The Agent ID Model
A Multidisciplinary Framework of Evolutionary Human Behavior

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Chapter 1

A Holistic Approach to Human Behavior

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Summary
Human behavior can be approached from multiple perspectives. These different perspectives led to the emergence and development of distinct human and social sciences, most notably psychology, sociology, economics, and political science. These sciences look at a same reality—how people decide and act in social contexts—and therefore they overlap in many respects. This book searches for a transdisciplinary view on human behavior. It does so in two ways: first, by presenting a series of studies in which human diversity and heterogeneity is highlighted (people are different regarding wealth and income endowments, personality, cognitive capabilities, political preferences, social skills, moral standards, and much more); second, by modelling behavior through a stylized agent-based model, in which each individual is endowed with a unique profile that distinguishes her / him from her / his partners in social relations. By establishing a set of relatively simple interaction rules, the model can simulate aggregate economic results and social trends. This first chapter highlights the main ideas that are approached in the detail throughout the book.
Keywords: Human behavior, Social sciences, Decision-making, Heterogeneity, Agent-ID model.

1.1 Introduction

This book is about individual human behavior and how individual behaviors combine to form emergent social and economic outcomes at the aggregate level. There are many sciences that study decision-making and the interaction processes between people. These are known as the social sciences. Anthropology, sociology, economics, psychology, and political science are some of the most prominent. They are different regarding the specific objects of their study, the methodologies they employ, and the message they aim at conveying to society and to policymakers. Nevertheless, they all study the same reality and, therefore, an integrated approach is certainly welcomed. This book pursues such an integrated approach, looking at human behavior through a variety of overlapping perspectives.

Besides this introduction and a final brief chapter that systematizes the book's contents at the light of the concept of transdisciplinarity, the book comprises nine chapters, which can be grouped essentially in two parts. In chapters 2 to 8, a series of studies are offered on a variety of issues pertaining to human behavior, heterogeneity, and interaction. Covered subjects include the crucial role of innovation and skills

as engines of growth, the formation of network structures in which social interactions unfold, and the variety of ways in which human behavior can be approached (ranging from moral behavior to collective actions and social choice).

The second part of the volume is formed by chapters 8 and 9. In these two chapters, an agent-based model is devised, with the objective of exemplifying how one can approach the complexity of human interactions. The model is baptized as Agent ID Model. The main idea underlying the proposed framework is to consider that each agent enters the economy with a specific profile that is unique to her / him, and that cannot be replicated to fit the behavior of any other individual. This profile is like the agent's DNA. Such socio-economic DNA is composed by a series of dimensions. Part of these dimensions are of an economic nature, and pertain to wealth, output, and income; others are eminently psycho-sociological as preferences, moral standards, or political ideologies. Given the unique ID of each agent, macro patterns emerge once we establish a series of simple rules through which agents with a distinct ID establish contact with one another.

In what follows, a brief note on the contents of each chapter is set forth.

Simple People in a Complex World. Chapter 2 stresses the need for a paradigm shift in economic analysis. This change of perspective in economics has started a few years ago (probably more than twenty) but it is still on its infancy. The revolutionary idea is that we should abandon the traditional way of thinking about economic problems, which is essentially a top-down perspective. The top-down approach conceives a simple world in which sophisticated agents act and interact. Sophistication is, in this case, associated with such strong ideas as optimization and rationality. The homo-economicus of orthodox economic models is capable of collecting all the relevant information, in every circumstance, in order to make the best possible decisions, which are, obviously, optimal decisions. If everyone decides optimally, then market equilibrium and full efficiency are unsurprising corollaries.

On the antipodes of the top-down interpretation of reality is a novel approach that can be classified as a top-down approach. In this new view, agents are simple and interact in a complex world. Agent simplicity signifies that most of the times people do not engage in sophisticated and overly elaborated plans to make decisions. On the contrary, they tend to save cognitive effort and often make what appears to be non-optimal satisficing choices. These choices vary with context and, therefore, unlike what one observes under the rational paradigm, in which all agents make a same decision when confronted with a same problem, now we open the door to a wide variety of different possible behaviors. The new economic agent is 'simple,' in the above-mentioned sense, but simplicity can manifest itself in many different ways, what makes agent heterogeneity a central piece of this new view upon socio-economic issues.

But the new interpretation of reality also innovates by considering a complex world. From the economic point of view, the sophistication of the world essentially signifies that markets cannot be complete. No one has the capacity to know and understand what everyone everywhere is doing and, consequently, one needs to search for information at the local level, i.e., at the level of interactions that are established between close neighbors (geographical or virtual).

From a network science perspective, complete markets would be networks in which everyone is connected with everyone. Neoclassical orthodox economics believe that this is the case. The reason to accept this view is attached with the mechanism of formation of prices: prices allegedly contain and synthesize all the relevant information about markets and, therefore, markets would in fact be complete. The bottom-up perspective does not subscribe this interpretation: it is virtually impossible to cope with the whole of the reality, because of the huge scale and complexity of market transactions and, therefore, searching for the specific network of relations through which people can engage in local interactions is vital for reaching a sensible understanding about how the economy truly works.

The bottom-up perspective requires interpreting the economy as a complex system. Hence, one can resort to concepts, ideas, and tools from the science of complexity to address economic issues. The prototypical complexity framework is the class of models known as agent-based models. These are, apparently, adequate to address bottom-up issues, because they specify simple and heterogeneous rules of behavior and interaction at the individual level and then, with such rules, they formalize a set of procedures (e.g., written under the form of a computer algorithm) that culminate in some aggregate outcome. These models are run instead of solved.

The most interesting feature emanating from interpreting the economy as a complex system is that a living organism is created. This organism is in constant mutation and, contrarily to conventional economic wisdom, it does not tend to a long-term steady state position where it remains still. On the contrary, there is perpetual evolution or, as argued in chapter 2, the economy becomes a body full of 'messy vitality.'

One should regard that once we take on board the complexity perspective of the economy, the distinction between micro and macro becomes blurred. It is the interaction at the micro level that conducts to the emergence of macro phenomena. The path from micro to macro is not always obvious and, therefore, simulating reality may generate surprising outcomes. The truth is that the complexity view is much better equipped to approach and explain abnormal and disruptive events than conventional economics. Agent-based models are today interpreted, by many economists, as enclosing the correct form of micro foundations.

Growth Drivers: Skills and Innovation. The complex system in which people interact is, above all, an evolving and growing system. The economy is dynamic not only because it never stops and rests in an immutable equilibrium, but also because there is an underlying implicit sense of progress. Since the world initiated the era of modern economic growth, more than two hundred years ago, prosperity has gradually and systematically increased and, therefore, one should interpret the economy not only as an evolving complex system but as a prosperity enhancing complex system.

The drivers of sustained growth are familiar to economists. Education, innovation, and scientific progress are at the forefront of the sources that make economies to accumulate wealth and prosper. Attached to these drivers of growth is a fundamental idea first enunciated by the renowned economist Joseph Schumpeter; this is the idea of creative destruction. The economies evolve and thrive not by repeating over and over again the same recipes, but by constantly generating novelty (new ideas, new goods, new production processes). Attached to the notion of creative destruction, is another well-known Schumpeterian concept: the concept of entrepreneur. The entrepreneur is the agent of innovation. She or he is the catalyst of new ideas, i.e., the individual willing to risk breaking up with the status quo and to bring novelty to the way things are done.

In chapter 3 matters pertaining to innovation, skills, and entrepreneurship are debated, essentially in the context of higher education institutions and how these can serve as laboratories to test entrepreneurial initiatives. Particular attention is given to the development of soft skills. People need to learn the technical competencies that allow them to perform specific tasks (these may be called hard skills), but they also need to develop a set of generic skills that, regardless of the particular activity at hand, are, in any case, helpful in getting the work done (the soft skills).

Soft skills are characterized by their non-technical nature, and they cannot be acquired solely through formal education and training (they are also associated with lifelong learning). If adequately ministered, formal education can assist in acquiring such competencies, but they come essentially from reflection, commitment, and a will to self-improve. Those who are successful in incorporating soft skills, tend to be more creative, to take better advantage from their cognitive capabilities, and to achieve more success in interpersonal relations.

Soft skills are, in part, also entrepreneurial skills. They correspond to the accumulation of a series of personal characteristics that lead individuals to be more prone to explore and identify opportunities, to foster innovative thinking, and to be encouraged and stimulated to participate in creative endeavors. Typically, an entrepreneur is someone with good communication capabilities and someone willing to value teamwork. Hence, by stimulating the acquisition of soft skills, entrepreneurship education can play a vital role in supporting creative enterprises and new economic opportunities, thus contributing to economic prosperity and growth.

The Structure of Interactions. Heterogeneity and interaction are two faces of a same coin. One does not exist without the other: if heterogenous people do not interact, they are homogeneous people in their own isolated world; if interaction occurs between identical agents, then nothing changes with interaction. This logic justifies why it is vital to look at the structure of interactions. This is the endeavor pursued in chapter 4 of this book.

Interaction occurs in society and in the economy in many different forms. It is virtually impossible to characterize all types of interaction that may eventually emerge. Nevertheless, science should search for patterns and regularities and, consequently, to identify, as accurately as possible, the most common types of interconnections. This identification process should then serve the purpose of stylizing networks in order to create meaningful prototypes for the analysis of economic and social events. Knowing the structure upon which interactions of all sorts take place is relevant, and this is why an autonomous scientific field dedicated to this subject has emerged: network science. Chapter 4 makes a thorough characterization of the accomplishments of network science, regarding the explanation of the most outstanding patterns of interconnectivity one observes in real life.

Networks are essentially the skeleton of many structures that are formed and that evolve in nature and society. Social networks are particularly relevant because they establish links between socio-economic agents. As it is easy to understand, socio-economic networks are not immutable bodies; they are entities in systematic mutation and evolution, given the ties that are established and broken at every instant between members of a society or an economic system. Socio-economic networks are the vehicles through which ideas, innovations, behaviors, and information spread. The specific features of such propagation are constantly changing, what makes the configuration of networks to be constantly changing as well.

Despite the complexity of evolutionary networks that involve the interaction among human beings, some stylized notions can be set forth. First, one should note that a network can be easily represented by a set of nodes and edges. Typically, nodes respect to agents (households, firms, or organizations), while the edges translate the contact across agents. Unsophisticated networks may consider that links just inform us about agents being or not being connected with one another (if a link exists or not between two individuals); more sophisticated representations can inform about the direction of the link (if it is unidirectional or bidirectional) or the strength of the connection.

There are many types of network topologies that have been studied in the literature. One of the most popular are the well-known scale-free networks. In scale-free networks, each node creates links to existing nodes with a probability proportional to the number of links the existing nodes already have. This generates a network with a few highly connected nodes (typically known as hubs) and many nodes with few connections. Not only the process of network evolution associated with scale-free networks is logical, but it also appears to explain well many social and economic phenomena. For instance, thinking about a network linked by economic power and influence, this type of framework is capable of explaining why the richer become progressively richer and the poor and poorly connected become poorer and more isolated.

The Logic of Collective Action. John Maynard Keynes brought to economics the notion of animal spirits, which he defined, in his General Theory, as a "spontaneous urge to action rather than inaction". Keynes was stating the importance of bounded rational behavior, and how this behavior can take surprising forms, mostly when one approaches it from the perspective of collective action. Herd behavior and similar phenomena, commonly observed in financial and other markets, are consequences of the proclivity for people to take actions in a social context that they would not normally take outside such context. In many circumstances, collective action exacerbates behaviors that depart from the rationality benchmark.

Contagion of sentiments and emotions is an observable evidence in many social and economic scenarios. The scientific disciplines of psychology and sociology try to explain such phenomenon; however, economics appears to have much more difficulty in addressing it. Neoclassical economics, in particular, fails in incorporating any aspect associated with sentiments and emotions. Less orthodox approaches have gradually incorporated many prominent features at this level, e.g., by distinguishing economic agents by their market sentiment, and thus separating between optimists and pessimists.

In chapter 4, animal spirits are addressed, and their impact illustrated. The context is financial and commodity markets, and animal spirits are attached to market uncertainty. In this study, uncertainty is not approached from a strictly rational perspective; on the contrary, it assumes that there are psychological strings attached. Choices made in financial and other markets are rooted in intricate neurophysiological processes, leading to emotional responses. The study is empirical, and uncertainty is associated with recent, impactful, and unexpected events (namely, the COVID pandemic and the geopolitical instability that emerged in various parts of the globe, mainly in Eastern Europe). The study finds strong ties between uncertainty and market performance, meaning that animal spirits and collective behavior play an important role and that sentiment contagion processes are present in many economic and financial environments.

The Invisible Hand Plus Moral Sentiments. Adam Smith published two influential and acclaimed works. On one of them, the better well known, Smith makes the apology of free market efficiency. In the Wealth of Nations, Smith praises the resilience of decentralized markets and the close relationship between self-interest and aggregate equilibrium. In the other, less popular, work (the Theory of Moral Sentiments), Smith states that for market relations to thrive a moral basis must govern human behavior. If people fail in acting ethically and morally, distrust sets in, and the economic relations are disrupted. Hence, as important as the invisible hand, also important is the moral code that is implicit in the willingness to engage in fruitful market transactions.

Chapter 5 addresses issues associated with moral behavior. Morality is a subjective concept. We all have different notions of where the boundaries between moral, immoral, or amoral behavior should be delimited. However, we all agree that without solid ethical principles economic relations become much harder and eventually collapse. Morality is associated with a wide array of emotions that range from anger, disgust or guilt to empathy or pride. As such, understanding how morality effectively influences economic and social relations is a hard challenge that social sciences need to ponder with care.

Moral behavior is intricately linked to the internalization of social norms. Social norms, in turn, are built by society and its institution. Therefore, strong institutions are a first step in shaping a system of moral values that everyone understands and that everyone shows availability to comply to. Morality generates confidence, and confidence is fundamental for the economy to thrive.

Damaging Economic and Social Behavior. Moral and ethics are, in every circumstance, important for a smooth unfolding of economic activity, because they convey a feeling of security and trust from which market participants can take advantage of to fulfil their own individual goals. Because economic relations

are also social relations, individuals and groups are, most of the times, equipped with the means to cope with unethical or immoral behavior. Manifestations of disapproval and sanctions of various orders are most of the times effective weapons against unethical behavior. Notwithstanding, there are unacceptable behaviors that go beyond morality and ethics and that are associated with the disobedience to the established rule of law. In this context, analyzing crime also becomes a vital element in the endeavor about the understanding of the complexity of human behavior.

In chapter 6, the interplay between crime and economics is addressed. The chapter seeks to understand to what extent can social and economic relations be damaged by criminal activity. It is also important to understand the roots of unlawful behavior: is pervasive crime a direct consequence of weak institutions? Does it relate to the inefficiencies of the judicial system and the incapacity to enforce the rule of law? Are cultural factors relevant? Are income inequality and poverty the primary sources of criminal behavior? These are vital questions linking behavior and the economy.

The chapter approaches crime from the perspective of its association with public policies and geographical distribution of economic activities. Fighting crime is crucial to attain two intertwined goals, namely a 'better society' and a 'stronger economy.' Among the crimes most relevant from an economic perspective, we find corruption and fiscal evasion and fraud. Economic and financial crime undermines confidence and hampers economic prosperity. Note also that a criminal event, namely those of an economic nature, always has spillover effects, pervasively affecting the whole economy.

The Will of the Whole: How to Manage Collective Choice. As already repeatedly mentioned, this book is about heterogeneity. Because people are heterogeneous they have different preferences, desires, and ambitions. How to consensualize these differences is one of the most challenging problems social sciences in general, and economics in particular, are confronted with. The challenge consists in fulfilling the will of the majority without overlooking and neglecting the needs and the rights of the minorities. This is not an easy exercise.

The way modern societies arranged to express collective choices is through voting. But voting is never exempt of controversy. There are many modalities through which votes can be expressed, and the procedure used in an election is relevant in determining the final outcome. Independently of the adopted voting system, doubts will always arise if whether alternative election procedures would generate or not the same result. Furthermore, there are circumstances in which not even through voting one can reach an unequivocal collective decision (just recall the Condorcet paradox and its underlying inconsistency of preferences).

Chapter 7 addresses collective choice through voting. The focus is on the discussion of the pros and cons of implementing electronic vote in political elections. Because changing the election method can change the composition of the effective voters, this can impact collective choice and, thus, it is an issue of primary relevance in what respects human choice in society.

A Multidimensional Model of Behavior. After discussing multiple behavioral contexts, we arrive to the final chapters of the book. These chapters formalize, simulate, and discuss a model in which individuals are multi-dimensional beings, endowed with a series of unique features that allow to distinguish them from one another. These features are associated with financial endowments, general and specific skills, preferences over goods, degree of connectivity with others, animal spirits, moral behavior, and political preferences. Individuals are all different regarding each of the eight mentioned characteristics and the combination of these characteristics for each individual make her or him to hold a unique ID profile that is different from the profile held by anyone else.

By establishing a few simple evolutionary rules of interaction, one can construct a straightforward computational model that, once run, reveals suggestive results. The model unveils the complexity of social and economic relations at the same time it leads to the emergence of a macro behavior, generated under a bottom-up perspective. Agents are endowed with a singular ID profile and the established rules of behavior and interaction allow to replicate the functioning of the economy.

The undertaken simulation exercise points to the emergence of a strong middle class regarding income and wealth, although agents with relatively high initial levels of wealth and connectivity eventually enter a virtuous cycle: they will save more, increase their connectivity, and end up with higher levels of wealth. Nevertheless, the results are always dependent on the assumptions about intertemporal choices. If everyone is able to formulate optimal consumption-savings plans, then extreme cases of poverty are excluded. However, if we separate the economy in optimizers and hand-to-mouth agents, the members of this last group will spend their income as they receive it, they never save, they do not accumulate wealth and, therefore, they remain forever poor.

Regarding animal spirits, moral behavior, and political view, these follow patterns of polarization. Starting with almost uniform distributions for these variables, the passage of time leads to the formation of a group of highly pessimistic agents and a group of highly optimistic agents; to a group of highly unethical individuals and a group of highly ethical individuals; to a group of political left extremists and a to a group of political right extremists. These observations suggest that society left to its own free will, without any institutional supervision, may turn into a polarized society. Policies and institutions should intervene with the goal of avoiding polarization, being it associated with confidence, morality, or ideology.

Chapter 2

Complexity and the World of Heterogeneous People

Orlando Gomes

Summary
For a long time, the science of economics has been dominated by the top-down paradigm, according to which sophisticated individuals, capable of efficiently allocating resources and of accurately predicting the future, make decisions within an unsophisticated world that everyone knows in detail and that brings no surprises. For reasons that are evident, the top-down view, although prone to rigorous scientific analysis, collides with concrete evidence: neither people are fully rational and efficient, nor the surrounding reality is easy to perceive and assimilate. Hence, a complexity view based on a bottom-up approach appears to be a more sensible way to address economic phenomena. In this chapter, the complexity perspective applied to economics is characterized and relevant literature is reviewed. Special attention is given to agent heterogeneity as a fundamental source of complexity. Moreover, agent-based models are highlighted as a fundamental tool in the study of complex economic systems.
Keywords: Complexity, Heterogeneous agents, Complex systems, Heuristics, Agent-based models.

2.1 Introduction

Research in social sciences, and in economics in particular, is shifting. The typical top-down analysis, characteristic of the orthodox economic thinking, is being progressively replaced by a bottom-up approach, a more sensible and reality-oriented viewpoint that clearly contrasts with the former.

In the orthodox view, the notions of equilibrium and rationality play strategic roles. In the new approach, on the contrary, no preconception is taken about the equilibrium state of the macro economy, neither individual agents are constrained to recurrently act in the exact same strict rational way. Instead, agents are viewed as being heterogeneous at a multiplicity of levels, as being endowed with a limited capacity to know and understand the world that surrounds them, and as being circumscribed to local interactions within incomplete decentralized markets (Stiglitz and Mauro Gallegati, 2011; Fagiolo and Roventini, 2017).

For some authors, these changes in the way economic processes are interpreted and approached constitute a true paradigm shift, a transition from one era of economic thinking to another. The new age might be designated as the era of complexity since the new paradigm basically interprets the economic system as a complex system. Under the notion of complex system, the economy is an entity comprising a large number of individual units that interact locally giving rise to unpredictable, irregular and unrepeatable emergent outcomes (Holt, Rosser Jr, and Colander, 2011; W. Arthur, 2014). Delli, Gaffeo, and Gallegati, 2010 explicitly claim for the urgency of the transformation: concepts and tools of the science of complexity are to be adopted in the analysis of economic phenomena and market economies need to be interpreted as complex adaptive systems.

Scholars have adopted the notion of agent-based computational economics (ACE) to designate economic models and theories developed under the complexity view (LeBaron and Tesfatsion, 2008). The terms complexity and computational go hand in hand in this context. The idea that one can conceive a system where the researcher sets the initial conditions and a few simple interaction rules and then the system is left on its own to generate results that are in no way externally constrained and coordinated, requires assembling and running a computational program or algorithm.

In computational complex models, agents have, at a given time period, a specific individual profile and a set of interaction opportunities and interaction skills, which should mimic real world counterparts; this is the part of the model subject to programming. Thereafter, the program runs without additional constraints and, desirably, it will be able to replicate reality as long as initial conditions and interaction rules are skillfully specified. ACE models are, thus, representations of virtual economies (Jaffé et al., 2017) that are meaningful and useful only if capable of reproducing with accuracy the dynamics observed in real economies.

The complexity view of economics is not exempt from criticism. On the one hand, this type of models involves large degrees of freedom in the choice of categories of agents, behavioral rules, and structures of interaction, making the existing approaches to be overly disperse (Lengnick, 2013). On the other hand, complexity models heavily rely on local interactions within complex networks. Local interactions, in turn, suggest that markets are incomplete, and that this incompleteness is generated in an ad-hoc way. Seen from this perspective, complexity models in economics apparently add little to conventional economic models where incomplete markets encounter justification in well-defined market anomalies, e.g., asymmetric information (Durlauf, 2012).

This chapter systematizes literature and reflects on the adaptation of the science of complexity to economics, with special emphasis being placed on agent heterogeneity and the operationalization of complexity frameworks through the use of agent-based models. This sets the scenario for the model to be developed at a later stage in the book, namely an agent-based computational model with heterogeneous interacting agents, whose patterns of interaction lead to emergent macro regularities. The chapter is organized as follows. Section 2.2 describes further what the complexity approach is about and how it applies to economics.

Section 2.3 presents a scheme that functions as a roadmap to better locate the various components of a complex system in economics. Section 2.4 emphasizes the role of heterogeneity as a central element of complex economic systems. In Section 2.5, decision rules that do not necessarily comply with the notion of optimal behavior are discussed. Section 2.6 approaches agent-based models and classifies them as the operational way of doing complexity science in economics. Section 2.7 concludes.

2.2 From Complexity Science to Complexity Economics

Along the process of scientific inquiry, researchers collect evidence, systematize data, organize knowledge, and test hypotheses, about the world in which we inhabit, regarding their physical, biological, and social dimensions. Nature and society are both complex systems, in the sense that they are composed by a large number of small components or agents, which interact with one another to form emergent collective outcomes that, once formed, feedback to individual entities influencing their posterior decisions and interaction processes. This endless loop is what makes a system complex: one cannot hope to understand micro behavior without knowing the macro structure and vice-versa. Therefore, studying natural and social phenomena requires taking a complex systems perspective, i.e., a viewpoint that we can designate as complexity science (Siegenfeld and Bar-Yam, 2020).

As remarked above, complexity science applies both to natural and social systems. However, there is a fundamental difference between the individual elements composing each of the systems. People are not the same thing as inanimate objects or, even, as less sophisticated forms of life. People think, take pondered decisions, forecast future events, and learn with their mistakes. Hence, a second layer of complexity emerges in socio-economic systems: not only they are complex given the interaction between a large number of small particles, but they are also complex because these small particles are human beings, with all the idiosyncrasies, whims, and strokes of genius we know people are often affected by.

The focus, in this chapter and in this book, is on socio-economic systems. To embrace the complexity view in the study of socio-economic phenomena, we should move away from the orthodox interpretation of economic human behavior, frequently associated with the concept of homo-oeconomicus. The homo-oeconomicus is the hyper-rational agent of neoclassical economics, an agent that is capable of processing all relevant information to arrive to optimal decisions, and whose behavior promotes equilibrium at an aggregate level (Thaler, 2000). Complexity economics is in the antipodes of such interpretation.

The complexity view conceives economic decision-makers as human beings that explore distinct options, try different courses of action, and strategically react to the behavior of others. In such setting, a steady state equilibrium result will hardly be formed; on the contrary, the economy becomes a living body, in constant evolution, and, in the words of W. B. Arthur, 2021, 'full of messy vitality'. Phenomena become emergent and contingent on patterns of interaction that are formed in circumstances that are unique. Out-of-equilibrium dynamics become the norm, and reality cannot be reduced to a small set of equations, as it happens in the neoclassical approach.

The economy is, undoubtedly, an evolving complex system and, therefore, it must be treated as such, what requires an algorithmic approach to the study of relevant phenomena. It is not a set of mechanistic equations that explain human behavior in society; instead, one should look for the simple rules of behavior that govern the actions of people and then combine them with the purpose of replicating observable collective patterns of evolution in society and in the economy.

One should remark that the complexity approach to socio-economic systems is not a replacement for mainstream economics. Instead, it is a step forward, that allows for a wider and deeper understanding of reality. The assumptions of rationality, perfect knowledge, and equilibrium are relevant to set the stage for the analysis. However, they are too rigid to fully understand the economy as it truly works, i.e., as a feedback system in which individual actions determine collective outcomes, and where collective outcomes decisively influence individual behavior.

Hence, one should interpret complexity economics not as a particular form of explaining reality that is concurrent to neoclassical economics. It is a more general perspective that can enclose some of the simplifying assumptions typically taken by the orthodox view, if they are necessary to clarify the analysis. Paraphrasing W. B. Arthur, 2021, complexity economics is economics done in a more general way.

As remarked by Ostrom, 2010, simple analytical models are useful to discuss particular issues in particular settings. However, science, and in particular economic science, must not be confined to a small set of toy models that allow us to perceive a reality that is often strongly constrained by the simplifying assumptions that are taken. It is for this reason that one should embrace complexity, i.e., to bring to the scientific analysis the multiplicity of institutional arrangements, the different scales of interaction, and the diversity of individual motivations, in order to improve theories, to better interpret empirical observations, to better predict future outcomes, and to stimulate more effective public policies.

Studying the economy as a complex system requires computational methods. Computation allows for the implementation of inductive reasoning and for large-scale simulation and experimentation, what is completely different from conventional economic theory, based in mathematical deduction. Mathematics do not have to be discarded, but computational methods assist in assembling the most useful frameworks equipped to explain and predict economic events. In many cases, the two approaches merge: computational algorithms establish a set of rules for the behavior of people, and these are nothing more than a set of equations that, together, constitute an economic model. The main advantage is that this model is typically more flexible than the traditional ones, in the sense that it allows not only for the behavior of people to be determined by the context but also for the context to be reshaped by the behavior of people.

2.3 Complexity in a Nutshell: a Simple Scheme

The fundamental ideas and notions associated with the conception of the economy as a complex system can be expressed under the form of a simple scheme. This scheme is displayed in Fig. 2.1.

In Fig. 2.1, the micro and macro plans are highlighted. However, these cannot be analyzed separately from one another. What happens at the individual level contributes for shaping the aggregate, and the macro structure influences individual behavior and interaction. At the level of the agent, heterogeneity plays a central role. Because agents are heterogeneous (and, thus, not fully rational, what would imply homogeneity) they employ simple rules to make decisions and establish, as well, simple processes of interaction. The simpleness at the micro level contrasts with the complexity of the generated macro outcomes, governed by the emergence of unpredictable phenomena, whose particular shape is contingent on the history of the process (path-dependence), and where, most surely, the system fails to arrive to a steady state (out-of-equilibrium dynamics are the norm).

The scheme in the figure synthesizes what has been said in the previous section about what a complex economic system is. The following sections will explore further some of the most relevant issues highlighted in the diagram. Specifically, the following two sections concentrate on agent heterogeneity and on the adoption of behavioral rules to govern behavior.

2.4 A Diverse World: the Economy Populated by Heterogeneous People

Complexity models are the adequate framework to approach agent heterogeneity and its consequences. As mentioned in the previous sections, complex environments are not just tolerant to a wide diversity of economic behaviors; diversity of behaviors truly constitutes the quintessential reason for the existence of complex environments, and without it they would lose any meaning.

Assuming agent heterogeneity undoubtedly adds realism to economic analysis. After all, heterogeneity is the essence of socio-economic relations. Households, firms, and other conceivable agents, are heterogeneous at a variety of levels; thus, a first step to understand the world in which we live in is to

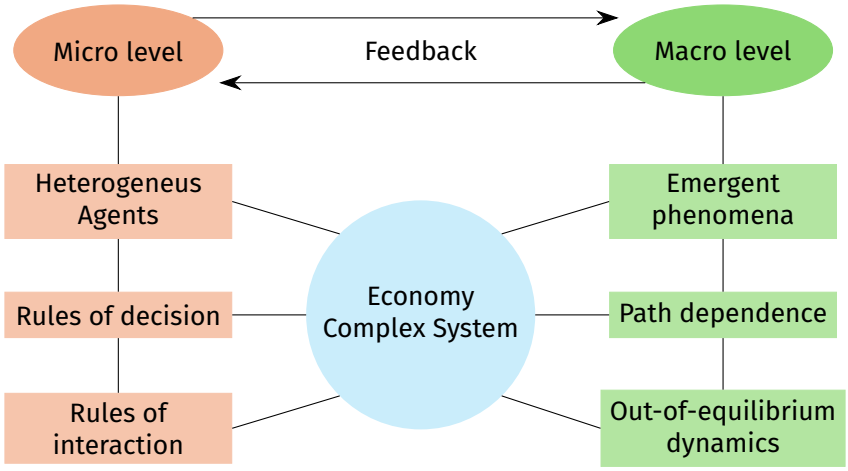

Figure 2.1: The economy as a complex system

typify different behaviors and to try to discern what kinds of interactions are established among different people, different organizations, and different institutions.

Heterogeneity is strongly attached to complexity. How each individual differently behaves forms a macro structure, i.e., a network of socio-economic relations. This network is unique, given the set of interactions that a series of unforecastable events has generated. Again, it is then the specific network structure that will feedback to the individual agents, determining their decisions and actions and eventually increasing the degree of underlying heterogeneity (Allen, Arkolakis, and Li, 2020).

Bookstaber and Kirman (2018) study a series of examples where heterogeneity and complexity go hand in hand. Specifically, they approach examples pertaining to the organization of markets and to the architecture of the financial system. In any case, the conclusion is that these systems, and markets in particular, are complex systems, with unique interaction processes, derived from the idiosyncrasies of each individual agent. It is an unfruitful effort to try to stylize markets into a single framework of analysis. Depending on a myriad of factors, including location, number and type of competitors, type of good or service, or information availability, each market must be addressed taking into account its specificities, what entails an approach that is not only scientific but also based on engineering principles. In this sense, agent heterogeneity becomes the underlying force behind the uniqueness of markets and other institutional arrangements.

Heterogeneity is one of the driving forces underlying the notion of radical complexity, as set forth by Bouchaud, 2021. The idea associated with the concept of radical complexity is that different micro settings may generate radically distinct macro outcomes. There are phase transitions and discontinuities that eventually trigger sudden and unexpected events. A small deviation in the behavior of the micro unit might lead to the emergence of a radically different aggregate result. Because such outcomes are hard or impractical to predict or anticipate, they constitute what scientists have designated by black swans, *i.e.*, rare events that allegedly take place only if a very exquisite set of circumstances is formed.

While conventional science has difficulty in dealing with black swans, the complexity approach is well equipped to explain how exceptional events may occur. This is because such approach is not based on a mechanistic view of the world neither it searches for absolute and well-defined results. Instead, complexity science relies on scenario identification and characterization. The way from micro to macro

is not always obvious (unlike what the representative agent premise of economists suggests); therefore, one needs to simulate the actual (and non-homogeneous) behavior of people in order to identify patterns of social evolution.

One of the issues with mainstream economic analysis, grounded on agent homogeneity, is that it does not allow for coordination failures. Because agents are rational and endowed with the capacity to fully understand the environment in which they act, there is a full coordination of actions leading to efficient outcomes. In a complexity scenario, where agents are boundedly rational, heterogeneous, and take decisions through the use of simple heuristics, the analysis of interaction and coordination is important, but perfect coordination is not taken as given.

In fact, the complexity approach does not rule out the existence of the invisible hand, but it does not accept it, as well, as given, *i.e.*, as a premise imposed to the economic system (as does the neoclassical paradigm). One might say that complexity economics is focused on testing the invisible hand, searching for the scenarios in which it applies without reservation, the scenarios in which it may be observed under certain circumstances, and the scenarios in which coordination in a decentralized economy is not, in any way, feasible.

In Hommes, 2021, the concern is to discuss the circumstances in which a rational equilibrium outcome might be achieved in a scenario where agents are heterogeneous, boundedly rational, and non-optimizers (they decide through the use of simple heuristics). Such outcome would imply the capacity to coordinate in the absence of a central planner and taking into consideration that different individuals are motivated by different goals. Cars Hommes suggests the use of laboratory experiments with human subjects to test how well different people coordinate in scenarios of decentralized interaction. The overall conclusion of the experiments made by this researcher is that coordination failures are common and, therefore, one should not expect convergence to a unique rational expectations equilibrium.

The results of the above-mentioned experiments are especially relevant to justify the inherent instability of markets in general, and of financial markets in particular. Traders and investors do not behave as in the perfect competition – perfect information benchmark (at least all of them) and, therefore, one should expect markets to be rather unstable, with small perturbations being amplified to generate large and persistent fluctuations. Eventual transitory equilibria that are formed are always path-dependent and emerging from self-fulfilling expectations.

Complexity frameworks can be applied virtually to all areas of economic thought: innovation studies, growth and development, economic and environmental policies, financial markets, and many others (Harré et al., 2021; Hidalgo, 2021). The points in common, throughout all these areas of study, are those already mentioned: the heterogeneity of endowments, capabilities, preferences, behaviors, and expectations, and also the different degrees of connectivity that shape the (emergent and constantly changing) network of relations over which agents interact.

Human beings are all different. Although some socio-psychological traits may be identified to bring us closer or to set us apart, the truth is that there are no two identical individuals. Therefore, setting up a model that takes into account agent heterogeneity requires making some simplifications and to consider some shortcuts. People may be grouped given the characteristics they eventually share and the objectives of the analysis, and therefore modelling heterogeneity may mean considering a more or less extensive list of allegedly homogeneous groups. Once these groups are formed, one needs to establish the rules of behavior for each group. The rules of behavior may emerge from empirical observation, or they can be set under purely logical terms. Once classes of individuals are defined and the rules of interaction established, economic relations unfold in a decentralized manner, without the need for any central coordinator (Caiani et al., 2016).

2.5 Rules of Behavior

The complexity view is directly associated with behavioral economics. It is through the identification of behavioral rules that one is able to understand how heterogeneous agents take decisions and interact with one another. Behavioral economics is a much-debated theme of research (a non-comprehensive list of surveys on the topic includes Camerer 1999; Akerlof 2002, Fudenberg 2006, Pesendorfer 2006, Bhargava and Loewenstein 2015; Thaler 2016; Thaler 2018; Wong 2020; Wong 2021; and Gomes 2023). Behavioral economics is relevant because it allows for a departure from strict rationality, thus leading to the possibility of a more detailed inspection of human behavior and to how such identification of behaviors can be attached to new modeling assumptions. In behavioral economics, as in complexity science in general, optimization is replaced by rules-of-thumb or heuristics; complete markets are replaced by local interaction taking place in complex networks; and the top-down approach is substituted by a bottom-up view of the world. Behavioral economics is the field of knowledge that one finds in the crossroad between economics and psychology (Berg, 2010).

Although the strict rationality paradigm is useful to arrive to uncontestable results about the way people act and interact, taking this approach implies abstracting from personality, sentiments, and cognitive idiosyncrasies. The mainstream economic models are as if models (i.e., models that explain how people would act if they were fully rational); under the behavioral perspective, one is searching for as is frameworks. The idea is to convey realism to the study of economic phenomena, even though it is much harder to systematize and stylize actual behavior than the ideal type of the rational being.

The rationality assumption is a phenomenally strong assumption. According to Mullainathan and Thaler, 2000, for this assumption to integrally and consistently hold, humans would have not only to be unboundedly rational, but they would have to possess the willpower necessary to always fulfill plans, and also to exhibit, in every circumstance, a selfish behavior. People are not like that and, therefore, their decisions are subject to a wide variety of errors and biases. Economists have to let go from the idea of homo-oeconomicus. Human beings are not one-dimensional; they are complex psychological entities, and one can only truly address human behavior if one accounts for such multi-dimensionality and for all the anomalies that decision-making is subject to. Such anomalies include, among others, overconfidence, conservatism, procrastination, anchoring, and framing effects (Kahneman, 2003; Bénabou and Tirole, 2016).

One of the problems associated with rational choice is that collecting and processing all the required information to take optimal decisions is a costly process (in terms of time, money, and other resources). Hence, the pursuit of full rationality might not be, in itself, a rational decision to take. Given the trade-off between efficient choice and the cost of choice, people often replace rational decision-making by heuristics or rules-of-thumb. Gigerenzer, 2008 defines a heuristic as a decision strategy whose aim is to generate fast and frugal choices; the way to adopt this strategy is to deliberately ignore part of the available relevant information or conscientiously not to try to collect all the meaningful data. This is, in fact, a rational decision: the agent is willing to trade the possibility of making a more accurate decision in exchange for more prompt and quicker resolutions.

Gigerenzer and Brighton, 2009 go even further by stating that, in many real-world scenarios, less is more, that is, the application of heuristics eventually outperforms rational choices. This is possible in contexts in which uncertainty is high and the underlying setting is an emergent and complex reality. Heuristics are not necessarily a second-best option and the gains concerning savings of cognitive and computational resources may not be the only gains; in fact, more accurate choices might be made.

Heuristics are relevant not only at the micro level, but at the aggregate level as well. Dosi, Roventini, and Russo, 2019 and Dosi and Roventini, 2019 apply the idea that less is more to the macroeconomy. Again,

the intuition is that the economy is populated by heterogeneous interacting agents, who are relatively simple in terms of their decision procedures and unable to understand and process all the relevant information (simple people interacting in a complex world). Hence, one should address the economy taking into consideration simple decision rules at the individual level and also simple coordination devices between people; this dual simplicity contrasts with the complexity that is, then, formed at the macro level. Heuristics are particularly well-suited to use in agent-based computational models, in contrast with the conventional analytical models that require a predictable course of action that everyone in the economy equally follows.

