How can we sustain cooperation and economic convergence in the European Union?

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***Abstract*—In this paper, we present an Agent-based model developed to investigate and assess the influence of inherent GDP growth disparities, the European Union's benefit distribution strategies, and the benefits of the European single market on the economic convergence and sustainable cooperation between regions. The model is comprised of 320 basic entities driven by self-interest to maximize their economic prosperity according to simple rules. In this model, the economic convergence is quantified using the Gini coefficient, while the economic cooperativeness is measured simply by the number of regions that stay in the union. It is concluded that economic convergence and sustainable cooperation are strongly dependent. Moreover, we find that the concept of economic convergence is possible only if many regions are willing to cooperate and vice versa. In this aspect, it can be concluded that it is necessary to ensure that the EU's policy is attractive to all kinds of economies. Therefore, it is crucial to establish a moderate EU benefit distribution policy only slightly skewed towards the countries in need, so that the cost of contributions for the top benefactors are out-weighted by the benefits stemming from the EU single market.**

***Index Terms*—ABM, Economic convergence, European Union, Cohesion Policy**

I. Introduction

The European Union was formed with the ambitious goal of promoting a convergent and sustainable development of countries, and establishment of a single market that would be beneficial for all member states [13]. This idealistic goal gave rise to EU's Cohesion Policy, aiming, among others, to reduce disparities in wealth and the level of development between its member states [13], [6]. The Cohesion Policy has been in place for over 30 years, and it has recently been disrupted by the departure of the United Kingdom from the union – one of the top contributors to the EU's budget [13]. The Brexit triggered a discussion on the feasibility of the goals and the actual performance of the EU Cohesion Policy. One of the main concerns is the fact that the top benefactors to the EU budget contribute more capital to the EU budget than they gain from the union [12]. On the other hand, the European Commission estimates that the concept of the European single market benefits each country at least 5 times its yearly contribution to the EU budget [1]. It seems to be almost impossible to quantitatively assess the effectiveness of the Cohesion policy, and evaluate its actual performance not only because of the complexity of the interactions between the EU member states, but also due to the fact that the EU's budget is also used to meet many other global challenges, such as addressing climate change and global warming [15], [5].

On a related topic, research has been conducted by G. Dosi et al. in her paper entitled ”Endogenous growth and global divergence in a multi-country agent-based model” in which she elaborates on her Agent-Based Model with multiple agent strategies [4]. Dosi presents a model developed to investigate the role of technological advancements in driving economic divergence among economically interdependent countries, and concludes that her model uncovers underlying inclination towards economic polarization [4]. Another approach is used in the exploration of the sustainability of regional cooperation via Game Theory in a research paper entitled ”Political tournament and regional cooperation in China: a game theory approach” [2]. This paper introduces three models that utilize game theory to analyze what political incentives motivate provincial officials to pursue regional cooperation [2].

The Brexit controversy prompted us to examine the current benefit distribution strategy and evaluate the prospect of sustainable cooperation and economic convergence in the European Union. Furthermore, the Cohesion Policy has recently been modernized and is scheduled for the next seven years 2021-2027 [15]. However, besides minor changes in prioritization criteria, the EU budget allocation strategies remain heavily dependent on GDP per capita disparities between the member states [15]. Therefore, the goal of this research is to investigate what factors lead to economic convergence and cooperation between regions which are driven by self-interest to maximize its economic prosperity. Furthermore, we will also attempt to evaluate the role of the EU as a governing body in mitigating the wealth disparities between the countries. We hypothesize that a governing body like the EU can reduce disparities between countries if the required percentage contribution to the EU budget, distribution of EU budget, and the profits stemming from trading on the EU's single market are beneficial for all member states.

In section II the theoretical background of our ABM model is presented. Sections III, IV, V and VI describe the model using the ODD+D protocol. In section VII we perform sensitivity analysis on the model parameters and in section VIII we describe other results. Finally we finish our report with the discussion and conclusion in sections IX and X respectively.

II. Background

A. Economic Convergence

The European Central Bank defines economic or sustainable convergence as “the process whereby the real GDP per capita levels of lower-income economies catch up, on a durable basis, with those of higher-income economies” [11]. They further elaborate on two types of convergence, which are β-convergence which "occurs when lower-income economies grow faster than higher-income economies", and σ-convergence which "relates to a reduction in the dispersion of income levels across economies".

We will only focus on β-convergence, more specifically on how different policies by the simulated EU can counteract inherent differences in GDP-growth among different regions and thus lead to economic convergence.

B. Gini coefficient

A convenient way of measuring economic convergence can be done with the Gini coefficient. The Gini coefficient is defined with the following formula:

$$G = \frac{\sum_i \sum_j |W_i - W_j|}{2n^2\hat{W}}, \tag{1}$$

where the summation is over all the regions, W_i indicates the wealth of the i-th region, n indicates the number of regions and $\hat{W}$ indicates the average wealth. The Gini coefficient is a measure for inequality and ranges from 0 (completely equal wealth) to 1 (all wealth is owned by one country) when wealth is non-negative. The Gini Coefficient can be used to quantify economic convergence or divergence as well as wealth inequalities. In our model, the Gini coefficient is taken for all regions and not just EU members to determine the impact that the EU can have on all the regions of the European continent.

III. Model overview

A. Purpose

The first objective of the model is to imitate complex interactions between regions of the European Union member states, thus establishing a framework for the exploration of the role of the European Union as a supervising agent promoting cooperation. Secondly, given the framework, the model allows for the assessment of the performance of the EU's budget allocation strategy and the benefits associated with the European single market on driving the economic convergence and sustainable cooperation between the EU member states. Finally, the model also allows investigating what factors contribute to further economic divergence, as well as explore what is necessary to promote sustainable economic convergence. The model is built on the fundamental realism's assumption that each region is driven by self-interest to maximize its economic prosperity [21]. Hence, an EU region is satisfied when its wealth accumulation outweighs the wealth it would have made without the EU. Moreover, we also implemented the concept of the neighborhood influence exerted by the neighboring regions on the cooperativeness of a region.

B. Entities, state variables and scales

In this model the EU supervising agent plays the role of the environment, being an omnipresent body that collects the taxes (contributions) from member states, and then distributes the budget back to members according to the benefit distribution parameter.

The model consists of 320 basic entities (agents) which directly correspond to 320 NUTS-2 (Nomenclature of Territorial Units) subdivisions of countries used by the European Commission to report on the influence of Cohesion Policy on advancing social, territorial and economic convergence of EU member states [16], [3], (Figure 1).

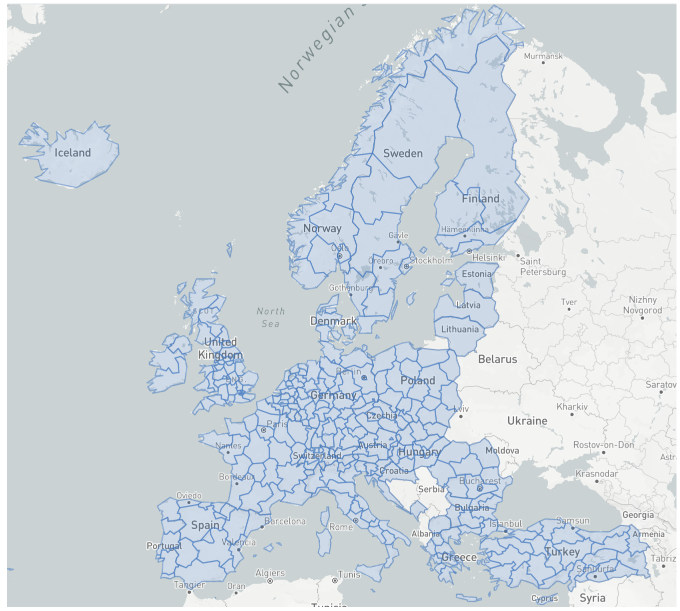

Fig. 1: Overview of the 320 NUTS-2 regions (2013) contained in the used GeoJSON dataset, displayed on top of a map of Europe.

