenous instead of heterogeneous and the locations and relations were not defined in the model, we would obtain the general equilibrium theory results. This would then lead to the same results as the ones obtained using a CGE model, therefore the computable general equilibrium models can be included within the wider group of agent-based models. Nonetheless, the assumptions are in that case simplistic and unrealistic.

Using downscaling and describing properly the markets in the agent-based model, the spatial levels of economic integration can be defined within certain autonomous units. At local level there are areas where a determined group of individuals and companies make a large proportion of its economic and financial operations with other agents *from the same* integrated area. The importance of spatial information lies in a large part in the fact that it allows for the identification of these areas which are likely to be affected to a greater extent by changes in policies or the implementation of infrastructure projects.

In ABM, the concept of agglomeration economies can also be introduced. Two areas (where no economic activity has been undertaken) are perceived differently by the potential investors. One of the areas can be used in future as an enterprise area or residential area. The agent-based approach allows for forecasting the spatial limits of urban agglomerations. The technique of downscaling can be used to determine the different prices of areas that seem to be similar in many aspects but are in different locations. For instance, the price of agrarian areas close to a large city is different than the price of those far from urban areas.

5. ARTEFACTS IN ABM

Agent-based modelling is one of the techniques that can be used to simulate social systems. Nonetheless, the proper construction and testing of the model is crucial to represent correctly social-economic phenomena. In this section, we discuss different types of errors and artefacts in the development and empirical validation of the agent-based models.

The empirical validation of the model is a relevant part of the research process in both traditional models and agent-based models. Nonetheless, researchers are aware of the existence of some problems that may occur during the validation process of the agent-based models (Galán et. al., 2009).

The first problem seems to be the proper definition of the agent-based model. Some of the properties of the ABM are not always correctly defined by the modellers and consequently they do not reflect appropriately human behaviour. In cases of using a more generic model that enables agents to learn, one can decide if the information should be stored in a neural network or whether a prediction model should be used. On the one hand, the modelling tools can be used to model a wide range of economic phenomena and the fit of data can be improved notably. On the other hand, it is not all about the flexibility. The model should always be chosen after a detailed analysis of the behaviour rules and relations between the agents that appear in the context of the economic activity.

Despite the problems previously mentioned, there are reasons to expect that researchers will be able to develop a robust methodology of empirical validation. Currently the empirical validation process seems to be a greater challenge for the ABM approach than the construction of such models. In future, once the necessary procedures of validation have been developed, researchers will proceed to connect the agents´ behaviours to the real ones in order to conduct experiments and extract conclusions about the real world.

There exist other empirical validation methods behind statistical data processing. One of them is the replication of the empirical characteristics at many levels and at multiple scales. In such contexts, the agent-based models offer the possibility of obtaining new empirical evidence, since the economy is described by micro data that is previously generated from macro data. This procedure is not available and cannot be used in other standard economic models. Without doubt, the ABM approach offers much more accurate validation methods than the traditional modelling one. For instance, there is the possibility of testing whether the simulated behaviour of the agents is well-aligned with the real subjects. Therefore it is essential to note that, beyond the simple time series, the ABMs allow observing and analysing the complete distribution dynamics of the economy. The features of the ABM system such as the distribution of wealth and company sizes can be compared with the corresponding real distributions in the economy. The micro-level distribution could be treated as an approximation to the empirical validation, but it requires data information that is not always available (Takadama et al., 2008). However, even limited data samples provide important feedback about the empirical plausibility of the model and the simulated distributions at micro level.

On the other hand, the validation of ABM fully based on probabilistic determination will be extremely complex and difficult to address. This difficulty comes from data mining (the multiplicity of data sources and the creation of one data base) and from linking agents with the space.

In the ABM approach, the agents' behaviour is approximated and is close to reality at a certain level of disaggregation, e.g. region, municipality, neighbourhood. It is highly improbable that we could obtain the results at individual level due to the randomness of the processes carried out within the model and the random construction of the agents, however the disaggregated results still provide more information to the policy-makers than the 'representative-agent' models. The challenge is to find the right procedure to obtain valid results, assuming the complexity of the model.

It should be borne in mind that the ABM models can display complex dynamics. These nonlinearities appear while we model the interconnections of agents and their activities. At the same time, the nonlinearity might raise difficult questions to be answered by traditional econometrics. Summarizing, the properties of the ABM approach make the empirical validation of such models interesting, but much more complex than in the case of 'traditional' models.