2.6 Operationalizing Complexity: Agent-based Models

The operational tool of complexity science is agent-based models (ABMs). Through ABMs, the researcher can set a series of simple rules of behavior and a set of simple rules of interaction, and then codify them and run the model. This will allow for the identification of aggregate patterns of behavior which, as already mentioned, form the macro structure on which agents need to continue to decide and interact. Note that the term 'run' was used; unlike conventional analytical models, which are 'solved', the algorithmic models of the complexity approach are 'run'. This is a fundamental difference not only of method, but from the point of view of the outcomes one may achieve; an algorithmic model allows for a large diversity of possible results, even when introducing only small changes to the setup.

The versatility of ABMs is important at a variety of levels. For instance, they have an important pedagogical facet. Rules of behavior and interaction are often intuitive and easy to understand, because they reproduce how we actually think and act (typically in ways much simpler than what the rationality paradigm suggests). Next, running the model is also a suggestive way of reproducing how the economy actually works and how the observed results are effectively obtained. These results tend to replicate observable phenomena. By simulating the economy through ABMs, the researcher or the student is capable of perceiving how the world evolves and how outcomes unfold.

Agent-based models applied to economics frequently take the designation of agent-based computational economics (ACE). Tesfatsion, 2023 characterizes an ACE as a model governed by seven basic principles. These principles allegedly reflect a living unfolding economy, where the interaction among agents produces unique and unpredictable events. The principles are the following:

1. Definition of agents. Agents are defined, in an ACE model, as software units encoded to possess a given set of characteristics;
2. Scope of agents. Agents may represent various entities, from traditional economic agents (households, firms) to any other type of social groups;
3. Local constructivity. This feature corresponds to the agent's attributes and state, leading to some action at some point in time;
4. Autonomy of agents. Agents are autonomous in the sense that they establish free interactions, given their motivations, and without the need for the intervention of any central planner;
5. Global constructivity. Global or system constructivity pertains to the notion that the state of the system at a given date is determined by agents and their interactions;

6. Historicity of the system. This principle is associated with the idea of path-dependence. Events, i.e., changes in agents' states, are historically determined by the interactions that have unfolded in the realized state of the world;

7. Modeler as experimenter. The role attributed to the researcher is simply to set the initial stage (agents and rules of interaction). Subsequent events are the strict and direct consequence of running the model, with the researcher simply becoming an observer and an analyst of the events that unfold.

The seven enumerated principles make it clear that an ACE model is nothing else than a computational laboratory that allows to perform a series of experiments over the artificial world that the researcher created. Tesfatsion, 2023 compares this method of analysis with the cultures in Petri dishes employed in biological experiments. The modeler has the role of preparing the experiment; the results of the experiment emerge as this evolves and there is no way of accurately predicting, at the starting point, what the results of the experiment will be. In Steinbacher et al., 2021, the seven mentioned principles are systematized into four main blocks: agents, environment, rules of action, and macro-structure. If the ABM concerns to a socio-economic setting, then agents are decision-makers endowed with dynamic attributes, the environment is a network of social or economic relations, the rules of action determine how each agent evaluates options when in contact with other agents, and the macro structure is both the macroscopic outcome of the micro interactions and the structure that shapes the environment in which socio-economic actions take place.

ABMs or ACE models became a generalized and popular way of doing science in the realm of social sciences in general, and in economics in particular. This occurred for two main reasons. First, a practical reason; to simulate these models, even those that are relatively simple and small in scale, strong computational power is required. This computational power emerged recently in history (in the last fifty years), and such capabilities have exponentially increased over the years. Second, the versatility they allow for, namely in what concerns the introduction of simple but powerful assumptions that bring us closer to reality (e.g., the use of plain behavioral heuristics by decision makers or the possibility of modeling interactions by resorting to stylized network structures, as it is the case of scale-free networks or small-world networks).

Axtell and Farmer, 2022 emphasize the relevance of ABMs, namely in what regards their explanatory power that comes from relaxing some of the assumptions that mathematical models typically make in order to keep them analytically tractable. In ABMs, the networks in which agents interact (social, spatial, or physical) may be exogenously specified or, instead, endogenously created. The aggregate outcome is emergent, in the sense that it is formed through the interaction among the large number of agents that are typically assumed. And a diversity of results may be accomplished: the dynamics may converge to an equilibrium (through decentralized coordination) or bounded instability / endogenous fluctuations may perpetuate in the economy.

ABMs are also an effective way of attributing micro-foundations to macro models (Schinckus, 2019; Cincotti, Raberto, and Teglio, 2022). Although conventional economic theory sustains the view that economic reasoning at a macro level requires micro foundations, such foundations are, in the orthodox view, simply the outcome of solving straightforward optimization problems. Because every agent is rational, every agent solves the same optimality problem and, thus, micro and macro are the same thing: the outcome of a straightforward utility maximization model solved by a representative agent. ABMs, and complexity models in general, go beyond this simplistic interpretation; they establish true micro foundations by allowing the macro outcome to emerge from the interaction between individual agents endowed with a small set of characteristics that allow them to act when in contact with others.

The ABMs offer a possible solution for the aggregation and coordination problems that standard economic models pose. They allow, effectively, for many economists, for the genuine micro foundations that oppose to the artificial micro foundations based on intertemporal optimization (Dosi, Roventini, and Russo, 2019; Dosi, Napoletano, et al., 2020; Haldane and Turrell, 2019). The underlying principle is the idea that simple individual behavior, grounded on simple decision rules, leads to an outcome that is complex and that no one, individually, can control.

The strong point of ABMs that intend to characterize the macro economy is the ability of the models in discarding the need for any ex-ante consistency in order to generate macro-outcomes; these emerge naturally as individual agents decide, take actions, and establish trading relations with others: macro properties are emergent.

Macroeconomic models based on complexity principles come in many forms. Some are small-scale toy models, constructed to present straightforward explanations for observable phenomena (as in the case of D. Gatti et al. 2008; D. D. Gatti et al. 2011; Gualdi et al. 2015; Gualdi et al. 2017; Dosi, Roventini, and Russo 2019; Fagiolo, Giachini, and Roventini 2020). Other models are not especially concerned with analytical tractability or with understanding some specific subjects and, on the contrary, focus on giving a pervasive overall picture of how the economy works. This is the case of the large-scale model Eurace@Unibi proposed by Deissenberg, Van Der Hoog, and Dawid, 2008 and Dawid, Gemkow, et al., 2012, whose main goal was to simulate an entire economy.

The complexity perspective, and its operational arm, the ABMs, have important virtues, as enumerated throughout the chapter, but they can also be criticized by their limitations (Richiardi, 2017; Dawid, Harting, et al., 2019). To start, there is no one-size-fit-all model under the complexity perspective. The types of agents, the decision rules, the networks of interaction, the structure of markets may vary from one model to another, what makes it difficult to compare and associate different frameworks. The problem is the one identified by Sims, 1980 under the expression 'wilderness of bounded rationality' and further explored by Lengnick, 2013, who expressed the concern that agent-based models leave to the researcher too many degrees of freedom.

Another issue, also relevant, concerns the replication of ABMs using actual data, which is not always easy (it is difficult to synchronize artificially endogenous generated phenomena with real-world events). Fagiolo, Guerini, et al., 2019 address the question of empirical validation of agent-based models, calling the attention for the need to make artificial data compatible with empirical evidence, in order to guarantee that models can be duly calibrated and estimated.

2.7 Conclusion

Science requires method, and different methods might be employed to approach and explain the same set of real-life events. In social sciences, and specifically in economics, the deductive method is typically employed: a set of assumptions is established from the beginning and the behavior of the agents that populate the model must conform with such assumptions. This might be problematic if the assumptions somehow depart from empirical observation, and in economics it is a fact that this indeed occurs. Mainstream economics perceives individuals as ruthless optimizers, endowed with an infinite capacity to collect and process the data required to make unequivocally right decisions. However, reality shows us a different kind of human being, often indecisive and vulnerable. Furthermore, heterogeneity is the rule: people are different concerning tastes, endowments, and life purposes.

Taking the above considerations in mind, an inductive approach to the study of economic behavior appears to have a greater potential. Induction can be associated to a complex view of the world, in

which heterogeneous agents apply simple rules of decision and interaction to pursue their goals in a complex economic environment. Small-scale interactions generate large-scale phenomena that shape the structure of the economy in which agents need to make their choices about how to act and whom to interact with.

This chapter has made the apology of the complexity perspective in economics. This perspective allows for an intuitive perception of how economic relations are established and how results emerge. These results do not correspond to a set of lemmas, propositions, and theorems, that we are used to receive from conventional economics. Instead, the outcomes reveal the 'messy vitality' that W. B. Arthur, 2021 highlights: the economy does not tend to rest in a steady state; on the contrary, it is always in motion, with the observed patterns of motion being contingent on past occurrences (there is path-dependence). Moreover, one may expect, in this case, abnormal outcomes to emerge from time to time; complexity is perfectly compatible with black swans.

One of the main messages brought about by the discussion in this chapter is that there is a set of features that are intertwined and that do not make much sense to consider in isolation: there is no complexity without agent heterogeneity; heterogeneity necessarily implies simple rules of behavior; complexity is attached to the formation of networks via interaction; and from the interactions between heterogeneous agents within given network structures, it emerges a series of complex aggregate patterns of evolution. It is with all these ideas and interconnections in mind that the book proposes, further ahead, a simple model of heterogeneous agents to explain economic relations. In this model, each agent is endowed with a unique profile or a unique ID. The interaction among agents will then lead to complex patterns of evolution. As in any ABM model, the model to explore will be transformed into an algorithm and run as a software program.

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Chapter 3

Innovation and Skills: a Contamination Lab Experience in Higher Education Institutions

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Summary
This chapter aims to explain innovation in higher education institutions to develop students' entrepreneurial skills through contamination lab experience. In the dynamic evolution of work, innovation plays a crucial role in ensuring both the survival and success of organizations and in leading professional behavior in higher education institutions towards the adoption of a new learning technique. Soft skills, as a psychosocial aspect, play a foundational role in students' inventive capacities, encompassing cognitive and interpersonal skills, willingness to engage in discourse and problem-solving, collaboration, and communication proficiency.
Keywords: Soft skills, Innovation, Higher education institutions, Entrepreneurial skill, Contamination lab, Creative skills.

3.1 Introduction

The capacity to identify, cultivate, and effectively apply one's skills is widely recognized as a crucial aspect of personal and professional advancement. Skills represent polyhedral constructs that empower humans to perpetually advance and expand their knowledge and abilities across diverse scenarios; embracing continual practice, experiential learning, and refining specific tasks and strategies is imperativ (Lamri and Lubart, 2023). These are skills that are very important in the workplace (Dell'Aquila et al., 2016). According to Weber and colleagues (Weber et al., 2009), soft skills are essential to the workplace as they encompass various behavioral, human, and interpersonal abilities that are useful when it comes to implementing technical knowledge and skills. These abilities are also referred to as personality attributes or drives, and this implies that they are mainly influenced by an individual's intellect. These abilities are also referred to as personality attributes or drives, and this implies that they are mainly influenced by an individual's

intellect (Wesley, Jackson, and Lee, 2017).

These include working as a team, communicating effectively, and being adaptable. In addition, soft skills refer to the various social-emotional capabilities that are vital for job performance, personal growth, and social involvement (Kechagias, 2011).

In this scenario, the case of contamination lab is designed to increase students' desire to become entrepreneurs and/or innovators by animating their entrepreneurial spirit and helping students develop those hard and soft skills (such as problem-solving, teamwork, etc.) that become increasingly requested by organizations operating in all sectors.

This chapter will be organized as follows: in section 3.2, we discuss the frame structure approach to the topic of soft skills. Following this, sections 3.3 and 3.4 show the innovative higher education initiatives to develop soft skills at the end the practical impacts of contamination labs. This chapter presents two main objectives: (1) the contribution to the body of literature of soft skills relevant for researchers; (2) the development of a conceptual approach of contamination labs experience. The approach introduces a new framework applicable both as a tool for enhancing the understanding of entrepreneurial skill development, and as a useful guide to future research on soft skills as a whole.

3.2 Overview of the Soft Skills and Hard Skills

There are two kinds of skills: soft and hard. The latter refers to the quantifiable and technical abilities related to using certain types of equipment, such as welding and driving cars (Lyu and Liu, 2021). These are typically acquired through education and training. On the other hand, the former is a more practical term that refers to the skills required to perform specific tasks (Rainsbury et al., 2002; Hendarman and Cantner, 2018). Since hard skills are commonly used in work, their relevance has been acknowledged. These abilities can be utilized to achieve quantifiable goals. On the other hand, soft skills are characterized by their non-technical nature and difficulties in quantifying and measuring them (Byrne, Weston, and Cave, 2020).

Contrary to popular belief, the development of soft skills is not done through formal education or training. Instead, they are usually acquired through reflection, self-improvement, and dedication (Wisshak and Hochholdinger, 2020). Table 3.1 highlights the definitions associated with helping individuals better understand soft skills' application in different areas.

Soft skills have varying meanings in different countries (M. Wats and R. Wats, 2009). For instance, in the United States, it is often regarded as a type of workplace know-how or employability skill, while in Australia, it is called key competencies, generic skills, and soft skills (Marin-Zapata et al., 2021). On the other hand, in Europe, this is referred to as life skills (M. Wats and R. Wats, 2009), and each country designates the term soft skills differently, as reported in Table 3.2.

Soft skills relate to life, transversal, critical, generic, and lifelong learning (Succi, 2019). A study from Harvard University, the Carnegie Foundation, and Stanford Research revealed that 85% of job success could be attributed to having well-developed people and transversal skills. In comparison, only about 15 per cent can be attributed to hard skills (Green and McGill, 2011). A survey conducted by the University of Michigan's Ross School of Business with Harvard and Boston College revealed that 20 per cent higher productivity could be attributed to the advancement and acquisition of soft skills (Adhvaryu, Kala, and Nyshadham, 2018). Other studies also noted that about 75% of chief executive officers of Fortune 500 companies have long-term job success. According to numerous studies, developing soft skills significantly impacts enterprise performance, surpassing technical expertise (Ibrahim, Boerhannoeddin, and Bakare, 2017).

Authors	Definition
Rainsbury et al., 2002; Weber et al., 2009	**Interpersonal skills** People, behavioral, or interpersonal skills are collectively known as soft skills. They are used to manage and conduct relationships effectively. Interpersonal abilities are used to apply knowledge and technical skills in a professional setting.
Laker and Powell, 2011; Kechagias, 2011; Robles, 2012	**Intrapersonal skills** are those that involve one's self-management, while interpersonal skills are used to manage and interact with others. These are important for personal growth, professional achievement, and social engagement. In addition, interpersonal qualities, typically defined as people skills and personal attributes, include various abilities such as adaptability, collaboration, and communication.
M. Wats and R. Wats, 2009; Robles, 2012; Ballesteros Sánchez et al., 2017; Stasz, 2001; Stasz et al., 2007; Andrews and Higson, 2008; Cinque, 2017; Stevenson and Starkweather, 2010; Majid et al., 2012; Succi, 2019; Hampson and Junor, 2005; Hampson, Junor, and Barnes, 2009	Soft skills are **qualities** of adaptability, versatility, accountability, politeness, honesty, professionalism, efficiency, reliability, and ethical work standards, openness to learning, acquisition of additional skills, diligence, and ability to work under pressure or in ambiguous conditions, communication skills, encompassing aspects of negotiation, conflict management, persuasive abilities, inclusivity, and articulation work – which involves synchronizing concurrent interactions among individuals, data, and technology.
Cimatti, 2016; Ballesteros Sánchez et al., 2017; Cinque, 2017; Thompson, 2019; Succi, 2019; Succi and Canovi, 2020	**Major soft skills:** leadership, self-management, creativity, and coping abilities. Some of these include analytical thinking and problem-solving. In addition, cognitive capabilities allow an individual to plan and achieve goals.

Table 3.1: Soft skills definitions an overview

Country	Denomination
Austria	Key Capabilities
Belgium	Transversal and Key Capabilities
Denmark	Key Capabilities
England	Scotland: Core Capabilities
	England & Ireland: Key Capabilities Life Capabilities, Key Transferable Capabilities, Cross Capabilities
France	Transversal Capabilities
Germany	Key and General Capabilities
Italy	Transversal Capabilities
Portugal	Essential Competencies, Transversal or Generic Competencies
Spain	Generic Competencies

Source: Cinque (2015).

Table 3.2: Different denominations of soft skills in Europe

The ability to acquire soft skills is a vital factor in advancing professional and personal capabilities in today's competitive environment. These interpersonal, communication, and emotional intelligence abilities complement technical expertise, fostering effective collaboration, problem-solving, and adaptability. In diverse contexts and changing professional terrains, developing soft skills amplifies individual effectiveness and nurtures cohesive and resilient communities. Soft skills must be incorporated into career development plans and resources to nurture the cooperative cohesion necessary to gain personal career growth, promote workplace connections and boost organizational success (Nigh, 2021).

3.2.1 Skills training and development

Each task undertaken by individuals necessitates requisite skills and contemporary knowledge to ensure effective and efficient execution. As tasks and roles grow increasingly intricate, the imperative for training and development becomes evident. Organizations must furnish their employees with training and development opportunities to remain viable. Training is a structured process to enhance employees' knowledge and skill repertoire, facilitating performance improvement and adaptation within the workplace (Sheeba and Christopher, 2020).

Learning constitutes a pivotal aspect of human resource management, gaining increasing importance in contemporary times for enhancing employee capabilities and fostering cognitive agility towards various subjects and ideas, aiming to bolster productivity G. Anwar and Abdullah, 2021. Training entails the strategic preparation of diverse learning techniques tailored for staff members to enhance their capacity to achieve predetermined objectives. In contrast, development delves into comprehending the underlying mechanisms of current processes while addressing future challenges and demands. Unlike training,

which focuses on immediate skill enhancement and individual responsibilities, development extends over a longer duration, encompassing broader organizational perspectives (K. Anwar and Ghafoor, 2017).

The synergy between training and development forms the foundational framework of a flourishing organisation, with its indispensability resonating across all spheres and times (Gardi et al., 2020). Continuous provision of necessary information and consistent feedback to employees is essential, recognising humans as the most dependable resource whose efficacy thrives when nurtured through comprehensive and academic training methodologies (Demir et al., 2021; Top and Ali, 2021).

3.3 The Innovative Higher Education Initiatives to Develop Soft Skills

The rapid emergence and evolution of digital technology have become a critical priority for higher education institutions (HEIs) in the 21st century (Soliman et al., 2021; Soliman et al., 2023). This imperative reflects the natural progression towards organizational evolution and competitiveness for institutions aspiring to lead change in their respective domains (Benavides et al., 2020). Universities play a vital role in fostering innovation, which is acknowledged as a critical factor in stimulating economic growth (Salem, 2014), especially in developing nations. It is also essential that higher education institutions develop a workforce that can meet the demands of a modern knowledge-based economy (Otham et al., 2018).

According to Khan and colleagues, academic leaders can help organizations foster an environment that is more innovative, adaptive, and creative by facilitating innovative behavior within the workplace (M. A. Khan et al., 2020). Consequently, studying the innovative work behavior of academics is essential for enhancing universities' capabilities to generate new knowledge (Yean, Johari, and Yahya, 2016).

These skills can help employees develop their personal and professional capabilities, so educational institutions should allocate funds for training initiatives (Dalima et al., 2023). In order to effectively implement new work behavior within the classroom, the faculty and staff members must have the necessary soft skills. One of the most critical factors an organization can consider when developing its global workforce is leadership (Osseo-Asare, Longbottom, and Murphy, 2005).

The evolving landscape of higher education, marked by increasing demand, cultural shifts, managerial diversity, and financial constraints, necessitates leadership adaptation and innovation (Alonderiene and Majauskaite, 2016). Educational leaders often prioritize core academic values over organizational ones (Marshall, 2012). Individuals from the Middle East have specific characteristics, such as prior experience, modelling, observation, and knowledge. Compared to business leaders, these individuals face unique challenges due to the varying stakeholder groups, including faculty and students (Siddique et al., 2011). Transformational leadership can help organizations foster creativity, innovation, and understanding among their staff members, which can increase employee achievement (M. J. Khan, Aslam, and Riaz, 2012). Transformational leadership involves a leader's vision for inspiring and transforming a group or individual. Although these types of leaders are known for their inspirational and motivational qualities (M. J. Khan, Aslam, and Riaz, 2012), their high self-efficacy levels can also help improve the work environment of their institutions (M. A. Khan et al., 2020). The self-leadership approach posits that individuals can influence their behavior and guide themselves according to their objectives, provided they possess the necessary skills and employ appropriate strategies (Manz and C. P. Neck, 2004).

According to Ibus et al., 2020, academics who exhibit self-management are motivated by their task performance, encouraging them to pursue innovative approaches to help them achieve their objectives. This form of drive, known as self-efficacy, is a person's belief that they can influence the events in their life that significantly impact them (Bandura, 1997).

Consequently, self-efficacy represents the cognitive process through which individuals assess their capability to execute tasks (Bandura, 1997). Academics present high levels of self-efficacy, showing strong beliefs and confidence in their abilities and skills, and appear to be more innovative in dealing with complicated issues and performing tasks (Ibus et al., 2020). Innovation within the education sector is crucial for generating new knowledge and facilitating improvement. Educational leaders must explore strategies to enhance academic self-efficacy levels, thereby promoting self-leadership. This, in turn, nurtures a culture of innovative behavior among academics. (Ibus et al., 2020). Meanwhile, self-efficacy empowers academics with the belief in their abilities, fostering confidence to tackle challenges and pursue innovative endeavors. Additionally, self-leadership enables academics to take charge of their actions, fostering a culture of autonomy and creativity within educational institutions. Together, these elements create an environment conducive to fostering innovative work behavior, driving the advancement of knowledge and improvement within the education sector.

3.3.1 The strategic role of acquisition of soft skills in HEIs courses

Acquiring skills and knowledge through higher education is paramount in today's dynamic world. Embracing higher education gives people the tools to tackle complicated situations and make a difference in their communities. To meet the changing needs of society and the workforce, universities are working toward equipping their students with the skills that will allow them to excel in today's competitive environment (Cornali, 2018).

Higher education aims to shape individuals with solid ethics, soft skills, and relevance to the workforce's requirements (Abbot, 2016).

Intriguingly, numerous studies have primarily concentrated on the technical / hard skills demanded by the labor market in recent years (Di Virgilio, 2024; Lyu and Liu, 2021). Instead, their critical role is irrelevant (Maddikunta et al., 2021; Paschek, Mocan, and Draghici, 2019). This strategy aims to gain a competitive edge by developing a blend of soft and hard skills, including transferable and core competencies (Clarke, 2018).

This indicates that society's economic, social, and cultural future requires an enormous investment in continuing education and lifelong learning (Qizi, 2020). Succi and Canovi, 2020 have shown that higher education institutions are placing greater emphasis on soft skills. Developing students' soft skills in higher education is very important to enhance their employability and professional capabilities (Tripathy, 2020).

It has been stated that the capacity of HEIs to offer market-driven competencies to their pupils has been under increasing scrutiny (Igwe, Lock, and Rugara, 2022). Employers and other stakeholders expressed their concerns about the quality of education provided by HEIs, especially regarding their inability to equip students with the necessary industry-specific skills (Abelha et al., 2020). This issue is especially apparent in the soft skills curricula, as these typically do not prepare students (Vera and Tejada, 2020).

While soft skills are significant for university students and graduates, their relevance varies across professions. Specific soft skills may take precedence for employers in one field while not being deemed essential in another (Fadhil, Ismail, and Alnoor, 2021).

Soft skills are recognized as essential skill sets that significantly contribute to an individual's success in both their career and personal life (Feraco et al., 2023). Moreover, organizations soft skills during hiring are more likely to experience fewer interpersonal conflicts within their ranks (Denney et al., 2020). The increasing number of employees with soft skills can also improve the company's harmony. Since organizations thrive on team performance, businesses that rely on this strategy are more likely to look into hiring people with strong soft skills, which is a requirement for success (Schmutz, Meier, and Manser, 2019). Table 3.3 highlights the prevalent soft skills that employers are looking for in their employees.

Soft skills	Meaning
Communication	The ability to accurately convey information constitutes a key communication skill. It can be expressed in various forms of media, including verbal and non-verbal. Some of the components of communication skills include reading, writing, speaking, and listening (Vasanthakumari, 2019).
Problem-solving	These competencies entail the capability to identify a problem, assess various alternatives, and devise viable solutions to address the specific issue at hand (Rahman, 2019).
Leadership	Leadership skills allow individuals to influence and motivate others so that actions can contribute to an organization's or group organization's shared objectives (K. M. Mwita and Tefurukwa, 2018).
Decision-making	Decision-making skills involve evaluating and choosing the most likely outcome after considering various alternatives (Asefer and Abidin, 2021).
Team-working	These capabilities encompass the abilities that enable individuals to collaborate effectively within teams. They involve how individuals work together with others to achieve shared objectives (Succi, 2019).
Innovation/creativity	These skills embody the capability to generate ideas and devise approaches or methods of accomplishing tasks that yield favorable outcomes in work environments (Asefer and Abidin, 2021).
Adaptability to change	These skills refer to the capacity of individuals to readily accept and embrace changes within work environments. Individuals possessing these skills act as receptors for change and demonstrate flexibility in adapting to new circumstances (Succi and Canovi, 2020).
Work ethic	This soft skill encompasses an individual's values, which influence their actions, thoughts, and decisions in the workplace. It serves as a guide for determining acceptable and unacceptable in professional settings. Individuals with strong work ethic exhibit self-control regarding adhering to rules and procedures within the workplace (Succi and Canovi, 2020).
Being tolerant of stress	This skill pertains to remaining composed when encountering difficulties and challenging circumstances (Succi and Canovi, 2020).

Source: K. Mwita et al., 2023

Table 3.3: Relevant soft skills

3.3.2 How soft skill affects the entrepreneurship culture

To enable HEIs to carry out their third mission and produce entrepreneurial graduates, they are promoted to entrepreneurial status (Henry and Lahikainen, 2024).

HEIs are inclined towards scientific and basic skills over employer preferences. This inclination could stem from society or history, which has shaped higher education expectations (Sebastião et al., 2023). Developing soft skills can help individuals enhance their entrepreneurial abilities in this context. Employers and educators recognize soft skills' importance and value them more than hard ones (Sebastião et al., 2023).

Entrepreneurship is identifying commercial or technical opportunities and developing a plan for pursuing those goals (Hayton, 2015). Scholars have varying perspectives on defining what constitutes an entrepreneur's competencies. Several of them have looked into the specific traits of organizations that are geared toward growth (Cooney, 2012; Kutzhanova, Lyons, and Lichtenstein, 2009; O'Hara, 2011).

Although imagination, bootstrapping and social skills constitute entrepreneurial skills (Brush, 2008), they also encompass a range of behaviors and abilities (Chell, 2013). These include the knowledge and attitudes required to create valuable and innovative products and services that cater to a specific market. Consequently, they contribute to achieving functional, social, or emotional objectives (Jardim, 2019). Fostering entrepreneurial competencies represents an effective avenue for enhancing the genuine potential of students' entrepreneurship (Linan, 2008). Recent research and studies have identified groups of skills known as 'global entrepreneurial skills', which are categorized as displayed in Table 3.4.

Concentration and availability to accept novelty	**Generation of value**	**Efficient communication**
Creativity and innovation	Strategic designing and assessment	Concise and eyesight communication
Sense of initiative	Troubleshooting and decision-making abilities	Digital communication
Self-efficacy and endurance	Transformational leadership	Collaboration and networking

Source: Jardim, 2021.

Table 3.4: Global entrepreneurial competencies

The first category concerns the propensity to be focused and open to new things. The entrepreneurial culture is centered around exploring and identifying opportunities, fostering innovation, and encouraging creative endeavors. Consequently, it involves a series of initiatives aimed at both processes and individuals, ultimately driving the pursuit of opportunities and emphasizing the importance of planning and execution, critical thinking and action, self-determination, and leadership (Dornelas, 2007). First and foremost, the ability to be creative and innovative, along with originality and perseverance in realizing a unique idea, is one of the hallmarks of being an entrepreneur (Isaacson, 2016; Jardim, 2019). The entrepreneurial spirit sets entrepreneurs apart, making it a primary focus in cultivating an entrepreneurial culture (McCallum et al., 2018). By being proactive rather than reactive, entrepreneurs take initiative and promptly implement their ideas until they discover optimal solutions (Jardim, 2021).

The last competency that has caught the attention of entrepreneurship researchers is self-efficacy, which is a belief that people have in their ability to achieve desired outcomes. This driving force helps

people pursue their well-being (Bandura, 1997). The second category of entrepreneurial skills revolves around entrepreneurs' capacity to be pragmatic in shaping their ideas and generating value, constituting the cornerstone of their success. Their pragmatism enables them to discern what needs to be done, resolve issues, implement plans, and explore the most suitable avenues to initiate their projects and the necessary steps to bring them to fruition (Jardim, 2020). Planning involves selecting and detailing the crucial activities necessary to accomplish specific objectives, arranging and allocating them within a defined timeframe, and coordinating the resources available to achieve them (Jardim, 2010). Strategic planning incorporates entrepreneurial skills to motivate and lead towards achieving results (Singh, 2018). Planning involves evaluating and mapping out what works effectively and what needs to be improved, identifying both the advantageous and hindering aspects of team dynamics and the attainment of expected outcomes. The importance of planning is highlighted by the need for proper training in allocating time and personal agenda management. Since it is a vital part of company management, it should be improved to increase productivity and competitiveness (Jardim, 2021).

Identifying the best solutions to their problems is a high priority for entrepreneurs. This is why decision-making and practical problem-solving skills are crucial components of many intervention programs (Kim et al., 2020). They discern the best solution among various alternatives through conscious mental analysis of the situation. Individuals who invest more time in discovering what to do than doing it might yield superior outcomes (Sternberg, 2005). Another entrepreneurial skill lies in effectively leading teams capable of generating original and valuable solutions. Transformational leadership proves to be well-suited to the present context (Burns, 2004). This leadership style involves a process that encourages people to go beyond their interests and focus on the organization's objectives, thereby achieving optimal performance. The transformative process can increase motivation and morality for followers and leaders by appealing to principles such as humanism, peace, and justice (Jardim, 2021).

Efficient communication skills are the last category, and entrepreneurs can be distinguished by their ability to effectively market their services or products to certain target groups, particularly through social media, digital forums, and print media (McCallum et al., 2018; Jardim, 2003).

Entrepreneurs exhibit a talent for clear and visually compelling communication, which stems from their pursuit of distinct objectives and honed communication abilities, which are crucial for their effectiveness. Visual communication involves conveying ideas through images. Messages built in this way attract interest, enable the acquisition of knowledge, and improve interaction with the audience (Huber and Veldman, 2019; R. J. Marzano, 2019; Glass and R. Marzano, 2018). Teamwork denotes collaborative efforts where individual interests yield to the group's efficiency, yielding more fruitful results than individual endeavors. In order to achieve this, one must operationalize skills, attitudes, and knowledge, which are necessary for carrying out collective action and maximizing the individual's potential (Jardim, 2010). According to J. Prüfer and P. Prüfer, 2020, eleven distinct entrepreneurial skills exist. These were ranked according to their significance:

- Ability to communicate
- Resourcefulness
- Designing and arranging
- Flexibility
- Cooperation

- Being creative
- Computational thought
- Troubleshooting
- Leadership
- Active learning
- Critical thinking

The list emphasizes that entrepreneurial skills are mainly concentrated in the soft skills category. In terms of the skills that employers consider when hiring and training workers, García-Álvarez et al., 2022 noted that entrepreneurial abilities are the most crucial. The various entrepreneurial skills that emerge in the transnational context include:

- Leadership competencies
- Creativity and innovation capabilities
- Design and project management skills
- Initiative and entrepreneurial mindset
- Risk-taking

Enhancing entrepreneurial skills serves as an effective means to bolster students' actual entrepreneurial potential (Linan, 2008). The nurturing of soft skills, the curriculum, and the self-expansion required to function effectively independently and within a team are factors associated with employability (O'Leary, 2012). The significance of soft skills or comprehensive competencies spanning communicative abilities, research, option analysis, decision-making, adaptation, versatility, creativity, and troubleshooting, among others, is underscored for employability (García, 2017). Entrepreneurship skills are indispensable for employment, given that leadership, initiative, and creativity foster innovation within a knowledge-based economy (Laguna-Sánchez et al., 2020).

Entrepreneurship skills are essential for employment as creativity, initiative, leadership, and dynamism support innovation within an interconnected knowledge-based economy (Laguna-Sánchez et al., 2020). Consequently, HEIS must integrate specialized programs aimed at improving graduate entrepreneurship into their curricula, as it is a crucial aspect of employability (Laguna-Sánchez et al., 2020; O'Leary, 2012). For entrepreneurship, requisite skills and abilities encompass taking calculated risks, assembling an effective team, coordinating essential resources, devising business plans, and identifying opportunities (Kolb, 2014). The intricate nature of entrepreneurship requires students' ability to navigate uncertain environments, emphasizing educators' role in fostering their exploration skills, strategic planning, and execution (H. M. Neck and Greene, 2011).

Entrepreneurship education can play a vital role in supporting creative enterprises and new economic opportunities (Gilje and Erstad, 2017), simultaneously enhancing the overall well-being of the economy and generating job prospects (Aldianto, Anggadwita, and Umbara, 2018). Scholars have proposed various definitions of entrepreneurial education. One is a procedure designed to equip human beings with the knowledge and abilities to identify overlooked possibilities and possess the intuition and self-confidence to begin when others falter (McIntyre, 2000). Entrepreneurship education refers also to any educational or

pedagogical process aimed at cultivating specific personal attributes related to entrepreneurship abilities and capacities (Fayolle, Gailly, and Lassas-Clerc, 2006).

Entrepreneurship education in HEIs encourages students to pursue their entrepreneurial goals and develop the necessary skills to be more innovative and proactive when creating value for others (Aldianto, Anggadwita, and Umbara, 2018). In addition to this, it enables students to improve their entrepreneurial competence, mindset, and behavior (Williams Middleton, 2013).

In order to actualize entrepreneurship education, fostering an entrepreneurial mindset among students is crucial (Othman et al., 2012). In addition to these, entrepreneurship education also requires a variety of interactive activities, such as group work and self-learning. This can be done through project-based learning and action-oriented pedagogy (Arranz et al., 2017).

To effectively implement entrepreneurship education in higher education, the institution must have a suitable environment conducive to generating knowledge. HEIs are responsible for creating an environment conducive to knowledge generation, which will serve as a basis for experiential entrepreneurship education (Ghafar, 2020).

By employing tools and techniques of divergent creativity within both classroom settings and extracurricular activities, entrepreneurship education empowers students to cultivate soft skills essential for securing employment opportunities and ensuring the success of new ventures (Schmidt, Soper, and Facca, 2012). The process of divergent creativity influences perception and confidence by imparting various creative skills, including those characterized in Table 3.5.

Creative Skills	**Meaning**
Fluency	The capacity to generate numerous ideas.
Flexibility	Diverse ranges of ideas, perceptions, and categorizations.
Elaboration	Demonstrating proficiency in generating ideas with associated characteristics and benefits.
Originality	Mindset and ability to identify gaps.
Complexity	The capability and willingness to conceptualize ideas with varying and intricate levels.
Curiosity	Eagerness to uncover hidden insights.

Source: Yar Hamidi et al., 2008.

Table 3.5: Creative skills

The evaluation of entrepreneurship courses' effectiveness is carried out according to their ability to stimulate the convergent creativity of individuals. This results in the desire to establish a new business (Ghafar, 2020). Entrepreneurship education is vital in higher education, especially regarding soft skills like critical thinking and communication. These are skills that would help people become successful business owners. Various targeted programs can help students acquire these abilities. These skills prepare students for entrepreneurial success and promote innovation and adaptability, thereby contributing to economic and social development. A targeted educational program in entrepreneurial education can offer students the opportunity to develop and enhance these crucial soft skills. Through courses, work-

shops, practical projects, and mentorship, students can become familiar with entrepreneurial concepts, explore business strategies, and develop the ability to innovate and adapt to new challenges. In conclusion, investing in entrepreneurial education within higher education institutions prepares students for success in entrepreneurship and helps create a more dynamic, innovative, and future-oriented society.

3.4 Contamination Lab Experience in the Higher Education Institutions

Contamination Lab Experience (CLabs) are physical (and, occasionally, also virtual) hubs designed to foster academic entrepreneurship, talent development, innovation, value co-creation, collaboration among ecosystem actors, and community development, where university students (and not only) with diverse expertise and academic backgrounds can learn, share ideas and experiences, build companies, and co-create value in multidisciplinary and stimulating environments. They attract both an academic audience and the different actors of the country (and adjacent) ecosystems, experiment with new learning models, and promote a culture of entrepreneurship, sustainability, innovation and learning-by-doing, as well as interdisciplinarity, to reduce the gap between academia and entrepreneurial ecosystems.

CLabs runs a rich set of activities to educate the new generation of entrepreneurs and innovators, develop their hard and soft skills, attract new talents and investors, promote the interactions among ecosystem actors, and create new innovative companies. Their activities include 1) Courses, workshops, and seminars on entrepreneurship and innovation to develop entrepreneurial skills; 2) Support in the idea development process; 3) Student competitions; 4) Networking opportunities and events; 5) Co-creation projects; 6) Other learning activities (i.e., visits to companies or innovation hubs, and similar). Among those, the Startup Program is the core of the whole organization. It is a path designed to help students learn how to innovate and bring their business ideas to life.

Despite the high number of diverse and specialized activities, however, the CLabs is a model of an innovation hub that can be quickly built by every university for different reasons: 1) the amount of capital needed to start its operations is small; 2) the university can rely on the totality of students, researchers and professors for its daily management and the innovation-related activities; 3) it is possible to enrich its activities with ease, by accessing to mentors, teachers, entrepreneurs, investors and facilitators in both the regional and the adjacent ecosystems, and also virtually, thanks to the various startup networks around the world; 4) although with different purposes and outcomes, they bring value to both nascent and mature entrepreneurial ecosystems.

3.4.1 CLabs in Italy and Europe

There are currently twenty-four universities across the Northern, Southern, and Central regions in Italy, with a higher concentration of projects in the Northern regions. The University of Cagliari's CLab stands out as the most successful, with over 800 students and 25 startups, raising more than €3.5 million in private investments. The university also leads the Italian Contamination Lab Network, connecting all Contamination Labs in Italy. Other notable projects include Ca' Foscari University in Venice and the University of Turin and Polytechnic of Turin. Italian Contamination Labs have formed a network, not only nationally but also in Europe, collaborating with various stakeholders to promote innovation culture and support startups. European universities have a rich tradition of promoting innovation and research. Noteworthy examples include:

- Aalto University, Finland: Known for fostering an innovative and entrepreneurial spirit through impactful incubators and accelerators, attracting over 6,000 students in the last six years.

- Copenhagen Business School, Denmark: Offering incubation and acceleration programs for students interested in entrepreneurship.
- Technical University of Munich, Germany: Hosting TUM Venture Labs, a hub supporting students in turning tech and life science ideas into entrepreneurial ventures, and UnternehmerTUM, a leading centre for innovation and business creation in Europe.
- Eindhoven University of Technology (TU/e), Netherlands: Operating TU/e Innovation Space, a dynamic hub for education innovation and student entrepreneurship, promoting collaboration on real-world challenges.