The agent's state variables are presented in Table II. Each region in the model is a heterogeneous agent characterized by 8 state variables: spatial location on the NUTS-2 grid, neighboring-regions, strategy, cooperativeness, wealth, efficiency (inherent mean value of GDP growth), has-traded and tax-paid. The heterogeneous characteristic of agents stems from the fact that each spatial location of the region is unique, and hence so is its neighboring-region state variable. There are 2 strategies that agent can attribute: strategy 1 indicating membership in the EU, and strategy 2 simply implying non-membership in the EU. The strategy used by each agent in each single iteration of the model is dependent on the current value of the cooperativeness state variable.

The cooperativeness state variable is initially sampled from a uniform distribution $\mathcal{U}(-1, 1)$, and is a dynamic state variable that can take values between $[-1, 1]$. The value of the cooperativeness state variable is updated after each iteration. Cooperativeness < 0 indicates non-cooperativeness, in other words, lack interest in being a member of the EU, thus directly indicating strategy 2. Whereas, cooperativeness > 0 implies EU membership (strategy 1). In case when cooperativeness of one agent is equal to 0 the choice of strategy for that specific iteration is chosen randomly.

Efficiency (GDP growth) is a pseudo-dynamic state variable, as its initial base mean value is sampled from a normal distribution $\mathcal{N}(\mu = 1.5, \sigma = \sigma_E)$ and its mean value is kept constant throughout the simulation. The pseudo-dynamic characteristic of this state variable is ingrained in the fact that the base GDP-growth state variable is subject to small stochastic

Sym	Parameter	Range	Explanation
I	International Trade	Boolean	Regulates whether regions can trade with any other region (internationally) or only with the neighboring regions.
σ_E	Efficiency STD	$[0, 2]$	The standard deviation for $\mathcal{N}(\mu = 1.5, \sigma = \sigma_E)$ from which agents efficiencies (GDP-growth) are sampled from.
τ	EU tax	$[0, 1]$	Percentage of wealth that each member contributes each round to the EU budget.
ι_N	Neighbor influence	$[0, 0.2]$	Determines by how much agents cooperativeness is modified based on the average cooperativeness of their neighbours.
ι_T	Tax influence	$[0, 0.2]$	Determines by how much agents cooperativeness is modified based on whether it was (it would be) beneficial to be the member of the union.
γ	Member trade multiplier	$[0.5, 3]$	The bonus multiplier of the trading reward for the trades made between two EU members.
β	Benefit distribution	$[0.8, 1.2]$	Regulates whether the benefit distribution is proportionally skewed towards the rich (> 1), the poor (< 1) or if everyone receives their initial contributions ($= 1$).

TABLE I: Parameters of the model.

Sym	State variables	Range	Explanation
C	Cooperativeness	$[-1, 1]$	Indicates the standing of an agent with respect to the union and determines strategy.
S	Strategy	1 or 2	Members adopt strategy 1, outsiders adopt strategy 2.
E	Efficiency (GDP growth)	$(0, \infty)$	Multiplier of logarithm of wealth per round.
T	Has-traded	Boolean	Whether an agent has traded already in the current round.
P	Tax paid	$(-\infty, \infty)$	Tax an agent has paid in the current round.
W	Wealth	$(1, \infty)$	Wealth of an agent
L	Spatial location		Defines a region's coordinates on the map.
N	Neighboring regions		Determines particular regions that are adjacent to the region of interest.

TABLE II: State variables of the agent.

perturbations in each iteration ($+\mathcal{N}(\mu = 0, \sigma = \sigma_E/4)$). The σ_E parameter also called efficiency (GDP-growth) standard deviation allows to not only increase the variance of the basic mean GDP-growth value assigned to each agent at the beginning of the simulation, but it also is a measure of the strength of stochastic perturbations that each agent's efficiency (GDP-growth) state variable is subjected to throughout the simulation. Hence, this parameter provides a comprehensive tool to adjust both initial and temporary GDP growth disparities between the regions for each simulation.

Furthermore, wealth is a dynamic state variable initially sampled for each agent from a normal distribution $\mathcal{N}(\mu = 10, \sigma = 2)$. The value of the wealth state variable is adjusted for each agent at each iteration and it depends on the trading interactions, efficiency (GDP-growth), and for members of the EU on the net gain or loss associated with the contribution to the EU budget. Similarly, the state variable tax-paid depends on the EU membership and is greater than zero only when a region is a member of the EU. Finally, the state variable has-traded is a boolean variable and is set to True if the region has traded in the current iteration. This allows to ensure that each agent trades only once in each iteration of the simulation.

The spatial scale of the model is defined by the NUTS-2 grid, yet the model is modular and it can be easily modified by running it on any type of shapes in a .GEOjson format. In terms of the temporal scale, each iteration of the model imitates one year, however, we consider the simulation to end when the system reaches equilibrium or when all regions share the same strategy.

C. Process overview and scheduling

The following Algorithm 1 describes the main actions happening each step of the model execution.

Algorithm 1: Model Step

```
while Current iteration < Max iterations do
    π = Random permutation of the list of agents
    Current iteration += 1
    for agent in π do
        Member if cooperativeness > 0, else outsider
        Update cooperativeness based on neighbours
        Execute natural growth (Equation 4)
        if No trade interaction this iteration then
            Pick available trade partner
            Trade with partner
    end
    Collect taxes from members
    Compute virtual benefits and update cooperativeness for
      outsiders
    Distribute EU budget and update cooperativeness for
      members
end
```

Time in this model is represented discretely by iterations of the model. For every iteration, each agent is activated once in a random order, with the order reshuffled every iteration. Figure 2 illustrates the process, distinguishing agents from the environment. Members are illuminated in blue and outsiders in red. When an agent is selected it will decide, based on the value of its state variable cooperativeness, whether it will trade as a cooperator or defector with another region, which also decides to cooperate or defect based on its own cooperativeness state variable.

Each agent chooses its strategy at the start of each iteration, after which agents update their cooperativeness based on the

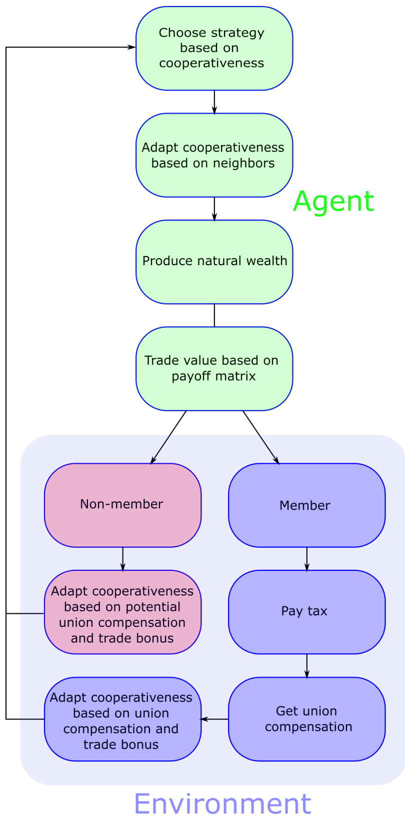

Fig. 2: Model Flowchart. Green represents the actions performed by all agents during each step. Blue and Red represent the actions that the model performs for the agent.

average cooperativeness of their respective neighbors. When the average cooperativeness of neighboring regions is larger (smaller) than zero the agent increases (decreases) their cooperativeness by an amount equal to the value of the parameter neighbor influence (ι_T). The agent then increases its natural growth, which is determined by the efficiency (GDP growth) of the region (Equation 4). If the region has not traded in the current iteration it chooses another region that has not traded yet as well. The trading partner region is chosen depending on the value of the parameter international trade (I), which is set either to True or False. When international trade is set to True, it means that regions are allowed to trade internationally (i.e. with any region different from the region itself), representing globalization. Whereas when international trade is set to False, only regions adjacent to the region of interest can be chosen to be the trade partner. In case a region does not have any neighboring regions, that region is allowed to trade internationally independently of the value of the international trade parameter.

