SCIENTIFIC REPORT 2023

RESONATE: *Worker flows, labor market outcomes, and agent-based modeling* (Project PN-III-P1-1.1-PD-2019-1180)

- ***Summary- Stage 2023***

Stage 3*- Objective 1:* Building a complex synthetic network of flows between workers and firms on the labor market, typical of national (or regional) economies - part 3

Objective 2: Applying the labor flow network and the associated agent-based model (ABM) to study current research themes in empirical labor market studies - part 1

The third stage of the research project (Stage 2023) aimed to formalize the agent-based model and its subsequent implementation. For this purpose, a detailed research was carried out on the principles that must be followed in the implementation of such a model, with an emphasis on the particularities of the labor market, which is the object of this research project. This approach has materialized in the article entitled "*The Synergy between ABM and Labor Market Dynamics*" (authors: Valentina Ioana Cheregi, Gheorghe Cosmin Silaghi), which details from an applied point of view how to combine the particularities of an agent-based simulation environment with the requirements of an labor market economic model. In parallel, the considerations described in the article from a formal point of view were translated into a programming language and simulations were carried out by gradually adding elements related to the reality of the labor market.

In addition, we considered the necessity of a comparative analysis between the agent-based methodology and the traditional estimation methods used in economics. In this sense, we conducted a parallel research, regarding the role of the labor force structure on the unemployment rate. The analysis (detailed in the paper "Is labor matching effectiveness dependent on education level, age or gender? A Beveridge curve approach", author: Valentina Ioana Cheregi) uses macroeconomic data and is based on the idea of matching between employees and companies, a process described within the Beveridge curve framework.

The following section briefly describes the stages covered in the scientific approach as well as the results obtained.

- ***Scientific approach***

The research carried out in the previous years within the project (Stage 1 and Stage 2) constitutes the basis of the research carried out in the current year, 2023. Specifically, the preliminary research of the existing literature highlighted the need for using agent-based methodology, an approach capable of capturing with greater accuracy the particularities of the labor market from a microeconomic perspective. The study of the literature strengthened our conviction regarding the importance of such an approach. In this context, the starting point of the third stage was to determine how this methodology can be implemented in practice.

I. In a first step, we carried out an analysis on the synergy between the agent-based methodology (ABM) and the study of labor market dynamics. To this end, we followed a computer science-specific methodological perspective to determine the essential elements (or ingredients) of an agent-based model. Afterwards, we tried to synthesize and determine to what extent the studies existent in the literature managed to incorporate these elements. The aim of this approach was to allow us in the end to provide a template, a guide regarding the essential elements of an agent-based research conducted in the labor market field. The results of the analysis carried out for this purpose were later synthesized in the form of an article with the suggestive title "*The Synergy between ABM and Labor Market Dynamics*" (authors: Valentina Ioana Cheregi, Gheorghe Cosmin Silaghi). We will detail in the following the main results obtained in this stage.

The motivation for using this dual-perspective approach was to go beyond simply reviewing the literature on the use of agent-based modeling in the study of labor market dynamics. We tried to highlight, starting from the existing examples in the labor market literature, the advantages of using this methodological approach compared to the traditional methodologies. Thus, our approach differs from existing works in that, starting from the advantages that the ABM methodology offers, it tries to serve as a guide for the implementation of ABM in topics related to the labor market. The paper developed a step-by-step procedure and detailed the main ingredients to consider when implementing an agent-based model for studying labor market characteristics.