Italian Contamination Labs have established a solid national and European network, with the University of Cagliari leading the way. They collaborate with various partners to cultivate an innovation culture and support startups. European universities, like Aalto, Copenhagen Business School, Technical University of Munich, and Eindhoven University of Technology, showcase best practices in promoting student entrepreneurship and innovation.

In this scenario, the critical dimensions are:

a) The experimentation of the CLab as an open place of interaction and learning that sees students and companies as protagonists and that has as its objective the development of skills for Industry 4.0. b) The training of teachers and administrative staff is not only through a specific training program in each university but also through the construction of a model for the training of teaching staff on entrepreneurial skills and digital skills to support CLab in each university.

Firstly, developing and learning entrepreneurial and digital skills is one of the key competences for the EU to face the occupational problems due to reconversion and automation of the productions. Moreover, the design, modelling, and experimentation of the Clabs (already successfully active at UNIMOL) can become a replicable model in all the European territorial contexts characterized by a low level of growth and a certain territorial marginality. The activation of Contamination Labs has an impact on students' skills and, therefore, on their employability, and on the capacity of small and medium-sized firms to produce process and service innovation and improve their competitiveness and productivity.

3.4.2 The practical impacts of CLabs

The labs are structured to involve a cyclical turnover of students, offering modular participation of 6 months, extendable for an additional 6 months based on the student's activities. The selection process relies on personal motivation and project capacity, with students applying through a motivational letter or video. From the program's commencement to its potential extension and eventual alumni status, the lifecycle of a CLab student is crafted to nurture a robust community. This community transcends a single lab, reaching out to form a national network supported by mentoring programs, sustaining the momentum of projects initiated within the CLabs.

The impact of CLabs goes beyond personal academic development; they serve as a bridge between academia and the surrounding community. Local, national, and international partnerships are crucial, enabling students to apply their learning in meaningful ways and addressing entrepreneurial needs in the region. CLabs aspires to be a node in a global network, engaging with European and worldwide partners to exchange best practices and establish lasting connections. This global outlook is complemented by a strong local dimension, with the labs becoming a nexus between schools, universities, and regional companies, enhancing educational experiences with local expertise.

For any organization and given the project's peculiarities, the success and sustainability of Contamination Labs rely on 1) a comprehensive evaluation strategy measuring both immediate and long-term impacts, such as the number of innovative projects initiated and businesses created; 2) a robust multilayered governance structure with strategic roles and defined responsibilities, specifically:

1. Measurement system: key performance indicators, including local impact, interdisciplinary collaboration, content quality, innovation, and international reach, take precedence to track progress effectively. These evaluation methods are standardized to gauge the collective impact of CLabs nationally. Sustainability is achieved by balancing economic, social, and environmental considerations, with stakeholder involvement being crucial. The project's financial health is supported by funding from universities and external partners, covering various developmental costs. Additionally, universities promote innovation through incentivized contests, often with third-party funding.
2. Governance: key managerial positions – the CLab Chief and the CLab Project Manager – lead the institutional and operational aspects, respectively, supported by a team sized according to student involvement. The governance framework and operational details are specified in the project proposal, serving as a blueprint for CLab's innovative and entrepreneurial endeavours.

The environmental sustainability of the project will be assured through the following measures:

- Sustainable infrastructure development / upgrade: implement sustainable building/reshaping practices when establishing Contamination Labs and related infrastructure. This involves optimizing energy-efficient lighting and incorporating renewable energy sources where possible.
- Waste reduction and recycling programs: establish waste reduction and recycling programs within the project, encouraging responsible disposal of materials and promoting recycling practices. This initiative can minimize the environmental impact associated with project activities.
- Digital learning initiatives: promote digital learning methods to reduce the need for printed materials, which can contribute to deforestation. Embrace online resources and platforms for educational materials, reducing the project's carbon footprint.
- Green transportation policies: encourage the adoption of environmentally friendly transportation options for project-related travel. This includes promoting virtual meetings, utilizing electric or hybrid vehicles, and implementing policies to minimize unnecessary travel.
- Community engagement and biodiversity conservation: involve local communities in the project's initiatives and consider biodiversity conservation measures. This could include maintaining green spaces around project facilities, promoting local flora, and implementing practices that protect local ecosystems.

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Chapter 4

Networks and Connectivity: Metrics and Models

Luís Cavique

Summary
This work explores network science to understand and visualize the intricate interconnectivity within organizations. The age of big data emphasizes the importance of deriving new insights by transforming data into networks to study their connections. The document introduces a three-step maturity framework for navigating network science, starting with the basics of network construction, moving on to standard metrics, and culminating in an examination of network topology and dynamics. The author aims to clarify the subject and encourage further exploration, suggesting that while network science may not have all the answers, it offers a critical analytical framework.
Keywords: Networks, Networks metrics, Networks models, Social networks analysis.

4.1 Introduction

The skeleton of many structures can be represented by a network, which constitutes a set of objects connected in a specific way. Routers on the Internet, neurons in the brain, and aviation routes are examples of networks. Currently, the branch of mathematics known as Graph Theory, initially proposed by mathematician Leonhard Euler, constitutes the basis of mathematical modeling for the study of network science.

Graph theory has been widely used in social network analysis due to its representational capacity and simplicity. A graph comprises vertices or nodes and links or edges that connect the nodes. In social networks, graph representation is also called sociogram, in which the nodes are the actors, and the connecting lines establish the set of relationships in a two-dimensional way.

A social network can be expressed mathematically by a graph comprising a set of nodes or vertices connected by edges that express a relationship between them. The social network concept can be described as a social structure composed of nodes related to other nodes using edges. The nodes represent people or organizations, and the edges represent their relationships.

A social network is a set of people or groups linked together by relationships that can be professional, family, or others. Studies in this field began in the thirties by Moreno and Jennings, 1934 with the graphic representation of social networks, the sociograms. The introduction of mathematical models was initiated by Rapoport, 1957 and continued by Erdös and Rényi, 1959 with the creation of random graphs.

Another relevant study in sociology was developed by Milgram, 1967, which led to the concept of a 'small world' and the notion of 'six degrees of separation'. The experience consisted of sending letters between two different points, from Nebraska, in the Midwest, to the east coast of the USA, in Massachusetts.

People were asked not to use the postal services but to use their contacts to send and resend the letters. The letters that reached their destination needed to pass, on average, through about six intermediary people, which led Milgram to conclude that, in this case, the Americans are approximately six steps away from each other.

The concept of social networks gained a new dynamic with the emergence of Web 2.0. In 2008, Facebook surpassed MySpace worldwide in total number of users, becoming the most extensive online social network.

Ellison, Steinfield, and Lampe, 2007 conducted a broad study indicating how Facebook allows actors to invest in new social ties. These characteristics show us that there is a change in the support of interaction, allowing conversations previously mapped only by observation.

Given the resources provided by Web 2.0, such as social networking sites, actors begin to record their conversations, their interactions, and their networks. With this, the mapping of these networks gains new potential in the sense that, for the first time, it is possible to map the tastes, acts, ideas, and connections of thousands of people, search for and establish patterns between these multiple networks, mainly through the interactions that are mediated by these tools.

A third school emerged after the mathematics and sociology approach to networks merged with new contributions from computer science, biology, physics, and economy: network science. The pioneering work by D. J. Watts and Strogatz, 1998, published in the Nature journal, studies graphs with small-world properties and free-scale degree distribution. It follows the model of A.-L. Barabási and Albert, 1999 and the SIR epidemiological models that define new frontiers for networks in dynamic systems.

Problem The contributions in network science are numerous, diverse (articles, textbooks, and science popularization books), and generally with excellent quality. Therefore, tackling this subject presents a significant challenge.

A pioneering textbook (A. Barabási and PÃ3sfai, 2016) introduces network science to an interdisciplinary audience and includes real-world examples. Newman, 2018 textbook integrates breakthroughs in network studies from multiple disciplines, covering network analysis, graph theory, mathematical models, and dynamical processes on networks. Scott, 2000 provides an introduction and comprehensive guide to social network analysis, catering to beginners and more seasoned social network researchers in the social network. Easley and Kleinberg, 2010 explore the new science of networks through an interdisciplinary lens, aiming to understand various modern societal phenomena. Additionally, the book examines how epidemics and financial crises can escalate quickly and with great intensity, reflecting the interconnected nature of contemporary society.

Regarding the science popularization books, some examples are highlighted. A. Barabási and Frangos, 2014, the expert in the new science of networks, takes us on an intellectual adventure to prove that social networks, corporations, and living organisms are more similar than previously thought. D. Watts, 2004 explores phenomena such as disease epidemics, financial market fluctuations, information search behaviors, organizational resilience, and the dynamics of personal relationships. Christakis and Fowler,

2010 study the influence of third-degree connections within our social networks, revealing their remarkable ability to mold various aspects of life. Our actions can potentially alter the behaviors, thoughts, and even the health of individuals we have never encountered directly.

Objective This work aims to create an overview guided by a framework that allows insights into network science by mixing areas such as mathematics, sociology, computer science, biology, physics, and economy.

Contribution The contribution of this work is a guided tour of network science with the three-step maturity framework with increasing complexity. The pipeline of Fig. 4.1 first details what networks are and how to create them, then lists the most usual metric for networks, and finally introduces two models: the topology of networks and the network dynamics.

Organization The remainder of this chapter is organized as follows. Section 5.2 defines graphs and networks. Section 5.3 presents the most usual network metrics. Sections 5.4 and 5.5 detail the models: topologic models and dynamic models. Finally, in section 5.6, we draw some conclusions.

4.2 Graphs and Networks

This section states some crucial definitions of networks and exemplifies the transformation of generic data into networks.

4.2.1 Definitions

A graph G is defined by the ordered pair (N, E), where N is a set of nodes / vertices and E is a set of edges. Each edge e belonging to the set E is denoted by $e = (u, v)$, a pair of nodes. The nodes u and v are the ends of the edge and are called adjacent nodes or neighbors. Berge, 1970 is one of the foundational references in graph theory.

In this work, it is relevant to differentiate various dichotomies in graphs: (undirected and directed), (unweighted and weighted), and obviously (graphs and networks). An undirected graph features edges that connect vertices bidirectionally without orientation, allowing travel between any connected vertices in both directions. On the other hand, a directed graph, or digraph, consists of edges with a specific orientation, represented as ordered pairs (u, v), permitting travel only from u to v unless an opposite directed edge exists. Unweighted graphs have edges without associated values or weights, representing connections between vertices. Conversely, weighted graphs assign weights to edges, often denoting distances, costs, or other metrics, influencing traversal relations and analysis by considering the significance of connections between vertices.

A graph is a formal mathematical concept studied in graph theory. On the other hand, a network uses the structure of a graph associated with real-world systems with entities connected in some way, such as computer networks, social networks, transportation networks, or electrical networks.

4.2.2 From data to networks

Today, in the intricate big data ecosystem, we are inundated with overwhelming data from various sources, including barcode scanners, Web 2.0 platforms, and IoT devices. Now, the question is not how to collect

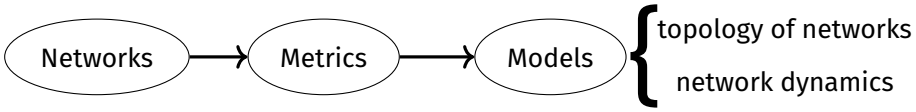

Figure 4.1: Pipeline of this work.[1]

data but how we can effectively utilize this vast data. This section shows a method for converting this data into structured networks (Scott, 2000).

The following running example uses supermarket data. The method begins by selecting two specific columns: customer and product. Next, construct a product-customer incidence 5×3 matrix, as illustrated in Table 4.1.

trans_id	customer	product
1	a	bread
2	a	butter
3	a	milk
4	b	oranges
5	b	butter
6	b	apples
7	c	bread
8	c	butter
9	c	milk
10	c	oranges

Products	customer a	b	c
apples		1	
bread	1		1
butter	1	1	1
milk	1		1
oranges		1	1

Table 4.1: Raw data and the incidence matrix product-customer

With the information on the incidence matrix product-customer, two matrices can be generated: the customer-customer matrix and the product-product matrix, as shown in Table 4.2. In the matrix customer-customer, the pair (a, c) equals three, indicating that both customers purchased bread, butter, and milk. The same reasoning is applied to all elements of the matrices.]

Given the matrices of customers and products, the undirected networks can be quickly drawn, as shown in Fig. 4.2.

A set of observations can be drawn from the networks. We can detect and infer the following from a simple visual analysis of the networks. Analyzing the customers' network shows that customers a and c exhibit more significant similarities. On the contrary, a and b show fewer similarities.

[1] From `https://gatton.uky.edu/about-us/stay-connected/news/2020/links-center-social-network-analysis-workshop-success`.

	a	b	c
a		1	3
b			2
c			

Matrix customer-customer

	apples	bread	butter	milk	oranges
apples			1		1
bread			2	2	1
butter				2	2
milk					1
oranges					

Matrix product-product

Table 4.2: Matrices of customer-customer and product-product

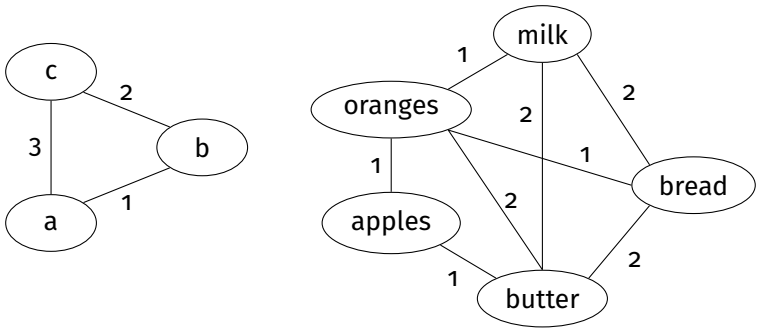

Figure 4.2: Networks of customers and products.[2]

In order to analyze the network of products, the clique concept must be defined. In graph theory, a clique is a subset of vertices within an undirected graph such that every two distinct vertices in the clique are adjacent; this means that every vertex in the clique is connected to every other vertex in the clique by an edge. The maximum clique in a graph refers to the largest clique within that graph. Two maximal cliques with three nodes with a weight equal to six are found, meaning that the most frequently bought together products are (milk, bread, butter) and (oranges, bread, and butter). The maximum weighted clique uses four nodes and weighs 10, meaning that the four most frequently bought together products are in the basket (milk, bread, butter, oranges).

4.3 Network Metrics

In this section, some of the most relevant network metrics are described. Centrality metrics are crucial for pinpointing influential nodes, while the degree of distribution provides insight into the network's overall connectivity framework. The clustering coefficients metric reveals local neighborhoods. Meanwhile, similarity, assortativity, and homophily explore the propensity for nodes to associate and form connections based on shared attributes.

[2]Adapted from `https://ultrabpm.wordpress.com/2013/03/25/social-network-analysis-part-two/`.

4.3.1 Centrality metrics

The measures of centrality arise in the context of network science. Intuitively, the most central vertices in a network are those from which we can reach any other more easily or quickly. The centrality measures identify an individual's position relative to others in their network. Thus, the more central the individual, the greater their influence and power in their network. This sub-section is based on the works of Landherr, Friedl, and Heidemann, 2010, Laranjeira and Cavique, 2014, and Newman (2010).

Degree centrality The most straightforward and intuitive concept regarding the centrality of a vertex is the number of direct contacts it has. A person in a position that allows direct contact with many others is seen by others as a significant channel of information, which is why we say they are more central. Thus, degree centrality is the count of the number of adjacencies of a vertex.

Let G be any graph with N vertices, and let x be a vertex of G. The degree centrality of x, denoted by $\sigma_D(x)$, is the number of edges incident to x. Given the adjacency matrix of the graph $A(G)$ and their elements a_{ix}, the degree centrality is given by:

$$\sigma_D(x) = \sum_{i=1}^{N} a_{i,x} \tag{4.1}$$

Closeness centrality Another measure, known as closeness centrality, is based on the sum of the distances from a vertex to all other vertices in the graph (Sabidussi, 1966). In various contexts, more important than having many connections is not being too far from the other elements.

Let G be a connected graph with N vertices, and let x be a vertex of G. The closeness centrality of x is given by the inverse of the sum of the distances from x to all other vertices in the graph, where $d_G(x,i)$ represents the distance from x to i:

$$\sigma_G(x) = \frac{1}{\sum_{i=1}^{N} d_G(x,i)} \tag{4.2}$$

Betweenness centrality Betweenness Centrality allows us to measure the capacity of an actor to influence their peers in a network. The idea behind this metric can be easily understood through the following analogy: a city integrated into various trade routes will undoubtedly have a strategic advantage, which motivates the idea that a critical node is part of many paths.

Let G be a graph (connected or not) with N vertices, and let x be a vertex of G. Given that g_{ij} represents the number of shortest paths from vertex i to vertex j, and $g_{ij}(x)$ indicates the number of those shortest paths that pass-through x, the betweenness centrality of x is given by:

$$\sigma_B(x) = \sum_{i=1}^{N} \sum_{i<j}^{N} \frac{g_{i,j}(x)}{g_{i,j}}, \; i,j \neq x \tag{4.3}$$

Eigenvector centrality This measure is based on the concepts of eigenvalue and eigenvector of the adjacency matrix of the graph G. It suggests that another way to interpret centrality is to think that the centrality of a vertex is a function of its neighboring vertices, that is, an important node has important neighbors (Bonacich and Lloyd, 2001).

Consider that the eigenvector centrality, $\sigma_E(x)$, is proportional (by a factor of λ^{-1}) to the sum of the centralities of its neighbors, $\lambda_{max}(A)$ is the largest eigenvalue (in magnitude) of the adjacency matrix A, and $v = (v_1, \ldots, v_n)^T$ is the eigenvector associated with it. The metric is given as follows:

$$\sigma_E(x) = \frac{1}{\lambda_{max}(A)} \sum_{j=1}^{N} a_{jx} \cdot v_j \tag{4.4}$$

Katz centrality The Katz centrality is a measure of centrality in a network that generalizes the concept of eigenvector centrality. Developed by Katz, 1953, it is designed to measure the influence of a node within a network by considering not only the immediate neighbors of the node but also all other nodes in the network, connecting through various paths of different lengths.

Unlike measures that only consider direct connections (such as degree centrality) or the shortest paths (like betweenness centrality), Katz centrality considers the total number of walks between two nodes exponentially attenuated by the length of each walk. This way, shorter paths contribute more to the centrality score than longer ones, but longer paths are not ignored.

PageRank centrality PageRank centrality, often called PageRank, is a measure of the importance or centrality of a node within a network. It was initially developed by Lawrence Page and Sergey Brin (Page et al., 1998), the founders of Google, as part of the algorithm used by the Google search engine to rank web pages in their search results. In this centrality metric, a direct network is taken into account.

PageRank's underlying concept is that a page's importance is determined by the number and quality of links, assuming that more relevant pages will likely receive more links from other pages. The PageRank of a node (or web page) is defined recursively and depends on the number and PageRank scores of all other pages that link to it (inbound links). A page linked to many pages with high PageRank receives a high rank.

Limitations of centrality metrics Centrality measures in networks each capture different aspects of a node's importance, leading to varied results depending on the specific measure applied, exemplified in Fig. 4.3. For instance, degree centrality focuses on immediate connections. In contrast, betweenness centrality emphasizes a node's role as a bridge in the shortest paths between others.

Therefore, no single centrality measure provides a comprehensive solution across all network types and contexts, making it crucial to select the most appropriate measure based on the specific characteristics and requirements of the analyzed network. In the following sub-sections, new metrics are explored, and in the following sections, concepts like the topology and dynamics of the network are developed.

4.3.2 Degree distribution

In network science, the degree of a node is a fundamental metric that quantifies the number of connections or edges a node has with other nodes in the network. It measures how connected a node is within the network's structure (Newman, 2010).

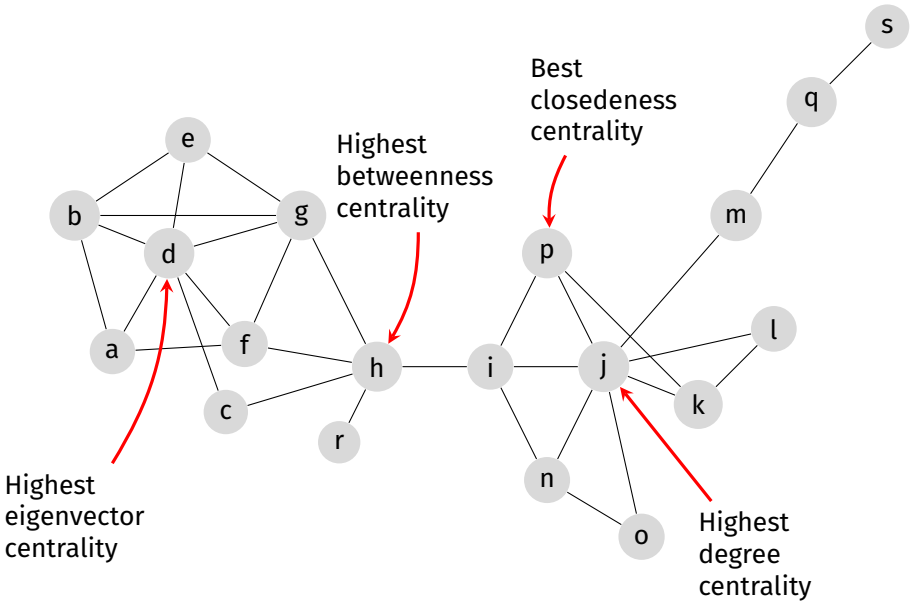

Figure 4.3: Results of different centrality metrics

In undirected networks, the degree of a node is simply the count of direct connections it has. In this case, the edges do not have a direction (or can be considered bi-directional), and the degree indicates the number of edges connected to the node. In directed networks, the degree concept is split into two distinct types. In-degree is the number of incoming edges to a node. It represents how many other nodes directly connect to the given node. On the other hand, the out-degree is the number of outgoing edges from a node. It shows how many nodes the given node is directing connections.

The degree distribution of a network is a fundamental concept in network science that characterizes the connectivity of nodes within a network. It provides insight into the structure and dynamics of complex networks, which are systems of interconnected elements or nodes.

Fig. 4.4 shows an undirected network and its degree distribution. Some nodes have a degree equal to zero, most have a degree equal to two, and a few have a degree equal to seven.

Degree distribution shapes network resilience, with scale-free networks vulnerable to targeted attacks but resistant to random failures. It also affects the speed of information or disease spread, with network hubs accelerating this process. Additionally, the degree to which distribution influences network dynamics and community structure impacts network growth, flow efficiency, and community formation and communication. This understanding is vital for analyzing and optimizing networks across diverse fields.

4.3.3 Clustering coefficient

The clustering coefficient is a measure that quantifies the degree to which nodes in a network tend to cluster together. It provides an insight into the extent to which nodes in a network tend to form tightly knit groups characterized by a relatively high density of ties (Newman, 2010). The clustering coefficient

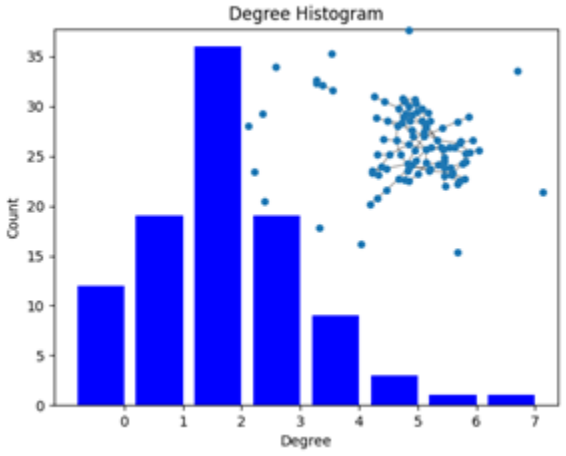

Figure 4.4: Degree distribution of a network.[3]

is based on triplets of nodes, where a triplet is three nodes connected by three edges. The clustering coefficient can be defined as the ratio between the number of closed triplets and the number of all possible triplets (open and closed). In other words, for an individual node, the local clustering coefficient C_i is calculated as follows:

$$C_i = \frac{(\text{\# pairs of neighbors of } i \text{ that are connected})}{(\text{\#pairs of neighbors of } i)} \tag{4.5}$$

The clustering coefficient can be defined for individual nodes and the entire network. For an individual node, the local clustering coefficient is calculated as follows:

$$\overline{C} = \frac{1}{N}\sum_{i=1}^{N} C_i \tag{4.6}$$

Fig. 4.5 shows the comparison of two metrics for the same node. A low-degree (equal to 3) and high-degree (equal to 6) are shown regarding the degree metric. Concerning the clustering coefficient, the low values are equal to zero, and the high coefficient shows an example with a value equal to one.

4.3.4 Similarity, assortativity, and homophily

Similarity refers to a measure of how alike two nodes are within a network based on specific attributes or patterns of connections. Similarity can be measured in different ways, taking into account various attributes like demographic characteristics in social networks or functional properties in biological networks, as well as the overall structure of the network (Newman, 2010). For example, in a social network,

[3]Source `https://networkx.org/documentation/networkx-2.3/auto_examples/drawing/plot_degree_histogram.html`.

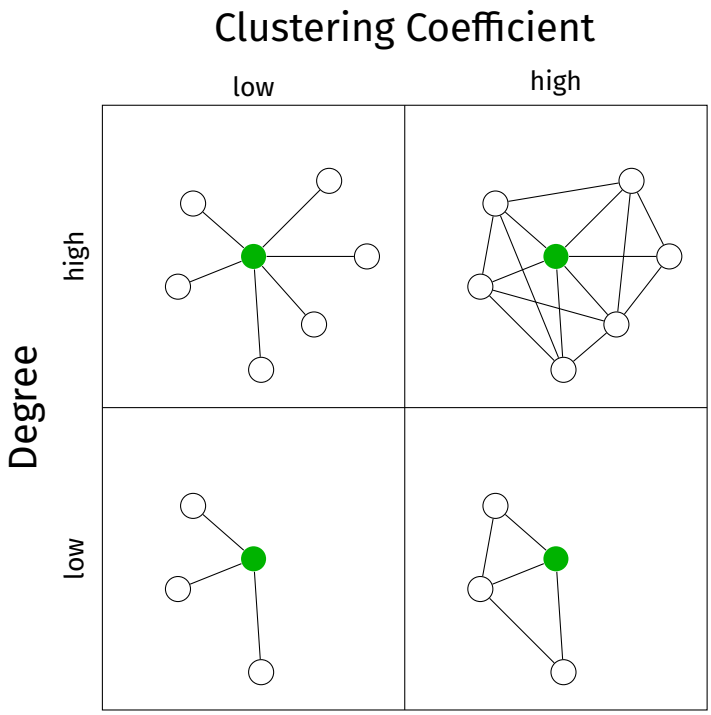

Figure 4.5: Clustering coefficient versus degree.[4]

two individuals might be considered similar if they share common interests, work in the same field, or have a similar social circle.

The notion of similarity between nodes encompasses a variety of metrics, each tailored to capture distinct aspects of node characteristics or their interconnectedness. Cosine similarity evaluates the alignment of vectors representing node attributes or connections, offering insight into their mutual orientation in a multidimensional space. Jaccard similarity, on the other hand, quantifies the overlap between the neighbor sets of two nodes, emphasizing their shared connections relative to their combined network footprints.

Pearson correlation delves into the linear relationship between node attributes, revealing the degree to which they co-vary. While Euclidean distance typically conveys dissimilarity through spatial separation, in some contexts, it inversely relates to similarity, with closer nodes being more alike. The structural similarity extends beyond individual attributes or pairs of nodes, incorporating broader network patterns to assess how nodes fit within the overall network architecture. Each metric offers a distinct way to understand a network's complex web of connections, helping to focus the analysis on particular qualities or patterns that matter.

Note that the metrics of similarity are related to distance metrics. However, similarity and distance are inversely related: as the distance between two points decreases, their similarity increases, and vice versa.

Assortativity is a property of networks that measures the tendency of nodes to connect with other

[4]Adapted from `https://www.researchgate.net/figure/Representation-of-the-clustering-coefficient-and-degree-Networks-have-nodes-with_fig5_261995698`.

nodes that are similar to them. Assortativity can be in terms of node degree (number of connections), called degree assortativity, or in terms of some nodal attribute, known as attribute assortativity. In assortative networks, high-degree nodes are more likely to be connected to other high-degree nodes.

Similarly, nodes with similar attributes tend to be connected more often than by chance. This concept is fundamental in understanding how networks form and evolve and how information or diseases might spread.

On the other hand, negative assortativity, or disassortative mixing, characterizes a network pattern where nodes preferentially connect to others that are unlike themselves, either in node degree or other attributes. In such networks, nodes with many connections often link to nodes with few connections and vice versa. This pattern contrasts with positive assortativity, where similar nodes tend to connect.

Homophily is closely related to assortativity and refers to the principle that contact between similar people occurs more commonly than among dissimilar people. Homophily can be based on various attributes, including but not limited to age, gender, ethnicity, education, and social status. It is a driving force behind the formation of social networks. It influences how networks are structured, affecting the flow of information, behaviors, and even the spread of diseases within the network.

4.4 Topology of Networks

This section discusses the Erdös-Rényi model of random graphs, where graphs are generated by connecting nodes randomly. Then, it introduces the Barabási-Albert model, a method for generating scale-free networks through preferential attachment. It highlights its applicability in representing real-world social, biological, and technological networks. After that, describe the Watts-Strogatz model, which bridges the gap between highly ordered and completely random networks, explaining the small-world phenomenon observed in real-world networks. It explores the concepts of cliques and their relaxations in network topology, focusing on identifying cohesive sub-groups within more extensive networks.

Additionally, it addresses the role of brokers in bridging structural holes between communities facilitating the exchange of information and innovation. Finally, it highlights the importance of visualization in network topology, presenting it as a crucial tool for understanding the complex relationships within networks.

4.4.1 Erdös-Rényi model

Random graphs are types of graphs that are generated using a random process. Given N nodes and E edges, the algorithm to generate a random graph $G(N, E)$ uses a random seed number and links a random pair of nodes.

The link density p can quantify the overall connectivity, the number of links divided by the maximum number of edges $E_{max} = N(N-1)/2$. The density $p = E/E_{max}$, in other words, $p = 2E/[N(N-1)]$. The degree k of a node is the number of its edges to neighbors. The mean degree is related to the density by $\overline{k} = p(N-1) = 2E/N$.

The Erd"os-Rényi model is a specific type of random graph model. The Erdös-Rényi model, named after Paul Erdös and Alfréd Rényi, is one of the earliest and simplest models for generating random graphs. It comes in two versions, denoted $G(N, E)$ and $G(N, p)$. In the $G(N, E)$ model, a graph is constructed by choosing exactly E unique edges from the possible combinations $(N, 2)$. The resulting graph has N vertices and E edges. The $G(N, p)$ model is the more commonly used version of the Erdös-Rényi model. It starts with N isolated vertices, and then each possible pair of vertices is connected with an edge with

probability (or density) p, independently from every other pair. The parameter p controls the density of the graph, where a higher p results in a graph with more edges.

The properties of graphs generated by the Erdös-Rényi model have been extensively studied. For example, one of the well-known results is about the phase transition related to the emergence of a giant connected component:

- When the average degree $\overline{k} < 1$, the fraction of nodes in its largest connected component is close to 0;
- When the average degree $\overline{k} > 1$, the fraction of nodes in its largest connected component grows as the average degree $\overline{k}$ grows; that is, the probability of a 'giant component' goes to 1.

Erdös, one of the most prolific mathematicians, wrote over 1 500 papers with more than 500 co-authors. Erdos represents the number zero in his social network, and the researchers who worked with him are called Erdos's number 1. Erdos' number of 1 co-authors is called Erdos's number of 2, and so on, building one of the oldest small world networks known. The work of Erdös and Rényi, 1959 presents interesting random graph properties. A relevant example of the "Erdos Number" can be found in Grossman, Ion, and Castro, n.d.

4.5 Barabási-Albert model

The A.-L. Barabási and Albert, 1999 model generates random scale-free networks using a preferential attachment mechanism. Albert-László Barabási and Réka Albert introduced it in their seminal work on scale-free networks. The model marked a significant shift in how scientists understand the structure and evolution of complex networks, such as the Internet, social networks, and biological networks.

The Barabási-Albert model starts with a small number of nodes (initial network) and grows the network by adding one node at a time. Each new node creates links to existing nodes with a probability proportional to the number of links the existing nodes already have. This 'rich-get-richer' mechanism ensures that already well-connected nodes are more likely to receive new links. The critical steps in the model are:

- Growth: The network starts with an initial small number of interconnected nodes. At every step, a new node is added to the network.
- Preferential Attachment: Each new node forms a fixed number of links to existing nodes. The probability that a new node will connect to an existing node is proportional to the degree (number of connections) of that existing node.

The term 'scale-free' comes from the characteristic degree distribution of these networks, which follows a power law, at least asymptotically. In a scale-free network, the probability $P(k)$ that a randomly selected node has k connections (or degree k) falls off as k raises to a negative power, typically $P(k) \sim k^{-\gamma}$ where γ is a parameter usually in the range $2 < \gamma < 4$. A scale-free network has a few highly connected nodes (hubs) and many nodes with few connections.

Unlike in Erdös-Rényi random graphs, where the degree distribution is binomial or Poisson in the limit of large network sizes, leading to a characteristic average degree, scale-free networks do not have a characteristic scale for the degree. This property has profound implications for the network's robustness,

its vulnerability to targeted attacks, and the dynamics of processes, such as spreading phenomena on the network. Fig. 4.6 shows the degree distributions and the topology of both models.

Regarding real-world applicability in social, biological, or technological networks, the Barabási-Albert model is more realistic than the previous one. Newman, A. Barabási, and D. Watts, 2006 exemplify the exponents of real-world networks of cinema actors, the World Wide Web, and electric power, $\gamma_{actor} = 2.3$, $\gamma_{www} = 2.1$, and $\gamma_{power} = 4$.

4.5.1 Watts-Strogatz model

The D. J. Watts and Strogatz, 1998 model, proposed by Duncan J. Watts and Steven Strogatz in their paper, is a mathematical model designed to explain the small-world phenomenon in networks. This model represents a bridge between the highly ordered lattice networks and the completely random networks described by the Erdös-Rényi model, capturing the small-world properties observed in many real-world networks.

The Watts-Strogatz model starts with a regular lattice network, where each node is connected to its k nearest neighbors in a ring topology. The model then introduces a small amount of randomness by rewiring each edge with probability p, where p ranges from 0 (no rewiring, and thus a regular lattice) to 1 (complete rewiring, resulting in a random graph).

Fig. 4.7 shows the critical steps in the process are as follows:

- Start with a regular lattice with a ring of N nodes, each connected to its k nearest neighbors.
- Small-world is found by rewiring it with probability p to a node chosen uniformly at random over the entire ring, avoiding self-loops and duplicate edges. The average shortest path length between nodes in a small-world network is shorter than expected for a regular lattice.
- A random network is found for probability $p = 1$. Given that an edge between two nodes is independent of any other edge in the network, the clustering coefficient is lower than in the small-world network.

By bridging the gap between regular and random networks, the Watts-Strogatz model highlights the importance of network topology in determining functional properties such as information transmission and robustness. The model's ability to capture the essence of small-world networks makes it fundamental to studying complex systems and network science.

4.5.2 Cliques, relaxations and structural holes

Cavique, Marques, and Gon5calves, 2018 study the themes described in this sub-section, focusing on data reduction to visualize communities and brokers in social networks.

A clique in a graph is defined as a complete sub-graph where each member has direct connections with every other member or node. It becomes a maximal clique if it cannot be included within any other clique. The maximum clique, denoted as the clique with the largest number of nodes, poses an NP-hard problem. To establish a lower bound for this maximization problem, researchers have proposed a heuristic method by Johnson, 1974 and a meta-heuristic approach employing Tabu Search, which was developed by Soriano and Gendreau, 1996. Further insights into these methods and related works can be found in the studies by Cavique, Rego, and Themido, 2002 and Cavique and Luz, 2009.

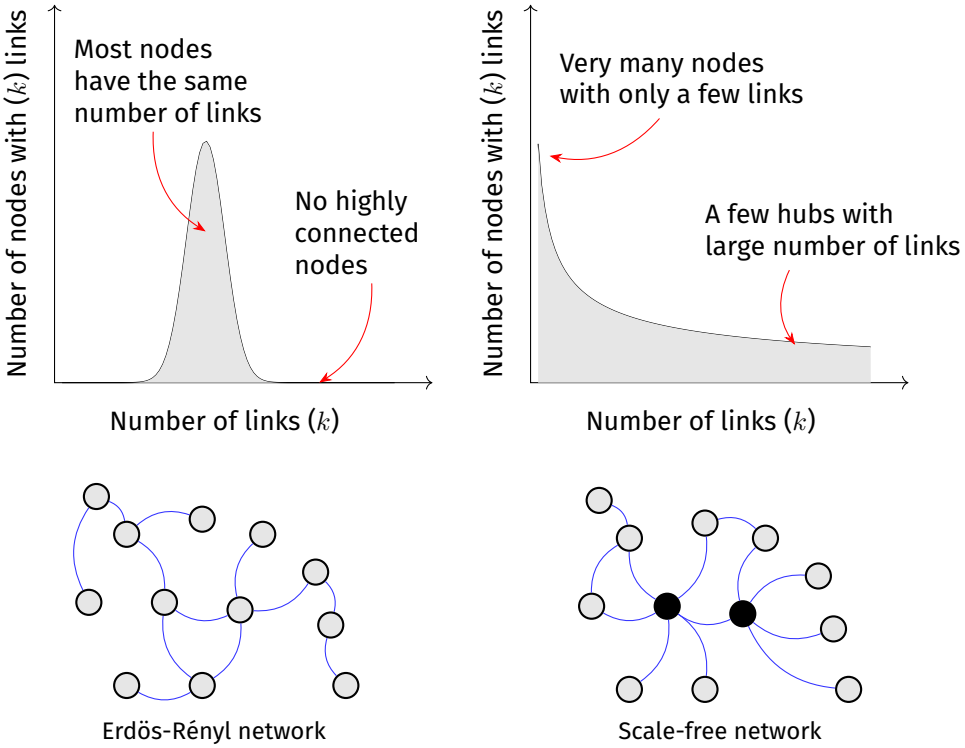

Figure 4.6: Degree distribution and topology of Erdös-Rényi and scale-free networks.[5]

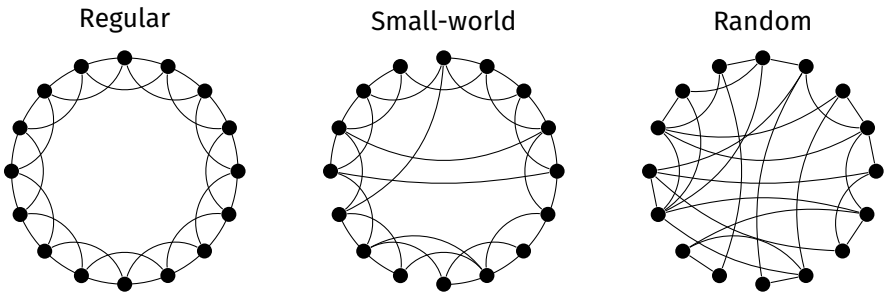

Figure 4.7: The three types of networks and probability of rewiring.[6]

The requirement for every pair of vertices to have an edge in a clique structure imposes significant limitations, which may not be realistic in social networks where such fully connected structures are rare. Alternative approaches for more flexible and cohesive groups have been proposed, including concepts

[5]Adapted from `https://edgeperspectives.typepad.com/edge_perspectives/2007/05/the_power_of_po.Htmlandhttps://pt.wikipedia.org/wiki/Ficheiro:Scale-free_network_sample.png`.