When every region has traded, the supervising agent collects taxes from the cooperating regions and redistributes benefits, after which each region calculates if it would have obtained more wealth, had it picked the opposite strategy. (This action for outsiders is denoted by compute virtual benefits and for the members it is part of distribute EU budget function in Algorithm 1). If the region made the decision that produced the most wealth, it adjusts the cooperativeness state variable by an amount equal to the value of tax influence (ι_T) to be more likely to take this same decision the next iteration. However, if the region would have produced more wealth by picking the opposite interaction, it is now more likely to pick the other option in the next iteration. Lastly, the union budget is distributed to the countries that cooperated that round in accordance to the benefit distribution parameter (β).

IV. Design concepts

A. Basic principles

Our model combines several ideas and concepts. First, our model is based on game theory and simulates the situation where agents trade with each other and can choose 2 strategies, cooperate (being a member) or defect (being an outsider). The payoff of each strategy profile is determined by the matrix in Table III, which we will expand on later.

The strategy an agent chooses depends on their cooperativeness, which in turn depends on two factors. One factor is neighbour influence, which is inspired by the Schelling model. The Schelling model investigates segregation among neighbourhoods and related dynamics [19]. Contrary to the Schelling model, agents in our model adapt their cooperation based on their neighbours instead of moving away from them. The observed effects are similar, as we will see in the next subsection.

The second factor that cooperativeness depends on introduces yet another concept, agents handling out of self-interest. The cooperativeness of an agent depends on what strategy will maximize their own wealth each step. While this behavior may lead to disparities in wealth, we introduce the EU as a union that agents can join. Members of this union pay tax but receive an extra trade multiplier on their trades, as well as benefits based on the tax paid and EU budget distribution policy. While not explicitly modeled as an agent, our goal of introducing the EU is to investigate which policies can achieve economic convergence despite agents handling out of self-interest.

B. Emergence

Complex interactions of regions in our model lead to the emergence of several macro behaviors, some being more unpredictable while others are more built-in. One emerging macro behavior that we observe is the formation of clusters, blocs of countries adopting the same strategy when the value of neighbour influence (ι_N) parameter is close to or higher than the value of tax influence (ι_T) parameter. This emergent macro-behavior is visualized in Figure 3.

Another emerging macro behavior is the segregation of wealthy (efficient) from poor (inefficient) countries, which heavily depends on the value of the benefit distribution parameter (β). In case the value of the neighbour influence parameter (ι_N) is significantly lower than the value of tax influence parameter (ι_T) and when the benefit distribution ($\beta < 0$), we observe that the union emerges into a coalition of the countries with the lower than average efficiency (GDP growth) value. This phenomenon is visualized in Figure 10. Furthermore, for the same benefit distribution setup, but in case the value of the neighbour influence parameter is close to the value of tax influence parameter, the segregation process becomes much more complex and hence less apparent.

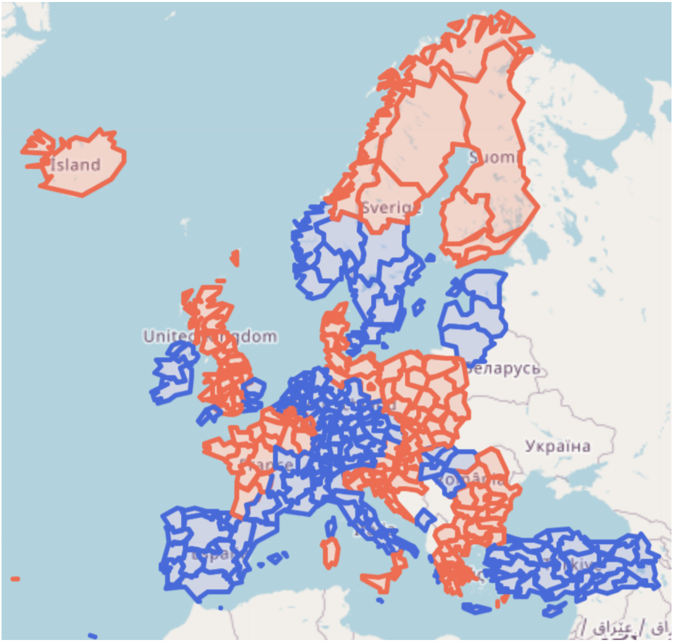

Fig. 3: Visualization of the emergent trading blocs adopting the same strategies. The model was run with the following parameter values: I = True, $\sigma_E = 1.75, \tau = 0.14, \iota_N = 0.07, \iota_N = 0.03, M = 1.01, \beta = 0.973$.

C. Adaptation

Agents adapt their strategy based on two factors. First, they seek to maximize their profits and minimize their losses in each iteration. They do so by comparing the wealth gained using their current strategy with the potential wealth they would have gained if they had chosen the other strategy. Afterward, they adjust their cooperativeness based on which strategy would have resulted in a greater wealth accumulation. The second factor influencing their strategy is their neighbours. Agents adjust their cooperativeness to move close to the average cooperativeness of their neighbours. Both of these influences are represented in Algorithms 2 and 3 respectively.

Algorithm 2: Tax influence Algorithm

for *regions in EU members* **do**
  if *benefit + trade bonus > tax paid* **then**
    cooperativeness + tax influence
  else if *benefit + trade bonus < tax paid* **then**
    cooperativeness - tax influence
  end
end

for *regions in outsiders* **do**
  if *v. benefit + v. trade bonus > v. tax paid* **then**
    cooperativeness + tax influence
  else if *v. benefit + v. trade bonus < v. tax paid* **then**
    cooperativeness - tax influence
  end
end

Algorithm 3: Neighbour influence Algorithm

for *regions in agents* **do**
  if *average cooperativeness of neighbours > 0* **then**
    cooperativeness + neighbor influence
  else if *average cooperativeness of neighbours < 0* **then**
    cooperativeness - neighbor influence
  end
end

D. Objectives

Agents have two objectives. They try to maximize their wealth each round and they try to fit in with their neighbours. The model contains parameters to configure the importance of these objectives. To maximize their wealth, they consider whether they would have made more or less money if they would have followed the other strategy. They then adapt their cooperativeness based on these results. As for neighbour influence, the objective of the agents is to move towards the average cooperativeness of their neighbours.

E. Sensing

The main decision an agent takes is their strategy, which depends uniquely on their cooperativeness state variable. Cooperativeness can take values in the range $[-1, 1]$ and is a dynamic state variable as it can be increased or decreased by either tax influence or neighbour influence. The algorithms that update the cooperativeness based on the tax influence and neighbour influence are presented in Algorithm 2 and Algorithm 3 respectively. Additionally, the complexity of agent's decision making is illustrated in Figure 4 and Figure 5.