Our approach arose from the belief that the study of labor market dynamics requires a methodology capable of explaining real-world characteristics without losing sight of the micro-behaviors that generate aggregate outcomes. Looking at the existing works in the literature on this topic, we noticed that agent-based modeling provides the premises for such an approach. The way in which the analyzed models were able to incorporate economic considerations and then to transpose them into computer code for simulation purposes, creates positive premises for a widespread use of ABM in the study of the labor market. As we mentioned in detail in the body of the paper, the ABM tool proves to be extremely useful in studying complex systems (including the labor market) because it is based on more relaxed assumptions and allows a better representation of reality. It is particularly useful in the labor market setting where aggregate outcomes are the result of interactions between firms and workers, and macroeconomic outcomes cannot be directly inferred by observing an individual's behavior in isolation. This bottom-up perspective brings useful information from the perspective of economic policy implementation, because it looks separately at the elements that lead to a certain aggregate outcome. In addition, in the ABM configuration agents are endowed with characteristics that differentiate them and determine how they act. The degree of heterogeneity (which we observed can vary substantially depending on the objectives of the simulation) increases the external validity of the model.

We were particularly interested in evaluating the use and applicability of agent-based modeling in the labor market field. To the best of our knowledge, the only paper that analyzes the use of agent-based models in the labor market related topics is Neugart and Richiardi (2018). We take a distinct approach by splitting the analysis into two directions. First, we

explore the methodological path used in building an agent-based model. Basically, we take a computer science perspective to investigate how well the existing models have been able to meet the requirements of an agent-based model. To this end, we divided the analysis based on the components of an agent-based model (namely: agents, interaction and environment) and investigated to what extent economic considerations are translated into simulations. For the traceability of the ABM features that we chose to present in the paper, we closely followed the definition proposed by Wooldridge (2002, p.19) which defines the agent-based system as "one that consists of a number of agents, interacting with each other, usually by exchanging messages through an infrastructure." We therefore identify three constitutive elements of an agent-based model, namely: the agents (possessing a set of attributes, a learning style and a decision-making algorithm); the interactions (between agents: worker-firm or worker-worker; or between agents and the environment) and the environment in which the agents interact. All the analysis carried out in the first part of the paper follows the particularities of each one of the components mentioned above.

In the second part of the analysis, we carry out the research from an economic perspective, to identify the topics related to the labor market in which this methodology demonstrates its applicability. The main sub-branches that have been identified are those related to the study of the causal relationship between different macroeconomic variables (such as the wage curve, the Okun curve or the Beveridge curve), as well as the analysis of how different economic policies regulating the labor market can rely on simulation models. In addition to these, a third relatively recent sub-branch focuses on the study of the role that social networks and employment referrals play in shaping labor market outcomes.

This dual-perspective approach is intended not only to provide a detailed picture of the use of ABM in the field of the labor market, but also to highlight its importance and advantages over other existing methodologies. Furthermore, this study differs from the existing literature in that it is intended to serve as a guide in the implementation of agent-based models in this field. To this end, the paper proposed a step-by-step procedure for implementing an agent-based model, highlighting the ingredients to be considered.

The novelty that results from this detailed analysis (of how to combine the theoretical considerations of an agent-based model with the elements of an economic model that studies the dynamics of the labor market) is that we can provide a practical guide for implementing an ABM in the labor market setup. The methodological view presented in the aforementioned paper demonstrated the multitude of elements and rules that can be incorporated into such a model, depending on the level of complexity that one desires to include. Therefore, a structured analysis is a prerequisite for the reliability of the study. The conceptual model we propose at the end of this analysis aims to be a guide that serves any economist for modeling purposes. From our perspective, the main elements that must be considered in building such a model are:

a. *Choosing a research topic and formulating hypotheses:* Similar to traditional economic research, any study using agent-based modeling should be based on strong theoretical foundations. It is well known that ABM uses a computational and

simulation oriented approach. But even so, it can prove useful in economic research only if it has the ability to bring insights to certain topics of interest. Thus, the first step is to identify the research question or hypothesis to be tested. Starting from the theory, the modeler should be able to think about the "ingredients" of the model. These are the agents, the interacting entities in the theoretical setup, as well as the dynamics assumed by the world being analyzed.

b. *Designing and equipping the model:* In this step, the simulation setup is created. Specifically, the theoretical considerations must be transposed in code. The labor market has to be described as a system comprising different categories of interacting agents. In this process of developing the model, the modeler should define the rules that describe: the agents (including their learning style and decision-making process); the interactions; and the environment.