[6]Adapted from `https://www.researchgate.net/figure/Algorithm-of-Watts-Strogatz-model-which-can-be-tuned-by-parameter-p-0-1_fig1_258120851`.

such as k-clique,k-clan/k-club, and k-plex, as suggested by Scott, 2000. This study introduces a combination of k-cliques to provide a more adaptable and realistic representation of network structures.

Relaxations: k-clique, k-clan/k-club and k-plex Distance and diameter serve as valuable metrics for analyzing social networks. The distance between vertices u and v in the graph $G(N, E)$ is symbolized as $d(u, v)$, representing the shortest path length between them. The diameter of G, denoted as $diam(G)$, is defined as $diam(G) = \max d(u, v) \; \forall \; u, v \in \mathbb{N}$.

Luce (1950) introduced the concept of a dense group based on distance, known as a k-clique, where k represents the maximum path length between any pair of vertices. A k-clique is a subset of vertices denoted as C, for which the distance $d(i, j) \leq k$. Specifically, a 1-clique is essentially equivalent to a regular clique, as the distance between its vertices is limited to just one edge. On the other hand, a 2-clique corresponds to a maximal complete sub-graph with a path length of either one or two edges. To illustrate a path distance of two, consider it the "friend of a friend" connection in social relationships. In social networking platforms like LinkedIn, each member can access their immediate connections and those two or three degrees away. As the value of k increases, it leads to a gradual relaxation of the criteria for clique membership. Refer to Fig. 4.8 for visual representation.

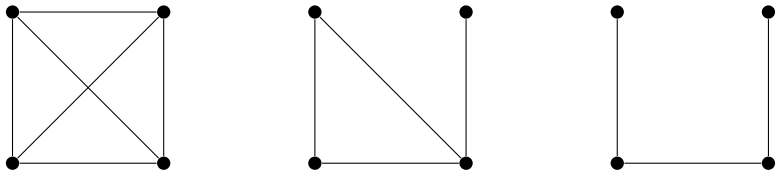

Figure 4.8: Examples of a 4-node graph of 1-clique, 2-clique and 3-clique

In graph theory, the concept of the k^{th} power of a graph, denoted as G_k, creates a new graph where two vertices are connected if their distance in the original graph G is at most k. Utilizing the k^{th} power of graph G in conjunction with a maximum clique algorithm allows us to identify all the maximal k-cliques within the graph. During this transformation process, additional edges are introduced to ensure that the distance between every pair of nodes is at most k.

A limitation of the k-clique concept is that some vertices may be distant from the group. The distance between two nodes may correspond to a path involving nodes not belonging to the k-clique. The cohesion groups based on diameter, called k-club and k-clan, were introduced to overcome this handicap. To find all k-clans, all the k-cliques S_i must be found first, and then the restriction $diam(G[S]) \leq k$ must be applied to remove the undesired k-cliques. In Fig. 4.9, the left graph shows the 2-clique $\{1, 2, 3, 4, 5\}$ is not a 2-clan because $d(4, 5) = 3$. Path 4-6-5 is not possible as node 6 does not belong to the sub-graph with the 2-cliques. Another approach to these diameter models is the k-club, which is defined as a subset of vertices S such that $diam(G[S]) \leq k$. In the same graph two 2-cliques can be found: $\{1, 2, 3, 4, 5\}$ and $\{2, 3, 4, 5, 6\}$, one 2-clan: $\{2, 3, 4, 5, 6\}$ and three 2-clubs: $\{1, 2, 3, 4\}$, $\{1, 2, 3, 5\}$ and $\{2, 3, 4, 5, 6\}$.

An alternative way of relaxing a clique is the k-plex concept, which considers the degree of the vertices. The degree of a graph's vertex is the number of edges incident to the vertex, denoted by $deg(v)$. The maximum degree of graph G is the maximum degree of its vertices and is denoted by $\Delta(G)$. On the other hand, the minimum degree is the minimum degree of its vertices and is denoted by $\delta(G)$. A subset of vertices S is a k-plex if the minimum degree in the induced sub-graph $\delta(G[S]) \geq |S| - k$. In Fig. 4.9, the right graph shows $|S| = 6$, and the degree of vertices 1, 2, 3, 4, and 5 does not exceed the value 3. Thus, the minimum degree in the induced sub-graph $\delta(G[S])$ is 3. For $|S| = 6$, $k = 3$ is obtained.

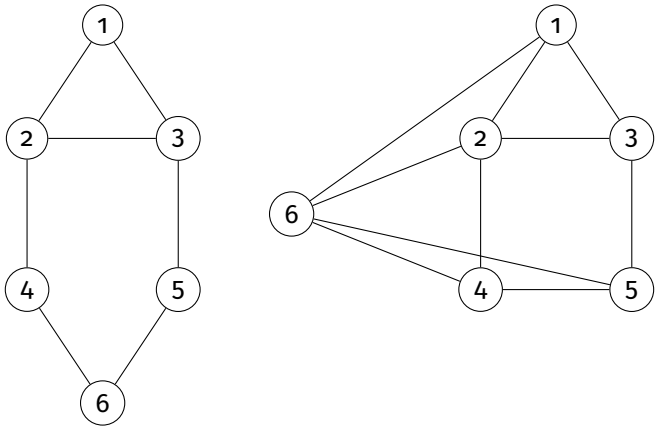

Figure 4.9: 2-clans, 2-clubs (left), and 3-plex (right).

Connectivity of Graphs and Brokerage A critical concept in community structure metrics is the notion of graph connectivity. This sub-section discusses node-connectivity and line-connectivity in graphs (Harary, 1969). In a connected graph, all nodes are reachable. On the contrary, a graph is disconnected if no path exists between any pair of nodes. A graph with only one node is also considered connected. Graph G can lose its connectivity when specific lines or nodes are deleted.

A node n is a cut-point (or cut-vertex) if the number of components in G_1 is fewer than the number of components in G_2 that results from deleting node n. Analogously, a bridge (or line-cut) is an edge critical to the graph's connectedness. Line l is a line-cut if the number of components in G_1 is fewer than the number of components in G_2 that results from deleting line l. Generalizing, a k-line-cut is a set of lines that, if deleted, disconnects the graph. A bridge is a 1-line-cut. Similarly, the k-cut-point is a set of nodes that, if removed, makes the graph disconnected.

Following the Triadic Closure property, Burt, 1992 developed a complementary approach called 'Structural Holes', which refers to the absence of links in a connected organization. He also introduced the term brokerage, meaning nodes that connect two dense groups.

Fig. 4.10 shows two ways of spanning structural holes using a bridge or a broker. Structural hole, bridge, and broker can be defined as follows:

- Structural hole refers to the lack of edges between components or communities;
- Bridge is an edge whose removal increases the number of components in the network;
- Broker or cut-vertex is a vertex whose deletion increases the number of components in the network.

Brokerage across structural gaps opens up fresh opportunities and fosters the exchange of innovative ideas. It is pretty standard to find structural holes between business unit organizations, which often result in rewards for the intermediary. Two distinct broker strategies come into play: the altruistic broker, referred to as the "Tertius iungens", embodies the idea of joining and connecting different communities, while its counterpart, the egoistic broker, known as the "Tertius gaudens," focuses on personal gain within these connections.

For many years, the centrality of actors within networks has been a significant concern in social network analysis. Central nodes, also known as hubs, can be identified using various metrics such as degree

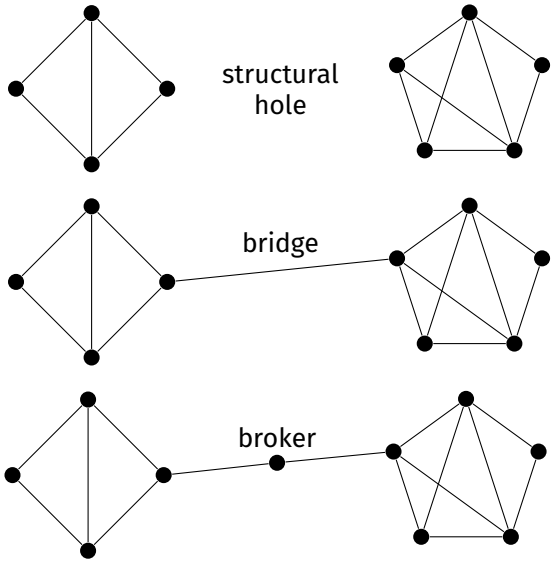

Figure 4.10: Structural hole, bridge, and broker

centrality, betweenness centrality, closeness centrality, or eigenvector centrality. Brokers share similarities with hubs, as both exhibit high centrality scores. However, the key distinction lies in the role of brokers, which involves bridging between different communities, whereas hubs are typically integral parts of a specific community.

4.5.3 Network visualization

Visualization is crucial in the topology of networks, highlighting the intricate relationships within various types of networks. Mapping connections visually provides immediate insight into the network's structure and key nodes, which might be otherwise hidden in complex data. They also bridge complex network theory and practical application, allowing for more informed decision-making. We propose five tools commonly used for network visualization and analysis.

- **Gephi**: An open-source network analysis and visualization software package written in Java, primarily for exploring and understanding graphs.
- **Cytoscape**: An open-source software platform for visualizing complex networks and integrating these with any attribute data.
- **NetworkX**: A Python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks.
- **igraph**: The igraph software is available in C/C++ and for the Python and R programming languages. It is a versatile library used across different platforms and in various programming environments.
- **Graph**-tool: An efficient Python module for manipulation and statistical analysis of graphs. It is built on top of the C++ Boost Graph Library, which makes it highly efficient and suitable for large networks.

Table 4.3 shows the tools' performance concerning the number of nodes. The tools Gephi, Cytoscape, and NetworkX perform better until 10 000 nodes are reached. On the other hand, the tolls igraph and Graph-tool are most appropriate for large networks.

	100 Nodes	10 000 Nodes	1 000 000 Nodes
Gephi	excellent for visualization	performance issues	not practical
Cytoscape	excellent for visualization	performance issues	not practical
NetworkX	excellent for visualization	performance issues	not practical
igraph	excellent for visualization	suitable for this scale	can handle some analyses
Graph-tool		very efficient	strong for analysis

Table 4.3: Tools performance concerning the number of nodes

4.6 Network Dynamics

This section covers percolation and diffusion models, relating percolation in physics to the spread of ideas, behaviors, or products in networks. Then, it elaborates on the SIR (Susceptible-Infected-Recovered) model, a cornerstone epidemiological model used to analyze how infectious diseases spread through populations. Finally, discusses the role of intelligent agents in the evolution of complex networks, highlighting their significance in modeling, simulating, and understanding network dynamics and emergent behaviors.

4.6.1 Percolation and diffusion models

In physics, percolation refers to the movement and filtering of fluids through porous materials. It is a critical concept in studying the behavior of complex systems and phase transitions, such as the transition from a non-conductive to a conductive state in materials as connections between conducting components reach a critical threshold. This concept is used in various fields, including materials science, geology, environmental engineering, and the propagation of forest fires. Fig. 4.11 shows an example of percolation in its final phase.

Percolation is related to the concept of model diffusion. Model diffusion in networks refers to the process by which ideas, behaviors, or products spread through a population via individual connections

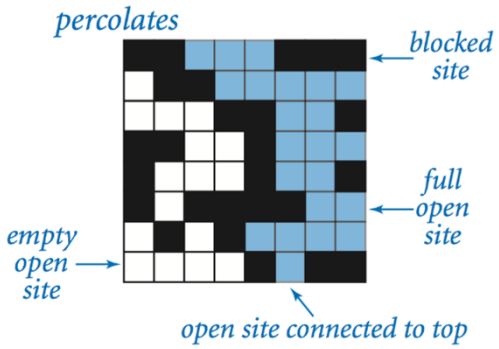

Figure 4.11: Percolation in the final phase.[7]

(Easley and Kleinberg, 2010). This process is influenced by the structure of the network and the rules governing how an entity decides to adopt something new based on its neighbors' choices. Diffusion models explore how these dynamics lead to the widespread adoption or rejection of innovations within a network.

An example of model diffusion is the spread of a new technology like smartphones. Initially, a few individuals adopt smartphones because they see a unique value in them (innovators). As more people observe these innovators and see the benefits, they, too, start using smartphones (early adopters). Gradually, the trend picks up, and a more significant segment of the population, influenced by the adoption of their network, begins using smartphones (early majority and late majority). Eventually, even the most resistant individuals (laggards) may adopt due to network pressures or seeing widespread utility.

In the diffusion of ideas, it is relevant to differentiate between cascades and clustering. The cascades refer to the rapid spread of ideas or behaviors across a network facilitated by a set of initial adopters. Clustering, on the other hand, represents tightly-knit groups within the network where members are densely connected. A complete cascade, where an idea spreads throughout the entire network, can occur if no clusters exist. The clusters act as barriers to the spread of cascades; their dense interconnections make it difficult for new ideas to penetrate these groups. Therefore, clusters in a network can halt or significantly slow down the spread of a cascade, making them a crucial factor in understanding the dynamics of idea diffusion.

4.6.2 SIR contagion model

The SIR model is a fundamental compartmental model used in epidemiology to understand how infectious diseases spread through populations (Newman, 2018). The acronym SIR stands for Susceptible, Infected, and Recovered, representing the three compartments into which the population is divided based on their disease status:

- Susceptible (S): Individuals who have not yet been infected with the disease are at risk of infection if they contact an infected person.
- Infected (I): Individuals currently infected with the disease can transmit it to susceptible individuals. These individuals are in the stage where they can spread the disease to others.

[7]Source: `https://medium.com/@mind_sFlight/union-find-data-type-disjoint-set-percolation-1028b31e036d`.

- Recovered (R): Individuals who have been infected and have either recovered from the disease, gained immunity to it, or have died. In the context of the SIR model, recovered individuals are typically assumed to be immune and no longer at risk of being reinfected or spreading the infection.

Fig. 4.12 shows the percentage of the population in each status. The pipeline with the rates of infection and recovery are also exhibited.

The model describes the flow of individuals between these compartments over time, driven by the rates of infection and recovery:

- Transmission rate (λ): The rate at which susceptible individuals become infected after contacting an infected individual.
- Recovery rate (δ): The rate at which infected individuals recover (and gain immunity) or die, thereby moving from the Infected compartment to the Recovered compartment.

The dynamics of the disease are typically described using a set of differential equations that represent the rate of change of the number of individuals in each compartment. These equations consider the transmission and recovery rates and the interactions between susceptible and infected individuals.

Several epidemiological models are related to the SIR model, each extending or modifying the basic framework to capture the nuances of different diseases better or incorporate additional factors affecting disease spread. Some of these related models include:

- SIS Model: In the Susceptible-Infected-Susceptible (SIS) model, individuals move from being susceptible to infected and back to susceptible again without entering a recovered state with immunity. This model applies to diseases where infection does not confer lasting immunity, allowing individuals to be reinfected repeatedly.
- SIRS Model: In the Susceptible-Infected-Recovered-Susceptible (SIRS) model, individuals can lose their immunity over time and become susceptible again. This model is relevant for diseases where immunity wanes after recovery, allowing for the possibility of reinfection.
- SVIR Model: The Susceptible-Vaccinated-Infected-Recovered (SVIR) model includes a vaccinated class to account for individuals who have been immunized against the disease and are, therefore, less likely to become infected.
- SIRD Model: The Susceptible-Infected-Recovered-Deceased (SIRD) model explicitly accounts for deaths due to the disease, separating those who die from those who recover with immunity.

Each model tailors the basic SIR framework to reflect specific diseases' characteristics more accurately or include additional epidemiological or demographic factors. The choice of model depends on the disease being studied, the available data and the specific aspects of the disease spread that researchers or public health officials are most interested in understanding.

4.6.3 Intelligent agents

In the evolution of complex networks, intelligent agents play a significant role in modeling, simulating, and understanding these networks' dynamics and emergent behaviors. Intelligent agents autonomously make decisions and act within their environments to achieve specific goals, characterized by their ability to perceive, react, and adapt. They interact socially with other agents or humans and can learn from their

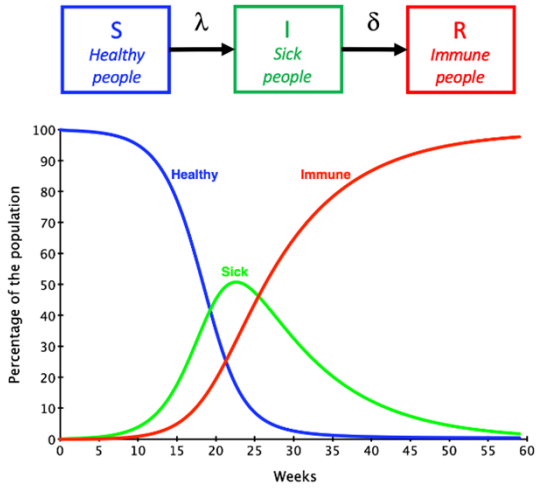

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Figure 4.12: SIR Model.[8]

experiences to improve over time. These agents are crucial in robotics, virtual assistants, and simulations, driving advancements and efficiencies across diverse applications.

To implement intelligent agents, NetLogo, as a software platform, is a powerful tool for implementing and visualizing models of complex networks. Fig. 4.13 shows the classic survival struggle of the grass, sheep, and wolves.

NetLogo allows the simulation of environments and the visualization of the results. NetLogo provides an accessible environment for creating models of complex networks populated by intelligent agents. It allows users to define agents' behavior, interaction rules, and the network's structure, making it an ideal platform for simulating complex systems. Moreover, NetLogo offers powerful visualization tools that help understand complex network dynamics. Users can visually track the evolution of the network and the agents' behaviors over time, facilitating the analysis of emergent patterns and network properties.

The LabMAg (agent modeling laboratory) in FCUL (faculty of sciences at the University of Lisbon) has worked in this area. An example of their work can be found in Lemos, Coelho, and Lopes, 2017 in ProtestLab. ProtestLab is an agent-based model for simulating street protests, featuring diverse agents such as protesters, police, and media. It includes scenario elements like obstacles and attraction points, and agents can exhibit various behaviors and states, including violence. The model offers quantitative metrics to analyze crowd dynamics, protest intensity, and police effectiveness. It was tested on a scenario resembling anti-austerity protests in Lisbon, accurately replicating observed real-life protest behaviors and interactions.

[8]Source: `https://www.researchgate.net/figure/SIR-Model-with-infection-density-Here-b-represents-the-infection-density-y0-represents_fig1_359517106`.

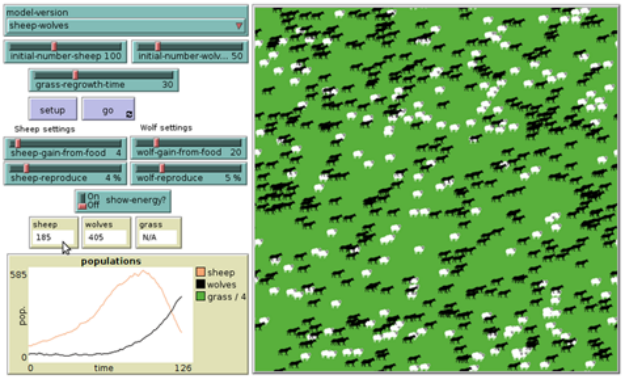

Figure 4.13: Grass, sheep, and wolves' model in NetLogo.[9]

4.7 Conclusions

Network science captures the essence of the interconnectivity in an organization, allowing us to visualize it as a skeleton of the system. Nowadays, in the big data era, extracting new knowledge is more and more relevant. One way to do it is to map that data into networks and explore their connectivities. Network science is characterized by a vast and varied array of high-quality contributions, making any new approach a challenge.

This work offers a structured exploration of network science through a three-step maturity framework that progresses in complexity. Initially, it outlines the fundamentals of networks and their construction, followed by an overview of standard network metrics. The final stage explores two key concepts: network topology and dynamics. Software packages for topological visualization and dynamic understanding are provided.

We believe this work clarifies the field and inspires readers to explore it. While network science may not solve every problem, it serves as a valuable framework.

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[9]Source: `https://edutechwiki.unige.ch/en/NetLogo_Wolf_Sheep_Predation_model`.

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Chapter 5

The Influence of Space and Environment on Crime and Economic Indicators: A Systematic Literature Review

João Santos and Vítor Moutinho and João Leitão

Summary
The focus of this study is the interplay between public policy, economic growth, regional science, and crime, and their mutual influences. Through a Systematic Literature Review, our objective is to explore the fundamental concepts underlying these domains and derive actionable guidelines for public policies aimed at promoting development at social, regional, and economic levels. Adhering to the PRISMA methodology, this review encompasses a comprehensive analysis of 232 articles sourced from the Scopus and Web of Science databases, spanning the period from 1997 to the beginning of April 2022. The selected articles were subjected to rigorous filtering and organization of data, enabling the establishment of meaningful connections, results, and conclusions. Additionally, the Vos Viewer software was employed to visually depict the relationships between data based on keywords and authors. Upon analyzing the findings, we observed that from an economic standpoint, crime as a social phenomenon is predominantly associated with corruption and tax/revenue-related offenses. Even with the inclusion of regional filters. We perceive regional science to be an exceptionally fertile ground for further academic exploration and inquiry.
Keywords: Crime, Literature Review, Public Policy, PRISMA, Regional Development.

5.1 Introduction

"We want a better society" and "We need a stronger economy" represent two elementary statements frequently employed in political campaigns and speeches. In our perspective, these statements are intrinsically interconnected, constituting an indispensable relationship. This correlation is particularly evident

from an economic standpoint, where developmental objectives can be pursued through comprehensive engagement across various strata and phases of society. One strategic approach to realize the aforementioned political objectives involves addressing instances of criminality through a holistic analysis and response, directed at combating all its manifestations, with particular consideration given to the comprehensive ramifications. While these conceptual tenets are readily comprehensible and agreeable, the realization of a nation's comprehensive policy encompassing all these facets remains an ambitious endeavor, verging on the idealistic.

The overarching concept of this research emerged from the endeavor to establish connections among various sides of economic growth, development, and their reciprocal impact with crime. This conceptual framework guided the initial inquiry, which delved into the interplay of economic growth and development with crime before extending its focus to incorporate linkages with institutional economics. Subsequently, the investigation progressed to a conclusive state, detailed in the subsequent section and further analyzed in the ensuing section. During the course of exploratory inquiries, a recurring theme gained prominence, marked by significant relevance and frequency. This thematic element, the Regional/Spatial economics perspective, was incorporated into our search formula as the most recent substantial update.

The four presented main topics, Economic Growth and Development, Crime Analysis, Institutional Economics, and Regional Science, were used as conceptual foundations to build this systematic literature review, by framing the research protocol and the study object.

This research, like many Systematic Literature Reviews (SLR), after the characterization of the conceptual path, moved to the definition of the query. This protocol formula works as a combination of all the knowledge areas that were mentioned by selecting keywords that relate to them between Boolean selectors that refines the outcome. All these steps are better defined in the next section.

Since we could not find any related previous work that combined the four mentioned areas of knowledge, we will provide a summarized and general overview of their evolution as concepts till the recent state of the art.

5.1.1 Economic Development and Growth

As the most iconic economic paradigms and issues, economic growth, and development represent one of the most common goals and benchmarks of the theoretical models. Economic Growth as an economic concept cornerstone can be defined as an aggregated improvement of all the major macroeconomic indicators, focusing essentially on three canons, production, income, and expenditure. According to the classical definition of growth, from David Ricardo to Robert Solow, it can be conceptualized as a process that generates economic output from Capital, Labor, and Technology (Feldman and Storper, 2018).

On the other hand, Economic Development, besides all that was stated in the previous concept brings life-quality variables to the equation, this perception has in Adam Smith's work, its deepest root (Wealth of Nations is widely considered in both economic and geography science fields as a conceptual foundation (Malizia, 1990)). Nowadays, development usually comes together with sustainability and with a special focus on the impact on the next generation (Marques, Fuinhas, and Gaspar, 2016). From both statistical and econometric points of view, these concepts are usually measured with GDP-related figures and concepts.

5.1.2 Regional Development

The spatial and territorial dimension of economics, as introduced by this field, underscores the significance and role of a region beyond its physical confines (Capello, 2009). This emphasis arises from the

acknowledgment that territory and space exert a pivotal influence on economic growth and development. Notably, within this economic subdiscipline, one can discern the enduring impact of Adam Smith's work, extending beyond the aforementioned considerations, and its consequential influence on scholars such as Walter Isard, particularly evident in his seminal paper, "Regional Science, The Concept of Region, and Regional Structure."

In contemporary discourse, regional science is conceptualized as a hierarchical structure comprising three branches. The initial branch encompasses enterprises, households, and local public institutions, given the profound impact of their daily decisions. The second branch is dedicated to the examination of relationships and connections among all agents within the territory and those beyond its borders. The final branch encapsulates tradition and customs, as the conceptual foundations from historical roots continue to wield influence on contemporary decision-making processes.

In addition to the aforementioned components, Regional Economics assumes a pivotal role by serving as the conceptual and territorial adhesive that harmonizes these diverse elements, facilitating a cohesive understanding of these interconnected concepts.

5.1.3 Institutional and Social Economics

This foundational element performs a role analogous to that of the Regional pillar, with these concepts exhibiting a robust interconnection, particularly when encompassing both state and non-state actors, the latter assuming an institutional character. As posited by Harbi and Anderson, 2010, economists classify institutions as either exogenous or endogenous. In the former category, as articulated by Douglass C. North in "Institutions, Institutional Change and Economic Performance," institutions comprise a set of rules, encompassing both formal and informal dimensions, conventions, and norms that establish behavioral standards for all members of society. The latter perspective, advanced by Masahiko Aoki, employs modern game theory applications to cultivate a conceptual and analytical framework for comprehending issues related to economic institutions, characterizing them as endogenous (Spithoven, 2018).

Irrespective of the theoretical framework, the aforementioned authors concur that all societal agents are subject to the influence of the institutional ecosystem in which they operate, and these institutions can either catalyze or impede development. In the present study, governance, well-being, and inequality will be incorporated to underscore the social dimension inherent in institutional economics.

5.1.4 Crime Reporting Analysis

This last section is dedicated to explaining and limiting this work's dependent variable, Crime. Illicit behavior, as an event, occurs when someone or something (besides individuals, also legal persons can be responsible for this type of action) acts in ways that are not in line with society's rule of law. Nowadays, descendants of the Hammurabi code aim to, protect people, property, and society as an entity, by defining both procedure and punishment of it. However, as a social phenomenon and isolated event, crime occurrences can appear to be random occurrences, nevertheless, if we add time, space and territory we realize that in a long run, it can be forecasted with increasing precision (Kounadi et al., 2020). This last sentence summarizes both motivation and purpose of this paper, which is to help reach higher levels of development by contributing to the design of public policies and measures. Focusing on foundations, in 1968 Gary S. Becker published Crime and Punishment: An Economic Approach which become the most prestigious seminal paper of this economic branch, by addressing crime (supply of offenses) occurrence's from an economic perspective and looking to develop optimal public and private policies to combat illicit

behavior. On his giant shoulders, as Isaac Newton said, stood numerous contributions and debates like the ones made by Ehrlich, 1973; Ehrlich, 1996, and Garoupa, 1997 among another's.

This study will follow its title as a research question aiming to reply with a theoretical framework and a research agenda, to the question of, how space and environment shape both crimes and economic figures, and even, how other concepts relate to and affect each other.

After this background chapter, the reader can find the methods section (a particularly relevant part for a PRISMA methodology article), followed by the results and discussion, which will present the outcome of our research, including, some bibliometric and bibliographic analysis involving the use of the software "Vos Viewer". This work ends with some other information regarding registration, protocol, and related materials.

5.2 Methods

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method provides a strict protocol that, in their 2020 version, gives 27 items to check, reply and follow to state a Literature Review as a SLR. This technique is quite usual in the Medicine and Health Care world, and it is becoming quite frequently used in other science fields due to its narrowed protocol that gives a certified quality to the research and to its impact on article selection that prevents higher levels of bias and prejudice.

5.2.1 Eligibility Criteria

Besides the protocol, the Inclusion Criteria (IC) are one of the core values of the PRISMA methodology and, in this paper, we designed four of them to have a rigorous selection of articles that allow us to full fill our aim. The first and second IC, are two of the most common ones, being fully available and published in English. The second one is particularly important because of IC4, which is presented in Table X, and it was chosen due to our need to fully analyze the document. The language criteria filter is a consequence of the authors' limitation, and due to our belief, that a major part of scientific documents is written in English. The economy-only criterion is a request related to the aim of this study that, besides all the academic applications and connections of the used concepts, wants only the ones regarding the economy as a science field.

Table 5.1: Inclusion Criteria

IC1	Required articles to be published in English
IC2	Required articles to be fully available
IC3	Required articles to be economy-related
IC4	Required articles to be related to, at least, two of the four defined areas.

After all this filtering, the selected articles were completely analyzed and clustered into one of six domains. This measure aimed to make it easier to access the trending issues by creating groups of documents according to their characteristics and subjects. The application of IC4 made the previous selection possible and feasible. The first three IC were a two stages process, that start as automated tool that was

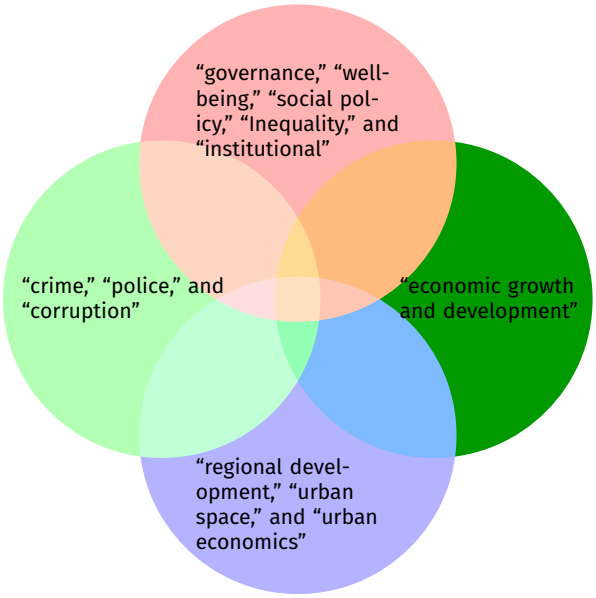

Figure 5.1: Graphical representation of the search query

humanly refined after that. The last IC, the fourth one, was an interpretation, selection, and clustering process.

5.2.2 Information Source and Search Strategy

All the papers came from two databases, Scopus and World of Science, that were last accessed in April of 2022 through the institutional access provided by the University of Beira Interior (UBI). The initial search, due to the lack of filters and limits generated a huge output that was automated and narrowed down with the help of some filters like language and document type.

The protocol in this paper, as briefly presented in the previous section, was the intersection of Economic Development and Growth, Regional Development, Institutional, and Social Economics, and Crime reporting analysis. To write the query’s recipe, we added both “economic development” and “economic growth” separated the Boolean operator “or” to gather the documents concerning both topics. The next included ingredient, Reginal Development, made its entrance through the words “regional development”, “urban space” and “urban economics.” The following step was delivering the institutional flavor to the formula, through the words “governance”, “well-being”, “social policy,” “Inequality,” and of course “institutional.” The last one aimed to bring the law enforcement perspective by including the crime reporting and occurrence analysis through the words “crime”, “police” and “corruption” to the search equation. The Boolean operators used on the query, AND and OR, had two different jobs. “AND” was used between clusters, to have all four groups represented during the search, on the other hand, “OR” separated each word of the concept, aiming to widen the range of each cluster. By increasing the size of each cluster, we expected (and got) a bigger interception area.

The final keyword search query was as follows: (“institutional” OR “governance” AND “well-being”

OR “social policy” OR “Inequality” AND “economic growth” OR “economic development” AND “crime” OR “police” OR “corruption” AND “Regional Development” OR “Urban Space” OR “urban economics”).

The result of this formula was a universe of more than four thousand documents, that through the inclusion criteria presented before, were narrowed down till we reach the final number of a few more than two hundred documents.

5.2.3 Selection and Data Collection Process and Items

Even after the use of the automated tools, there was still a considerably large number of articles to be processed, mostly because of the topics inside the query that provided a wide range of documents. Seeking to narrow the group, we initiate a 3-step process to refine the outcome supplied by the Scopus and WOS databases.

First, all the documents were downloaded (the ones that were not fully available, even after the automated tool, were not considered), then an abstract, keywords and title analysis were conducted (to reinforce the application of IC3 and IC4). The last step was a 12 fields spreadsheet that will have its results presented in the next section. Title, aim, journal, year, authors, methods, variables, application context, sample, results, keywords, and domain were the information fields that were filled for each selected article. Keywords and domain are specially related and were extremely important regarding the application of the synthesis methods. After the full reading of the selected document, we selected the two most representative keywords (in the case that there were no keywords from the author, we provided them). After this new selection, we included each one of them in one of six domains. Each domain represented a direct link between two of the four areas that we aim to link and use as our doctrinal foundations. To maintain rigorous control of the process, this stage had the intervention of three isolated reviewers.

Besides the bibliographic view and scrutiny, we conducted also a metanalysis. By extracting a RIS document from Mendeley,[12] we were able to have all our document’s data in one file. This file was then submitted to assessment on VosViewer and will have its outputs presented in the last part of the next chapter.

5.3 Results

5.3.1 Study Selection and Characteristics

The final number of 232 documents was the product of the three stages process represented in Fig. 5.1 (identification, screening, and inclusion). The starting phase, identification, congregated both searches on the databases and resulted in 4092 documents. From that amount, 3320 were removed from scrutiny because of not being fully available. Screening, as a stage, removed 564 documents, 20 due to language criteria, 382 because of not being economy papers, and 161 in the title, abstract, and keyword analysis. During the last stage, twenty-four papers were added due to our initial search group due the date this

[1] An RIS file is a bibliographic citation file saved in a format developed by Research Information Systems (RIS). It contains a series of lines delimited by two-character codes and a corresponding value. RIS files provide information such as title, author, publication date, keywords, publisher, issue number, and start and end page, adapted from https://fileinfo.com/extension/ris.

[2] Mendeley is a free reference manager that can help you store, organize, note, share and cite references and research data: Automatically generate bibliographies, collaborate easily with other researchers online, easily import papers from other research software find relevant papers based on what you’re reading and access your papers from anywhere online, adapted from, https://www.elsevier.com/solutions/mendeley.

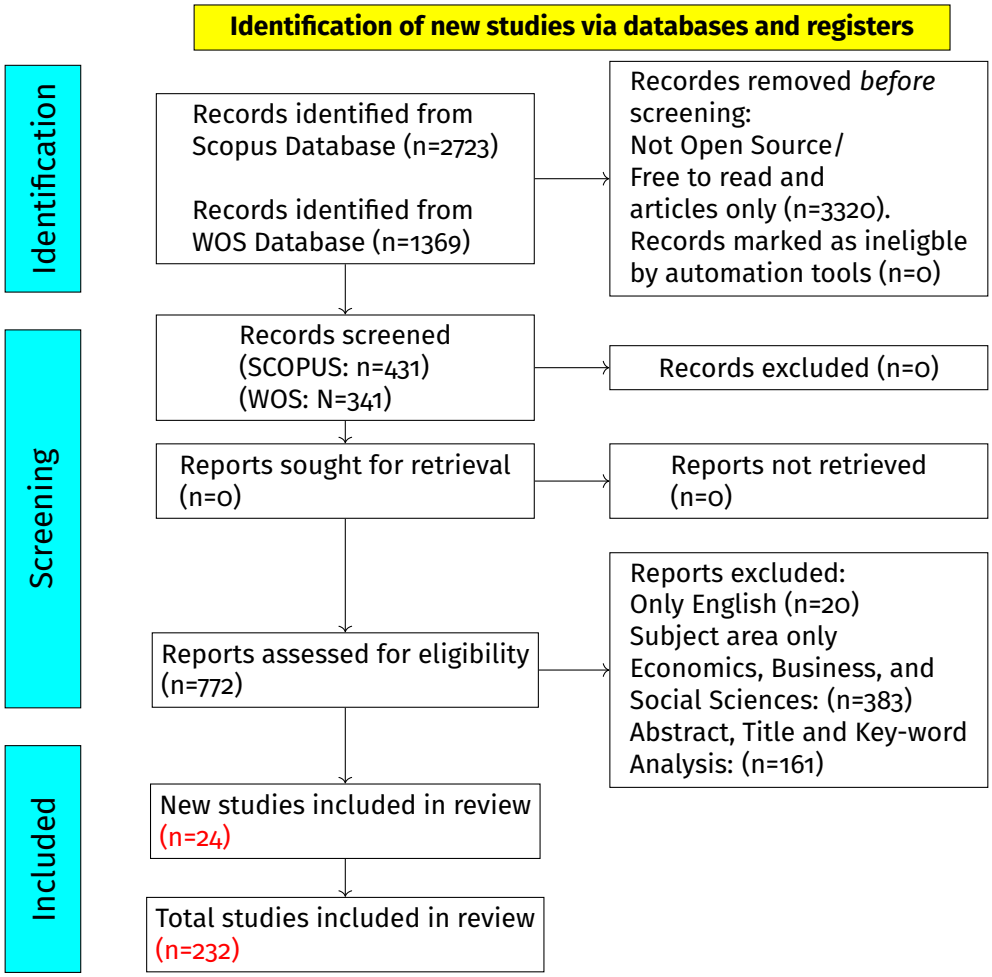

Figure 5.2: PRISMA Flow diagram

one, October of 2021. These studies were the result of applying the same method to both databases with the filter of having been published during the time gap between the first search and April of 2022.

The remaining group of articles was the result of the application of all the inclusion criteria. A superficial assessment allows us to state, from all documents, that 69 studies are literature reviews or have done a complete chapter dedicated to that (surprisingly, none of them used PRISMA methodology) and that 45 have chosen the econometric model Ordinary least Squares (OLS) as the main method. Focusing on the context of the application, we realized that 34 of all studies had a sample of more than 50 countries, 37 concerned either the Europe Union or a European group of countries, and 81 articles focused only on one country. From a time, perspective, our oldest document was published in 1997, while the most recent ones are from2022.