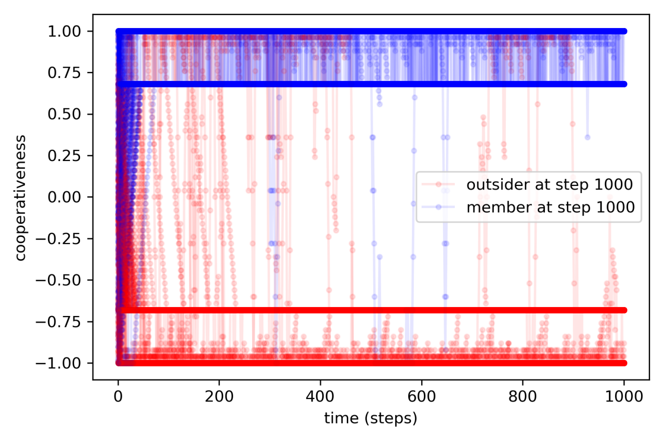

Fig. 4: Visualisation of the cooperativeness of 320 agents over 1000 steps of the model. In blue are the agents that end up being members, in red are the agents that end up being outsiders at the last step. the following parameter values: I = True, $\sigma_E = 3, \tau = 0.2, \iota_N = 0.36, \iota_T = 0.32, M = 1.01, \beta = 0.8$.

F. Interaction

The main type of interaction between agents is trading. Having found a trading partner, both agents trade. Our model

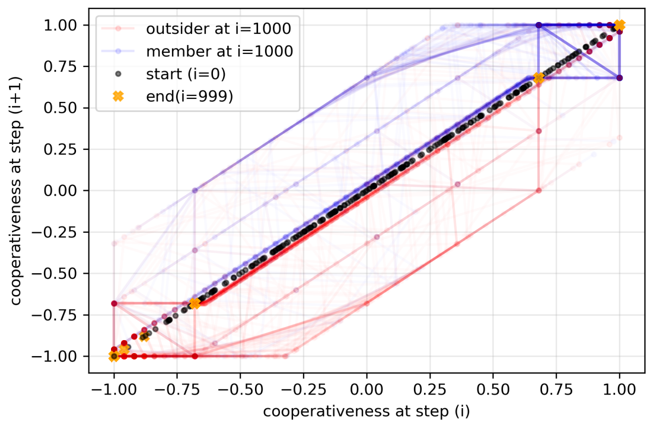

Fig. 5: The cooperativeness of all 320 agent at each step plotted against their cooperativeness at the next step. In blue are the agents that end up being members, in red are the agents that end up being outsiders at the last step. Parameters: I = True, $\sigma_E = 3, \tau = 0.2, \iota_N = 0.36, \iota_T = 0.32, M = 1.01, \beta = 0.8$.

consists of 3 types of trading: trading between two members (M, M), trading between a member and an outsider (M, O) or (O, M), and trading between two outsiders (O, O). The payoff matrix for all types of trading interactions is presented in Table III. The baseline reward for trading is the logarithm of the average wealth of the two traders. When both trading agents are members, then the trading reward is multiplied by the value of the member trade multiplier (γ). The reward is then added to the wealth of both agents. Besides this reward, a trade bonus is also computed. The trade bonus is the difference between the reward that two members received and the baseline reward. The value of trade bonus is later used by agents to evaluate whether they would have made more profit with the alternative strategy.

	Member 2 (M2)	**Outsider 2 (O2)**
Member 1 (M1)	$\gamma \cdot \ln\left(\frac{W_{M1}+W_{M2}}{2}\right)$	$\ln\left(\frac{W_{M1}+W_{O2}}{2}\right)$
Outsider 1 (O1)	$\ln\left(\frac{W_{O1}+W_{M2}}{2}\right)$	$\ln\left(\frac{W_{O1}+W_{O2}}{2}\right)$

TABLE III: The payoff matrix for trading. According to this matrix, being a member is a nash equilibrium and weakly dominates being an outsider for $\gamma > 1$. However this matrix does not take the EU tax into account.

G. Stochasticity

The initial values of cooperativeness and consequently the strategy of an agent, its initial wealth, and its initial efficiency (GDP growth) are initiated randomly. We have made this choice to make the model behavior less dependant on initial conditions. Moreover, to make the efficiency (GDP growth) more dynamic, we subjected its base mean value to random perturbation of $+\mathcal{N}(\mu = 0, \sigma = \sigma_E/4)$.

The key stochastic process is the choice of trading partner. If international trade is enabled, agents chose a trading partner at random from all of the available (available as in having not yet traded this round) agents. If international trade is disabled, then agents chose an available trading partner at random among their neighbours, and only if none are available they consider international trading.

H. Collectives

Our model has two collectives. We have the explicit collective of the European Union, and consequently the implicit collective of the outsiders (non-members). The EU collective is represented by the agents whose cooperativeness state variable is above 0. Members of the EU influence each other in different ways. If they trade with each other, their resulting reward is multiplied by member trade multiplier (γ), which represents the real-life concept of benefiting from European single market and trade agreements. Moreover, members also influence each other more indirectly by contributing to EU's budget. Afterward, the EU's budget is distributed among members with respect to rules imposed by the benefit distribution parameter (β).

However, there are also emerging properties of the EU collective, such as it becoming a 'club of the rich' or 'club of the poor' depending on the value of the benefit distribution (β) parameter, and on the fact if there is a considerable disparity between regions' wealths.

I. Observation

Throughout the process of the model development, we used the data collector from mesa to collect and visualize different types of output data at each step of the simulation. The collected output data were: the number of the union members and outsiders, the average wealth and the average efficiency of members and outsiders, the Gini coefficient, and the average cooperativeness of all regions. At that point, the output data was used to analyze and ensure that the model performs appropriately with respect to the design concepts.

Moving forwards, in order to perform sensitivity analysis and the investigation of the influence of various factors on the economic convergence and cooperation, the same output data were collected, however, this time they were collected only at the last step of each simulation.

V. Initialization

The model initialization can be divided into two parts. The first part is independent of the values of the model parameters – i.e. the number of agents and 7 out of 8 of their state variables: the initial value of cooperativeness (and consequently the strategy in the first iteration), initial wealth, spatial location, neighboring regions, has-traded and tax paid. During the initialization of the model, 320 agents, their spatial locations and neighboring regions are retrieved from a GEOjson file and initialized by the mesa-geo framework. Furthermore, the state variables tax-paid is set to 0 for all the members, as well as the has-traded is set to False. The rest of the above-mentioned state variables are initially randomly sampled from their respective random number distributions. The cooperativeness is initially sampled from a uniform distribution $\mathcal{U}(-1, 1)$, whereas wealth is sampled from a normal distribution $\mathcal{N}(\mu = 10, \sigma = 2)$.

The second part of the model initialization is dependent on the value of the efficiency std σ_E parameter. Agents' state variable efficiency (GDP growth) is initially sampled from a $\mathcal{N}(\mu = 1.5, \sigma = \sigma_E)$, hence increase in the value of the σ_E directly influences the variance of the base mean values of regions efficiencies. Additionally, the state variable efficiency (GDP growth) is subject to small stochastic perturbations at each iteration (Efficiency $+\mathcal{N}(\mu = 0, \sigma = \sigma_E/4)$, which also depends on the value of the efficiency std σ_E parameter.

VI. Input Data

Apart from the input parameters to initialize the Model class, the only other input required is a GeoJSON file containing the agents. In this file, each agent is represented by a "Feature" that contains among other information: a shape length, shape area, and the shape of an agent as a polygon that is defined by a set of coordinates.