   In a first stage, the main actors that populate the model are identified, on theoretical grounds. Typically, agent-based models of the labor market use two types of agents: workers and firms. Agents are then equipped with a set of endowments/information that are relevant to their behavior. Simple or more complex rules of behavior are used to define their actions. A distinction is made between those attributes or rules that are fixed and those that must be determined endogenously in the model and continuously updated.

   Second, one should model the nature of interactions that occur between agents. In the labor market, we are particularly interested in modeling the interactions that occur in the matching process between firms and workers. More specifically, the main problem is to define the mobility model for each type of agent and to choose the set of rules that govern worker movements between firms or changes in employment status.

   The third step is to define the environment. The norms and rules governing the framework in which labor market participants interact should now be defined. In this phase, the modeler should decide how the structure of the labor market is represented (as a physical place or as a social network between agents); which labor laws and regulations are relevant to the analyzed market; and who is responsible for setting policies.

c. *Model parameterization and calibration:* Given the purpose and structure of the model, the next important step is to identify the data sources. For labor market analysis using agent-based models, large-scale databases are a key element, as they create the premises for a more accurate representation of real-world phenomena. Some variables might be available and ready to use, others might need calibration or parameterization. A distinction is made between parameters that are fixed throughout the simulations and those that can vary as the simulation evolves.

d. *Model execution*: Model implementation requires the use of a programming language to translate the model into computer code. Various toolkits and software - using different programming languages - are available for this purpose, including: Repast, Netlogo, MASON, Mesa. The choice between them is based on a set of considerations such as: the level of complexity that the model incorporates, the computing power, the effort required to develop the model, the programming language used or the learning effort. Regardless of its nature - theoretical or applied - any agent-based model has

some input variables. Depending on the objective of the study and the computing power used in the simulations, the following are determined: the number of agents that populate the model, the time unit (day, week, month, year), the number of generations/periods in which the population is allowed to evolve for observing targeted dynamics, or the number of replications of the model.

e. *Data collection:* In this step, the advantages offered by an ABM are highlighted and the results from the computational model are practically exploited. Because agent-based modeling allows aggregate variables to be generated from individual behavior at the agent level, we can draw valuable conclusions about how individual actions generate different outcomes at the population level. In this way, a set of variables can be extracted from the model and then compared to the information we have from the real data. To give just a few examples, we may collect data on: labor force fluctuation, unemployment rate, the intensity of job search, the dynamics of the population of workers or firms, etc. The flexible data collection process within ABM allows the modeler to decide which data is relevant and which should be extracted and how often it should be reported. Once the data is extracted, we need to put the results into a general context of the labor market. Basically, the circle closes and we should return to the theory to see how the conclusion obtained from the simulation fits with the assumptions made at the beginning.
f. *Model evaluation:* Considering the degree of novelty brought by agent-based modeling for labor market analysis, it could be of great interest for model validation to compare the results with some reference models used in the literature. A useful comparison is to assess the reliability of the model against econometric models. This process is not simple, however. The two modeling techniques are based on different assumptions and follow different steps in the analysis. Basically, if we find results that converge from the two "competing" models, this gives validity to the proposed method. In other cases, it is only useful to evaluate the model against some counterfactuals, by simply reproducing the simulations under different conditions, as a measure of robustness.

Therefore, in this stage of the research, we evaluated the use and applicability of agent-based modeling on labor market topics from a dual perspective. The first aim was to determine - from a methodological perspective - to what extent labor market models using ABM have succeeded in meeting the requirements of such a model. For this, we relied on the computational perspective of agent-based modeling and tried to highlight how economic considerations are translated into model simulations. Afterwards, we focused our attention on the main topics analyzed in the specialized literature, in order to highlight how this methodology demonstrates its applicability.