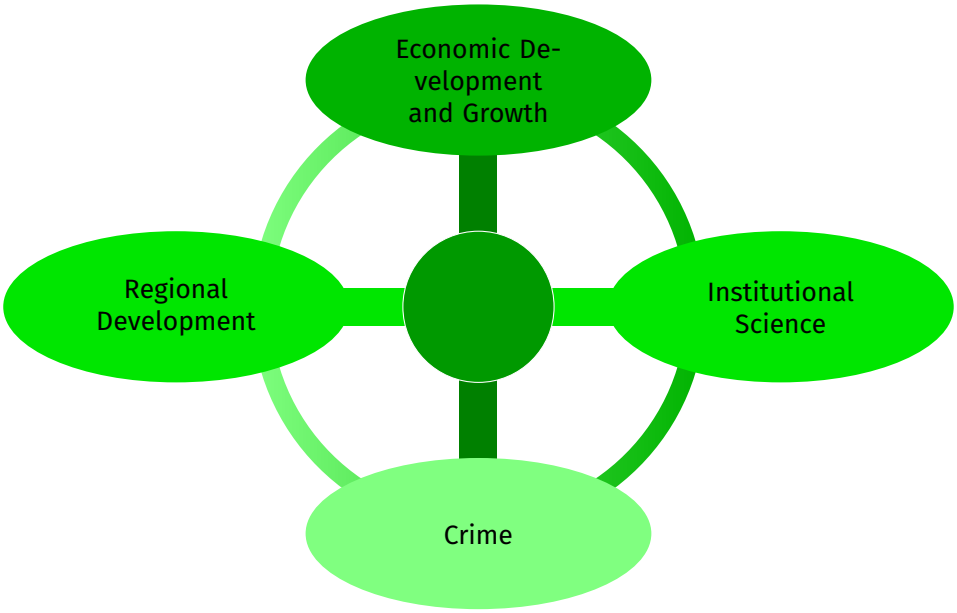

Figure 5.3: Graphical representation of the chosen domains

5.3.2 Results of Individual Studies and Syntheses

Not being fully available, as stated before, was a necessary criterion due to our need to fully analyze each selected paper. This need, besides aiming to gain individual knowledge and criteria approval, was crucial to organizing the documents in domains. Concerning this clustering process, it was our choice to summarize and synthesize the main ideas and topics to establish some links, connections, and conclusions.

Therefore, after all this adding and filtering, there was a final list of two thousand and eight articles, that were organized into thematic areas, domains, authors, and year of publishing, among other topics. Another look at the timeline, with a little help from the figure below, provides more information regarding the date of publishing. We did realize that there was, since 1997 a growing trend, that after 2015 started to have twice the documents per year as before that. To complement this general behavior analysis, we will present the same data, but with clustered effects.

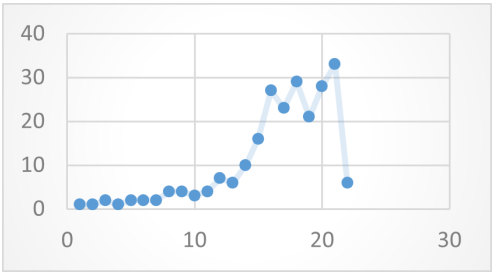

Figure 5.4: Documents per year

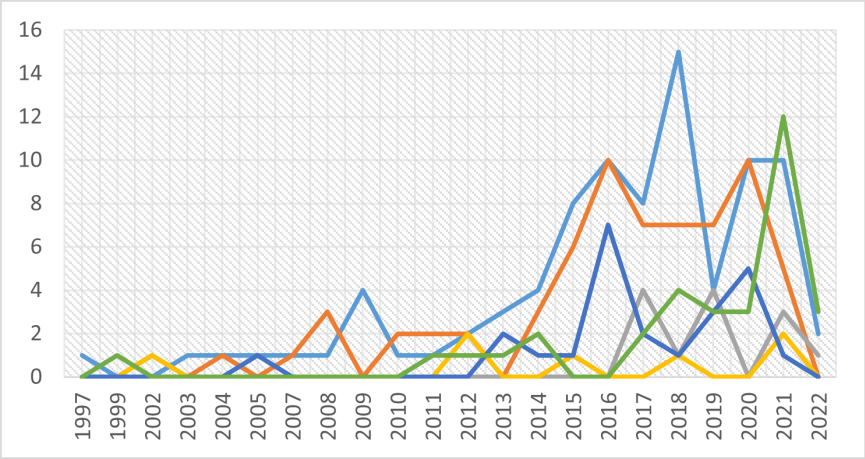

Figure 5.5: Evolution of domains per year

All the domain's performance follows the same trend as the aggregated output (as presented in the previous illustration). However, if the reader looks at each domain individually, he can notice some aspects. Shallow scrutiny of the figure below allowed us to realize that the two most representative domains have almost 70% of all documents and that 3% is the lowest percentage that resulted from this clustering process. The science fields areas of the two most representative ones are Institutional theory, Economic Growth, and Development of Regional Economics. On the other hand, the science fields of the two less representative ones have one brunch in common, Reported Crime Analysis.

Domain I: Institutional Socio-Economics impact and Regional Development / Urban Economics Starting with the domain with the oldest article, Institutional Socio-Economics impact, and Regional Development / Urban Economics we can highlight that it is the domain with more representation of 88 articles in total (38% of all studies), more documents in most of the years and more documents in just one year, fifteen during the year of 2018.

This first cluster examines the institutional impact and theory with regional canons. This wide range of documents has 10 papers with an application context of more than 50 countries and 36 that focus on country-level data. Still, regarding the application context, we emphasize that 20 documents related to European Union or European countries only, 7 to the USA, and 5 to Africa, or African countries. Concerning the chosen method, we highlight 28 Literature Reviews, besides 11 variations of OLS and 3 applications of game theory.

Domain II: Institutional Socio-Economics impact and Economic Growth and Development The second domain dresses in orange and had its first document in 2004. With 66 articles, Institutional Socio-Economics impact and Economic growth and Development occupies the second place in the representation ranking and has 12 documents with a sample of more than 50 countries. Looking at their focus we found 6 papers regarding Europe or a group of only European countries, 6 concerning Africa or African countries, and 12 with a scope of Asian countries. Regarding the method, we have 15 literature reviews and 8 applications of OLS.

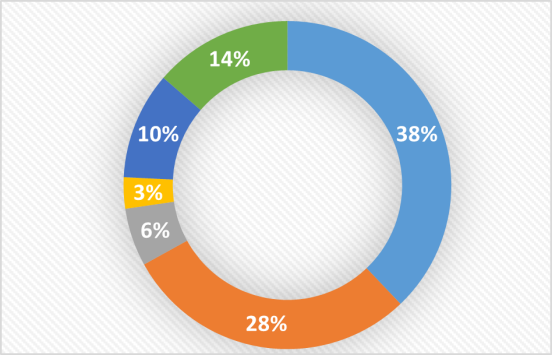

Figure 5.6: Domain's distribution

Domain III: Crime, Police or Corruption and Regional Development / Urban Economics The third domain relates only to 14 studies and brings together the crime's topics with the regional perspective under the denomination of Crime, Police or Corruption, and Regional Development / Urban Economics. While like the following one, this group has a special focus on location and their environment and impact (despite sometimes addressing the local institutions). Regarding their application context, we recognize the relevance of the USA, due to having three related papers (two at the city level and one at the country level). From the methodology field, we have two literature reviews and one case study, and 5 variations of the OLS model. We also have two interesting applications of Game Theory, one concerning the choice of a police officer as a professional career that takes place in Germany, and the other, regarding the issues of owning private property in West Africa. The most used variables gather the social local indicators (like average income, education, employment, and distance to city centers, for instance), and crime reporting figures (like murder, robbery, burglary, weapons, and arrests, among other rates).

Domain IV: Crime, Police or Corruption, and Institutional Socio-Economics impact The next domain, Crime, Police or Corruption, and Institutional Socio-Economics impact add the institutional view and theory to the crime-related issues, nevertheless, had the lowest number of papers of all clusters, seven. The documents selected for this domain look for the institutional link with crime, especially from public organizations. This cluster has two literature review articles, one as a full chapter, five econometric methods, two OLS, and three fixed-effects models. Four of them focus on the national level, while two regard South America and a sample of 47 countries. Concerning the used variables, we realized the predominance of crime statistical indicators and GDP-related concepts.

Domain V: Crime, Police or Corruption, and Economic growth and Development With a dark blue color, Crime, Police or Corruption and Economic growth and Development gets some expression in the most recent years and has a total of 24 articles. Corruption is the most representative keyword in all the papers, being stated in 18 of them. Besides keywords, we also realize its presence in the models by being a selected variable, such as Corruption Perception Index (CPI), Countries own Corruption index, or even as World Bank corruption index (CPIA). In this pool, we have no literature reviews, and the most relevant econometric models are OLS (used in 5 papers) and Logistical regressions, also the main method for 5 other studies.

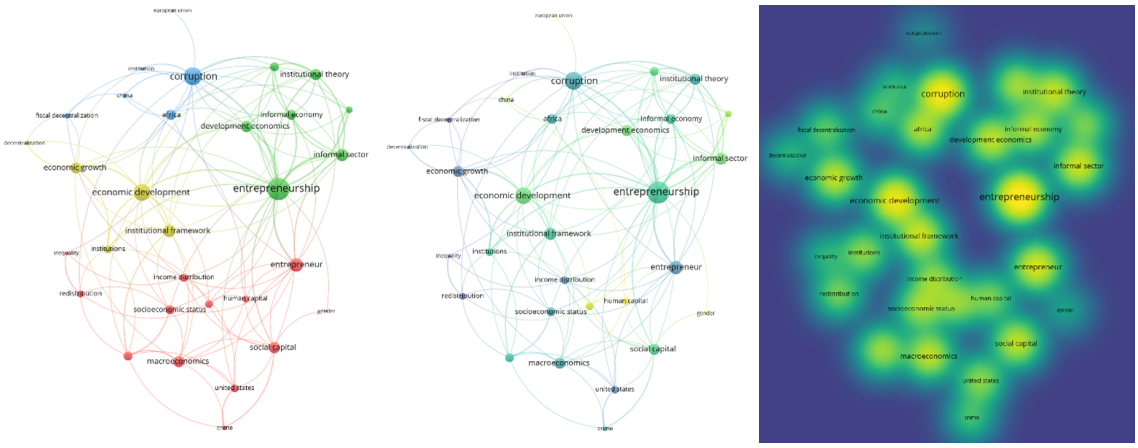

Figure 5.7: Keywords analysis' visualization

Domain VI: Regional Development / Urban economics and Economic growth and development The last one, painted in green, Regional Development / Urban Economics and Economic growth and development, has a similar trend as the previous one, with higher relevance in the recent past (having 15 of its documents published during 2021 and 2022) and a total sum of 33 related documents. This cluster gathers two bases' concepts of this paper and targets the territorial part of growth and development. this statement can be proven by the documents' most representative keywords, Inclusive Growth, Social Capital, Urbanization, and Decentralization. Focusing on the context of the application, we realized that from all studies, 11 targeted more than 10 countries, and from those, four have a wide range sample of more than 50. We also highlight the presence of 12 country-level papers. Regarding the method, we emphasize the use of three main methods: OLS (with application in seven studies), Logistical Regression (with different uses on five documents), and Fixed Effects (presented in four papers). Besides all econometric models, we also have three literature reviews.

5.3.3 VOSviewer

Besides the previous results, both data-bases outputs were analyzed through VosViewer Software.[3] This program offered a general and graphical overview of the bibliographic data in a word map. That view will focus on three sources of information, first, the keywords, followed by the authors till the final scrutiny of titles and abstracts.

Keyword's Perspective From a universe of 884 keywords, 31 meet our criteria (having at least four occurrences) and will be painted in three tones, group colors, time shade, and a heat map.

All three images represent the same keyword network connection, however, each one of them allows different views of the same landscape. The one on the left shows us the 31 selected keywords organized

[3]VOS viewer is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations. VOS viewer also offers text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature, https://www.vosviewer.com/.

in four groups. The red one has 13 words from which we can highlight, due to their relevance, "Social Capital," "Human Capital," and "Entrepreneur." The green group gathers seven concepts, from which we find more significance in "Entrepreneurship," "Informal Sector," and "Institutional Theory." From the following cluster, we highlight "Corruption" and "Africa" from a total of six concepts. The one with yellow colors relates five keywords, from which we emphasize "Institutional Framework," "Economic Development" and Economic Growth."

Not surprisingly, the output reflects the search query of this paper, however, if our assessment starts with a general overview, we can easily identify four different territories Africa, China, Europe, and the United States of America. Two countries and two continents are connected in this network but to different groups and concepts. Unexpectedly, Africa, China, and Europe are linked in the blue cluster through the concept "Corruption." For several reasons, the previous concept has different impacts on each one of the landmasses. On the other hand, the USA stands alone painted in red and connected with concepts like "Social Capital," "Human Capital," "Entrepreneur," and "Crime". From this topic, we can assume that corruption either to their manifestation or fighting is a hot topic in these territories.

"Entrepreneur" and "Entrepreneurship" as keywords, allow the concept to be the one with more occurrences, followed by "Corruption" and "Economic Development". The first one, Entrepreneurship, is a recent and widely used concept while the other two are some of the most common variables of economic models and studies. From a time perspective, and focusing on the second picture, it is possible to realize (the brighter the color, the newest concept's application) that "Human Capital" and "Economic Development" are the concepts with the most recent applications, on the other hand, "Economic Growth" seems to be the eldest concept. This time deduction is quite in line with the evolution of economics as a science in recent past years (on a major scale).

This graphic representation allows us to have a time' guideline of the keywords evolution, starting with "Economic Growth," "Fiscal Decentralization," and "Income Distribution", then moving to "Institutional Theory," "Corruption," and "Informal Sector", to reach "Institutional Theory", "Economic Development" till we reach Human Capital as the conceptual end state. So, *grosso modo*, we have a keywords journey that starts with a clear focus on income and growth, moves to non-regular economic players, till it reaches human and social development concepts.

Co-authorship Perspective By selecting a minimum of 2 documents as a requirement, we end up with 42 authors (from a universe of more than four hundred) which is a very different result from a usual SLR. This result, in our opinion, is strongly related to the query's keyword selection that allowed a wide range of articles, with no relevant co-authorship network connection. The only exception, is a 12-document cluster from Williams and Liu, 2019, Williams and Kosta, 2020a, Antonietti et al., 2020, Williams and Kedir, 2018, Hill et al., 2020, Williams and Horodnic, 2016, Bouzid et al., 2020, Ostapenko and Williams, 2016, Williams and Kosta, 2020b, Ladan and Williams, 2019, Williams and Shahid, 2016. Focusing on time, it is possible to realize that most of the documents presented in those pictures are pre-2018, even in the most relevant cluster.

Titles and Abstracts Perspective For the third trial run, we gathered the words from both titles and abstracts and demanded a minimum of 20 occurrences be selected. This decision allowed us to reach a final number of 13 concepts graphically represented in those images above.

The first look easily targets "country" as the more relevant (meaning more occurrences) and central concept, still, on a territorial level, we can also point out "region" as a related concept. Regarding time, network, and all the concepts, we do realize that there are two clusters connected through "Country"

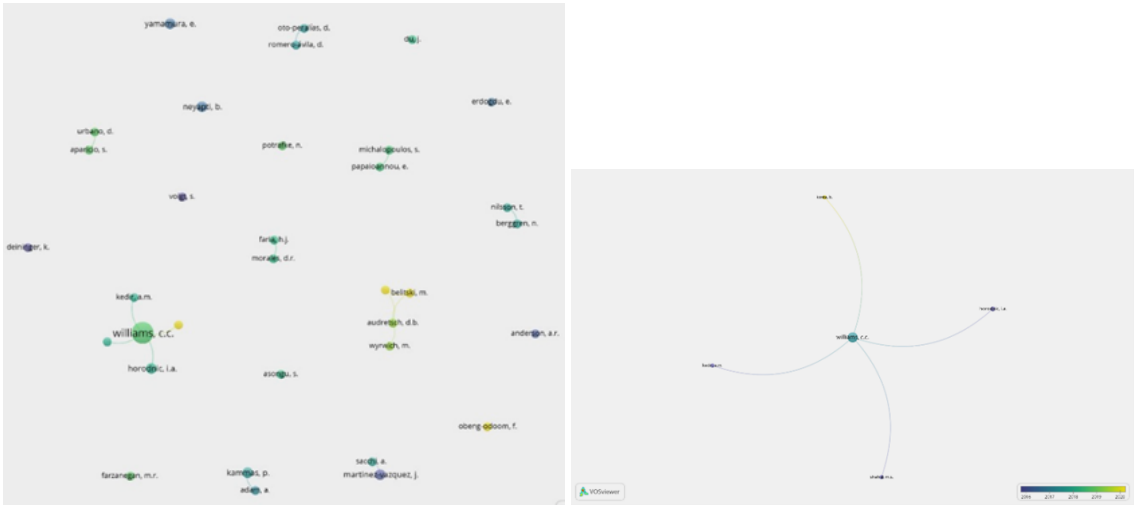

Figure 5.8: Co-authorship network

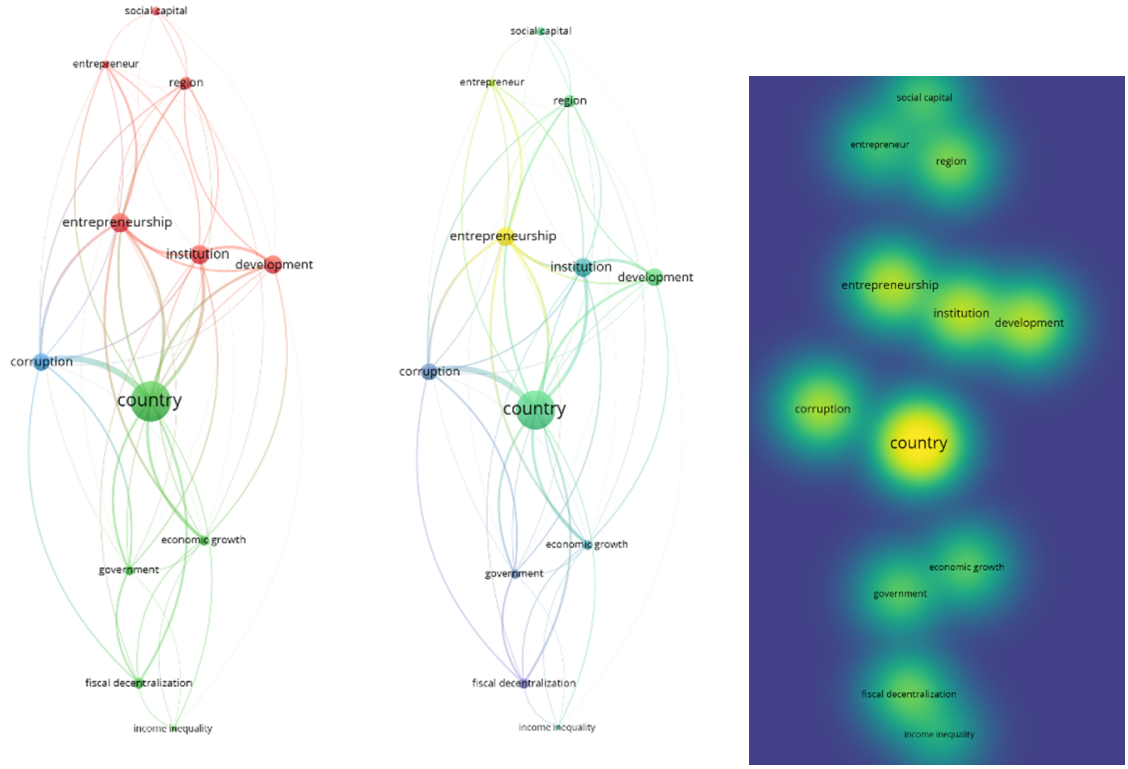

Figure 5.9: Titles and Abstracts data analysis

and “Corruption.” The first group, the one colored in green and located in the lower part of the picture, gathers concepts like “Economic Growth,” “Fiscal Decentralization,” “Government,” and “Income inequality”, besides these, they are also the concepts with the prior use according to the time frame. The other cluster is dressed in red, and has words like “Social Capital,” “Entrepreneur,” “Region,” “Institution,” and “development”.

However, from this last use of Vos Viewer, it is possible to state the most common territorial unit, in all these studies, Country. This premise will be a call to action in the following two chapters of this paper.

5.3.4 Citation Analysis

One way to access both acceptance and preponderance of the study in the academic community is to check for its citation figures. The following tables summarize the data of all the papers of our selection that in March of 2022 had more than 50 citations (according to their database information). After the citation filter, the fourteen’s most cited works were organized in two tables, one regarding the method, and the other focusing on their aims and key findings/ main contributions.

Table 5.2: Citation and methodology analysis

	Cited by	Title	Context	Sample	Method	Variables
(Xu, 2011)	942	The fundamental institutions of China’s reforms and development	China	All counties in China from 1993 to 2004	Ordered Probit regression	Dependent Variable, turnover of political leaders; Provincial annual GDP growth rate; Provincial average GDP growth rate; Provincial average per capita GDP growth rate; Provincial average per capita GDP; the growth rate of the immediate predecessor; Age; Education; Central connection; Tenure; Lagged per capita GDP.
(Michalopoulos and Papaioannou, 2014)	201	National institutions and subnational development in Africa	Africa	32 partitioned ethnicities using data from the 2005 Afrobarometer	Multiway clustering method/method of moments (GMM)	Dependent variable reflects the level of economic activity in the historical homeland proxied by light density; Mean elevation; Land suitability for agriculture; Malaria stability index; Oil deposit indicator; Diamond mine indicator; distance to the capital city; distance to the seacoast; Distance to the border; Rule of law; Control of corruption.
(Urbano, Aparicio, and Audretsch, 2019)	138	Twenty-five years of research on institutions, entrepreneurship, and economic growth: what has been learned?	World	25 years (1992–2016)	Systematic Literature Review	NA#

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	Cited by	Title	Context	Sample	Method	Variables
(Williams and Horodnic, 2016)	129	Informal entrepreneurship and institutional theory: explaining the varying degrees of (in)formalization of entrepreneurs in Pakistan	Pakistan	2012 survey of 300 entrepreneurs	Ordinal Logistic Regression	To evaluate the degree of informalization of entrepreneurs, the three variables discussed in the introduction that define informality amongst entrepreneurs are employed, namely: (1) legal status; (2) type of accounts kept and (3) tax registration status. Legal status; Type of accounts kept; Tax registration status; Age; Income; Education; Gender; Age of business; Economic marginality; Tax level; Public sector corruption; Risk of detection; Resistance against the state; Difficulty of registration; Tax morality.
(Alesina and Angeletos, 2005)	110	Corruption, inequality, and fairness	NA#	NA#	Dynamic Model: non-overlapping-generations model.	NA#

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	Cited by	Title	Context	Sample	Method	Variables
(Williams and Kosta, 2020b)	97	Determinants of the Level of Informality of Informal Micro-Enterprises: Some Evidence from the City of Lahore, Pakistan	Pakistan	2012 survey of 300 microen-terprises	Multivariate-ordered logistic regression	Three variables are used to construct an index of the level of informality of an informal enterprise, namely: (1) its legal status; (2) its tax registration status, and (3) the types of accounts kept. This enables a four-point scale of the level of informality to be constructed ranging from totally formal through low levels of informality and high levels of informality to totally informal; Female, Age, education; Household income; Main earner. **Model 2:** Own account worker; Firm Sector; Business premises, Started business; bank account, business size, sources of financing, firms age; **Model 3:** resentment, high taxes; burdensome regulations; public sector corruption; unawareness of registration. **Model 4:** tax morality; risk of doing business informally; efficiency, economic growth and investment, income inequality and poverty, macroeconomic stability, regional disparities.
(Warner and Clifton, 2014)	83	Marketisation, public services and the city: The potential for Polanyian counter movements	USA and Europe	NA#	Literature Review	NA#
(Stuetzer et al., 2016)	81	Industry structure, entrepreneurship, and culture: An empirical analysis using historical coalfields	Great Britain	19th century	IV regression models	Dependent Variable: Distance to coalfield; Employment share in large- scale industries 1891; Watermills around 1800; Market potential 1891 Cities around 1290; Universities prior 1500 Harbors around 1290; Limits to agricultural use Depth to rock; Mean July temperature Ruggedness; Employment 1891; Population density 1891.

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	Cited by	Title	Context	Sample	Method	Variables
(Harbi and Anderson, 2010)	67	Institutions and the shaping of different forms of entrepreneurship	36 countries	1995 to 2006	Fixed effect model	Dependent Variable: self-employment rate in country; variables: Business freedom Bus; Trade freedom Trade; Investment freedom INV; Corruption perception index CPI; Freedom from government Gov.
(Neyapti, 2010)	66	Fiscal decentralization and deficits: International evidence	16 countries	1980-1998	OLS	Dependent Variable: Overall deficits (% of GDP) Expenditure decentralization; Revenue decentralization; GDP GDP growth rate (constant LCU); (Log of) gross national income per capita Index of population; Governance; Local Elections; Ethnology frac.
(Oort et al., 2012)	58	Multilevel approaches and the firm-agglomeration ambiguity in economic growth studies	Netherland	28,637 firms	Two case studies; two random coefficient models / random intercept probit model	Case Study 01; Probit: Dependent Variable: probability of survival of new establishments in the advanced producer services; average survival or growth rate of new firms in the advanced producer services; sector-by-region, region; sector; Initial establishment size (ln) Localization economies (ln) Competition (ln) Urbanization economies (ln) Human capital (ln) R&D expenditures (ln). Case Study 02: Dependent Variable: Firm's Productivity; Firm-level variables; Region-level variables; Cross-level interaction effects.
(Du, Lu, and Tao, 2012)	57	Institutions and FDI location choice: The role of cultural distances	China	foreign invested enterprises (FIEs) in China on the period 1993-2001	Discrete choice model; Conditional Logit regression	Dependent Variable: profit that firm i derives from setting up a manufacturing operation in region j at time t; Contract enforcement; Regional IPR protection; Government intervention in business; Regional corruption; Agglomeration home; Agglomeration domestic; Backward agglomeration; Forward agglomeration; Wages; Highway density Education.

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	Cited by	Title	Context	Sample	Method	Variables
(Pham and Talavera, 2018)	52	Discrimination, Social Capital, and Financial Constraints: The Case of Viet Nam	Vietnam 2011, 2013, and 2015 results of the Micro, Small, and Medium Enterprise Survey;	Probit response model with sample selection	Dependent Variable: loan approval and apply; Need; Apply; Business network; Official network; Veteran/Communist; Ethnicity; Education; ROA; Age; Firm age; Size; Export; Accounting.	
(Winston, 2013)	50	On the performance of the U.S. transportation system: Caution ahead	United States	NA#	Literature Review	NA#

Note: NA# stands for not applicable.

The table two has seven fields of scrutiny, author, citation number, title, the context of application, sample, method, and variables, which will be examined with a special emphasis on both citation figures and chosen methodology. The citation gap has 50 as the lowest number and 942 as the highest, Winston, 2013 and Xu, 2011, respectively. The first paper is a literature review from 2013 concerning the evolution of all the scientific fields of transportation economics regarding especially nowadays limitations and future challenges of the United States of America. The other one, besides being the most mentioned document, uses an Ordered Probit Regression to evaluate China's development of its institutions and governance. To measure it, the author accesses the political instability (Turnover of political leaders) using variables like provincial GDP growth rate, provincial GDP growth rate per capita, and growth rate of the immediate predecessor among other ones.

Regarding methodology, we have three literature reviews (one being a systematic one) and 11 quantitative methods, from which, and due to their relevance, we highlight the use of three applications of Probit Regressions and three of Logit Regressions. The Probit methods were used to evaluate the loan's approval in Pham and Talavera, 2018, the probability of survival of new establishments in the advanced producer services in Oort et al., 2012, and political instability in Xu, 2011. On the other hand, the Logit Regressions allowed Du, Lu, and Tao, 2012 to measure the regional impact of Foreign direct investment on the Chinese mainland, and Colin C. Williams to dissect Lahore's entrepreneurship environment. This last author, Colin C. Williams, has two papers in this restrict list, and they're both regarding the same application context and sample a 2012 survey of 300 entrepreneurs from Pakistan. One of these documents analyzes the level of informality in the Pakistanis' city of Lahore focusing on their entrepreneurs and the other, using the same data, looks for the impact of the institutions on both entrepreneurship and development.

Table 5.4: Aims and key findings perspective

	Journal	Aims	Highlights/ Key Findings	Domain
(Xu, 2011)	Journal of Economic Literature	This paper analyzes China's institutions, a regionally decentralized authoritarian system. The central government has control over personnel, whereas subnational governments run the bulk of the economy; and they initiate, negotiate, implement, divert, and resist reforms, policies, rules, and laws.	1. Regional competition and experimentation governed by China's RDA regime have effectively alleviated potential incentive and informational problems. 2. To some extent, competition among subnational governments encouraged or forced them to create implicitly the institutions essential for a well-functioning market; 3. During its process of transition and development, China has created market-supporting institutions in an evolutionary way. 4. However, it has been well argued that reform and economic development involves complementary institutional changes to be carried out by the government.	Institutional socio-economics impact and Regional Development / urban economics
(Michalopoulos and Papaioannou, 2014)	The Quarterly Journal of Economics	Investigate the role of national institutions on subnational African development in a novel framework that accounts for both local geography and cultural-genetic traits.	1. We take advantage of the fact that the arbitrarily drawn colonial borders that endured after African independence partitioned several ethnic groups in different countries, subjecting identical cultures residing in geographically homogeneous territories to different country-level institutions. 2. This finding nevertheless is in line with studies of the African historiography that downplays the role of national institutional structures, stressing instead the key role of ethnic-specific traits, related to the role of chiefs, culture, and pre-colonial organization. 3. Our evidence suggests that research on the role of institutions on development should move beyond average effects and examine the delicate interplay between formal institutions, state capacity, and ethnic traits.	Institutional socio-economics impact and Economic growth and development

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	Journal	Aims	Highlights/ Key Findings	Domain
(Urbano, Aparicio, and Audretsch, 2019)	Small Business Economics	This paper analyzes an emergent stream of research shedding light on the institutional factors shaping entrepreneurial activity and its effect on economic growth. This integrative analysis spanning a broad spectrum of diverse literature enables a distinction between two different research lines in the field of entrepreneurship	1. Some scholars have analyzed the determinants that encourage entrepreneurial activity. On the other, entrepreneurship research has focused on the effects of new business creation. 2. The idea that institutions shape human behavior in order to enhance economic growth, we explored the papers that analyze how institutional factors through entrepreneurial activity affect economic growth. 3. Through quantitative and qualitative techniques, the authors conclude that institutions affect entrepreneurship, but informal institutions have a higher and more positive effect than formal institutions. 4. To consider an integrated model including institutions, entrepreneurship, and eco nomic growth could advance research in the entrepreneurship and economic fields. Also, this model permits distinguishing by type of institution (formal, informal, etc.), entrepreneurial activity (necessity, opportunity, etc.), and economic performance (growth, development, etc.).	Institutional socio-economics impact and Economic growth and development
(Williams and Horodnic, 2016)	Entrepreneurship and Regional Development	The aim of this article is to further advance this institutional approach by evaluating the varying degrees of informalization of entrepreneurs and then analyzing whether lower levels of formalization are associated with higher levels of institutional asymmetry.	1. This article has thus provided the first known study to enumerate and explain the degree of formalization of entrepreneurs and the characteristics of entrepreneurs displaying varying degrees of formalization. 2. The major contribution of this article is that it reveals that reducing the asymmetry between the formal and informal institutions will improve the level of formalization of entrepreneurs.	Institutional socio-economics impact and Regional Development / urban economics

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	Journal	Aims	Highlights/ Key Findings	Domain
(Alesina and Angeletos, 2005)	Journal of Monetary Economics	We formalize these insights in a simple dynamic model based on three key ideas. The first is that bigger governments increase the private gains from corruption, lobbying, and other forms of rent seeking. The second is that the distribution of these gains is uneven in the population. The third is that societies consider inequality originating in corruption and rent seeking more unfair than inequality originating from productive effort and market competition.	1. The main message of our analysis is that redistributive and regulatory policies intended to reduce inequality or improve the fairness of economic outcomes may bring about even more opportunities for corruption. This creates a policy dilemma: a small government does not correct enough for market inequalities and injustices; a large government increases corruption and rent-seeking.	Crime, Police or Corruption and Economic growth and development
(Williams and Shahid, 2016)	Journal of Economic Surveys	In this paper, we offer a comprehensive and updated review of the impact of fiscal decentralization on the economy, society and politics. Our first target is the examination of two crucial and yet unsolved issues in the empirical literature on decentralization: the proper measurement of decentralization itself and its potential endogeneity in econometric estimates.	1. It reveals that squeezing all enterprises and entrepreneurs into one side or the other of an informal/formal dichotomy fails to recognize that the majority operate in both fields; 2. It reveals the strong association between the level of informality and the characteristics of entrepreneurs and enterprises, showing that in Lahore higher levels of formality are associated with women, older age groups, those with higher levels of education 3. Third contribution is that it reveals that the motives of entrepreneurs and the wider formal and informal institutional compliance environment has relatively little influence on the level of informality compared with the characteristics of entrepreneurs and enterprises.	Regional Development / urban economics and Economic growth and development

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	Journal	Aims	Highlights/ Key Findings	Domain
(Warner and Clifton, 2014)	Cambridge Journal of Regions, Economy and Society	Mobilizing Polanyi's concept of double movement, we analyze how marketisation of public services both creates and constrains the potential for urban counter movements in the USA and Europe.	1. Cities are on the frontline as the crisis has accelerated a renewed wave of market-oriented policy for service delivery. 2. We see in these urban strategies the continued evolution of Polanyi's double movement at work. In the USA local government 'riding the wave' shows acquiesce to market but an attempt to harness it, which, ironically may further enhance marketisation. 3. Cites in the EU may respond to citizen resistance by harnessing the market, but that will lead to more marketisation. So, in the end marketisation will continue to penetrate cities but the double movement offers creative opportunities for city response.	Institutional socio-economics impact and Regional Development / urban economics
Stuetzer et al., 2016	European Economic Review	We aim to explain current regional variation in entrepreneurial activity and culture with the historical presence of large-scale industries during the Industrial Revolution in Great Britain.	1. We have shown that the presence of large-scale industries in British regions in the 19th century negatively affects entrepreneurial activities and entrepreneurship culture in recent times. Thereby, 2. Thus, the presence of large-scale industries during the Industrial Revolution in Great Britain seem to have left a long-term imprint that negatively affects different aspects of entrepreneurship, entrepreneurship culture and the actual entrepreneurial activities, even after the large-scale industries have lost their dominating role in the regional economy.	Institutional socio-economics impact and Regional Development / urban economics

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	Journal	Aims	Highlights/ Key Findings	Domain
(Harbi and Anderson, 2010)	Journal of Socio-Economics	Our aim is to estimate the relationship between entrepreneurship and the institutional context from different countries over different periods of time	1. Perceived corruption Our findings imply that when the perceived corruption index increases (which means that when business men and analysts perceive that the business becomes cleaner and more free from corruption), the self-employment rate decreases. 2. Investment freedom When investment freedom, which is related to foreign investment policy, increases, the self-employment rate increases too. 3. Perceived corruption The perceived corruption index is positively related to patented innovation; that is when the perceived corruption index increases (i.e. the economy is seen as very clean) patented innovation increases too.	Institutional socio-economics impact and Economic growth and development

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	Journal	Aims	Highlights/ Key Findings	Domain
(Neyapti, 2010)	European Journal of Political Economy	The current paper is the first to investigate the effect of FD on government budget deficits in a panel sample, explicitly accounting for the structural and institutional factors that the literature suggests affect this relationship.	1. The research on the relationship between socio-economic variables and fiscal decentralization (FD) has been rather inconclusive about the benefits of FD; 2. The evidence that has been presented reveals a significant negative effect of fiscal decentralization on deficits. 3. the evidence also reveals that country characteristics and institutional features significantly influence the effectiveness of fiscal de-centralization in reducing deficits. 4. While expenditure decentralization is more effective in case of low degrees of ethnolinguistic fractionalization and governance, these features do not seem to influence the effectiveness of revenue decentralization. 5. FD also seems to be more effective in the absence of local elections.	Institutional socio-economics impact and Regional Development / urban economics
(Oort et al., 2012)	Journal of Economic Surveys	In this paper, we argue that addressing the micro–macro level heterogeneity and interrelationships – basically, questioning which types of firms profit from which types of agglomeration economies – is served by multilevel modeling. Furthermore, we argue that these insights help to clarify the agglomeration–performance ambiguity.	1. We have shown that multilevel analysis provides an analytical tool to assess the extent to which a link exists between the macro level and the micro level. 2. Our two case studies show that cross-level interactions and cross-classified (multiple membership) variants of the multilevel model have considerable advantages over other estimation methods (e.g., spatial econometrics) in capturing the firm- and context-level heterogeneity in firm performance.	Institutional socio-economics impact and Economic growth and development

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	Journal	Aims	Highlights/ Key Findings	Domain
(Du, Lu, and Tao, 2012)	Journal of Asian Economics	Using an extensive data set on foreign invested enterprises (FIEs) in the Chinese mainland, we compare the sensitivities of the location choice of foreign direct investment (FDI) from six major source countries/areas (Hong Kong, Taiwan, US, EU, Japan and Korea) toward the variation in the strength of economic institutions across China's regions.	1. Foreign direct investment by multinationals of developed countries/areas has been shown to be important for transition economies as well as developing economies, for it brings capital, advanced technologies, and management know-how. 2. We find that FIEs from the source countries/areas that are culturally more remote from China often exhibit a stronger aversion to regions with weaker economic institutions. Moreover, this pattern is slightly more salient when FDI takes the form of fully-owned	Institutional socio-economics impact and Economic growth and development
(Pham and Talavera, 2018)	World Development	This paper examines the relationship among gender, social capital, and access to finance of micro, small, and medium enterprises in the manufacturing sector in Viet Nam. Our	1. In contrast to our expectations, we do not observe the disparity in the number of loan applications made by female- and male-owned firms. 2. We also find that the likelihood of female-owned firms obtaining a bank loan is higher than the male-owned ones. Moreover;	Institutional socio-economics impact and Regional Development / urban economics
(Winston, 2013)	Journal of Economic Literature	Assess the performance of the transportation system and consider how it could be improved by analyzing whether the United States has the optimal mix of public and private provision.	1. Transportation is friction—a cost in both money and time—that must be incurred by individuals and firms to complete almost any market transaction. 2. Transportation economics could greatly advance its standing among economists and with the engaged public by broadening its perspective and cross-fertilizing with other fields to explain more fully how transportation affects labor markets, urban and regional economies, international trade patterns, and industry competition.	Institutional socio-economics impact and Regional Development / urban economics

The third table connects our serialization in two domains with the stated aim of the study and its main findings. Starting with a shallow overview of the papers and their selected domains, we realize that the distribution at this restricted level follows the one at general's, being Institutional socio-economics

impact and Regional Development / urban economics the domain with more documents in both absolute and highest citation analysis. Besides the first, the second domain with more articles in overall also follows the same trend. From a major concept point of view, we stress three main topics, Decentralization (both fiscal and regional), Foreign Direct Investment, and Corruption.
Especially related to government size and structure and their governance, the concept of decentralization was particularly relevant and frequent in this SLR. The institutional approach and impact and the regional perspective allowed the concept to gain notoriety. Also, corruption played an important role due to its reciprocate effect on decentralization.
Foreign Direct Investment is a remarkable indicator of the world's perception of a country in a holistic way. Besides its steady numbers, its variation works like a sovereign credit rating where investing countries and entities look for AAA places to allocate their capital.
The last one, corruption is strongly related to the previous concepts and can be measured using them both. For instance, remembering that Foreign Direct Investment consists of the amount of capital that is invested at a specific time from a foreign country, we can easily agree that a country with a lower perception of corruption index is more likely to receive more monetary units and more frequently than one with a higher index.
On the other hand, and according to several papers, such as Baskaran, Feld, and Schnellenbach, 2016 and Xu, 2011, the government's size and public/ private employment ratio are good reflections of the local administration's inefficiency as well as the effects of a corrupted system.