VII. Sensitivity Analysis

In this section we present the results of the variance-based sensitivity analysis. Variance-based sensitivity, also called Sobol sensitivity analysis consists of investigating how the output variance depends on various input parameters. Parameters are sampled from low-discrepancy sequences such as the Sobol sequence, hence the name. The total output variance is then decomposed and analyzed to determine which parameters or parameter interactions contribute most to it. In this report, we will focus on first- and total-order sensitivity indices, and not on any higher-order sensitivity indices in-between.

The first-order sensitivity index S_i of a parameter i is the "expected reduction in variance that would be obtained if X_i could be fixed" [18]. It measures the percentage of variance that a specific parameter contributes to the total variance, and can be used for factor prioritization.

The total-order sensitivity index S_i^T of a parameter i is "the expected variance that would be left if all factors but X_i could be fixed" [18]. It measures the variance of all the interactions a specific parameter is involved in and can be used for factor fixing.

Going back to the model whose variance we want to analyze, we currently have the following outputs:

- Member and outsider count, wealth, efficiency
- Mean and standard deviation of cooperativeness
- Gini coefficient

Preliminary investigations revealed that all outputs provide similar results (as they are inherently correlated). Furthermore, Gini coefficient output incorporates many micro-behaviors that are not captured by other outputs, hence we decided to use it as our fundamental output for the sensitivity analysis.

As for the inputs, we have used wide bounds centered around nominal values for each parameter. The exact bounds for each parameter from which the low discrepancy sequences are sampled are shown in Table IV. One important thing to mention is that the International trade parameter is a boolean, so we analyze independently the cases where it is on (True) or off (False). Concerning the technical parameters, we used the Saltelli algorithm provided by the Python SALib library with 1 replicate, 6400 distinct samples, and 1000 steps.

Sym	Parameter	Bounds for SA
I	International Trade	True or False
σ_E	Efficiency STD	$[0, 5]$
τ	EU tax	$[0, 1]$
ι_N	Neighbor influence	$[0, 1]$
ι_T	Tax influence	$[0, 1]$
γ	Member trade multiplier	$[0.1, 5]$
β	Benefit distribution	$[0.1, 3]$

TABLE IV: Parameter ranges for Sensitivity Analysis.

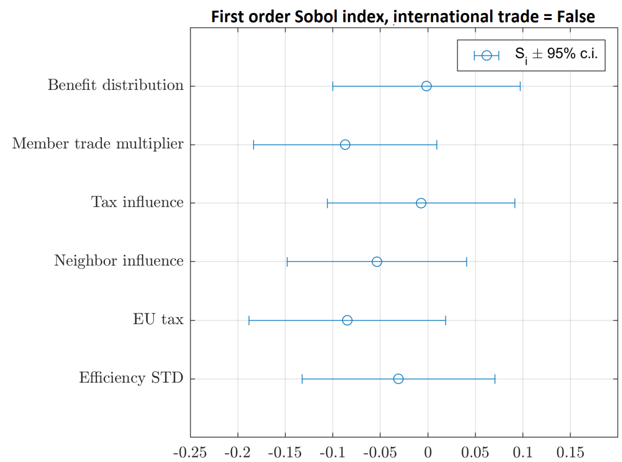

Fig. 6: First-order Sobol indices with international trade off.

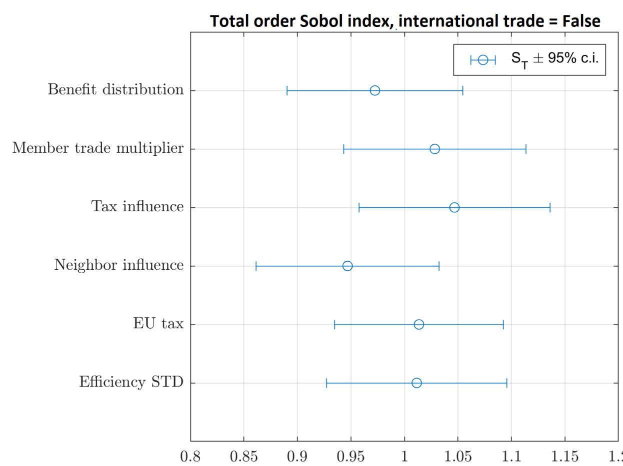

Fig. 7: Total-order Sobol indices with international trade off.

Figures 6 and 7 show first-order Sobol indices S_i and total-order Sobol indices S_i^T respectively with international trade off. From Figure 6 we can observe that values are all close to 0, which can indicate that the parameters individually, sampled for different combinations of the other parameters, have an insignificant effect on the variance of the output.

This claim is supported by Figure 7. All total-order indices are close to 1, which in turn means that the joint effect of the parameters mostly influences the variance of the output. The neighbor influence parameter ι_N is slightly lower than the rest, but this could be an irregularity since the standard deviations are quite large given our 95% confidence interval. From this, we can derive that the model output variance is mainly caused by higher-order interactions between parameters. As far as parameter fixing or prioritization is concerned, given the relatively inconclusive nature of our results, we do not consider them.

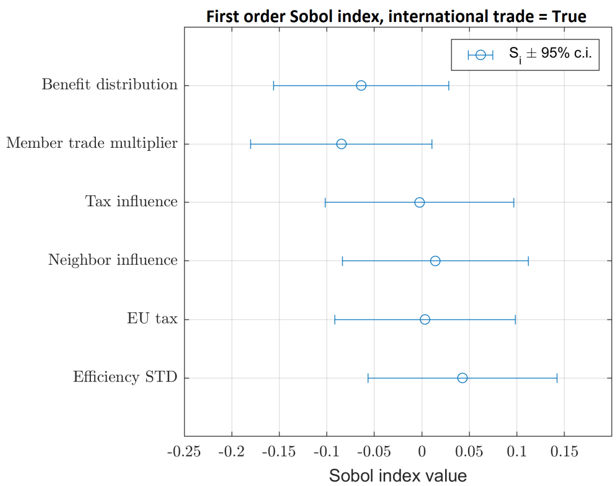

Fig. 8: First-order Sobol indices with international trade on.

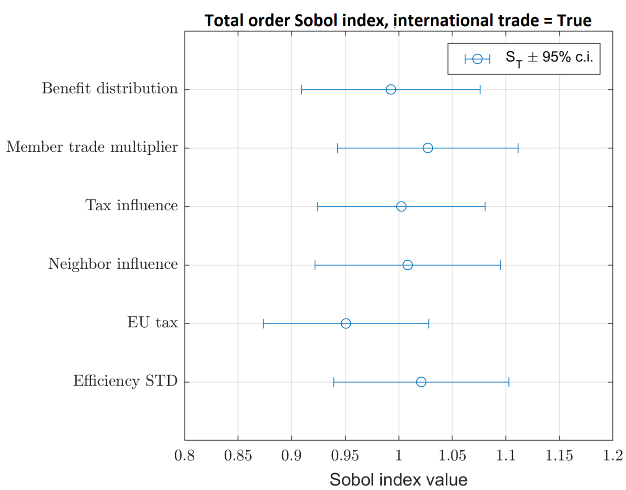

Fig. 9: Total-order Sobol indices with international trade on.

Figures 8 and 9 show first-order Sobol indices S_i and total-order Sobol indices S_i^T respectively with international trade on. For Figure 8, just like in Figure 6, the values are close to 0. Turning international trade on does not seem to change the first-order Sobol indices in a meaningful manner.

In Figure 7, values are again close to 1 and there are no significant changes to the total-order indices due to international trade. Again, the inconclusive results prevent us from further considering parameter prioritization or fixing.

VIII. Results

A. Inequalities in GDP Growth affect economic divergence

The sensitivity analysis is followed by the investigation of the influence of various model parameters on the output, mainly the Gini coefficient value and the number of the member states. In this section, we will attempt to understand the importance of inherent efficiency (GDP growth) inequalities on driving the economic divergence. (The choice of the parameter value $\tau = 0.1$ is reasoned in section VII D.)