Finally, it is also essential to raise the issue of the potential applicability of the agent-based models in the public-policy-incidence analysis. The potential of the ABM approach is huge, and policy-makers may try to use the ABM to expand their knowledge and to evaluate the incidence of the public policy on society and economic activity, as well as to expand their power. Policy-makers could use the ABM to explore important changes in the political configuration, taking into account the behavioural rules of the agents that are defined in the system, and may be affected by public and prudential policies. A remarkable example is that of the Obama campaign during the U.S. elections in 2012. In this case, the use of micro data elaborated and processed by the researchers using complex analysis techniques to model and analyse behavioural rules, was crucial for winning the elections. The model focused only on those agents who were prone to change their decision during elections (Beas, 2012).

Another main problem of the ABM is related to the violation of the law of one price. Nonetheless, it was proved that the violation occurs only in the short term. In the long term, the average price equals the historical equilibrium price. Moreover, there is empirical evidence of the significant dispersion of prices on the markets, including those deeply integrated, such as national markets within the European Union's internal market. This feature of the ABM could also be seen as a positive characteristic of the modelling procedure.

The process of imitation is fundamental in the agent-based approach. In fact, it has been considered as a second-class learning process in economic theory, nonetheless the role of imitation in the evolutionary models has always been prominent. For instance, in the case of the genetics, the offspring inherits all the genes of the parents, with a very low rate of mutation. The cultural transmission is the dominant process in biology, anthropology and sociology, and the importance of culture depends largely on the ability of agents to imitate. In contrast, individual learning, especially based on personal experience, is the most widespread mechanism in economic theory, although it is usually slow and inefficient. On some occasions, market conditions can make the imitation highly ineffective, such as in the case of market volatility (Conlisk, 1988). Yet the mimetic capacity is still higher in human beings than for other animals. In order to define the imitation patterns correctly, the networks of agents should be developed adequately. The establishment of such networks between agents is highly subjective and no sufficient empirical backup has been given, since there are no statistics and studies sufficiently developed to provide information about the way individuals convey information and how they respond to the economic situations they face such as job searching, investment and consumption.

6. INADEQUACIES OF SPATIAL ECONOMETRICS ANALYSIS FOR POLICY FORECASTING

The main problem of the CGE models is related to the lack of resistance to the Velupillai critique. The same arguments will be tested in the context of spatial econometrics. The aim of this section is to clarify the concept of spatial econometrics and to compare the arguments in favour and those contrary to the use of spatial econometrics in economic studies, especially if the aim of the research involves public policies.

The term spatial econometrics appeared for the first time in the late 1970s during the annual meeting of the Dutch Statistical Association (Paelinck and Klaassen, 1979). In the opinion of the authors, spatial econometrics is “a blend of economic theory, mathematical formalization and mathematical statistics” and its main features are related to “the asymmetry of spatial relations, the role of spatial interdependence in spatial models, the importance of explanatory factors located in other spaces, the differentiation between ex-post and ex-ante interaction and the explicit modelling of space”.

The contributions of spatial econometrics to economics are remarkable, especially in regional economics. Recently these models have been also used in research on financial market linkages and the spillover effects of public and macroprudential policies. Successful research of this type was carried out by Karamyshev and Seregin (2018). Hence, it is not surprising that many international experts dedicated their work to spatial econometrics modelling (Isard, 1960; Maddala, 2001). Nevertheless, a few areas of research are still left unexplored. A good example of the problem in spatial econometrics is that of spatial dependence among contiguous residuals of a linear regression. Maddala analyzed this problem, which falls into the category of spatial correlation. In practice there are two ways the error terms might be correlated. One of them is related to omitted variables and the so-called “keeping up with the Jones’s” effect. This effect describes the correlation of variables (e.g. for households) in the same neighbourhood. The second way is related to the problem of error terms for contiguous states that usually tend to be correlated. Hence, spatial correlation models are aware of this important issue, usually ignored in the analysis undertaken with other tools in applied economics (LeSage, 2008).

With the growing popularity of New Economic Geography, spatial econometrics tools have become part of mainstream economic analysis.

Frequently, spatial econometric models have been used to represent a narrow and specific part of the economic reality. Hence they ‘simply do not worry’ about the remaining processes not taken into account. A good example can be found in (García-Milá and Montalvo, 2007). The authors try to evaluate the impact of new highways on a business location. The creation of new highways constitutes an example of public policy and in addition to the increase in infrastructure’s availability, the business owners might vary their behaviour due to the change in their expectations. Traditionally, this kind of infrastructure is developed to spur growth. A significant increase in local economic activity may result in a lack of additional public investment. On the other hand, a smaller increment in the number of businesses located near new highways will change the expectations of rational business people, who would anticipate new investments. In any case, the expected result would be a somewhat insignificant increment in the number of businesses, but the analysis undertaken with spatial econometrics tools cannot conclude the ultimate causes of the observed result.