In parallel with this research, we tried to implement a model on which to perform simulations at the agent population level. The model is programmed in Python and implemented in MESA. We chose this approach because the core features of Mesa – the simulation modules (agent and model classes and space); the analysis tools (for data collection and multiple runs) and the interactive visualization module – allow us to deploy the model, run simulations, and

extract data from the model. To validate the results and analyze the aggregated data, multiple iterations of the simulated model will be performed through the module provided by Mesa.

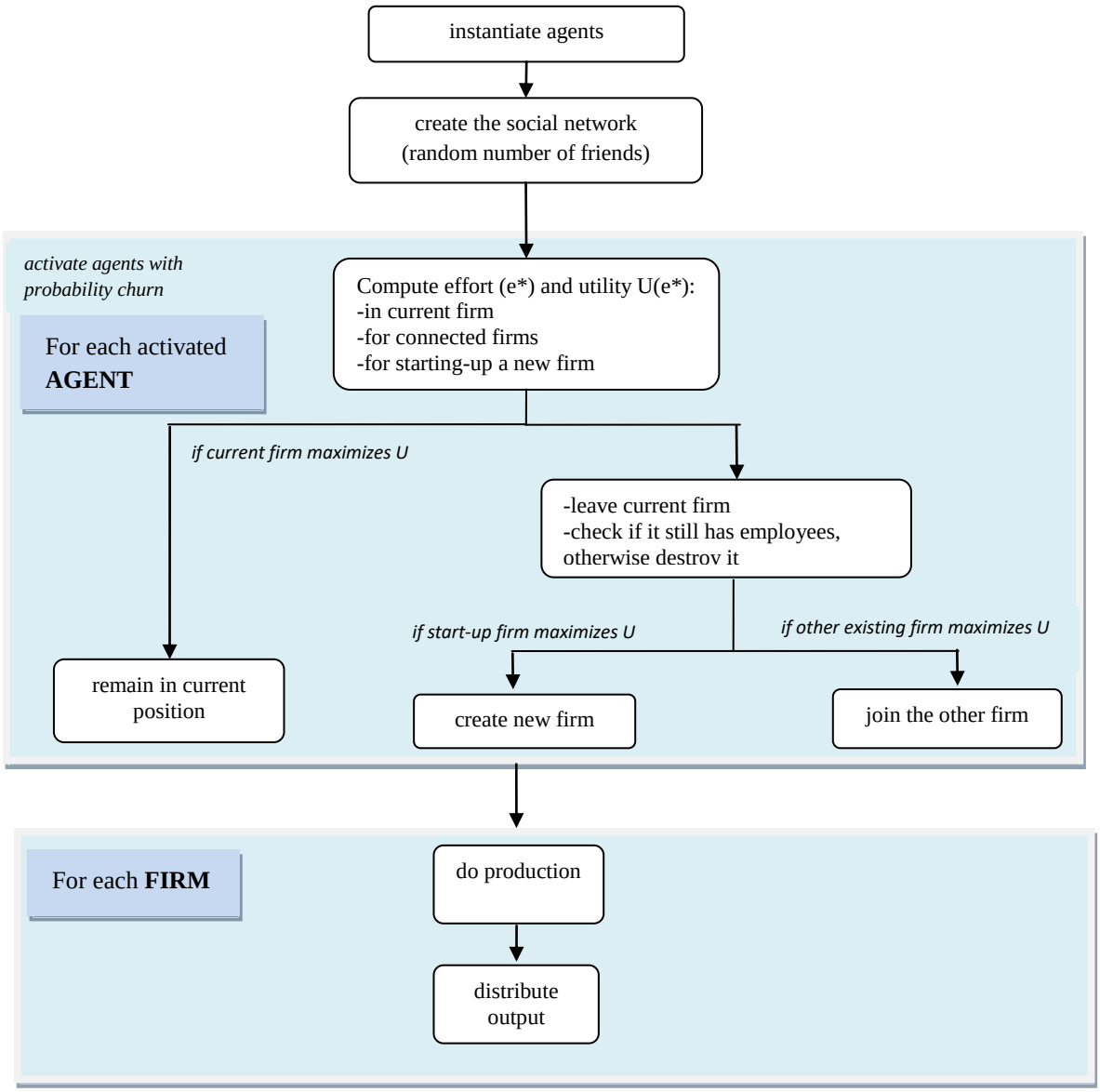
The simulation environment is populated with two categories of agents: workers and firms, each characterized by a number of attributes that define their actions within the simulation. In this model, the labor market is represented as a network where the nodes are workers or firms (groups of workers). The existence of a link between two nodes (ex. two agents) indicates that those agents know each other, which facilitates the flow of information between them. Basically, an agent's social network is represented by the number of connections it has. Searching and finding a job is in this case limited to an agent's social network. Therefore, we assume that workers who are looking for a new job choose the potential firm to hire from among their friends' employers.