Our first investigation will be to verify how our model behaves under various levels of inequality. To represent changes in inequality, we will investigate the output of the model for different values of the efficiency standard deviation parameter σ_E. As already mentioned, this parameter stands for the standard deviation of the normal distribution from which initial efficiencies are sampled from ($\mathcal{N}(\mu = 1.5, \sigma = \sigma_E)$). Since countries increase their wealth in each step proportionally to their efficiency (GDP growth), increasing the standard deviation of the distribution from which they are initially sampled from, will result in some countries having a considerable higher GDP growth than others and hence leading to growing wealth inequalities.

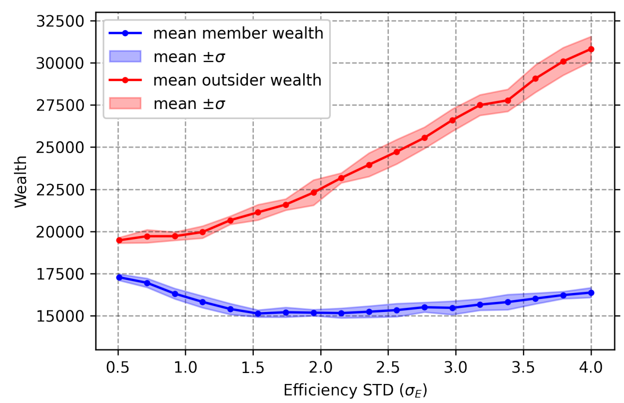

Fig. 10: Member and outsider wealth after 500 iterations, 10 simulations, and with varying σ_E and the following parameter values: $I = True, \tau = 0.1, \iota_N = 0.05, \iota_T = 0.1, \gamma = 2, \beta = 0.95$

In Figure 10 we can observe that for small values of σ_E, mean member and outsider wealth are relatively close. This is because the difference between their base mean GDP growth values is not very significant. However, as we increase the efficiency std (σ_E), wealth disparities increase. Since for these simulations the parameter value of ($\beta < 1$), the EU becomes a 'club of the poor' as this benefit distribution strategy appears to predominantly attract regions with lower than average efficiency (GDP growth) values. On the other hand, the wealthy countries with higher than average efficiency (GDP growth) values leave the union to avoid the EU taxes. It is noteworthy that the type of segregation depends on the EU's benefit distribution policy, as we could as well observe the inverse i.e. the EU becoming a 'club of the rich' for ($\beta > 1$).

Figure 11 further highlights the aforementioned findings as it shows that the value of Gini coefficient increases as

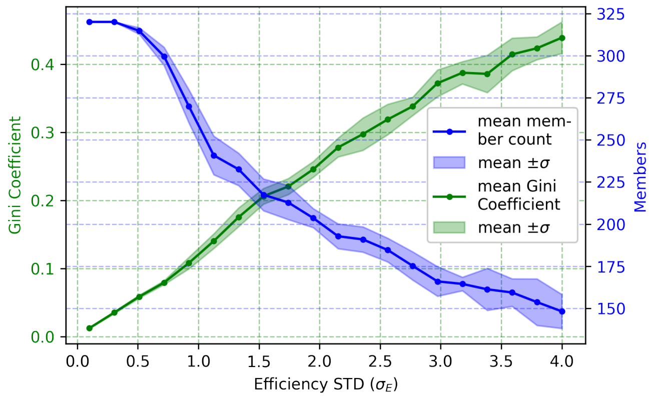

Fig. 11: Gini coefficient for all regions combined after 500 iterations over 10 simulations with varying σ_E and the following parameter values: $I = True, \tau = 0.1, \iota_N = 0.05, \iota_T = 0.1, \gamma = 2, \beta = 0.95$

the efficiency difference (σ_E) increase. The main takeaway is that as GDP growth disparities increase, the economic divergence emerges. In the real world, different countries also are characterized by diverse GDP growths, so we can not really avoid these inherent disparities in growth. Instead we have to look at how we can counterbalance these wealth disparities driven by GDP growth disparities.

B. Importance of member trade multiplier

A very obvious way of counterbalancing the wealth inequalities stemming from the inherent GDP growth disparities would be to increase the benefits from the European single market. Hence, in this section, we investigate the influence of the member trade multiplier γ on counteracting the wealth inequalities.

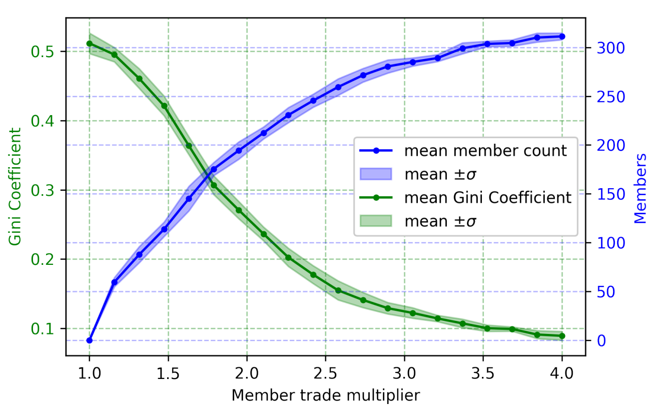

Fig. 12: Visualising how member count and Gini coefficient react to changes in member trade multiplier. The model was run for 500 steps an with 10 simulations. Parameter values: $I = True, \sigma_E = 2, \tau = 0.1, \iota_N = 0.05, \iota_T = 0.1, \beta = 0.95$

Figure 12 reveals that one simple way of achieving economic convergence would be by increasing the member trade multiplier γ, thus making it more profitable for any type of economy to become a member of the EU.

However, increasing member trade multiplier may not be the easiest solution in a real-life scenario. Although EU members profit from macroeconomic benefits of the European single market, which allowed for the reduction of the trading costs, it is not easy to state what else could be done to enhance these benefits even more [22].

Therefore, we will continue to investigate in what other ways it is possible to improve economic convergence.

C. EU policies to achieve economic convergence

1) Interaction of EU tax percentage and benefit distribution: In this section, we will investigate how changes in EU policy can help achieve economic convergence and decrease wealth inequalities. In our model, EU policy is parametrized with two independent factors: the EU Tax percentage (τ), and the EU benefit distribution strategy (β). In real-life these are also factors that can be more realistically changed via policy changes as opposed to GDP growth or member trade multiplier.

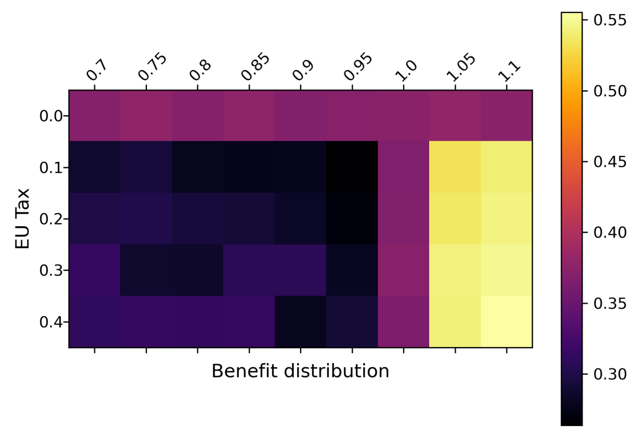

Fig. 13: Visualising the Gini coefficient for range of values of EU tax collection (τ) and EU benefit distribution (β). Each data point was generated using 10 simulations. The model was run for 500 steps with the following parameters: $I = True, \sigma_E = 2, \iota_N = 0.05, \iota_T = 0.1, M = 2$

Figures 13 and 14 show how member count and Gini coefficient depend on both EU tax and EU benefit distribution. We can observe a clear T-shaped structure in both matrices. This structure represents scenarios where there is no wealth redistribution, which is the case if EU tax $(\tau = 0)$ or if the benefits distribution $(\beta = 1)$ (i.e. benefits each country receives is exactly the same as its contribution to the budget).