Besides its scarcity, several examples can be found that aim to depict all the economy using spatial econometrics in addition to other tools, usually input-output matrixes to assess the sector relations and interactions. Regional IOE (Input-Output Econometrics) "models can and generally do have a wide range of specifications, depending on the region type and purpose of design (impact analysis, forecasting, demo-economic, income distributions fiscal policy evaluations, etc.)" (West, 1995). They do not endogenize government revenue and expenditure, and they usually introduce impacts on the demand, as in standard IO models. This kind of approach represents an attempt to overcome the Lucas critique and to achieve attention-grabbing results, prevailing over CGE models in the study of small areas.

Taking into account the previous comments, one can assume spatial econometrics cannot constitute a new paradigm in macroeconomic forecasting and policy assessment. However, new approaches to the concept of a region widen the scope of this approach and make its results more reliable and accurate. A key reference to this topic is the recently published book "Defining the Spatial Scale in Modern Regional Analysis" (Vázquez and Morollón, 2013*)*. The aim of this book is to explore the potential of spatial economics in the socioeconomic analysis of territory.

Traditionally, databases have been available only at regional level, but nowadays increasing numbers of geolocated microdata and data sources at municipal level are available. This novelty makes it possible to complement the results obtained using traditional regional economics tools. The study of the concept of region appears to be a fundamental issue to analyse prior to the specification of the model. Moreover, the restriction imposed by the level of disaggregation of data available is becoming less frequent in the analysis. Thus not only will the appropriate methodology be chosen in each case of the study, but also the most convenient spatial unit for the purpose of analysis. The first step of the research is to discuss the importance of the selection of the spatial unit and the redefinition of the concept of region that is to be made by the aggregation of local units that cease to have an administrative character but instead gain additional economic content. Beside the fact that there are an increasing number of publications of spatial time series at lower (micro) level, there are occasions when no such data is available. In such a case, particular statistics and econometric tools will be used to estimate disaggregate data.

In the first part of the aforementioned book, F. Sforzi redefines the concept of region for regional and geographic economies, analysing it also from the political point of view. The administrative regions have traditionally been used to carry out most of the studies in the regional economies. Even in the early traditional studies, new concepts such as Functional Economic Areas and Local Labour Markets, have already appeared. These changes improved significantly the results extracted from the analysis and their usage is becoming increasingly widespread in spatial economics. This new approach, when combined with the appropriate analysis carried out with spatial econometrics, can lead to developing powerful models. These models are beginning to be useful to estimate the effects and determinants at the lowest possible scale, and its use in regional analysis will undoubtedly increase in the future, yet they cannot integrate all the actual heterogeneity of individuals and the complexity of their underlying behaviour.

CONCLUSIONS

In order to compare and extract the conclusions from the analysis, the main features and characteristics of the three methodologies are presented in the Table 1. Although all the methodologies have their strong and weak points, the superiority of the agent-based modelling is noticeable. Both computable general equilibrium models and agent-based models resist the Lucas critique. However, the agent-based approach is especially useful when complex economic phenomena are under study. Both types of models are reliable forecasting tools and can be used to predict the incidence of public policies. One of the weak points of computable general equilibrium models and spatial econometrics is that the models do not adjust according to the behavioural rules. Moreover, there is no possibility to limit the rationality of the agents. Both CGE and SE are directly affected by the Velupillai critique, especially in the context of regional spatial economics, while the agent-based approach implements algorithms and seems to overcome this critique.

Another feature that allows us to compare the models is the level of spatial disaggregation. The CGE models are developed at national or regional level while spatial econometrics and agent-based models use disaggregated data at any scale. At the same time, the adjustment capacity to represent realistically the socio-economic relations and the economy is low in the case of spatial econometrics models, medium for the CGE and higher for agent-based models. The lower capacity of other models is related to:

- the econometric specification that can only be slightly adapted in spatial econometrics,

- to the modular and limited redefinition of equations for computable general equilibrium models.

One of the main characteristics of agent-based modelling is the definition of the prime learning process. In any conventional model, the behaviour is assumed to be based on experience and the estimation technique requires the use of long-term series. This is not necessarily the case in agent-based modelling.

The agent-based approach emphasizes the importance of networks, which makes this approach especially interesting and useful in economic and financial modelling. Moreover, the actual degree of heterogeneity can be included in the agent-based models, while in the case of the spatial econometrics models only spatial heterogeneity can be fully considered. The heterogeneity of agents is completely omitted by the CGE models that assume the representative agent paradigm.