5.4 Discussion

This study aims to access and analyze the issue of reported crime with economic concepts and perspectives on a regional/local level. The dependent variable on this theoretical method was crime as a social concept (not looking to distinguish between any sorts of its manifestations). The chosen independent ones were economic growth and development, regional development/ urban economics, and institutional and social economics.
These variables and concepts, according to our prior beliefs and also, to this SLR assessment, are strongly related, and this last chapter will focus on framing an answer to our research question using the same four pillars.

5.4.1 Crime's Fallacy

Nowadays, the most common economic view of crime is corruption-related, even when a regional filter is added. This lack of concerning other types of illicit manifestations and their impact, is in our perception the most fertile ground for future endeavors, as stated in our agenda.
Due to its characteristics, as a social phenomenon, we should always address the statistical number/ index of some reality as a part number. For instance, if the reader finds an article that presents the level of informality of Lahore's entrepreneurs', it is strongly recommended that, besides the presented trends, and absolute figures, the reader takes a step back and realizes that is quite possible that he is not looking to the utopic full picture, but analyzing a good sample of it (Williams and Shahid, 2016).
This recommendation is even stronger when violent or property crimes are dissected, where or when fear of retaliation, lack of trust, or just disinterest are enough to prevent the victim from filing a criminal complaint (Jennings, Farrall, and Bevan, 2012). Still, regarding victims and criminal charges, it's also quite difficult to have a clear perception when the victim is the State. For instance, it's easier to have someone

blowing the whistle about some theft or burglary, than about buying cheaper gas or purchasing something without paying valued added tax.
Besides the incident, a criminal event has several spillover effects that are both causes and consequences of the environment around the crime scene. This means that according to our research for some occurrences it's possible to establish some causal connections and realize why the place was, in fact, an environment that somehow fostered those behaviors or events. The usual connections go around lower income areas, inequality, lack of social ties, agglomeration of non-native residents in small areas, and non-efficient public policies (concerning both social, policing, and repression measures).

5.4.2 Economic Growth and Development

Inequality, as a consequence of lack of development, is one of the most acknowledged crime catalyzers. One way to prevent it is to invest in inclusive growth (Ajide, Osinubi, and Dada, 2021). This path leads to fewer asymmetries among the population, and by doing that, works on two different crime vectors. First and in theory, with more development and less inequality, there will be less need to commit a crime to satisfy any need. Second, with less inequality, there will also be less appropriate environments that foster that kind of behavior and events (for instance, the likelihood of more public policies towards less inequality and more sustainability).
Nowadays profit-driven crime works like entrepreneurship, by analyzing the context, using the available resources, lack of offer or/ and innovative procedure, particularly when the talk is about organized crime (Calderoni and Superchi, 2019). These characteristics together with the current means of transport and communication make it extremely hard for law enforcement agencies to gather evidence of its methods and means. Knowledge, as well as the new means of communication and transport, had, too a strong impact on crime "quality" (Griffiths and Norris, 2020). Tv shows like CSI, COPS, Law and Order, and so on, had made the general audience aware of police investigation techniques and methods (like wiretaps, undercover units, surveillance routines, etc), which beyond entertaining the prime time, also increase the general perception of police work.
Lack of development can also have other consequences, especially regarding public services, and corruption (Peiffer et al., 2019). This effect of less development will be one of the topics of the next section.

5.4.3 Institutional and Social Economics Impact

Institutions adjust to their environmental society, and vice-versa. Accordingly to Batinti, Costa-Font, and Hatton, 2021, the spread of democracy in European countries since the middle of the 19th century was enough to ensure an increase in health care measured variables. Another example of this type of interaction is stated in a recent paper from Madanipour and Thompson, 2020, where they examine the combinational effects of globalization, wealth, democracy, political stability, and legal efficiency on the perception of state corruption among the OECD's members (Organisation for Economic Co-operation and Development). Similarly but different is the Kingston 2014 study, where he highlights the public effort to keep up with the private dynamic like in the early days of maritime insurance.
Besides interacting, there is also a strong impact from non-state actors (Calderoni and Superchi, 2019) and (Bel and Holst, 2018), with repercussions between and beyond a country's borders. A good example of this are the Italian mafia-type organizations and the South American drug cartels.
After this background, it's easy to realize the impact between all actors, state or not state. As a conclusion of this section, we will focus on two types of organizations, Law enforcement agencies, and criminal organizations.

Law enforcement agencies are the first line against crime, in both first response and investigation points of view. However, when the scope is prevention/precaution and deterrence, it opens space for several institutions to work as a complement to a country's both judiciary and Law enforcement systems. This ecosystem (also connected with social care and contract concepts, (Sobhy, 2021)) allows a public (from the state) response to a crime event aiming to work on the victim, offender, and, if suitable, environment. On the other hand, when they have a substantial degree of development,[4] criminal associations become an organized crime and besides the direct link to the safety and security index and measurements, Bove and Gavrilova, 2017 and Weisburd, 2019, they also have an impact on a countries economic performance, foreign investment, and citizens' life quality. Consequences that make it imperious for the state to target these deviant manifestations (Bovenkerk, 2011).

5.4.4 Regional, Space, and Territorial context

In 2016, Edmund Soon-Weng Yong published a book titled "I Contain Multitudes," which explores the human microbiome and its profound influence on various aspects of life. This captivating book not only provides an engaging read but also offers an opportunity for comparison. Just as living organisms exhibit certain behaviors regardless of scale, territorial units display similar characteristics. By drawing upon this analogy, we can present our line of argument.

Yong's analysis involved examining samples from diverse animals across different regions. Through data processing, he established connections between dietary choices, environmental factors such as cold temperatures and humidity levels. Similarly, when we adopt a spatial/regional/territorial perspective, we uncover intricate relationships that manifest in concepts like agglomeration economy, clusters, transportation, and urban economics. These concepts can be seen as consequences resulting from a multi-level dissection of reality, much like Russian nesting dolls.

The Russian doll analogy highlights the idea that territorial units, irrespective of their scale, behave akin to living organisms. Just as diverse ecosystems can exist within the human stomach or skin, teeming with various organisms and their interrelations, a shift in scale allows us to analyze the entire individual in relation to the environment and other individuals. The same principle applies when examining regions, where we can comprehensively evaluate a neighborhood with a wealth of data or expand the perspective to cities, districts, regions, countries, and even supranational entities.

Another important insight from this biological lens is the notion of ecosystem balance or equilibrium. Just as a flu virus can impact an entire nation of poultry, the decrease in steel production and sales in Eastern Europe can drive up construction costs in the Portuguese city of Fundão. This observation aligns with the magnetism behavior exhibited by regions, where larger regions tend to exert more influence and attraction, including illicit activities. This dynamic resonates with Walter Christaller's Central Place Theory to some extent.

Furthermore, this study underscores the understanding that space and environment extend beyond mere physical containers; they interact with various features and inputs within and around them. Consequently, it is not surprising that they shape economic dynamics. To examine and assess our theoretical premises, a research agenda will be presented in the subsequent section.

[4] Meaning a certain number of associated members (more than three in most European countries), hierarchical structure, and a clear purpose of the entity for generating income through crime events.

5.5 Research Agenda and Future Investigation Endeavours

This study establishes a robust theoretical framework that is ready for empirical testing and validation using real-world data. In line with the four pillars of the Systematic Literature Review (SLR) conducted, we propose a potential research agenda to explore the interrelationships between various factors. This agenda begins with a comprehensive analysis of global-level data, incorporating macroeconomic indicators, social indicators, quality of life measures, crime reports, crime rates, and other relevant variables. The objective is to identify connections between development and violent crimes, growth and property crimes, as well as the association between healthcare resources such as hospital beds and ventilators with community policing units and programs.

Building on this macro perspective, we can proceed to perform an in-depth analysis and comparisons within individual countries, focusing on their regional organization, such as the Nomenclature of Territorial Units for Statistics (NUTS). This approach allows for tailoring and designing specific policies and measures for each spatial unit, aligning with our goal of achieving the desired end state.

An alternative avenue to explore involves spatial regression analysis, which would enable a more targeted examination of crime occurrences and the underlying factors influencing them. Conversely, employing spatial logistic regression could provide valuable insights into understanding the determinants of crime. Additionally, it may be worth considering presenting the main findings of this research to local authorities through interviews or inquiries. This approach serves the dual purpose of gathering their perspectives on reality and engaging in a meaningful discussion about the practical implications of our research and its potential contributions to policy measures.

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Chapter 6

Insights on Animal Spirits

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Summary
Given the significance of behavioral insights on public policies and markets, this study aimed to explore the bidirectional impacts among Twitter-based Uncertainty Index (TEU), Standard and Poor's 500 valuations, and the prices of Gold and Oil during the COVID pandemic and the Russo-Ukrainian War. The impact of uncertainty on the aforementioned dimensions has been examined. Yet, the dynamics between uncertainty and other variables across distinct periods warrant further investigation (Alamah, Elgammal, and Fakih, 2024). Additionally, analyzing how the S&P 500 valuation, along with Gold and Oil prices, influence the uncertainty reflected in Twitter sentiment, represents an innovative facet of this chapter. In this sense, Lag-Augmented VAR (LA-VAR) regression was applied. The findings indicate bidirectional effects only during the Covid pandemic crisis. Furthermore, no effect of S&P 500 valuation, Gold and Oil prices on the uncertainty was verified in both periods.
Keywords: Animal Spirits, Gold, Oil, S&P 500, Twitter-based Uncertainty Index

6.1 Introduction

According to OECD, 2017 behavioral insights have been considered by policy makers around the world in order to promote more efficient public policies. In this sense Keynes, 1936, p. 161 indicated that "even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than on a mathematical expectation, whether moral or hedonistic or economic. Most, probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as a result of animal spirits - of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities." Hence, the concept of animal spirits plays a crucial role in the formulation of public policies due to its influence, notably on business cycles as outlined by Chatterjee and Milani, 2020, by affecting the facets of aggregate demand (Barsky and Sims, 2012), including investment activities in general (La Cava, 2023; Lainé, 2021), and stock market behaviors in particular (Ilomäki and Laurila, 2018). Given the inadequacy of market mechanisms to fully address the complexities associated with animal spirits, the literature has

emphasized the significant role that governments play (Akerlof and R. Shiller, 2010).

Conversely, dimensions such as beliefs and uncertainty play a role in shaping animal spirits, as explored by various scholars (Azariadis, 1981; Benhabib and Farmer, 1994; Brock and Hommes, 1997; Cass and Shell, 1983; De Grauwe, 2011; Farmer and Guo, 1994; Lainé, 2022). La Cava, 2023 evidenced the relevance of uncertainty in different circumstances such as economic crisis. Paradoxically, recent studies indicated that confidence is an important transmission channel of uncertainty (Chatterjee and Milani, 2020; Ha and So, n.d.; Lainé, 2022). This uncertainty can come from different noise-generating information sources, which raise the psychological shocks effects on asset prices (Berardi, 2022). R. J. Shiller, 2021 highlighted that even the way that information is transmitted (its narrative) may have an impact on animal spirits and economic decisions. Lainé, 2022 evidenced the high level of contagion of emotions in financial markets. Consequently, financial decision-making is rooted in intricate neurophysiological processes that encompass elements like cost-benefit analysis and emotional responses (Bossaerts, 2009), including panic (Consoli, Pezzoli, and Tosetti, 2021). Within this framework, uncertainty is perceived as a condition marked by fear, thereby increasing the attention towards risks (Bagneux, Font, and Bollon, 2013). Uncertainty emerged during crises generally raises the level of investors' caution (Khalfaoui et al., 2022).

Given the significance of behavioral insights on public policies and markets across various contexts as discussed, this study aims to explore the bidirectional impacts among Twitter sentiment (reflecting uncertainty), Standard and Poor's 500 (S&P 500) valuations, and the prices of Gold and Oil during the COVID pandemic and the Russo-Ukrainian War. The impact of uncertainty on the aforementioned dimensions has been examined, as highlighted in the literature review. Yet, the dynamics between uncertainty and other variables across distinct periods warrant further investigation (Alamah, Elgammal, and Fakih, 2024). Additionally, analyzing how the S&P 500 valuation, along with Gold and Oil prices, influence the uncertainty reflected in Twitter sentiment, represents an innovative facet of this chapter. Subsequent sections include a literature review, data and methodology, results, and a discussion.

6.2 Literature Review

Recent research has underscored that economic uncertainty, particularly during crisis periods like the COVID pandemic, plays a significant role in the volatility of company valuations, including those within the S&P 500 (Choi, 2020). Cash reserves are crucial for a company's ability to respond to geopolitical events (Alam, Devos, and Feng, 2023). Choi, 2020 also notes that various crises impact stock volatility in distinct ways.

In respect of social media information, it has an impact on investors behaviors and stock prices (W.-Y. Chen and M.-P. Chen, 2022; Jabeen et al., 2022; Liang et al., 2020). According to Fan, Talavera, and Tran, 2020 the discord in Twitter messages during Donald Trump's presidency may be associated with price volatility in the stock market. The importance of such information channels warrants further investigation, especially given the increasing frequency of social media's impact on the stock market in recent years (Van Dieijen et al., 2020).

Market sentiment has also been linked to Gold (Shen et al., 2017) and Oil markets (Polyzos, 2023; Shen et al., 2017). Gold, recognized for its "safe haven properties" (Elsayed, Gozgor, and Lau, 2022), is also affected by uncertainty (Balcilar, Gupta, and Pierdzioch, 2016). (Beckmann, Berger, and Czudaj, 2019) found that fluctuations in gold prices were positively correlated with economic policy uncertainty. Moreover, sentiments expressed on Twitter, such as happiness, have been shown to influence Gold prices (Swamy and Lagesh, 2023). Aysan et al., 2023 discovered that the correlation between the Twitter-based economic

uncertainty index (TEU) and both Gold and Oil is evident even in virtual reality environments. Furthermore, Arfaoui and Ben Rejeb, 2017 have noted associations between the prices of oil and gold.

Uncertainty is similarly critical in the context of climate change markets (Khalfaoui et al., 2022). Specifically, regarding oil prices, policy uncertainty has been shown to have a clear linkage with this sector (Kang and J. Wang, 2018). The relationship between stock and oil markets, particularly how the former influences oil prices, has been documented by researchers such as Piñeiro-Chousa et al., 2018 and Oberndorfer, 2009. Conversely, fluctuations in oil prices negatively impact stock returns (Joo and Park, 2021; Xiao and Y. Wang, 2022; Wen et al., 2022). Arfaoui and Ben Rejeb, 2017 identified a connection between oil and stock returns in emerging markets. Yet, this relationship varies over time; for instance, during the Covid pandemic period, the oil market's influence on stock returns diminished (Z. Zhang and Y. Zhang, 2022). Other studies have also highlighted the interconnections among S&P 500 valuations, and Gold and Oil prices (Basher, Haug, and Sadorsky, 2011; Jones and Kaul, 1996; Miller and Ratti, 2009; Mollick and Assefa, 2013; Tang and Xiong, 2012; Z. Zhang and Y. Zhang, 2022; Jabeen et al., 2022). Given these considerations, this chapter proposes two hypotheses:

- **H1**: TEU-USA, S&P 500 valuation, Gold and Oil prices presented bidirectional effects during the Covid pandemic crisis.
- **H2**: TEU-USA, S&P 500 valuation, Gold and Oil prices presented bidirectional effects during the Russo-Ukrainian War.

6.3 Data and Methodology

This study analyzed the daily values of the Twitter-based Uncertainty Index (TEU-USA), Oil, Gold, and S&P 500 during the Covid pandemic period (from January 1, 2020, to February 20, 2022) and the Russo-Ukrainian War (from February 21, 2022, to April 21, 2023). The TEU-USA represents the frequency of Twitter users in the United States mentioning the word "uncertainty" in English. This information was sourced from the EPU website . For the S&P 500, daily valuations were considered, while the study focused on the daily market prices for Oil and Gold (Table 6.1).

Variable	Database	Description
TEU-USA	EPU	Daily value
S&P 500	Bloomberg	Daily value
Oil	Bloomberg	Daily value
Gold	Bloomberg	Daily value

Table 6.1: Variables

The effect of causality in economic terms can be studied using econometric methodologies. The validation of hypotheses about whether the variable X_{2it} has a causal relationship with Y_{it} uses econometric tests to test the proposed hypotheses. In this study, it was used the methodology developed by Shi, Phillips, and Hurn, 2018 which makes it possible to ascertain the direction of causality between the

variables studied in the model. To achieve this, we applied the Lag-Augmented VAR (LA-VAR), where we assumed a two-variable model Y_{it} and X_{2it}, the LA-VAR regression can be described as follows:

$$Y_{it} = \alpha_{10} + \alpha_{11,t} + \sum_{i=1}^{k+d} \beta_{1i} Y_{1i-t} + \sum_{i=1}^{k+d} \delta_{1i} Y_{2i-t} + \epsilon_{1t} \tag{6.1}$$

$$X_{2it} = \alpha_{20} + \alpha_{21t} + \sum_{i=1}^{k+d} \beta_{2i} X_{2i1t-i} + \sum_{i=1}^{k+d} \delta_2 i X_{2t-i} + \epsilon_{2t} \tag{6.2}$$

with k being the lag and d the maximum order of integration (Raifu, 2022).

Causality relationships can be affected by various factors. When this is the case, the causality test is carried out on the entire sample and the statistical model presented by Shi, Phillips, and Hurn, 2018 is applied. The null hypothesis of Wald's test posits that X_{2it} has no causality in Y_{it} and can be expressed as $H_0 : X_{2it} \not\to Y_{it}$ or $H_0 : \delta_{11} = \ldots \delta_{1k} = 0$ (Shi, Phillips, and Hurn, 2018; Shi, Hurn, and Phillips, 2020). In the LA-VAR model, which is commonly employed for such analyses, the structure is generally described as follows:

$$y_t = \gamma_0 + \gamma_1 t + \sum_{i=1}^{k} J_i y_{t-1} + \sum_{j=k+1}^{k+d} J_i y_{t-j} + \epsilon_t \tag{6.3}$$

In which, $J_{k+1} = \ldots = J_{k+d} = 0$ together with d represents the maximum order of integration of the dependent variable (Shi, Hurn, and Phillips, 2020). This equation can be written as

$$y_t = \Gamma \tau_t + \Phi x_t + \psi z_t + \epsilon_t \tag{6.4}$$

$$\Gamma = (\gamma_0, \gamma_1)_{n \times (q+1)} \tag{6.5}$$

$$\tau_t = (1, t)'_{2 \times 1} \tag{6.6}$$

$$x_t = (y'_{t-1}, \ldots, y'_{t-k})'_{nk \times 1} \tag{6.7}$$

$$z_t = (y'_{t-k-1}, \ldots, y'_{t-k-d})'_{nd \times 1} \tag{6.8}$$

$$\Phi = (J_1, \ldots, J_k)_{n \times nk} \tag{6.9}$$

$$\Psi = (J_{k+1}, \ldots, J_{k+d})_{n \times nd} \tag{6.10}$$

The alternative hypothesis of Granger Non-Causality is given by the constraint $H_0 : R\emptyset = 0$ (Shi, Hurn, and Phillips, 2020). The null hypothesis for Wald's test $H_0 : X_{2it} \not\to Y_{it}$ or $H_0 : \delta_{11} = \ldots \delta_{1k} = 0$ asserts that the coefficients associated with X_{2it} in the lag matrices (β_j) are jointly equal to zero, indicating no causality between X_{2it} and Y_{it} (Shi, Phillips, and Hurn, 2018; Shi, Hurn, and Phillips, 2020). Consequently, the Wald statistic W is used to test the hypothesis (Shi, Hurn, and Phillips, 2020).

$$W = \left[\vec{\hat{\Pi}}\right]' \tag{6.11}$$

The row $\vec{\hat{\Pi}}$ corresponds to a $2(2p+1) \times 1$ vector containing coefficients derived from the matrix $\hat{\Pi}$. The matrix R is defined as a $p \times 2(2p+1)$ matrix. The determination of the maximal forward expanding

(FE) involves extracting the first row of matrix R, while the maximal rolling (RO) is identified by isolating the largest factor present in the principal diagonal of R. Finally, the maximal recursive evolving (RE) is characterized as the most substantial component within the integrated upper triangular matrix (Baum, Hurn, and Otero, 2022). The three supremum Wald tests are capable to check time-varying causality between the variables, through the equation $SW_f(f_0)(f_1, f_2) \in \Lambda_0, f_2 = fW_{f^2}(f_1)$ (Raifu, 2023).

6.4 Results

Table 6.2 displays the Pearson correlation coefficients depicting the relationships among variables across Models 1 in 2 periods: Covid pandemic and Russo-Ukrainian War. The correlation analyses conducted for Models 1 and 2 across three distinct periods reveal varying degrees of linear associations among the variables. Notably, a moderate positive correlation of 0.5861 is observed between S&P 500 Index and Oil Price, while comparatively weaker positive correlations exist between S&P 500 Index and Gold Price (0.6272) as well as Oil Price and TEU USA (0.3589). However, these associations do not present substantial interdependencies.

Covid pandemic				
Model 1				
	S&P 500	Oil Price	Gold Price	TEU-USA
S&P 500	1			
Oil Price	0.9142^{***}	1		
Gold Price	0.3164^{***}	0.0798^{**}	1	
TEU-USA	-0.7925^{***}	-0.8003^{***}	-0.2356^{***}	1
Russo-Ukrainian War				
Model 1				
	S&P 500	Oil Price	Gold Price	TEU-USA
S&P 500	1			
Oil Price	0.3029^{***}	1		
Gold Price	0.6240^{***}	0.069	1	
$TEU - USA$	-0.3890^{***}	-0.5162^{***}	-0.1929^{***}	1

Note: *** 99% confidence, ** 95% confidence, * 90% confidence.

Table 6.2: Model 1

As shown in Table 6.3, during the Covid crisis, the S&P 500 has a positive and significant effect on the price of oil, and the price of oil also positively and significantly influences the S&P 500. The price of gold does not significantly influence any of the variables. On the other hand, the TEU-USA positively

and significantly influences the S&P 500. During the period of the war in Ukraine we find some changes in bilateral relations: the price of oil positively and significantly impacted the valuation of the S&P 500 and the price of Gold, and the TEU-USA positively influenced the S&P 500 and the price of oil. The other variables do not show relationships that are considered significant.

Covid pandemic		**Russo-Ukrainian War**	
Model 1	χ^2	Model 1	χ^2
S&P 500 - Oil Price	21.482^{***}	S&P 500 - Oil Price	1.4806
S&P 500 - Gold Price	2.1821	S&P 500 - Gold Price	4.4668
S&P 500 - TEU-USA	3.0223	S&P 500 - TEU-USA	1.969
S&P 500 - All	50.513^{***}	S&P 500 - All	14.27
Oil Price - S&P 500	12.421^{***}	Oil Price - S&P 500	11.647^{**}
Oil Price - Gold Price	4.3602	Oil Price - Gold Price	9.4324^{**}
Oil Price - TEU-USA	3.0801	Oil Price - TEU-USA	2.6824
Oil Price - All	38.787^{***}	Oil Price - All	27.152^{**}
Gold Price - S&P 500	2.0071	Gold Price - S&P 500	7.277
Gold Price - Oil Price	4.9207	Gold Price - Oil Price	4.1749
Gold Price - TEU-USA	7.2596	Gold Price - TEU-USA	1.4735
Gold Price - All	16.87	Gold Price - All	17.632
TEU-USA - S&P 500	12.418^{***}	TEU-USA - S&P 500	8.4525^{*}
TEU-USA - Oil Price	2.6902	TEU-USA - Oil Price	9.4649^{**}
TEU-USA - Gold Price	4.9995	TEU-USA - Gold Price	3.8807
TEU-USA - All	50.988^{***}	TEU-USA - All	31.067^{***}

Note: *** 99% confidence, ** 95% confidence, * 90% confidence.

Table 6.3: Time Varying Granger causality - Wald tests Model 1

6.5 Discussion

The primary findings of this research highlight significant links between uncertainty and stock markets, and, notably in the final period, the price of gold. Regarding the hypotheses, H1—which posited bidirectional effects during the Covid pandemic crisis—was partially validated: a bidirectional relationship was observed between the S&P 500 and Oil price. Additionally, TEU-USA exerted a significant influence on the S&P 500. As for hypothesis 2, pertaining to the Ukrainian War period, Oil price had an impact on both the

S&P 500 and Gold price. TEU-USA influenced the S&P 500 and Oil price.

More specifically, in the Covid pandemic period, the results indicated that uncertainty on Twitter was significantly associated with capital flows towards S&P 500 stock index and, consequently, its valuation. During this period, the degree of uncertainty did not have a significant effect on both the price of Oil and Gold, as expected. In the latter case, these findings align with the theoretical notion that Gold serves as a haven for stock investors, particularly as Gold and stock markets often exhibit opposing movements (Elsayed, Gozgor, and Lau, 2022). The results concerning Oil can be attributed to shifts in economic production during the Covid period, which even led to a negative variation in Oil futures prices.

In the case of the Russo-Ukrainian war period, the relationship of uncertainty with S&P 500 remained significant. This can be linked to the observation that large companies with substantial cash reserves are better equipped to navigate crises (Alam, Devos, and Feng, 2023). The absence of a significant relationship between Gold price and uncertainty on Twitter was also confirmed. The dynamic of uncertainty's relationship changed between the Covid and Russo-Ukrainian War periods, particularly in its association with Oil price. Unlike during the Covid pandemic, Oil price was significantly and positively impacted in the latter period, likely due to the escalation in energy prices, especially since Russia, one of the world's largest Oil producers, was involved. The higher volatility demonstrated by Oil indexes during the Russo-Ukrainian War has been reflected in different indexes such as West Texas Intermediate WTI (Shaik et al., 2023). No further significant relationships were founded. Thus, no effect of S&P 500 valuation, Gold and Oil prices on the uncertainty was verified.

In this study, the significance of uncertainty to the stock market was affirmed and observed to a lesser extent in the case of Oil. This configuration heterogeneity is in line with previous studies (such as Jones and Kaul, 1996; Aouadi, Arouri, and Roubaud, 2018; Mollick and Assefa, 2013) which indicated that the interaction between assets can present different relationships in different economic periods. Contributing factors to these findings include certain markets' heightened sensitivity to tweets about conflicts (Gjerstad et al., 2021)and their increased latency in reacting to information shared on Twitter (Polyzos, 2023).

Recent research has demonstrated that shocks in Economic Policy Uncertainty (EPU) have impacted Oil, Gold, and stock markets during periods of crisis (Elsayed, Gozgor, and Lau, 2022), suggesting the importance of policy formulation and implementation in managing uncertainty. Governments possess various mechanisms to mitigate market uncertainty, as well as Central banks (Annicchiarico, Di Dio, and Diluiso, 2024).

The primary limitations of this chapter stem from the temporal closeness of the two periods analyzed, which obstructs the full separation of each crisis's effects. Moreover, to homogenize the periods in the economic cycle analysis poses significant challenges. Finally, the two periods under consideration do not contain an equal number of observations.

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Chapter 7

On the Economics of Moral Behavior

Michelle Lins de Moraes, Renato Domingues, Giulia Fantini, and Luiz Biondi

Summary
Moral Behavior has emerged as a focal point of inquiry across diverse domains, reflecting its pervasive influence on individual and societal dynamics. Given the multifaceted nature of MB and its far-reaching implications, this chapter embarks on an introductory exploration of its scholarly discourse. The primary objective of this study was to delve into the evolution and characterization of publications on MB, examining the theoretical frameworks and dimensions considered across various disciplines. To achieve this aim, an approach that encompasses both bibliometric analyses and systematic literature review across a spectrum of scientific disciplines was adopted. The findings indicate that Moral Behavior burgeoning literature draws upon a rich theoretical framework, encompassing various dimensions such as environmental influences, moral identity formation, cognitive processes, and the intricate interplay of emotions. Emotion emerges as a salient theme underscored by both bibliometric analyses and systematic literature reviews, affirming its pivotal role in shaping MB. Delving deeper into this nexus, this study revealed a spectrum of Moral Emotion emotions, including but not limited to anger, disgust, empathy, guilt, pride, and shame, which are central to moral judgment.
Keywords: Emotion, Moral Behavior, bibliometric, systematic review.

7.1 Introduction

In the intricate tapestry of human interaction and decision-making, the traditional economic paradigm portraying individuals as isolated, self-regarding agents fails to capture the richness of social reality. Contrary to this simplistic view, scholars such as Manner and Gowdy, 2010 have argued persuasively that human behavior is deeply embedded within a complex web of social relationships. This insight challenges the academia to revaluate the understanding of individual decision-making, recognizing the profound influence of social context and the behavior of others on individual choices.

Recent studies have further underscored the importance of morality as a guiding force in our daily lives. Strikwerda-Brown et al., 2021 highlighted morality as a central aspect shaping our decision-making processes, permeating various facets of human behavior. From the seemingly mundane choices of everyday life to high-stakes decisions in business and governance, moral considerations play a significant role

in shaping our actions and interactions.

Indeed, Moral Behavior (MB) has emerged as a focal point of inquiry across diverse domains, reflecting its pervasive influence on individual and societal dynamics. At the micro level, studies have explored, for example, the role of moral considerations in guiding sustainable intentions among individuals, illuminating the interplay between personal values and environmental stewardship (Hopwood et al., 2023). At the meso level, investigations into corruption in both private and public sectors shed light on the ethical dilemmas faced by organizations and the broader implications for governance and accountability (Afzali, Colak, and Fu, 2021). Meanwhile, analyses of pricing regimes in markets revealed the intricate balance between profit-motives and ethical considerations, underscoring the complexities of moral decision-making in economic transactions (Ockenfels, Werner, and Edenhofer, 2020).

Central to the understanding of MB is the process of internalization, wherein individuals absorb and integrate social norms and ethical principles into their cognitive and emotional frameworks (Tangney, Stuewig, and Mashek, 2007). This internalization occurs through a dynamic interplay between individual aspects, societal expectations, and cultural influences, shaping the moral landscape within which individuals navigate their choices and actions.

Given the multifaceted nature of MB and its far-reaching implications, this chapter embarks on an introductory exploration of its scholarly discourse. The primary objective of this study is to delve into the evolution and characterization of publications on MB, examining the theoretical frameworks and dimensions considered across various disciplines. To achieve this aim, an approach that encompasses both bibliometric analyses and systematic literature review across a spectrum of scientific disciplines was adopted.

More specifically, it was endeavored to deepen the understanding of MB through a systematic analysis of the literature, uncovering emergent subthemes and trends identified through the bibliometric analysis. By structuring the inquiry in this manner, it was sought to provide a nuanced understanding of the complexities inherent in MB and its scholarly discourse.

Overall, this study's interdisciplinary approach and rigorous methodology provide valuable insights into the complexities of MB. The structure of this chapter unfolds as follows: we commence by delineating the data sources and methodologies utilized in our study, providing transparency and context for our analyses. Subsequently, we present the findings of our research, offering a comprehensive overview of the landscape of MB literature and the key themes that emerge. Finally, we synthesize our findings, offering insights into the implications for future studies.

7.2 Data and Methodology

The methodology employed in this study aimed to conduct a thorough investigation into the literature on MB by integrating both bibliometric analysis and systematic literature review techniques. The Web of Science (WoS) Core Collection database was selected for its widely recognized quality and extensive coverage, ensuring a comprehensive sample of relevant publications (Mulet-Forteza et al., 2019). Data collection was meticulously carried out in January 2024 to capture the most up-to-date and pertinent literature available.

In conducting the bibliometric analysis, publications were chosen based on the inclusion of the dimensions "Moral Behavior" or "Moral Behaviour" in their main topics, resulting in the identification of 1,400 records (Fig. 7.1). Additionally, for the systematic review focusing on MB literature that incorporates an analysis of emotion studies published between 2014 and 2024 were considered, in a total of 211 outputs.

VOSviewer software (version 1.6.20) was used in the bibliometric analysis, enabling the visualization

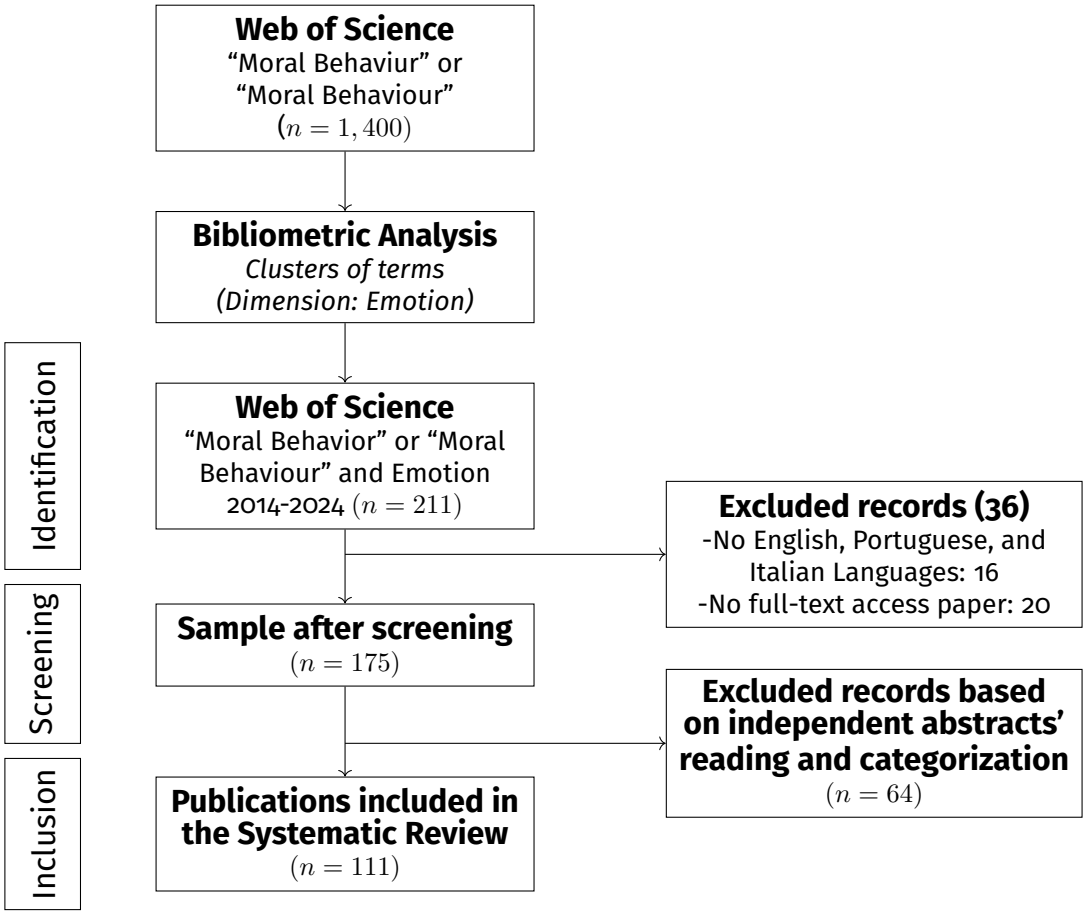

Figure 7.1: Flow Diagram

and examination of bibliometric clusters of co-citations and terms. With a minimum threshold of 20 occurrences for co-citations and 10 occurrences for terms, this approach facilitated the identification of theoretical frameworks and key themes prevalent in the literature under scrutiny.

The systematic literature review adhered to the structure outlined by PRISMA (Moher et al., 2009), ensuring transparency and methodological robustness throughout the review process. All 211 identified publications underwent screening for language and accessibility. Subsequently, studies were included based on a thorough examination of abstracts and their classification within the designated field of MB literature incorporating an analysis of emotion. During this phase, two authors independently assessed and categorized the studies. Ultimately, 111 publications met the inclusion criteria for the systematic literature review.

The research question guiding the systematic literature review was meticulously formulated as follows: "What are the primary aspects explored in this literature concerning emotion dimensions, its triggers, and outputs related to moral behaviors?" This question was designed to delve deeply into the prevalent themes and insights within the literature concerning the intricate interplay between emotion and MB. By synergizing bibliometric analysis and systematic literature review methodologies, this study aims to provide a comprehensive understanding of the multifaceted nature of MB and its complex relationship with emotion.

7.3 Results

7.3.1 Bibliometric analysis

The analysis of publications related to MB unveils a compelling trend of increasing research activity, with a noteworthy 77% of studies emerging since 2008, indicative of a growing interest in understanding the intricacies of moral decision-making (Fig. 7.2). Delving into the historical trajectory, the earliest identified study, dating back to 1952, focused on a psychological exploration of generosity across diverse demographic groups, laying foundational insights into the complexities of MB (Ugurel-Semin, 1952). Notably, Aquino and Reed, 2002 emerges as a towering figure in this literature, accruing over 1,830 citations according to WoS, underscoring its seminal influence to MB studies.

Across disciplinary boundaries, the landscape of MB literature unfolds, with Psychology emerging as the predominant domain, accounting for 47.6% of the publications. This is closely followed by contributions from Education (8.4%), Ethics (7.9%), Philosophy (6.6%), Business (5.6%), Economics (4.8%), Religion (4.6%), Neurosciences (4.4%), Computer Science (4.1%), and Management (3.9%). In terms of countries, USA taking the lead with 35% of publications, followed by England (10%) and China (8.6%), reflecting a global engagement with the subject matter.

Delving deeper into the intellectual landscape of MB, co-citation analysis reveals four main theoretical frameworks within the literature (Fig. 7.3). The green cluster, predominantly rooted in psychology, contemplated foundational studies on empathy and prosocial behavior (Eisenberg and P. A. Miller, 1987) likewise moral identity and moral functioning (Blasi, 1984). The study with the highest weight in this cluster, also mentioned in the last paragraph, presented a moral identity construct and its associations with moral thought as well as behavior (Aquino and Reed, 2002). The influence of moral emotions (Tangney, Stuewig, and Mashek, 2007) and political spectrum (Graham, Haidt, and Nosek, 2009) on MB also were observed.