The number of workers is determined exogenously and fixed during the simulation period (since we consider the population relatively stable over a short period of time), and the number of firms is determined endogenously in the model, since it is based on the decision of the employees. More specifically, the workers are the ones who (once activated) decide based on a utility function what is more favorable to do, having to choose between three options: to stay in the current company in the current position; to leave the company to start their own company; or to change their current job, leaving it for one of the companies where one of the agents who are part of his social network works. Therefore, a firm is created when workers decide that it is better to associate to generate market-level outcomes, or it is destroyed when workers find better job opportunities elsewhere and decide to leave the current firm.

The interactions take place in the model between agents that are connected through a social network. When created, agents are connected to a number of agents in the population, and these will represent their social network. This social network takes the form of a random graph, with each agent assigned a random number $v \in [2,6]$ of acquaintances/friends. They are randomly assigned at model initialization and do not vary over time. Thus, the movement of agents between firms is restricted by their social network. In each step of the model, agents are activated with a certain probability. When enabled, the agent must consider the following options based on its utility assessment: a). to stay in his current firm, b) to join one of his friends' firms, or c) to start a new firm.

Below we detail the logical structure that guides the implemented model, a model that is intended to be a prototype of a labor market simulation model.

Figure 1 – **Model configuration**



The labor market dynamics used in this paper is based on the particularity that the matching process between workers and firms does not follow the conventional practice in labor economics which uses an aggregate matching function and assumes that the matching between job applicants and available jobs takes place random. Instead, it follows an approach that tries to explicitly model the structure of the labor market, taking into account certain patterns of mobility with the use of labor flow networks. In each step of the model, active agents evaluate their current position and, if better opportunities are identified, actively search for a new position among their friends' employers or try to create new firms with one of the individuals who form their social network.

III. The second sphere in which we directed our research effort has focused on conducting a comparative analysis using estimation methods traditionally used in economics. In this regard, we wanted to see in what way the labor force structure influences the aggregated variables at the macroeconomic level. Basically, we wanted to see how is validated from the econometric point of view the well-known negative relationship between unemployment and the vacancy rate, known as the Beveridge Curve (BC). The results are detailed in the article "*Is labor matching effectiveness dependent on education level, age or gender? A Beveridge curve approach*", and will be briefly presented in what follows.

Our study starts from the existing literature in the field and develops it in several ways. First, this paper is the first regional-level study that attempts to study unemployment and job vacancy dynamics using the Beveridge curve approach for this particular sample of Central and Eastern European countries. We have identified a gap in the literature regarding the study of the possible sources leading to fluctuations in frictional unemployment for these countries, fluctuations caused by difficulties in finding a job associated with the sample of workers. Second, although BC dynamics have been analyzed individually for certain Central and Eastern European countries, empirical analyzes do not usually take into account the structure of the labor force (in terms of age, gender or education). Third, as more recent data become available, we are able to account for changes in the Beveridge curve in the periods which preceded and followed two major economic downturns: the global financial crisis of 2008-2010 and the COVID-19 crisis.