To the left and right of this T-shape we also observe interesting results. It can be noticed that for $\beta < 1$, the value of the Gini coefficient (G) is $G < 0.40$, whereas for $\beta > 1$, the value of the Gini coefficient is $G > 0.40$. This behavior stems from the underlying EU benefit distribution algorithm. For values $\beta < 1$, the wealthiest regions contribute more to the EU budget overall, while at the same time the poorest regions are recipients of a greater portion of the budget. The opposite EU benefit distribution strategy is utilized for $\beta > 1$.

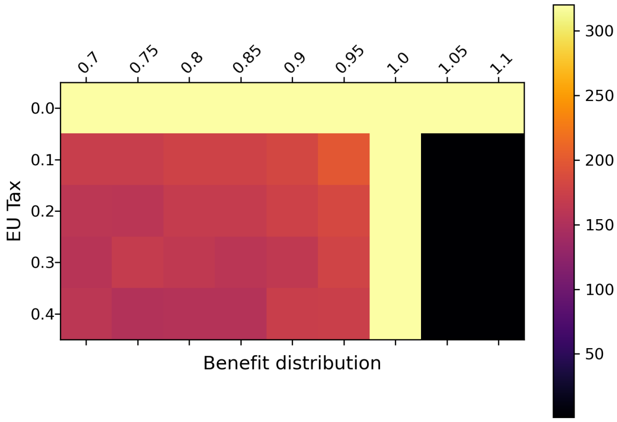

Fig. 14: Visualising the member count for range of values of EU tax collection (τ) and EU benefit distribution (β). Each data point was generated using 10 simulations.The model was run for 500 steps with the following parameter: $I = True, \sigma_E = 2, \iota_N = 0.05, \iota_T = 0.1, M = 2$.

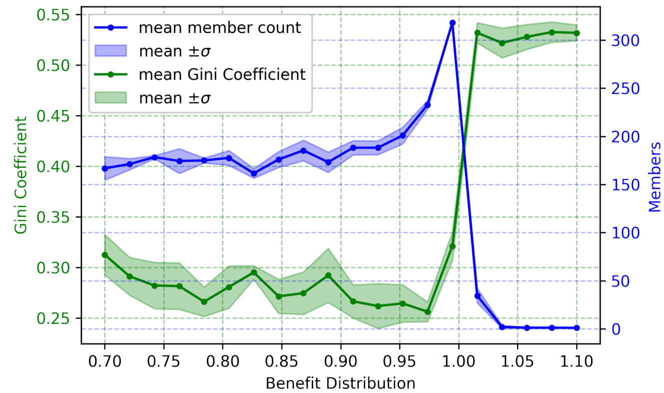

Fig. 15: Plotting the mean member count and its standard deviation as well as the mean Gini coefficient and its standard deviation of 10 simulations with 500 steps each. The model was run with the following parameter values: $I = True, \sigma_E = 2, \tau = 0.1, \iota_N = 0.05, \iota_T = 0.1, M = 2$

Moreover, it also appears that EU tax percentage seems to have a significant impact on the outcome, therefore we will further verify this observation with a statistical test.

2) Two-sample Z-test: As can be observed in Figure 13, the two closest mean Gini coefficient values are Gini coefficient $= 0.2638 \pm 0.0160$ for ($\beta = 0.95$, $\tau = 0.1$) and Gini coefficient $= 0.2700 \pm 0.0143$ for ($\beta = 0.95$, $\tau = 0.2$). In order to determine whether the difference between these two mean Gini coefficient values is significant, it would be necessary to conduct the same exploration of the (β, τ) space with a significantly larger number of simulations per each parameter combination. However, given our computational limitation, we decided to further investigate whether the difference between Gini coeffcients obtained for ($\beta = 0.95$, $\tau = 0.1$) and for ($\beta = 0.95$, $\tau = 0.2$) are significantly different. Hence, we perform 60 simulations for ($\beta = 0.95$, $\tau = 0.1$) and for ($\beta = 0.95$, $\tau = 0.2$) which lead to the following mean Gini coefficient values: $= 0.2599 \pm 0.0177$ and $= 0.2733 \pm 0.0190$, respectively. We further use these values to perform the Two-sample Z-test. Therefore, we state the following null and alternative hypotheses for our test:

$$H_0 : E(Gini))_{\beta=0.95,\tau=0.1} = E(Gini))_{\beta=0.95,\tau=0.2} \quad (2)$$

$$H_1 : E(Gini))_{\beta=0.95,\tau=0.1} \neq E(Gini))_{\beta=0.95,\tau=0.2} \quad (3)$$

We perform the Two-sample Z-test with $p = 99\%$. The critical value (CV) is determined to be 2.56, while the actual value is found to be 4.01. Hence, with 99% confidence we can conclude that the Gini coefficients obtained for ($\beta = 0.95$, $\tau = 0.1$) and for ($\beta = 0.95$, $\tau = 0.2$) are significantly different. Hence, we will further continue with investigating the Gini coefficient values for $\tau = 0.1$ as it leads to an overall lower mean value of the Gini coefficient.

3) Focusing on the EU benefit distribution: Figure 15 reveals how member count and Gini coefficient depend on the EU benefit distribution (β). It can be noticed that when the EU benefit distribution is slightly skewed towards the rich regions ($\beta > 1$), the EU will very quickly become a 'club of the rich', where only the wealthiest regions profit from being members of the union. Naturally, this creates a lot of disparities revealed by the elevated Gini Coefficient, as poor regions left out of the union are unable to profit from the member trade multiplier. Moreover, we can also observe that when EU benefit distribution is skewed strongly towards the poor ($\beta < 1$), the opposite happens as all regions, except the poor ones, are better of leaving the union. This creates less disparity as the inverse since in this case, the poorest regions can benefit from the member trade multiplier. However, it appears that an ideal situation exists if the EU benefit distribution is skewed slightly towards the poor.

In Figure 15 we can observe that there appears to be some optimal value between $\beta = 0.95$ and $\beta = 1$ which leads to the lowest mean Gini coefficient value. Surprisingly, the $\beta = 0.9737$ resulted in a lower mean Gini coefficient than the simulations for $\beta = 0.9947$, even though there is a significantly higher number of members in for $\beta = 0.9947$.

Nevertheless, our results reveal that a moderately socialist policy, benefiting the poor, but not to a degree where it disincentivizes the rich, leads to the lowest mean Gini coefficient value. Furthermore, we observed that higher number of members helps in reducing the value of the Gini coefficient, but also it appears that when there are too many members the process of economic convergence is slowed down. In order to identify the optimal value, and ensure its statistical significance it would be necessary to perform a more thorough investigation of this parameter space, which is out of the scope of this investigative report.

IX. Discussion

In this paper we developed a simple agent-based model in which countries are motivated by economical reasons to join or leave the European Union. The main assumption in this model is that countries make rational decisions for optimizing their wealth gains with respect to simple rules. It should be noted that this assumption does not completely hold in real life. As an example, we can take Greece and the Netherlands. Although Greece has a net investment gain of 3.38 billion [10], the overall perception of the European Union is worse than in the Netherlands [20], which has a net investment loss of 2.37 billion [14]. This clearly shows that economical reasons are not the only factor that regions or countries take into account.