Conversely, the red cluster encompasses a broader array of disciplines, ranging from biology, economics, and neuroscience, offering multifaceted perspectives on moral cognition and behavior. For instance, in behavioral biology, Trivers, 1971 discussed the occurrence of “reciprocal altruism” and how

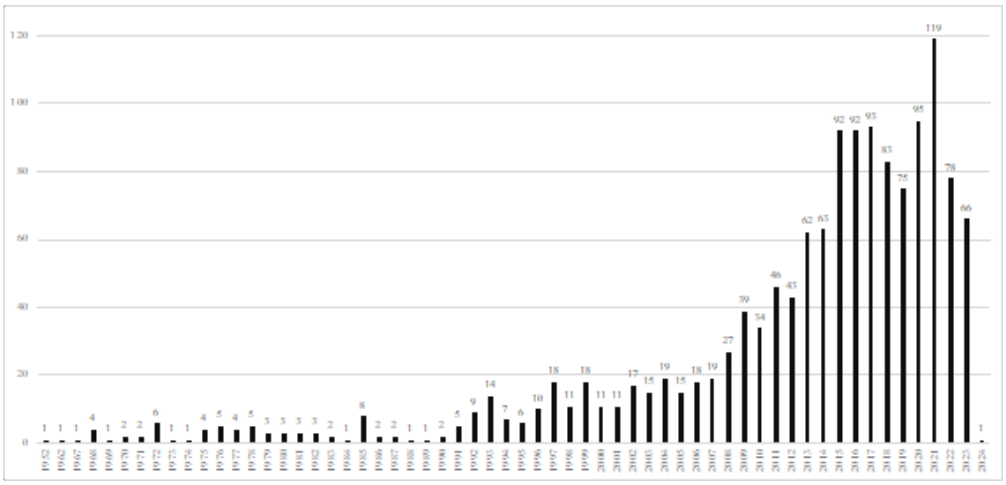

Figure 7.2: Publications per year

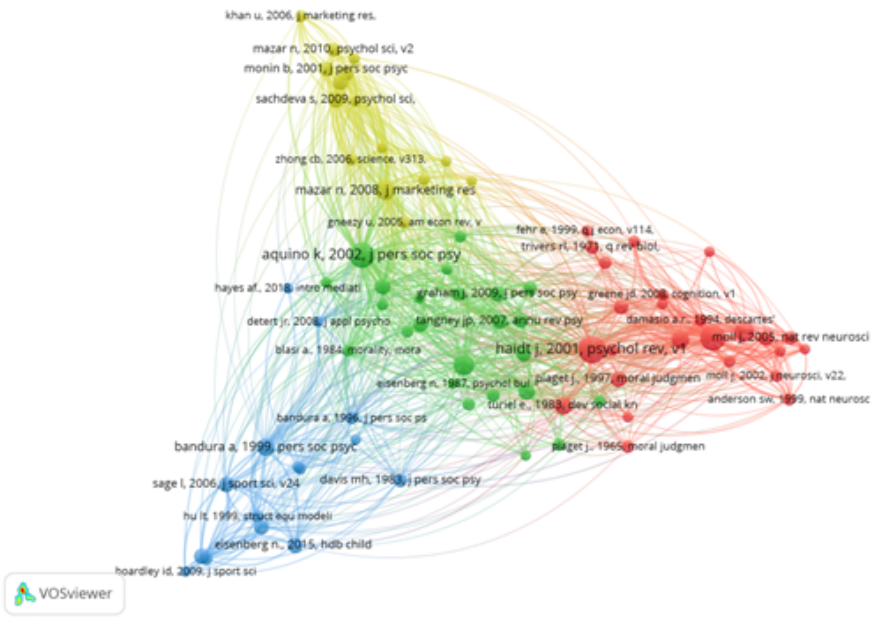

Figure 7.3: Clusters of co-citations

natural selection acts against "cheater." The author suggested that tendencies towards selfishness and altruism are influenced by social and ecological factors, with various aspects of human interactions, such as friendship, moralistic aggression, gratitude, sympathy, trust, trustworthiness, dishonesty, hypocrisy, among others, regulating altruistic behavior. Once the human economy is made by beings that have gone through evolutionary processes that would influence behavioral tendencies, it is to be expected that the creation of an "economic environment" is subject, at least to some extent, to the processes proposed by Trivers, 1971. In this sense, Fehr and Schmidt, 1999 highlighted the impact of the economic environment in the prevalence of fairness or selfishness. Neuroscience research delve into the relationship between brain functioning and moral cognition (Anderson et al., 1999; Moll, Zahn, et al., 2005), brain functioning and emotions (Moll, Oliveira-Souza, et al., 2002), and rationality and emotions (Damasio, 2005). Philosophical inquiries explored concepts such as convention, public and private morality (Turiel, 1983). In this cluster, the main study in the field of psychology verified the importance of intuition in moral judgments (Haidt, 2001), alongside investigations into the relationship between cognitive load and utilitarian judgment (Greene et al., 2008), as well as the effects of moral pressure on individual behaviors. These interdisciplinary perspectives underscore the intricate interplay of biological, economic, and social factors in shaping moral decision-making processes.

The blue cluster incorporates studies from the methodology (Hayes, 2022; Hu and Bentler, 1999) and sport science fields. Specifically, Boardley and Kavussanu, 2009, used structural equation modelling to investigate how environment created by coaches and their competencies influence both positive (prosocial) and negative (antisocial) behaviors in athletes. Additionally, Sage, Kavussanu, and Duda, 2006 looked into the effects of athletes' self-esteem on their behaviors, examining how an athlete's ego can lead to different outcomes. Furthermore, characteristics of individuals were studied and published in psychology journals, encompassing traits like empathy (Davis, 1983; Detert, Treviño, and Sweitzer, 2008), moral identity (Detert, Treviño, and Sweitzer, 2008) and moral disengagement (Bandura, 1999; Bandura et al., 1996). Eisenberg, Spinrad, and Knafo-Noam, 2015 highlighted additional factors identified in literature that promote prosocial behavior.

Furthermore, alongside psychological studies, the yellow cluster encompasses research published in marketing journals. In this context, Mazar and Chen-Bo Zhong, 2010 analysed the influence of external and internal incentives on self-concept maintenance. Khan and Dhar, 2006 explored the effect of prior intentions on present and future behaviors. Other studies within this cluster, classified under psychology, investigated the relationship between past intentions/actions and current/future attitudes (Mazar and Chen-Bo Zhong, 2010; Monin and D. T. Miller, 2001; Chen-Bo Zhong and Liljenquist, 2006) as well as the impact of moral self-worth on behaviors (Sachdeva, Iliev, and Medin, 2009). Additionally, Gneezy, 2005, in a study published in an economics source, highlighted the significance of the consequences of lying on decision-making processes, both for the individual who lies and for others involved.

Regarding the primary terms found the literature related to MB (Fig. 7.4), green cluster highlighted dimensions such as emotion, moral judgment, decision, and self. The yellow cluster, on the other hand, focused on aspects including prosocial/antisocial behavior, moral reasoning, and moral functioning. Meanwhile, the purple cluster instead, underscored aspects such as child, education, teacher, and parent. The red cluster encompassed categories such as ethic, society, and virtue. Within the blue cluster, dimensions such as human being, brain, capacity, and technology emerged prominently. The temporal overlay visualization of terms (Fig. 7.5) enables the observations of the dimensions that have been the subject of study over time.

Considering the significance and the innovative nature of the "Emotion" dimension in this literature, the following section of this chapter will undertake an in-depth examination of this aspect within the framework of MB. The systematic review of literature will be organized into three primary themes: emotion

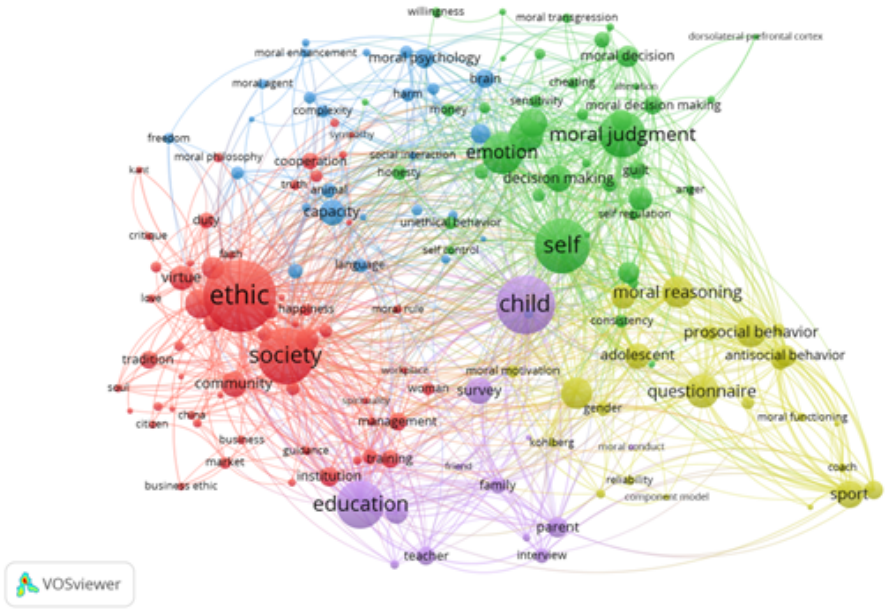

Figure 7.4: Cluster of terms

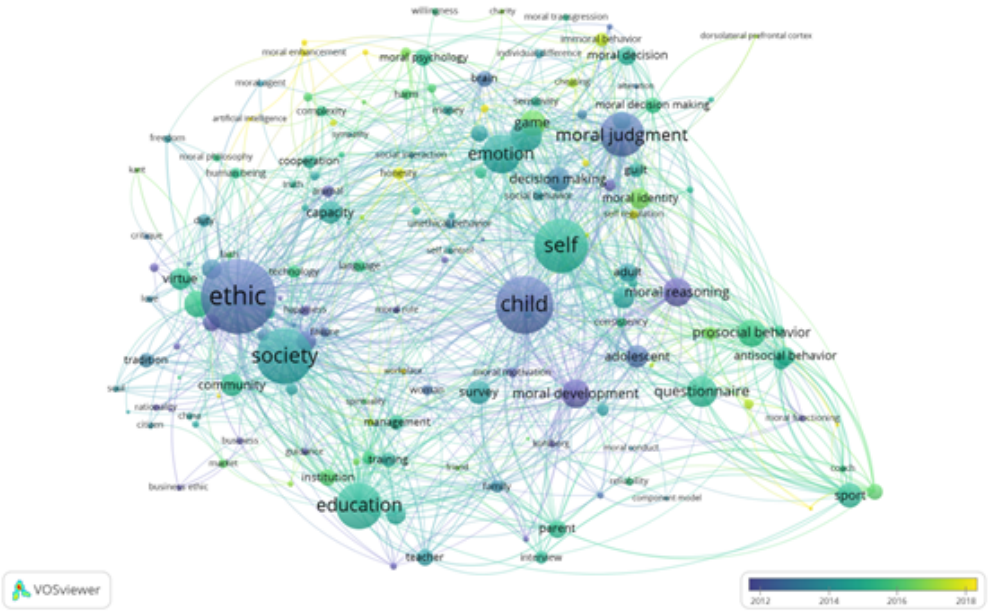

Figure 7.5: Temporal overlay visualization of terms

dimensions, triggers, and outputs, providing a comprehensive exploration of the complex relationship between emotion and MB.

7.3.2 Systematic literature review

The systematic exploration of emotion dimensions within the context of MB offers a comprehensive understanding of the intricate relationship between emotions and ethical decision-making processes.

The discussion about emotions in science gained significant attention starting from 1872, with the seminal work of Charles Darwin, "The expression of emotions in man and animals". Despite ongoing debate about the nature of emotion (Adolphs, Mlodinow, and Barrett, 2019), Paul Ekman contributed significantly to the field by defining fear, anger, sadness, disgust, enjoyment, and surprise as basic emotions through a series of psychology articles (e.g. Ekman, 1992b; Ekman, 1992a; Ekman, 1999). In the sphere of Moral Emotions, Tangney, Stuewig, and Mashek, 2007 delved into the human moral apparatus, highlighting the significance of emotions such as pride, gratitude, shame, guilt, and embarrassment, in shaping MB.

Consequently, within this burgeoning field of inquiry, "Moral Emotion" emerges as a multifaceted category, encompassing a spectrum of emotions (Table 7.1). Studies like that of Bland et al., 2020 provide valuable insights into the comparative emotional experiences among agents, shedding light on nuanced differences that inform our understanding of moral culpability and responsibility. Moreover, investigations into the moral emotions of artificial agents not only broaden the scope of inquiry but also prompt critical reflections on the boundaries of moral agency and artificial intelligence (Balkenius et al., 2016).

The emotional triggers influencing MB are varied and diverse. Among the different emotional triggers highlighted in this literature are emotional intelligence (Feruglio et al., 2023; Bajovic and Rizzo, 2020; Bisquerra Alzina and López-Cassà, 2021; Hofmann et al., 2018; Pittarello et al., 2017; Baumeister and Alghamdi, 2015)(Schütz and Koglin, 2022), exposure to violence (Zucchelli and Ugazio, 2019), the impact of information and communication technologies (Lokhvytska et al., 2022), reflective learning practices (Hedberg, 2017), external opinion (Pascual, Conejero, and Etxebarria, 2019), cuteness-perception (Z. Zhang and Zhou, 2020), physical contact (Hsieh and Y. Y. Chen, 2019), culture (Singh et al., 2021), morality (Y. Wang et al., 2022), moral identity (Christner, Pletti, and Paulus, 2020; Hertz and Krettenauer, 2016; Kavussanu, Stanger, and Ring, 2015), past (un)ethical behaviors (R. Wang and Chan, 2019; Waddell, 2019), and anxiety (Zasiekina and Zasiekin, 2020; Carnes and Winer, 2017).

Additionally, factors such as facial attractiveness (J. Wang et al., 2015) and brain responses to aesthetic judgments (Cheng et al., 2021) were identified as emotional triggers. Aesthetics, as defined by Chenjing Wu and He, 2021, refers to "a psychological state of emotional pleasure caused by the properties of an object. It defines the characteristics of beauty as a pleasurable experience."

Neuroscience studies have also highlighted the significance of aspects such as cerebellar-amygdala connections (Leutgeb et al., 2016), activity in the anterior insula (Seara-Cardoso et al., 2016), neurotransmitters like dopamine (Pellegrini et al., 2017), and serotonin (Yang et al., 2019), substances like psilocybin (Pokorny et al., 2017), and oxytocin (Scheele et al., 2014), noradrenaline (Terbeck et al., 2016), chemotherapy (Barlinn et al., 2015), as well as brain stimulation techniques (Di Nuzzo et al., 2018), and conditions such as brain diseases (Mendez, 2023; Strikwerda-Brown et al., 2021; Ponsi et al., 2021; Santens et al., 2018).

This literature also addressed aspects related to moral bioenhancement, defined as "the potential practice of manipulating individuals' moral behaviors by biological means" (Crutchfield, 2015, p.389). In this regard, Lavazza (2019, p.15) suggests the possibility of using new molecules or genetic alterations to achieve moral bioenhancement. Critics, however, argue against such interventions at the genetic level, fearing a loss of personal freedom Cioiu, 2020, p.82.

Emotion	Studies that contemplated the dimension
Anger	Grugan et al., 2020; Stollberger et al., 2020; Zasiekina and Zasiekin, 2020; R. Wang and Chan, 2019; Bortolan, 2016; Doorn, Zeelenberg, and Breugelmans, 2014; Onat Kocabiyik and Kulaksizoğlu, 2014.
Disgust	Yu et al., 2021, p.115; Fagiolo and Roventini, 2017; Parisi et al., 2021; Zasiekina and Zasiekin, 2020; R. Wang and Chan, 2019.
Empathy	Schütz and Koglin, 2022; Bell and Showers, 2021; Balconi and Angioletti, 2020; Z. Zhang and Zhou, 2020; Heide, 2020; Zasiekina and Zasiekin, 2020; Zucchelli and Ugazio, 2019; Dunfield et al., 2019; J. Chen, 2017; Pokorny et al., 2017; Decety and Yoder, 2015; Decety and Cowell, 2014; Onat Kocabiyik and Kulaksizoğlu, 2014.
Guilt	Mitkidis et al., 2023; Piretti et al., 2023; Giroux et al., 2022; Maftei and Merlici, 2021; Parisi et al., 2021; Myyry et al., 2021; Han et al., 2021; Bland et al., 2020; Zasiekina and Zasiekin, 2020; Newman and Brucks, 2018; Bortolan, 2016; Klerk, 2016; Seara-Cardoso et al., 2016; Kavussanu, Stanger, and Ring, 2015; Graham-Rowe, Jessop, and Sparks, 2014; Onat Kocabiyik and Kulaksizoğlu, 2014,Stanger, Kavussanu, and Ring, 2020; Newman and Brucks, 2018; Krettenauer and Casey, 2015.
Shame	Mitkidis et al., 2023; Piretti et al., 2023; Maftei and Merlici, 2021; Myyry et al., 2021; Han et al., 2021;Herjanto, Bagozzi, and Gaur, 2021; Bland et al., 2020; Zasiekina and Zasiekin, 2020;Bortolan, 2016; Onat Kocabiyik and Kulaksizoğlu, 2014.

Table 7.1: Main emotion dimensions

The primary output found in these publications was MB (**CehajicClancy2020**; Vabba et al., 2022; Segovia-Cuéllar, 2021; Johnson and Park, 2021; Balconi and Angioletti, 2020; Stanger, Backhouse, et al., 2018; Stanger, Kavussanu, and Ring, 2020; Roberts, Henry, and Molenberghs, 2018; Hao and Chunsha Wu, 2019; Osman and Wiegmann, 2017; Kusev et al., 2016; Plebe, 2015; Plebe, 2016; Hertz and Krettenauer, 2016; Stets, 2013; Fumagalli et al., 2015; Teper, Chen-Bo Zhong, and Inzlicht, 2015). More specifically, aspect of MB were explored in these publications, including (dis)honest behaviors (Feruglio et al., 2023; Mitkidis et al., 2023; Pittarello et al., 2017; J. Wang et al., 2015), decisions to engage in digital piracy (Herjanto, Bagozzi, and Gaur, 2021), meat consumption intentions (Hopwood et al., 2023), minimizing food waste (Graham-Rowe, Jessop, and Sparks, 2014), favouritism and discrimination in/out-group (Mei, W. Zhang, and Yin, 2020), third-party compensation (Gummerum et al., 2016), charitable giving (Schwitzgebel, McVey, and May, 2022), prosocial donation (Bell and Showers, 2021), cheat less (Zhao et al., 2022), moral transmission (Carnes and Winer, 2017), and moral judgment (Yang et al., 2019). One paradoxical finding within this literature was the relationship between anger and prosocial behaviors (Doorn, Zeelenberg, and Breugelmans, 2014). Conversely, some studies demonstrated the impact of MB on emotions (Lee et al., 2023; Miles, Upenieks, and Orfanidis, 2022; Ellemers et al., 2019; Walter and Redlawsk, 2019; Waddell, 2019).

7.4 Conclusions

The surge in Moral Behavior publications in recent years indicates a growing scholarly interest in unravelling the complexities of ethical decision-making. This burgeoning literature draws upon a rich theoretical framework, encompassing various dimensions such as environmental influences, moral identity formation, cognitive processes, and the intricate interplay of emotions. Emotion emerges as a salient theme underscored by both bibliometric analyses and systematic literature reviews, affirming its pivotal role in shaping MB. Delving deeper into this nexus, this study revealed a spectrum of Moral Emotion emotions, including but not limited to anger, disgust, empathy, guilt, pride, and shame, which are central to moral judgment.

Moreover, the synthesis of emotional triggers presents in this chapter contributes to a better understanding of a myriad of factors that modulate moral responses, spanning from individual-level attributes like emotional intelligence and past (un)ethical conduct to broader societal phenomena such as exposure to violence, cultural norms, and advancements in technology. This comprehensive understanding of emotional antecedents' sheds light on the multifaceted nature of moral decision-making processes.

The predominant output of this research landscape revolves around manifestations of MB, prominently characterized by (dis)honest behaviors and ethical decision-making tendencies. Nonetheless, it is imperative to acknowledge the bidirectional influence between MB and emotions, as evidenced by studies demonstrating the reciprocal impact of moral actions on emotional states.

Given that MB is intricately linked to the internalization of social norms through emotional processes, the insights gleaned from our analyses hold considerable relevance for the development of models aimed at replicating human behavior in societal contexts. However, it is essential to note the inherent limitations associated with the database utilized in this study, signalling a need for future research to explore alternative sources and corroborate findings. Future studies can enrich our understanding of moral dynamics and contribute to the ongoing discourse on ethics and human behavior.

Chapter 8

Behavioral economics and electronic voting

Michelle Lins de Moraes and Marcela Montalvão Teti and João Vasco Gama

Summary
The relevance of Behavioral Economics for the development of Public Policies influenced the number of scientific publications on trust. Another historical challenge within the scope of Public Policies is the legitimization of the policies themselves, which, in turn, includes the legitimization of their proponents and, therefore, their election. In order to contribute to a better understanding of relevant opportunities and challenges related to the implementation of electronic voting, the objective of the present study was to carry out a quantitative and qualitative analysis of part of the literature on electronic voting and trust. According to the studies analyzed, trust, in the context of electronic voting, is influenced by factors such as some demographic categories, the technology and legislation adopted, its effect on reducing inequalities, in addition to the positioning of national parties and trust in the current voting ritual.
Keywords: behavioral economics; elections; electronic voting; trust.

8.1 Introduction

At the dawn of the 20th century, a range of development theories began to gain considerable prominence. Among these, the work of Jean Piaget (1896-1980) and Sigmund Freud (1856-1939) emerged as foundational and continues to be highly influential in our understanding of human development. According to Figueiredo and Santi (2008), despite the significant differences in their theoretical frameworks, both Piaget and Freud based their ideas on genetic and biological assumptions regarding the formation of the moral subject. As noted by Papalia and Feldman (2013), these pioneering theorists established universal and deterministic models, proposing that development unfolds through a series of sequential phases. In this view, experiences during childhood are crucial, leading to permanent changes in behavior and cognition in adulthood. Piaget posited that environmental stimuli play a pivotal role in the biological development of the brain, fostering increasingly complex and adaptive cognitive functions (Figueiredo and Santi, 2008). Freud, on the other hand, emphasized the impact of tense and rigid interpersonal relationships in repressing childhood emotions, which later resurface in adulthood as psychological distress

and contradictory behaviors (Fadman and Frager, 1986). These theories suggest that maladaptive behaviors in adults can often be traced back to inadequate stimulation or emotional abuse during childhood, resulting in behaviors that hinder adult development.

In the latter half of the 20th century, a shift occurred as psychologists with different approaches to development, known as contextual theories, began to emerge (Papalia and Feldman, 2013). Erik Erikson (1902-1994) introduced the concept that development transpires across eight distinct psychosocial stages throughout a person's life (Erikson, 1971). While the initial stages significantly influence adult development, each stage involves the acquisition of new skills shaped by the preceding and subsequent stages. Lev S. Vygotsky (1896-1934), a Belarusian-born psychologist (Bortolanza and Rigel, 2016), argued that an individual's cultural and social environment plays a more critical role in shaping their life and choices than biological and genetic factors. He believed that biological potentials can be transformed through socially and culturally mediated activities (Gonzalez and Mello, 2014). Urie Bronfenbrenner (1917-2005), originally from Russia and later based in the USA, emphasized that an individual's culture and historical context profoundly influence their lifestyle and decision-making processes. Bee and Boyd (2011) regard Bronfenbrenner's Bioecological theory of development as the most influential systems theory. This theory posits that the family acts as a crucial filter through which broader societal influences are mediated, helping to socialize new members while also shielding them from potentially harmful cultural elements: "the family is the filter through which the wider society influences the child's development. As such, it can help the broader culture achieve the goal of socializing new members, but it can also serve as a buffer against harmful elements in the culture at large" (Bee and Boyd, 2011, p. 362).

Distinct from other theorists, Bronfenbrenner aimed to understand a wide range of phenomena, including parenting, resilience, drug use, and violence, among others (Carvalho-Barreto, 2016, p. 276), through the interplay of environmental and interdisciplinary factors with a child's biological makeup. Contrary to the assertions of Freud and Winnicott, Bronfenbrenner contended that the influence of the family on a child's life extends beyond the mother-baby dyad. According to Oliveira (2019), if a family is impoverished and the mother experiences depression due to adverse living conditions, these circumstances will negatively impact the mother-child relationship. Anna Freud (1895-1982), as noted by Fontoni and Fulgêncio (2020), explored differences in mother-child relationships between those in sheltered environments and those who are not. She observed that children in such situations often develop excessive defense mechanisms, leading to permanent alterations in their character. During the same period, European researcher Paul B. Baltes (1939-2006) and his colleagues advanced our understanding of human development by adopting a lifespan approach (Neri, 2006, p. 18). Baltes articulated seven fundamental principles of human development that illuminate how daily choices are guided throughout life. These principles are widely endorsed in developmental studies (Papalia and Feldman, 2013). According to Baltes, development is characterized by: a) continuous changes throughout life, where each preceding period influences subsequent phases; b) multidimensionality, encompassing biological, psychological, and social aspects that progress at distinct rates; c) multidirectionality, occurring across various domains such as professional, personal, love, family, and social spheres; d) the interplay of biological and cultural changes, with this balance evolving over time; e) differentiated allocation of resources, allowing for growth, conservation, recovery, and coping with loss; f) plasticity, meaning that various capacities can be cultivated and altered; g) the impact of the temporal and locational context in which an individual exists.

Beyond the previously discussed factors, research indicates that socioeconomic status (SES) significantly influences an individual's emotions, behaviors, and cognitive abilities. Papalia and Feldman (2013) assert that poverty can directly affect development by destabilizing the emotional state of the family and the home environment due to resource scarcity such as inadequate food supply.

Additionally, poverty can have an indirect impact if the individual resides in a deprived neighbor-

hood. High unemployment rates within one's social milieu can undermine feelings of security and trust. Furthermore, aspects such as gender, race, ethnicity, and nationality play pivotal roles in shaping the decisions individuals make throughout their lives. The level of violence, insecurity, and resource scarcity experienced during development shapes one's responses to the world. Consequently, the economic and political history of a country, its international alliances, and its future aspirations are critical factors that influence individuals on both a micropolitical (Guattari and Rolnik, 2008) and microsystemic level, affecting their trust and decision-making processes.

In summary, human development theories have greatly evolved from the early 20th century to the present, reflecting a deeper understanding of the myriad factors influencing growth. Pioneers like Jean Piaget and Sigmund Freud underscored the significance of genetic and early childhood influences, while later theorists such as Erik Erikson, Lev Vygotsky, and Urie Bronfenbrenner expanded the focus to include social, cultural, and environmental contexts. Paul B. Baltes introduced principles emphasizing the multidimensional and dynamic nature of development. Additionally, factors like socioeconomic status, gender, race, and nationality are crucial in shaping an individual's emotions, behaviors, and cognitive potential. The socioeconomic and political environments, along with specific developmental experiences, profoundly influence individuals' trust and decision-making processes. This comprehensive understanding highlights the complex interplay of biological, social, and cultural influences on human development, guiding future research and practical applications in fostering healthy development across the lifespan.

Recent scientific publications on Behavioral Economics (BE) that analyze the dimension of "trust" have seen a significant increase. This surge is largely driven by the emphasis on understanding BE dynamics for the development of effective Public Policies. According to the Organization for Economic Co-operation and Development (OECD, 2017, p.3-4), "behavioral insights, or insights derived from the behavioral and social sciences—including decision making, psychology, cognitive science, neuroscience, organizational and group behavior—are being applied by governments with the aim of making public policies work better. If behavioral insights are to realize their full potential, guiding principles and standards must be established to direct future applications and maintain the trust of public bodies and citizens."

A historical challenge in the realm of Public Policies is the legitimization of the policies themselves, which includes the legitimization of their proponents and their election. One key issue currently under discussion is the use of electronic voting, which remains not widely adopted or thoroughly studied (Solvak & Vassil, 2018). To enhance the understanding of opportunities and challenges associated with electronic voting, this study aims to conduct both quantitative and qualitative analyses of the existing literature on electronic voting and trust. This research seeks to shed light on the potential benefits and drawbacks of implementing electronic voting systems, contributing to the broader discourse on policy legitimacy and electoral integrity.

The aforementioned literature analysis initially segmented the investigation into three terms: E-Voting, I-Voting, and M-Voting. Although there is no consensus in the literature on the precise definitions of these terms, some studies associate E-Voting with Electronic Voting (Pegorini et al., 2021), I-Voting with Internet Voting (Germann & Serdült, 2017), and M-Voting with voting via mobile devices such as cell phones (Moloja & Mpekoa, 2017a). In some publications, E-Voting is used synonymously with I-Voting. Despite the lack of consensus on these terminological definitions, the relevance of this initial segmentation remains intact due to the exploratory nature of the present study.

The study is organized into the following sections: presentation of the methodology, results of the quantitative and qualitative analysis of the literature, and final considerations. This structure aims to provide a comprehensive overview of the current understanding and debates surrounding the implementation and impact of different electronic voting systems, thereby contributing to the broader discourse on electoral integrity and public trust in digital voting mechanisms. By systematically examining the litera-

ture through these distinct yet interrelated lenses, the study seeks to clarify the nuances and implications of E-Voting, I-Voting, and M-Voting, offering insights that are crucial for policymakers, researchers, and stakeholders interested in the future of voting technologies.

8.2 Methodology

The publication databases used in this study were accessed through the Web of Science Core Collection. Data collection was conducted in January 2024. For the bibliometric analysis, the following search sequence was applied to the main topics: "E-Voting" under the category "Political Science"; "I-Voting"; "M-Voting"; and "Trust" together with anyone of the former. These terms were defined based on methodologies from studies like Turnbull-Dugarte & Devine (2023). The searches yielded a total of 86 records for "E-Voting" and "Political Science," 41 for "I-Voting," 13 for "M-Voting," and 28 for the combined terms (Table 1). For the systematic literature analysis, all 28 studies encompassing the terms "E-Voting" (and "Political Science"), "I-Voting," or "M-Voting" were reviewed.

Bibliometric Analysis		Systematic Analysis	
Terms	Nº Publications	Terms	Nº Publications
E-Voting and category Political Science	86	Trust and E-Voting (and category Political Science) or I-Voting or M-Voting	28
I-Voting	41		
M-Voting	13		
Trust and E-Voting (and category Political Science) or I-Voting or M-Voting	28		

Table 8.1: Bibliographic analysis

VOSviewer (1.6.20) software was utilized to conduct the bibliometric analysis of co-citations, revealing the theoretical framework of the analyzed literature. For creating co-citation clusters, a minimum threshold of four occurrences was set. In the systematic analysis of the literature, which also includes the dimension of trust, the research question posed was: "What were the main results of these studies?" The research focus was not confined solely to the aspect of trust due to the limited number of literature reviews on the intersections of "Voting" and trust. Consequently, there was a need for an initial, broader understanding of the relationships between these dimensions. This approach allowed for a more comprehensive exploration of the existing studies, providing insights into the various ways in which voting technologies and trust interconnect and influence each other.

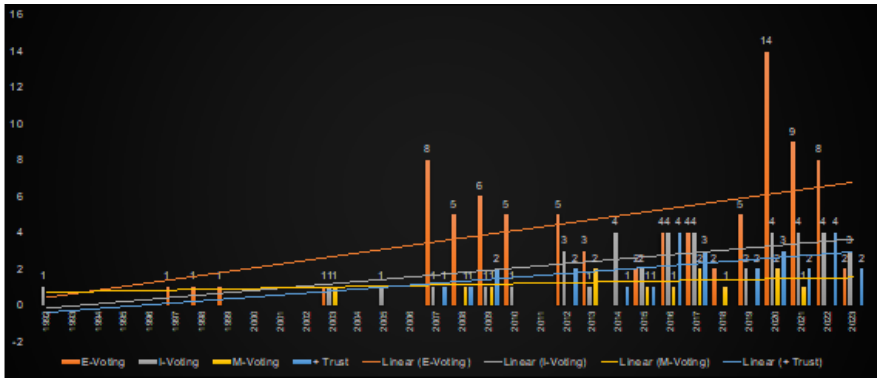

Figure 8.1: Number of publications per year and trend

8.3 Results

8.3.1 Bibliometric analysis

Fig. 8.1 presents the number of publications per year of each category and a linear fit of the time-evolution per category. These results indicate that E-Voting was the most studied dimension in the sample, with 86 works, representing over 51% of the studies and showing the highest growth trend. Following this, I-Voting accounted for 24% of the studies, while works that analyzed trust constituted 17%.

In terms of geographic distribution (Table 2), the countries with the most publications in the three voting dimensions (E, I, and M) were the United States (14%), England (9%), Germany (8%), Estonia (5%), and Spain (5%). The United States and England also had the highest number of publications related to "trust." Notably, the Netherlands and South Africa showed significant results in the context of M-Voting, highlighting their contributions to this area.

Regarding the content of the five most cited works in these literatures (Table 3) , the trust dimension is notably relevant in studies on various types of voting. Highly cited publications on E-Voting and I-Voting, for example, examined the relationship between blockchain technology in voting and voter trust (Moura & Gomes, 2017; Shahzad & Crowcroft, 2019; Wilks-Heeg, 2009). This highlights the critical role of trust in the implementation and acceptance of new voting technologies.

Other E-Voting publications examined the dynamics of politics in the digital era (Kurban et al., 2016) and the impact of E-Voting on electoral participation (Petitpas et al., 2021; Solvak & Vassil, 2018). Participation analysis was also a focus in studies related to I-Voting and M-Voting, as highlighted in Table 3. Notably, Germann & Serdült (2017), Nemeslaki et al. (2016), Carter & Bélanger (2012), and Dukic & Katic (2005) contributed significant insights into these voting methods. Additionally, security concerns were prominent in I-Voting studies (Springall et al., 2014), which examined vulnerabilities and potential safeguards. Similarly, M-Voting research by Moloja & Mpekoa (2017a; 2017b) addressed the security challenges associated with mobile voting. These studies collectively underscore the importance of understanding both participation and security to ensure the effectiveness and trustworthiness of digital voting systems.

Regarding co-citations in the literature on the three voting categories that also explicitly consider the dimension of trust, two predominant clusters are identified (Fig. 8.2) . The green cluster mainly consists of publications that explored the role of electronic voting over time (Gibson et al., 2016) and voter participation in Estonia (Alvarez et al., 2009; Vassil & Weber, 2011). Vassil et al. (2016) noted that in Estonia,

Country	E-Voting %	I-Voting %	M-Voting %	Total %	+ Trust %
USA	13%	22%	-	14%	18%
England	8%	15%	-	9%	11%
Germany	12%	-	-	8%	4%
Estonia	5%	7%	-	5%	4%
Spain	5%	7%	-	5%	4%
Netherlands	5%	-	8%	4%	4%
Poland	4%	4%	-	4%	4%
Luxembourg	5%	-	-	4%	4%
South Africa	1%	2%	31%	4%	4%
Russia	3%	4%	-	3%	-

Table 8.2: Number of publications by country

E-Voting		I-Voting	
Publication	Nº Citation	Publication	Nº Citation
Moura & Gomes (2017)	37	Springall et al. (2014)	101
Solvak & Vassil (2018) 19 Shahzad & Crowcroft (2019)	61		
Kurban et al. (2016) 16 Germann & Serdült (2017)	54		
Wilks-Heeg (2009) 16 Nemeslaki et al. (2016)	25		
Petitpas et al. (2021) 12 Carter & Bélanger (2012)	14		
M-Voting		(E + I + M) Voting + Trust	
Publication	Nº Citation	Publication	Nº Citation
Moloja & Mpekoa (2017a)	2	Shahzad & Crowcroft (2019)	61
Moloja & Mpekoa (2017b)	1	Moura & Gomes (2017)	37
Dukic & Katic (2005)	1	Nemeslaki et al. (2016)	25
-	-	Carter & Bélanger (2012)	14
-	-	Antoniou et al. (2007)	7

Table 8.3: More cited publication

Figure 8.2: Clusters of co-citations of (M+E+I) Voting + Trust literature

voter participation through electronic voting became widespread only after three elections. Another region studied in this cluster was Switzerland, where Germann & Serdült (2017) found that the new voting method did not increase voter participation in Geneva and Zurich. These studies highlight the varying impacts of electronic voting on voter engagement in different contexts, emphasizing the importance of examining long-term trends and regional differences to understand the effectiveness of electronic voting systems.

The red cluster, featuring a study on the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), includes publications exploring the relationship between trust and electronic voting systems (Schaupp & Carter, 2005). This cluster examines various territories, including Ghana (Agbesi, 2020), the United States, and South Africa (Warkentin et al., 2018; Gefen et al., 2005).

8.3.2 Sistematic Analysis

As previously mentioned, this systematic analysis of the literature on "Voting" categories involving trust aimed to answer the research question: "What were the main results of these studies?" The relationship between trust in both electronic and in-person electoral systems and the intention to use electronic voting has been extensively analyzed by several authors. Key studies include works by Carter & Bélanger (2012), Carter (2014), Decman & Kozel (2023), Lisi & Luís (2022), Mpekoa & Van Greunen (2016, 2017), Nemeslaki et al. (2016), and Shat & Pimenidis (2016). These studies explore how trust impacts the adoption and utilization of electronic voting systems.

However, research by Turnbull-Dugarte & Devine (2023) delved deeper into this relationship, evaluating the factors that influence trust in electronic voting, which generally has a lower confidence level compared to face-to-face voting. Their study highlighted the crucial role of trust in garnering support and intention to use internet voting. Concerns were raised about the accuracy of data processing and storage, as well as the integrity of the voting infrastructure (Turnbull-Dugarte & Devine, 2023, p. 102679). They found general uncertainty regarding the system's effectiveness and its implications for inequality. While there was little evidence that ideology moderates support, the relationship with demographics was

mixed, though higher education correlated with increased trust and intention to use electronic voting. Support for electronic voting was largely driven by its potential positive outcomes, such as reducing inequality and increasing voter turnout.

Other obstacles to the use and trust in electronic voting identified in the literature include partisan attachments (Ehin & Solvak, 2021), lack of trust in political parties and their practices (Lisi & Luís, 2022; Agbesi, 2020), and confidence in the traditional voting "ritual" (Fragnière et al., 2019).

On the other hand, factors facilitating trust in electronic voting systems include the continued development of legal (Schmidt et al., 2009) and technological (Ehin et al., 2022) frameworks, the utilization of appropriate technology such as blockchain (Barański et al., 2020; Moura & Gomes, 2017; Shahzad & Crowcroft, 2019), smart card (Estaji et al., 2020), and Voting Service Providers (Langer et al., 2008). Interestingly, the literature suggests a neutral stance on the population's distrust of politicians (Kozel & Dečman, 2022).

8.4 Final considerations

The quantitative analysis revealed that E-Voting was the most extensively studied dimension, followed by I-Voting, trust, and M-Voting. While publications were dispersed across various territories, the United States, England, Germany, Estonia, and Spain emerged as the top contributors. Notably, the Netherlands and South Africa showed prominence in M-Voting research. The significance of the trust dimension was underscored throughout the literature, evident in its presence across many seminal works on all three categories of "Voting."