In this article we analyzed the role of the workforce structure on the efficiency of the labor matching process. Quarterly data were used for a sample of ten countries in Central and Eastern Europe (Bulgaria, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia) from 2005 to 2023. From a methodological point of view, the analysis is based on dynamic panel estimation, and we relied on the Dynamic Ordinary Least Squares estimator.

The main objective was to determine which are the sources that might determine Beveridge curve shifts, and to see if they might be influenced by the way in which the workforce is structured in terms of education, age and gender. In addition, we include in the estimations a set of institutional variables to determine the role of national policies in the regulation of the labor market and in the stabilization of unemployment.

The results of the study confirm the validity of the Beveridge curve and point to a significant impact of education, gender and age on labor market outcomes. In particular, the association between employees and companies is facilitated by a greater share of the workforce that has higher education, while the opposite is true for the share of women and younger people in the workforce, both coefficients estimated in regression indicating a greater probability of deteriorating the matching process.

Furthermore, the estimates reveal significant changes in BC when labor force structure is explicitly included in the model. In particular, an outward shift of the Beveridge curve is associated with a higher share of women and young people in the labor force, while a higher share of people with higher education causes the opposite effect, i.e. an inward shift. In other

words, matching is easier the higher the share of the population that has higher education and is more difficult the higher the share of youth and women in the labor force.

The results regarding the structure of the employment pool are robust to different specifications of the model, specifications in which we included, in turn: passive or active policies associated with the labor market, or the role of the COVID pandemic or in which we tested the validity by using a different estimator (Fully-Modified OLS). In addition, in performing the robustness tests, we identified some interesting results related to the role of active and passive policies in the labor market. The results obtained in our sample of CEE countries show that the role of active labor market policies predominates in facilitating the match between employers and employees. Specifically, the higher the share of active labor market policies in gross domestic product, the lower the unemployment rate will be. Conversely, even if small, the impact of unemployment benefits on the unemployment rate is rather negative. This result is consistent with previous findings in the literature, as a growing body of research shows that unemployment benefits are negatively associated with frictional unemployment (Bova et al., 2018), while unemployment benefits have mostly a negative effect on the association process (Destefanis et al., 2023), especially when they exceed a certain threshold (Ricetti et al., 2013).

From the policy oriented perspective, these results highlight the need to implement active policies to reduce unemployment, aimed at different sub-structures of the labor force. Considering that we have identified through this study that the level of education is a facilitator of the matching process, this requires policies aimed at reducing the existing gaps in competences by promoting training, for example. This result is consistent with the one related to the role played by active labor market policies, which should be promoted as they seem to have a greater impact on reducing unemployment. There is also a need to improve the process of finding a job for young people and women, by developing policies aimed at stimulating employers to hire these population categories.

- ***Summary:***

The results obtained in this stage of the research are embodied in two articles. Each of the two articles was presented at a conference as follows:

1. The article: "Is labor matching effectiveness dependent on education level, age or gender?" A Beveridge curve approach" (author: Valentina Ioana Cheregi) will be presented at the beginning of December 2023 at the conference: Cluj Economics and Business Conference (CEBC 2023), (Third Edition), 7-9 December 2023, organized by the Babeș-Bolyai University, Faculty of Economic Sciences and Business Management, Cluj-Napoca, Romania. This paper was sent for publication to the "Empirical Economics" Magazine (ISI magazine in the field of Economics, Q3, with ASI=0.623 according to JCR June 2023), being in the evaluation process.