The next feature is the possibility of empirical verification. In the case of computable general equilibrium models, there does not exist a wide consensus on their overall performance. Their accuracy is outstanding under normal conditions but they have no capacity to predict or perform well during stress periods such as during the recent financial and economic crises. The spatial econometrics models have been frequently taken under empirical verification. The spatial econometric models achieve their goals and they are able to extract the effects of every determinant involved in the studied process. The most unexplored field is the empirical verification of ABM. There is no general consensus on this subject, although the ABMs have revealed their capacity in many fields of studies such as social science, biology, and politics. The main difficulty of ABM is still its reduced applicability. The empirical validation has not been carried out in a standardized way, which is one of the main drawbacks of the ABM approach applied to economics and finance. However, this methodology allows carrying out the validation at multiple levels: aggregate results, spatial results at multiple scales and individual performance, taking into account that in the latter case it is unfeasible to achieve complete accuracy. On the contrary, CGE and spatial econometrics models have already defined standard evaluation methods that permit to access their performance and significance; undoubtedly all of these models have their pros and cons. In this particular case all the features will be taken into account with the adequate weights. Nevertheless, if the objective is evaluating the impact of public policies properly, ABM emerges as the convenient procedure.

Table 1

Comparison of CGEM, SE and ABM

Characteristics	Computable general equilibrium models	Spatial econometrics	Agent-based models
Affected by the Lucas critique	NO, they can predict adequately the incidence of public policies	YES, their parameters do not adjust according to the behavioural change	NO, they can predict adequately the incidence of public policies
Affected by the Velupillai critique	YES, they use equations	YES, they use equations	NO, they are implemented with algorithms
Spatial disaggregation	LOW, they are built at national or regional level[2]	HIGH, the spatial disaggregation can have any scale	HIGH, the spatial disaggregation can have any scale
Adjustment capacity to represent realistically the economy	MEDIUM, they are modular and their equations can be redefined	LOW, the econometric specification can be adapted slightly	HIGH, these models are not based in any pre-defined theory and can take any specification
Prime learning process	EXPERIENCE, importance of long time series	EXPERIENCE, importance of long time series	IMITATION, importance of networks
Capacity to represent heterogeneity	LOW, the representative agent paradigm can be removed and it is possible to include agents with different characteristics (e.g. income level)	MEDIUM, the spatial heterogeneity can be included in the models	HIGH, the actual degree of heterogeneity can be included in the models
Verified analysis capacity	NO CONSENSUS, their overall performance is accurate in periods of growth but they fail in economic depressions	YES, they accomplish their aim and they are able to extract the effect of every determinant involved in the process under study	NO CONSENSUS, they revealed their capacity in other sciences but their applications in economics are still incipient
Standard evaluation method	YES, there are methods to evaluate their performance and adjustment to real data	YES, there are plenty of econometric tools to evaluate their performance and significance	NO, these models cannot be evaluated following a standard method (yet)

Source: own elaboration.

[2] Several attempts have been made in order to introduce a higher spatial disaggregation in CGE. A prototypical example can be found in Bröcker (1998). Nevertheless, the results of these attempts have not been as promising as they seemed to be at that time. Regional CGEs are not infrequent but their implementation is getting more complicated as a higher spatial disaggregation is used.

In conclusion, the need for assessing and predicting the effects of public policies has made it necessary to adopt different CGE models. However, these models have various drawbacks such as the homogeneity of agents and their inability to predict abrupt changes but they cannot report on the spatial effects and the resulting distribution of the included variables. These models do not assess correctly whether the impact of the public policy is positive or negative and how high this incidence is. Moreover, as these models focus on the equilibrium, they cannot correctly predict the path in deep recessions.

Due to these serious shortcomings, it is necessary to promote a new type of models that can predict the adjustment processes during economic and financial crises and the effect of policies on heterogeneous individuals. Moreover, due to the drawbacks of the spatial econometric models, it is essential to find a new kind of approach to capture spatial effects. This novel approach seems to be the agent-based approach that puts an emphasis on individual agents, the differences between them and their interactions. The behaviour of the agents is determined by the environment and the relations with other individuals. The learning by imitation is taken into account in the agent-based models. This element has hardly been studied in other methodologies and models. Nevertheless, agent-based models also have their own problems. The open question is how to validate them and how to choose a convenient scale. Furthermore, in terms of needs, statistical matching techniques and downscaling should be developed according to the objectives of each model.

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