Other factors that could possibly explain the choice of being in the European Union or not are perceptions [23] of how the European Union handles different topics like the refugee issue, peace negotiations, and whether or not it promotes prosperity. This may be taken into account in a future model, although it could be hard to determine a quantitative impact for these factors from surveys. Besides these factors, a stochastic component in the model would also be needed, because individuals that make choices for others, which is often the case in politics, are characterized by an increased gambling propensity [17]. A simple way to include this would be to introduce some noise on the cooperativeness of each region, but for policy decisions, a more thorough investigation should be made to quantify the amplitude of this noise. A similar stochastic component of extreme events also was not included since it is both hard to predict the nature and impact of such rare events, but the role of such events may become more significant with the increasing power of technology and single individuals.

Additionally, our model included regions that are not in the European Union, which may cause dynamics that would not be present in real life. Likewise, our model also did not include regions from different continents, which have an increasing impact on the European Union with the rise of globalization [9]. The European Union also performs trade negotiations with the rest of the world [7], which may further influence the desire for countries or regions to join the European Union, which was also not included in the model.

Another possible flaw is the level of analysis, which is regional in our model, but since policy decisions are often made on a country level this may also change dynamics. This could be included by grouping regions together in countries which then make decisions as a composite function of the individual desires of the regions of which it consists.

This brings up another issue with the model, which is the lack of data derived parameters. Although a logarithmic wealth income gave interesting results, and even results in which e.g. the Gini coefficient aligned well with European values in some cases [8], the motivation for it stems from mathematical convenience since it prevents exponential growth. This was needed in order to make the Gini coefficient usable since it would often grow towards one, which would make the results useless.

Furthermore, for the outcomes of the simulations, we cut off the simulations at 500, or 1000 steps which may not have been appropriate in some cases, because fluctuations in outcomes can occur later in the simulation and for some parameter values there is no clear convergence at all. Having stated these issues it should be noted that no policies should be derived from this simple, non-data-driven model.

X. Conclusion

In this paper, we propose a simple framework for modelling membership dynamics of the European Union based on economical reasoning. The model is able to produce interesting dynamics, while the results are still interpretable.

First, we were able to show that wealth disparities are driven by the differences in the inherent GDP growth values. We also observed the process of segregation of regions based on their wealth. The European Union became either a ‘club of the rich’ or a ‘club of the poor’ depending on the policy imposed by the EU benefit distribution parameter. Additionally, for a benefit distribution parameter favoring the poor regions, we also observed a negative correlation between the Gini coefficient value and the member count, which indicates that a higher number of EU members fosters the economic convergence.

Furthermore, we also qualitatively assessed the importance of the member trade multiplier in counterbalancing the wealth inequalities stemming from the GDP growth disparities. As we saw, one way to decrease inequality is by increasing the member trade multiplier, thus making it more profitable for any type of economy to be EU member. As a result, we observed that the economic convergence is only possible if the EU has a lot of members, which means it must be attractive to all kinds of economies. However, as already mentioned increasing the member trade multiplier may not be the best solution, given that the actual trading policies of the European single market are not that easily modifiable.

Afterward, we also explored the cumulative impact of various EU tax and benefit distribution strategies on promoting economic convergence. It was determined that both percentage tax and the benefit distribution strategy has a significant impact on the economic convergence and cooperation. Additionally, we hypothesize that there may be some optimal value for the benefit distribution parameter that would allow obtaining the lowest Gini coefficient value. However, it would be necessary to perform a more in-depth analysis of the parameter space, followed by optimization to verify this statement.

In conclusion, we were able to show that in order to achieve the lowest wealth disparities and hence strongest economic convergence, a moderate policy skewed slightly towards the poor regions works best for all kinds of economies. Such a policy allows poor regions to receive help, while the rich ones can still make a net profit from more profitable trades. However, the models’ main assumption is slightly flawed and the parameters are based solely on non-empirical values, making it hard to make quantitative conclusions about the real world.

The research could be extended by more in-depth analysis of changes of the cooperativeness state variable and factors that influence it (Figure 16 and 17). Also, it could be interesting

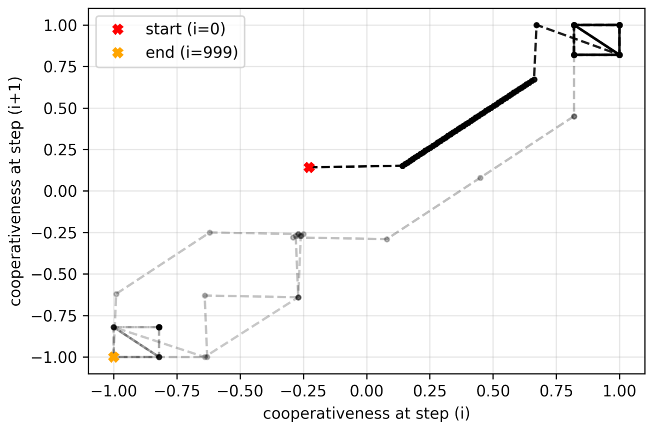

Fig. 16: The cooperativeness of an agent at each step plotted against the cooperativeness at the next step. Every 5 steps, the opacity of the path plotted is linearly reduced to visualise the temporal aspect. Parameter values: I = True, $\sigma_E = 3.93, \tau = 0.4, \iota_N = 0.19, \iota_T = 0.18, M = 1.01, \beta = 0.889$.

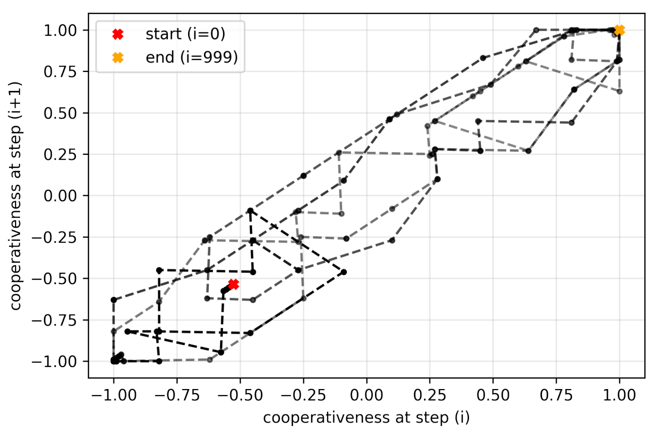

Fig. 17: The cooperativeness of an agent at each step plotted against the cooperativeness at the next step. Every 5 steps, the opacity of the path plotted is linearly reduced to visualise the temporal aspect. Parameter values: I = True, $\sigma_E = 3.93, \tau = 0.4, \iota_N = 0.19, \iota_T = 0.18, M = 1.01, \beta = 0.889$.

to analyze the underlying network that emerges due to the region-neighboring region connections. This could potentially further reveal the regions that are much more prone to the tax influence or neighbour influence.

Appendix A
Equations

The natural growth of a region changes stochastically every iteration and is given by

$$c_i = \log w_{i-1}\epsilon_i, \tag{4}$$

where c_i is the capital gained on the i-th iteration from natural growth, w_{i-1} is the wealth in the previous iteration and ϵ_i is the efficiency at iteration i and is samples from the probably distribution

$$P(|\epsilon_i|) \propto e^{-8(\epsilon_i-\epsilon_\mu)^2/\sigma_E^2}, \tag{5}$$

where ϵ_μ is the average productiveness of a region, which is defined in the initialization section. The absolute value makes sure that regions always have a positive produce.

Appendix B
Code

The code of the model can be found at https://github.com/charelF/ABM.

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