2. The article "The Synergy between ABM and Labor Market Dynamics" (authors: Valentina Ioana Cheregi, Gheorghe Cosmin Silaghi) was presented in October 2023 at the International Conference Globalization and Higher Education in Economics and Business Administration

(GEBA 2023), (Edition XV), October 19-21, 2023, organized by the Alexandru Ioan Cuza University in Iasi, Faculty of Economics and Business Management. This paper has been submitted for publication to the Journal "Simulation Modeling Practice and Theory" (ISI Computer Science journal, Q3, with ASI=0.637 according to JCR June 2023), and is under review.

References

1. Bova, E., Tovar Jalles, J., Kolerus, C., (2018), Shifting the Beveridge Curve: What Affects Labour Market Matching?, International Labour Review, 157(2), 267–306.
2. Destefanis, S., Fragetta, M., Ruggiero, N., (2023), Active and passive labour-market policies: the outlook from the Beveridge curve, Applied Economics, 1-13.
3. Neugart, M. and M.G. Richiardi (2018). Agent-Based Models of the Labor Market". In: The Oxford Handbook of Computational Economics and Finance. Oxford University Press.
4. Riccetti, L., Russo, A., Gallegati, M., (2013), Unemployment Benefits and Financial Factors in an Agent-Based Macroeconomic Model, Economics Discussion Papers, No 2013-9, Kiel Institute for the World Economy.
5. Wooldridge, M. (2002). An Introduction to MultiAgent Systems. John Wiley& Sons, LTD.

Main research investigator,
Cheregi Valentina Ioana

Executive summary

The research conducted in the stage 2023 (Stage 3 of the project) had the following objectives: Building a complex synthetic network of flows between workers and firms on the labor market and Applying the network of labor flows and the agent-based model (ABM) to study current research themes in empirical labor market studies. The steps taken towards this objective were divided in two main directions.

• A first approach of the research aimed to determine how the synergy between the agent-based methodology and the study of labor market dynamics can be achieved in practice. The analysis has been materialized in a paper that describes the scientific approach necessary to be followed in such a context, paper entitled "*The Synergy between ABM and Labor Market Dynamics*" (authors: Valentina Ioana Cheregi, Gheorghe Cosmin Silaghi). Starting from the definition of the agent as it is accepted in computer science, we tried to see how the elements of economic theory map onto these requirements. The novelty of this analysis is the fact that it provides a practical, step-by-step guide to creating an agent-based model on topics related to labor market dynamics. In parallel, we created an agent-based simulation model starting from the theoretical and practical considerations described in this paper.

• The second objective was to analyse the well-known relationship between the dynamics of unemployment and the dynamics of vacancies, namely the Beveridge curve. We wanted to see from a macroeconomic perspective how the structure of the workforce influences this relationship. The article "*Is labor matching effectiveness dependent on education level, age or gender? A Beveridge curve approach*" (author: Valentina Ioana Cheregi) is based on the idea of matching between employees and firms and uses data for a panel of ten countries in Central and Eastern Europe between 2005 and 2023. The results of the study confirm the validity of the Beveridge curve and indicate towards a significant impact of education, gender and age on labor market outcomes. In particular, an outward shift of the Beveridge curve is associated with a higher share of women and young people in the labor force, while a higher share of people with higher education causes the opposite effect, i.e. an inward shift.

The results were disseminated by participating in two conferences: Globalization and Higher Education in Economics and Business Administration (held between 19 and 21 October 2023 at the Alexandru Ioan Cuza University in Iasi) and Cluj Economics and Business Conference (held between 7-9 December 2023, at Babeș-Bolyai University, Cluj-Napoca).

The results obtained at this stage confirm the importance of the approach carried out within the research project, and highlight the role of agent-based modeling in accurately describing the dynamics of the labor market. The complexity of such a model remains the main challenge in the process of implementing ABM in practice and requires the expertise of the one who applies the model in order to choose the essential elements of the simulation model, in order to provide the greatest possible degree of realism from an economic point of view.

Main research investigator,

Cheregi Valentina Ioana