The studies analyzed reveal that trust in electronic voting is influenced by various factors, such as adopted technology and legislation, its impact on reducing inequalities, and the stance of national parties. Confidence in the traditional voting process also plays a significant role. Additionally, electoral participation emerges as a central concern within this literature.

This chapter tries to by provide a comprehensive analysis of trust within the context of electronic voting systems. By synthesizing findings from diverse studies, it sheds light on the multifaceted nature of trust and its implications for the adoption and effectiveness of electronic voting technologies. Moreover, it identifies key factors that influence trust, including demographic considerations, technological advancements, and legal frameworks. By elucidating these factors, the chapter strives to offer valuable insights for researchers and policymakers seeking to enhance trust in electoral processes, while also trying to provide a nuanced understanding of the challenges and opportunities associated with electronic voting systems.

Chapter 9

The Agent ID Model: Motivation and Formal Presentation

Orlando Gomes

Summary
In this chapter, an agent-based model is assembled to approach macro phenomena in socio-economic system. The framework takes the designation of Agent ID Model, and it studies the interaction across a population of agents who are connected through a variety of channels. Each agent is unique in the sense that she / he is endowed with a series of idiosyncratic features pertaining to financial endowments, general and specific skills, preferences over goods, degree of connectivity, animal spirits, moral behavior, and political preferences. The model unveils the complexity of social and economic relations and it is capable of approaching aggregate outcomes through a bottom-up perspective
Keywords: Agent ID Model, Agent heterogeneity, Endowments, Skills, Preferences, Connectivity, Animal spirits, Moral behavior, Political views.

9.1 Introduction

In the previous chapters, a series of relevant issues pertaining to the organization and to the unrolling of social and economic relations were highlighted and discussed. These issues ranged from income inequality to social and political choices, with attention being placed also on the topics of skill heterogeneity, individual preferences, network connectivity, psychological biases, and moral behavior. What the studied subjects have in common is their capacity to show us how different people are from one another, and how different also are the positions they occupy, for a series of reasons, in society and in the economy. People are heterogeneous regarding their wealth endowments, their ability to generate income, their tastes, their socialization skills, their cognitive proficiency, their moral values, and their political ideology.

If science intends to offer plausible and credible explanations for people's behavior and for the organization of life in society, such multi-dimensional heterogeneity must be accounted for. The complexity of social and economic relations that was debated in the first chapter of this book encounters its origin in the fact that everyone is different at multiple levels, what certainly leads to complex patterns of interaction that culminate in complex and nonlinear outcomes (i.e., in trajectories of variables, namely aggregate

outcomes, that do not tend to rest in a steady state but, in opposition, endlessly fluctuate in a non-regular way). In this chapter, the previously discussed ideas are analytically translated into a small-scale model that typifies the behavior and the interaction among individual agents in a given socio-economic environment.

Because each agent is different from one another with respect to a multiplicity of dimensions, the model is designated by Agent ID model, in the sense that each individual has its own set of characteristics that define her or his identification (ID). The model is simple in its conception, taking two essential elements: the definition of individual profiles (the IDs) and the establishment of a minimal set of rules of interaction among the heterogeneous agents. This chapter presents and characterizes the structure of the model, which is then codified and simulated in the following chapters. The bottom-up methodological perspective is clearly present in this approach: individuals are differently endowed, they interact through simple rules, and this interaction leads to the emergence of large-scale aggregate phenomena that are unfeasible to predict or forecast given that they depend on the idiosyncrasies of each individual populating the economy at each moment in time.

9.2 Claims on Observable Facts and Regularities

In his seminal work, the growth economist Robert M. Solow asserted that "All theory depends on assumptions which are not quite true. That is what makes it theory" (Solow, 1956). In our Agent ID model, a few basilar assumptions must be taken into consideration; although these are supposed to describe with some degree of accuracy observable facts and regularities, they do so necessarily in a general and stylized fashion, thus requiring making a few caveats. The main assumptions are supported on six claims, which we discuss below in light of the available empirical evidence and of the conceptual reasoning provided by the work of prominent economists and social scientists (and also in accordance with what preceding chapters have highlighted as relevant observable regularities).

Claim 1 *Wealth and income of the individual agent are derived from Pareto distributions.*

A large body of literature on wealth and income inequalities holds the view that observed levels of wealth and income are roughly spread across the population under a Pareto distribution or a power law. This has been explicitly stated by a series of scholars, including, among others, Jones, 2015, pp. 32-33,

> *At least since Pareto, 1896 first discussed income heterogeneity in the context of his eponymous distribution, it has been appreciated that incomes at the top are well characterized by a power law.*

followed by Gabaix, 2016, p. 191,

> *Income and wealth also follow roughly power law distributions, as we have known at least since Pareto, 1896.*

and also by Blanchet, Fournier, and Piketty, 2022,

> *It has long been known that the upper tail of the distribution of income and wealth can be approximated by a Pareto distribution, or power law (Pareto, 1896).*

The Pareto distribution simply indicates that a large portion of wealth and income in an economy is held by a small share of the population, a regularity that is pervasive in time and space. This regularity materializes in a more pungent way, as mentioned in the above sentences, when taking the upper tail of the distributions. Gabaix, 2016, p. 191 further notes that

> *The distribution of wealth is more unequal than the distribution of income: this makes sense, because differences in growth rate of wealth across individuals (due to differences in returns or frugality) pile up and add an extra source of inequality. Typically, the Pareto exponent is around 1.5 for wealth and between 1.5 and 3 for income (recall that a lower Pareto exponent means a higher degree of inequality in a distribution).*

In the Agent ID model, wealth and income inequality will be both a starting point for the analysis, and also the inevitable outcome of the interaction relations that unfold across the set of agents that populate the socio-economic environment. The intuition is that inequality feeds itself: an initial state characterized by a low degree of inequality allows for the maintenance of a relatively equitable society; if the starting point is one of strong inequality, economic and social relations tend to increase the gap further and further.

Claim 2 *Goods are produced under different qualities and varieties, agents have preferences over different varieties, and prices signal quality.*

The Agent ID model will involve a simplified market mechanism, where traded goods are supplied in an array of different qualities and varieties, where consumers have distinct preferences over varieties, and where prices reflect the quality of the traded goods. The economic literature has made extensive use of such ideas. Considerations about product quality are part of the foundations of the endogenous growth theory, as highlighted in the following citation,

> *Almost every product exists on a quality ladder, with variants below, that may already have become obsolete, and others above, that have yet to be discovered.*
>
> *Grossman and Helpman, 1991, p. 43*

Similarly, product variety is an important element of economic analysis, e.g. in what respects international trade theory,

> *In discussing the origins and implications of international trade, economists usually emphasize comparative advantage, increasing returns to scale, and consumer love of variety (...) In new trade theory, the welfare gains from trade accrue from a combination of economies of scale and the expansion of product varieties available to consumers.*
>
> *Bernard et al., 2007, p. 112.*

Consumers are heterogeneous with regard to the varieties they prefer (this assertion will be basilar for the formulation of the ID model); concerning quality, there is an obvious choice that every agent makes: goods of higher quality are preferred to those of lower quality; however, purchasing decisions must account not only for quality but also for prices, and prices are positively correlated with quality in the proposed framework. Specifically, it is assumed that transaction prices will reflect the quality of the supplied good, following a plain intuition,

> *Intuition asserts that a product's price and quality are positively correlated. Finding evidence counter to this basic intuition is often difficult, especially when product attributes are objective and easy to evaluate.*
>
> *A. Gneezy, U. Gneezy, and Lauga, 2014, p. 153.*

Claim 3 *Markets are not complete and agent connectivity depends on wealth and moral behavior.*

The incompleteness of markets signifies that interactions occur locally and that agents have the possibility of engaging in transactions only with a fraction of the players in the market. Although this is a view common to a wide array of contemporaneous economic models, we specifically associate the idea to the complex systems view of network formation,

> *(...) the complex systems view of interactions that occur between agents is that they are often direct. In other words, interdependences between agents are not always mediated by what in economics is known as 'complete markets.'*
>
> *Durlauf, 2012, p. 48.*

As it was the case for wealth and income, we assume that the connectivity degree tends to follow a power law distribution, meaning in this case that few agents function as 'hubs' with a strong degree of connectivity with others, while the large majority is able to establish a relatively small number of contacts in each time period. This reflects evidence on many social and economic networks, and can be logically explained under the following reasoning,

> *A common property of many large networks is that the vertex connectivities follow a scale-free power-law distribution. This feature was found to be a consequence of two generic mechanisms: (i) networks expand continuously by the addition of new vertices, and (ii) new vertices attach preferentially to sites that are already well connected. A model based on these two ingredients reproduces the observed stationary scale-free distributions, which indicates that the development of large networks is governed by robust self-organizing phenomena that go beyond the particulars of the individual systems.*
>
> *Barabási and Albert, 1999, p. 509.*

Because wealth, power, influence, and connectivity, go hand in hand, a correlation will be considered between the distributions of financial endowment and connectivity.

Furthermore, market connectivity will be associated also with moral behavior. Agents that are less self-centered and show a stronger pro-social attitude will increase their connectivity and vice-versa. The following arguments support this belief:

> *A major flaw in Walrasian economics is the assumption of "self-regarding" agents - economic actors make decisions independently of social context and without regard to the behavior of other consumers and firms. (...) Forgotten in the analysis is that even Adam Smith grounded his faith in markets on the belief that people are not entirely self-interested. Smith believed that love of family and duty to others are fundamental characteristics of human civilization.*
>
> *Manner and Gowdy, 2010, pp. 753-754.*

> *That self-interest leads to socially optimal outcomes has been part of the DNA of economics since Adam Smith described the dance we do with the butcher and the baker in the Wealth of Nations. We simply accept as a truism that it is self-interest that drives the creation of wealth, not some altruistic tendency to help the other guy. (...) So which version of economics - "greed is good" or "do no evil" - is correct? This article will present a variety of data to support the thesis that market exchange requires morality*
>
> *Zak, 2011, pp. 212-213.*

Claim 4 *Animal spirits influence consumption decisions.*

In the simple economy to be engineered below through the Agent ID model, individuals will consume a fraction of their current wealth. The extent of such fraction, the marginal propensity to consume out of wealth, is linked, in the proposed setting, to sentiments, confidence or animal spirits. It is well documented in the economics literature how behavioral elements impact the consumption choices of individuals, with optimism about the future state of the economy stimulating current consumption and pessimism leading to a retraction of the respective value.

To support the previous argument, we highlight a few of the multiple comments in the literature about the influence of confidence levels over consumption:

> *At least since the work of John Maynard Keynes, economists have pondered the ways in which consumer and investor sentiment - what Keynes, 1936, Ch. 12 referred to as "animal spirits" - might influence the real economy.*
>
> *Ludvigson, 2004, p. 29.*

> *Empirically, as shown for instance by Carroll, Fuhrer, and Wilcox, 1994, measures of consumer confidence are highly correlated with real consumption. (...) Overall, the results show that the consumer confidence index can be in certain circumstances a good predictor of consumption.*
>
> *Dees and Soares Brinca, 2013, pp. 3-4.*

> *It remains poorly understood, however, what "nonfundamental" fluctuations in consumer sentiment reflect. The traditional interpretation is that they capture intangible psychological factors that vary over time and have independent causal effects on consumers' willingness to spend. Such factors are variously described as "animal spirits," optimism or pessimism, outlook, mood, or emotional response to uncertainty.*
>
> *Starr, 2012, p. 1097.*

Claim 5 *The political ideology impacts on income and wealth distribution.*

This claim is intuitive and has to do with the foundations of political ideology. Left-wing parties tend to favor a more egalitarian distribution of income than right-wing politicians. Furthermore, political parties that take governing responsibilities will reflect, in democratic societies, the overall political view of the population.

The relation between ideology and wealth and income distribution has been subject to scrutiny in the economic policy literature, as the following two assertions illustrate,

> *(...) pro-market (right-wing) politicians commit to lower public provision of goods and income taxation schedules that implement larger income inequality than pro-government (left-wing) politicians.*
>
> *Lopez Rodriguez, 2012, p. 1.*

> *Low-income individuals, as well as left-wing voters, do indeed tend to favor a more compressed income distribution than high-income individuals and right-wing supporters (...)*
>
> *Piketty, 1999, p. 1*

Claim 6 *Animal spirits, moral behavior and political view are shaped by two mechanisms. Reversion to the mean and tendency to extremism.*

Albeit the developed model is essentially focused on an economic process, there are three important psycho-sociological features that are taken as central. These, as already highlighted, have impact on consumption choices, market connectivity and wealth distribution. We assume that each of these three elements are subject, over time, to two contradictory forces: one that pulls to the middle (a mean-reversion mechanism) and another one that pushes to the extremes.

Social interaction models that investigate the causes and consequences of the coexistence of the two mentioned forces have been explored in the scientific literature. One of such models, named the relative agreement interaction model, was presented by Deffuant et al., 2002, who concluded that

> *For small general uncertainty, the influence of the extremists is limited to those agents which were initially close to them, and we get a central convergence. For high general uncertainty, the extremes tend to prevail, leading either to a bipolarisation or to the convergence to a single extreme.*
>
> *Deffuant et al., 2002, p. 7.1*

On a more general level, Flache et al., 2017 also contrast the two forces that are typically relevant in shaping social and political phenomena (and that are relevant to our analysis), i.e., assimilation and rejection,

> *For one thing, while assimilation seems to be the predominant pattern in interpersonal interactions, people may not only influence each other to become more alike, but also sometimes reject attitudes or behavior of those they interact with, and even seek to become more different from them.*
>
> *Flache et al., 2017, p. 1.2.*

The above six claims provide a set of clues about how the behavior of individuals affects the collective, and how the collective impacts individual decisions. These ideas constitute a fundamental reference required to sketch the Agent ID model as described in the following sections.

9.3 Assembling the Agent's ID

In this section, the profile of the individual agent is characterized, taking into consideration the regularities that the previous section has exposed. Once the profile of the agent is established, one can define a set of simple interaction rules, which will attribute to the model the structure required for understanding the sequence of events and the behavior of aggregate variables. The model is programmed and simulated in the subsequent chapters.

Begin by considering an economy populated by $\tilde{N}$ individual agents. At the initial date, $t = 0$, a unique ID profile is assigned to each agent; this ID contains eight features, which are sequentially detailed below.

ID1 - Financial endowment The first feature of the agent's ID concerns the level of wealth the individual holds at the beginning of each time period (W_t). At the initial date, $t = 0$, the level of wealth of the agent is derived from a Pareto distribution (claim 1).

Over time, individual wealth increases with the revenues of sales of produced goods (Y_t) and decreases with consumption (C_t). The following three ID features explain what the individual agent produces and which goods she or he acquires to fulfill her or his needs. An interest rate, r, can be added to the analysis, case in which a typical budget constraint may be assumed to characterize wealth dynamics:

$$W_{t+1} = Y_t + (1 + r)W_t - C_t,\ W_0 \text{ given} \tag{9.1}$$

ID2 - General skills Agents are endowed with a given level of skills, which allows them to produce a good of a given quality. The better the skills, the more productive the agent is and the higher is the quality of the produced good (claim 2). Each general skill / type of produced good is indexed by $q \in \mathbb{Q} = \{1, \ldots, Q\}$.

At the initial date, $t = 0$, the skill level of the agent is derived from a combination of two Pareto distributions: the first distribution is the same that generates the initial wealth levels (skills are correlated with wealth via resource availability to invest in human capital), duly scaled to fit set Q; the second distribution is independent from the first and translates innate qualities of the individuals. A given parameter $\theta \in (0, 1)$ will translate the relative weight of each of the two forces in the society.

The assignment of skills under Pareto distributions indicates that most people have average competences with which they participate in the productive process to generate low ranked goods in the assumed quality scale, while a few individuals have or acquire exceptional capabilities that allow them to locate higher in the mentioned scale. The skills' endowment of each individual is assumed to remain constant over time, and it will reflect on income, via sales of the good they are capable of producing.

The good of quality q produced by the agent with skill level q can be sold to other individuals in the market at a given price $p(q) = aq^{\alpha}$, with $a > 0$, $\alpha > 1$ (claim 2). The agent can produce as many units of the good as the market demands.

ID3 - Specific skills Given the general skill, and the respective type of produced good, the individual agent will specifically produce a single variety of the good $j \in \mathbb{J} = \{1, \ldots, J\}$ (claim 2). It is assumed that all types of goods are potentially supplied in J varieties.

The variety produced by an agent is randomly chosen from J under a uniform distribution. As the general skills, the specific skills do not change over time, once defined at $t = 0$ for the universe of agents.

ID4 - Preferences over goods Agents will want to consume the goods produced by others, and they will purchase them in the market, at the prices defined above in ID2. However, they have specific preferences: they want to acquire goods of any quality, but for each quality they choose to purchase only varieties on a specific subset of J (claim 2).

The lower and upper bounds of the subset of J, respectively J_L and J_H, are randomly derived from a uniform distribution (agents with peculiar tastes will be those with a narrower subset $\{J_L, \ldots, J_H\}$; those who are not picky will desire to acquire a wider range of varieties). The preference set is assumed to be immutable in time. In the next section, when enunciating the rules of interaction, the dynamics of market relations are briefly explored.

ID5 - Network connectivity Market interactions occur at a local level (markets are not complete; claim 3). Assuming that the total number of agents in the economy is a value $\tilde{N} \in \mathbb{N}$, each agent will be able to establish contact with $N \leq \tilde{N}$ other individuals. At the starting date, the value of N will be contingent on the initial level of financial wealth (it will be the integer of the value of wealth after scaled to fit the assumed population). With this assumption, we want to represent an association between financial capabilities and the ability to stay in contact with others (claim 3).

Agents' connectivity will change over time, reacting to personal movements on wealth and also to moral behavior (claim 3). Moral behavior will be measured by an index B_t defined in the interval $[-1, 1]$ and it will be the subject of further appreciation below, on agent ID7. Negative values of this index represent dishonesty and a self-centered behavior, while positive values respect to altruistic behavior and honesty.

The level of connectivity will increase with positive changes in wealth and with positive moral behavior, under the following rule,

$$N_{t+1} - N_t = int\{[w(W_t - W_{t-1}) + bB_t]N_t\},\ w,\ b > 0 \tag{9.2}$$

Dynamic equation (10.2) must satisfy, in any case, boundary condition $N^0 \leq N_{t+1} \leq \tilde{N}$ with N^0 the minimum number of links an agent may possess with the remainder of the economy. Links that are broken or added are randomly selected, across the population.

ID6 - Animal spirits Animal spirits reflect, in this context, the confidence level of the agents in the future performance of the economy. This will determine the marginal propensity to consume out of their financial endowment (claim 4). We will consider that animal spirits (A_t) are represented by a value in the interval $[-1, 1]$, with the extremes relating to full pessimism and full optimism (-1 and 1, respectively). The initial value, at $t = 0$, is given by a normal distribution with zero mean (truncated in order to transform its infinite support in a finite support obeying the mentioned boundaries).

Animal spirits evolve according to two processes (claim 6): reversion to the mean of the part of the population with whom the individual is in contact (A^m) (this is a 'follow the crowd' effect), and a natural proclivity for extremism (to approach full pessimism or full optimism); this rule writes as follows:

$$A_{t+1} - A_t = g(A^m - A_t) + \gamma(\cdot) \tag{9.3}$$

with $\gamma(\cdot) = -\gamma(1 + A_t)$ for $A_t < 0$, $\gamma(\cdot) = 0$ for $A_t = 0$, and $\gamma(\cdot) = \gamma(1 - A_t)$ for $A_t > 0$; $0 < g < 1$, $0 < \gamma < 1$, A_0 given. Under this rule, there is a tendency for two groups to be formed, one of pessimistic agents and another one with optimistic agents.

As mentioned above, animal spirits determine the marginal propensity to consume out of the financial endowment, $c(A_t)$. This function has a minimum (c_L) and a maximum (c_H), with the minimum value attained for $A_t = -1$ and the maximum value accomplished for$A_t = 1$. An inverse tangent function will translate this idea:

$$c(A_t) = \frac{1}{2}\left[(c_L + c_H) + (c_H - c_L)\frac{atan\left[\frac{a}{2}A_t\right]}{atan\left(\frac{a}{2}\right)}\right],\ a > 0,\ 0 < c_L < c_H < 1 \tag{9.4}$$

The potential consumption level will correspond to $C_t = c(A_t)W_t$, i.e., the agents will consume a constant share of their available wealth.

ID7 - Moral behavior Moral behavior was already mentioned in point ID5. This is an index $B_t \in [-1, 1]$, with negative values representing an individual conduct that the society does not approve and, as a result, makes some links of the respective network to be broken. If the value is positive, morality, honesty and altruism contribute to an increase in the number of links of the individual with others. A normal distribution of mean zero is assumed for the selection of moral behavior of the individuals at $t = 0$ (once again, the distribution needs to be truncated in order to guarantee the required finite support).

Moral behavior changes, in the end of each period, as the agent is influenced by the moral behavior of the agents in the network that she or he has contacted. We consider similar dynamics to those taken for animal spirits (i.e., reversion to the mean and tendency to extremism – claim 6):

$$B_{t+1} - B_t = z(B^m - B_t) + \zeta(\cdot) \tag{9.5}$$

with $\zeta(\cdot) = -\zeta(1+B_t)$ for $B_t < 0$, $\zeta(\cdot) = 0$ for $B_t = 0$, and $\zeta(\cdot) = \zeta(1-B_t)$ for $B_t > 0$; $0 < z < 1$, $0 < \zeta < 1$, B_0 given. Parameter B^m represents the mean value of the moral behavior index of the individuals with which the agent under consideration is in contact with.

ID8 - Political view The political view is an index that measures the opinion of the individual about redistributive policies. Similarly to the animal spirits index and to the moral behavior index, we define it in the interval $[-1, 1]$, with the initial level given by a (truncated) normal distribution of mean 0 and the respective evolution over time expressed by a mean reversion / tendency to extremism equation (claim 6):

$$X_{t+1} - X_t = x(X^m - X_t) + \omega(\cdot) \tag{9.6}$$

with $\omega(\cdot) = -\omega(1 + X_t)$ for $X_t < 0$, $\omega(\cdot) = 0$ for $X_t = 0$, and $\omega(\cdot) = \omega(1 - X_t)$ for $X_t > 0$; $0 < x < 1$, $0 < \omega < 1$, X_0 given, and X^m a mean value. A value of X near -1 expresses a left-wing position that supports wealth redistribution; a value of X near 1 (right-wing political position) refers to an agent that opposes strong redistribution of wealth.

The political view of the individuals, when taken on the aggregate (mean of all political views), determines the extent of public redistribution of wealth. In the end of each period, the government levies a tax on those having a financial endowment that is more than average and redistribute to those that have a lower-than-average financial endowment. The extent of the redistribution depends on the prevailing political view (claim 5).

Let the following dynamic equation represent the redistribution of wealth for each agent,

$$W_{t+1} - W_t = \tau(X^{agg})(W^{agg} - W_t) \tag{9.7}$$

Value $\tau(X^{agg})$ is the rate at which wealth levels approach, which depends on the aggregate average of X (note that X^{agg} differs from X^m because the first value is the average of the political views of the whole universe of agents, while the second value is the average of political views of the agents with which the assumed individual agent is in contact with). The equation states that if the level of wealth of the agent is above the average of the population (W^{agg}) then it falls through the redistributive policy; the opposite occurs when $W_t < W^{agg}$.

The above-described process is such that government intervention will make wealth levels to approach in the transition from period t to period $t + 1$. The extent of this redistribution depends on the

value of $\tau(X^{agg})$, which is bounded between -1 and 1. If all people are left extremists then $\tau(-1) = 1$, meaning a full redistribution (at $t+1$ every agent will have an identical level of wealth:$W_(t+1) = W^{agg}$); if all people are right extremists, no redistribution takes place and $\tau(1) = 0$, meaning no redistribution: $W_{t+1} = W_t$. The relation between τ and X, with the proposed features, might be analytically translated as follows,

$$\tau(X_t) = \frac{1}{2}\left[1 - \frac{atan\left[\left(\frac{u}{2}\right)X_t\right]}{atan\left(\frac{u}{2}\right)}\right],\ u > 0 \tag{9.8}$$

9.4 The Agent ID Model at Work

After having characterized each of the features of the ID profile of the individual agent, this section describes the operationalization of the Agent ID model through the characterization of the agents' interplay, given the eight features that were enumerated.

To implement the model, we first need to specify the number of agents in the economy, $\tilde{N}$. For each one of the $\tilde{N}$ agents, we then have to generate an initial ID profile, with the above eight features. Next, given the network connectivity value (ID5), the specific agents with which each agent interacts are randomly selected. An additional step is, then, the computation of the marginal propensity to consume (ID6), as well as of the potential level of consumption of each individual.

Having prepared the above setting, agent interaction begins. For every agent in the economy, the procedure is as follows: given the number of interactions allowed for the agent (ID item 5), contact is established with every connection in a sequential way, starting with partners with more links, until the number of possible interactions is exhausted. Relatively to each contact, one has to ask the following question: does the contacted agent produce a good variety in the $\{J_L, \ldots, J_H\}$ interval of the agent's preferences (ID3, ID4)? If yes, the agent buys the good for consumption, at a price $p(q)$. The transaction lowers the financial wealth of the individual that buys the good and increases the wealth of the agent selling the good, by an amount $p(q)$. This process is repeated until the potential consumption level (as defined in ID6) is reached, or the number of allowed contacts is exhausted.

After proceeding as indicated in the above paragraph for every agent in the economy, one will have post-transaction levels of financial wealth (W_t) and also consumption (C_t); these can be summed up across all individuals to obtain the aggregate levels of wealth and consumption. If one calculates the amount of goods sold by each individual, one will be also able to compute the level of generated income (equal to the number of units sold of the produced good multiplied by its price).

At the end of the first time period, a series of events takes place: 1) network connectivity of each individual changes, given the period's wealth and moral behavior variations; 2) income is redistributed given the prevalent political view (ID8); 3) animal spirits, moral behavior and political view evolve, for the following period, given the defined rules of motion (ID6, ID7, ID8). Levels of wealth in the end of the period (after transactions and redistribution) can be computed.

The previous steps may, then, be repeated for a selected number of periods, to generate trajectories of individual and aggregate wealth, consumption, income, connectivity, animal spirits, moral behavior, and political view.

An additional element may yet be included. This is the renewal of generations. At each period, a prespecified number of agents is 'killed' (randomly selected), and an equal number of new individuals (with reset initial ID features) enters the system. All of these features are tested in the next chapter, through the computational codification of the model.

9.5 Conclusion

Who we are and what we do in society and in the economy is driven by a series of factors. The relevant point is that, regarding each of such factors, we are tendentially different from one another: our political views, our moral standards, our skills, our ability to interact with others, our wealth endowment at a given date, our preferences, all vary across individuals and, therefore, the representative agent standard often employed to approach economic phenomena (see, e.g., A. P. Kirman, 1992; Gallegati and A. Kirman, 1999; Hands, 2017; Jackson and Yariv, 2019) is useless if the goal is to approach social and economic relations where individual differences are the norm.

The above observation is the main motivation for the development of the Agent ID model. In this model, the individual agent is initially endowed with a set of features, which are decisive to determine her or his performance in the economic and social system. People are intrinsically different, and these differences emerge when the ID of the agent is generated. The initial heterogeneity is, then, determinant to shape subsequent behavior and outcomes. Because individuals are born with distinct sociability levels, their capacity to interact with others may attenuate or exacerbate initial differences.

In this chapter, we have begun by highlighting half a dozen observable regularities that are helpful in assisting to assemble the ID of each agent and in clarifying what the rules of interaction should be. However, both the identification profiles and the interaction rules were presented and explained solely in theoretical terms. To fully grasp on the intricacies and complexities of a socio-economic environment that considers the individual profiles and the interaction rules one has designed, the framework must be translated into computer code, which must be run to generate patterns that, hopefully, replicate observable regularities which, again, should conform with the various claims presented in the beginning of this chapter. This is the task to be undertaken in the following chapter.

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Chapter 10

Implementing the Agent ID Model and Simulation Results

Paulo Fagandini

Summary
In this chapter we implement the model introduced in Gomes, 2024 and show the main results of a simulation in the long run so the user has the notion of its "convergence." We present the code, which is done with Python and MESA, and suggest potential variations that could be created to tackle diverse economic problems.
Keywords: Agent-Based Models, ABM, Economic Dynamics, Inequality.

10.1 Introduction

While in the natural sciences experimentation is an integral part of the daily activities in every laboratory around the world, social scientists have no such privilege. Aside from all the social and ethical dilemmas that this poses, it is enormously difficult to isolate the effect intended to be measured.

Economists have come up with novel and sophisticated statistical techniques to overcome some of these difficulties. Another set of techniques to approach the experimental framework used in natural sciences, is illustrated by the recent literature on natural experiments, field experiments, and laboratory experiments. For several of these advances, economsits have to thank applied economists working on problems of public policy, labor economics, human capital, development economics, among others. For all the good these methodologies are, each serves a different purpose, and comes with its own set of caveats that are not the focus of this article.

Another approach used by all kinds of scientists, but that has struggled to make its way in the economic profession is the use of simulations. Within the business setting, these techniques are more commonly used by researchers on Decision Sciences and Operations Research. For Social Scientists, and economists, Agent-based models (ABMs) represent a very enthicing way to study aggregate economies. These models allow the researcher to set up behavior of individual agents, give them an endowment, set up a schedule that dictates their interaction, sometimes set up the world in which they act (and/or move for some models), and observe what is happening be it at a micro or a macro level in the desired variables. In other

words, this allows to simulate the whole economy, and serves as a very approachable counterfactual to study the impact of different economic policies.

The main reason ABMs have found it difficult to gain terrain in the economic science is mainly because the economic theory tradition has been to start with a single set of assumptions (axioms) that clearly identify an objective function for each agent and optimize the behavior using traditional mathematical tools. This is very useful to understand marginal changes in the behavior of the agents, however, this makes it very difficult to solve problems involving a large number of heterogeneous agents, and imposing very strict mathematical constraints on the problem, oftentimes making it analytically insolvable.

ABMs, on the other hand, work in the opposite direction. Assuming an agent's behavior (which need not be optimal nor suboptimal), focus its attention on the outcome of these multiple interactions. A good example of these models, and that is fresh in the memory of everyone who went through the recent COVID-19 pandemic, is the one used to study contagion under several different scenarios. Scientists (often mathematicians, virologists, etc.) presented models with simulated contagion rates under different prevention measures: using masks, being confined to the house, to a certain neighborhood, etc., and then observed how many agents had gotten the virus, how fast the desease sepreaded among the population, or how many individuals got infected simultaneously, and thus allowing to provide suggestions to optimize, for example, the load the emergency health services. In this situation, there was no intention (nor need) to optimize the behavior of each individual agent. Instead the goal was to compare the result of different policies (parameters) by imposing restrictions on individual behavior.

In this chapter, we implement the simulation for the model introduced in Gomes, 2024, where many heterogeneous agents, with several different characteristics, interact with each other. The richness of the model allows us to introduce the effects of different political views, moral behaviors, skills, preferences over goods, and animal spirits into the dynamics of the economy. These forces interact to drive the aggregate variables (consumption, wealth, inequality, etc.) in the economy.

We will present the main results of a canonical simulation, which will be useful to illustrate the characteristics of the model, and also to identify opportunities where some features can be adjusted to adapt it to different purposes.

As stated in Gomes, 2024, agents will be endowed with wealth, general and specific skills, preferences over goods, a political view, a moral behavior, and animal spirits. Some of these variables mutate with the influence of the peers and economic interaction with other agents (wealth, political view, moral behavior, animal spirits). Others, such as general and specific skills, remain constant.

These characteristics affect each agent's connectivity, which in turn defines with how many peers the agent will interact, be it by offering a good to trade, or by consuming a good offered by them. These peers will affect the agent's views over the world, entering in the dynamic of the moral behavior, animal spirits, and political view. At the same time, the aggregate political view is modelled to affect the wealth redistribution, by means of a tax and a subsidy on each agent.

A remarkable, and recent, example of the use of AMBs for modelling the whole economy, with the goal of analyzing policy effects on the population is Moreira et al., 2019. In that work, the authors model the Portuguese economy to simulate the sustentability of the country's pension system. Their model though, did not incorporated any interrelationship between the agents political views and a change in policy. Instead, their runs were done as predetermined independent experiments.

10.2 Model Implementation

The implementation of the model is done with MESA (Kazil, Masad, and Crooks, 2020). This package was developed for Python, and in particular we use Python 3 in our simulations.

This library requires the implementation of the class Agent, and, after the attributes initialization, with the model parameters, we declare the functions that represent the laws of motion for these parameters. Within this class, it is necessary to define the *step* function. This function schedules exactly what the agent will do when it is its turn to move, which variables get updated when the agent moves, and how it consumes goods sold by its contacts. The model, later, in each step will call this function for each agent in a random order.

Next, we need to write the model, which extends MESA's *Model* class. This class is more akin the economy as a whole, and it will create the agents, and in activate them in each period. For each period also, it is here where we need to collect aggregate data. Also, here we define here the data collector, another class in MESA, that allows us to obtain at the end of the simulation a Panda's dataframe with the variables we chose, be it at aggregate level (model) or individual level (agent).

The model class, just like the agent's class, requires that a step function be defined. This function will call the scheduler to activate each agent in each separate step. It also allows to implement aggregate actions that should happen every period, be it before or after each of the agents has been activated. In this part, we define:

- The initial connectivity for every agent depends on the wealth relative to the population.
- Specific skills which are also relative to the rest of the population.
- The tax and redistribution, as this is collected (or given) after every agent has moved.

Finally, this step also activates the aforementioned data collector. In this implementation, we force the system to collect, besides each period's data, the initial state variables by invoking the data collector *before* activating the agents (only during the first step).

In the appendix, we present all the functions that rule the dynamics here mentioned, and the code is also available in a public Github Repository.[1]

10.3 Simulation Design and Analysis

10.3.1 Simulation setup and parameters

For the simulation, we set the parameters to reflect the highest degree of balance between the different forces that move this economy. For example, we weigh 50% the effect of the initial endowment and 50% for the inherent skills on the general skills of the agents. In the same fashion, when the variables move according to the effect of the peers and the mean reversion, or the tendency to the extremes, we weigh 50% each effect. The complete list of parameters can be found in Table 10.1.

Noting that the computational load and time increases exponentially with the number of agents (since the larger the number of agents, the larger the number of interactions by each agent); we limit the scope to a model with only 500 agents. We used 4,500 periods because we observed stabilization of the variables

[1] https://github.com/pfagandini/ABM-Project-ISCAL.

Model level		
Variable	**Description**	**value**
r	Interest rate	0.25%
$\tilde{N}$	Population	500
T	Periods	4,500
Agent level		
Variable	**Description**	**value**
`inequality_wealth`	Wealth P.D. α	1.5
`inequality_skills`	Generic Skills P.D. α	3
θ	Meritocracy, Wealth's weight on gen. skills	0.5
Q	Qualities	20
J	Varieties	10
`min_connectivity`	Min. Connectivity	10
`max_connectivity`	Max. Connectivity	100
w	Δ wealth on connectivity	0.5
b	moral behavior on connectivity	0.5
g	impact of peers on an. spirits	0.5
γ	mean reversion on an. spirits	0.5
c_l	min. propensity to consume	0.1
c_h	max. propensity to consume	0.9
z	influence of peers on m. behavior	0.5
ζ	mean reversion on m. behavior	0.5
x	impact of peers on pol. view	0.5
ω	mean reversion pol. view	0.5
a	linear constant for the good's price	0.2
α	power constant for the good's price	1.5

Note: P.D. stands for Pareto Distribution, and α for its parameter.

Table 10.1: Parameters of base simulation

at an earlier stage. We ran simulations for a larger number of periods (100,000); however, we did not observe changes in the conclusions or the accuracy of the predictions.[2]

In each run, at the model level, we record the tax rate for each period. At the agent level, we collect the following variables: consumption, wealth, political view, animal spirits, connectivity, and moral behavior.

As the data are collected into a Panda's dataframe, the use of Jupyter notebooks for the data analysis becomes an obvious choice, and we make available all the files necessary to run the simulations on this project's repository on GitHub.[3]

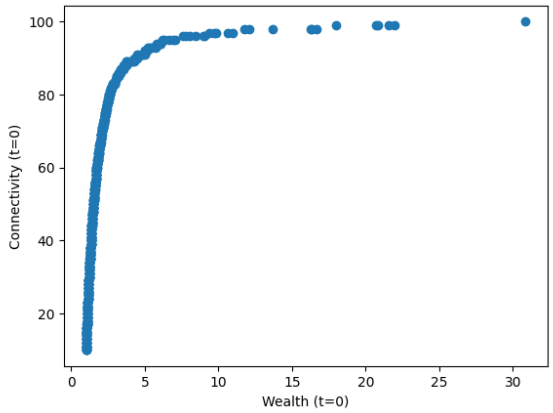


Figure 10.1: Initial network connectivity according to wealth.

10.3.2 Simulation dynamics

Wealth

The simulations of this economy tend to be polarized and with a tendency to equality. This is not surprising as the interest rate affects everyone's wealth equally, and after so many periods, and considering everyone is saving each period (propensity to consume is set to never exceed 90%) the aggregate wealth inevitably tends to increase. On the other hand, wealthier agents will have more connections, and therefore will visit more agents from whom to purchase, and therefore will tend to spend more than those with fewer connections, tending to reduce their wealth.

The wealth dynamics are captured by Fig. 10.2 and Fig. 10.3. Fig. 10.3 shows the wealth distribution at the beginning (at $t = 0$) which follows a Pareto Distribution with $\alpha = 1.5$, as suggested by Gabaix, 2016, p. 191, and with time, it evolves into a bell-shaped distribution centered around a larger mean (because of the mentioned effect of the interest rate). The appearance of a strong middle class is significant. We can observe the individual wealth changes over time in Fig. 10.2. Note that the effect of the interest rate becomes very dominant in the dynamic, in particular because of the large number of periods.

[2]As a reference, one of these simulations, with 1,000 agents for 2,000 steps, takes almost half an hour, on a machine with Windows 11 Pro 64bits, running on an AMD Ryzen 9 5900x CPU (12c, 24t), and 64GB of DDR4 RAM.

[3]https://github.com/pfagandini/ABM-Project-ISCAL

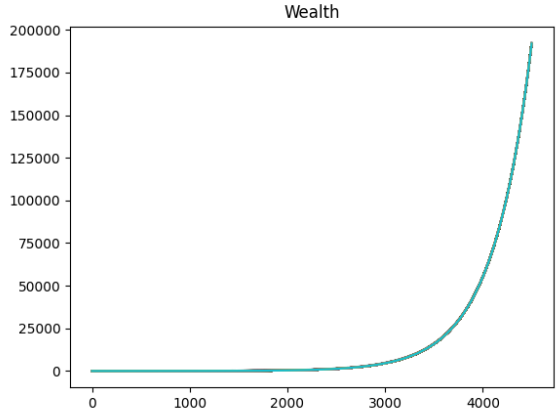


Figure 10.2: Wealth over time.

Fig. 10.4a illustrates the correlation between final wealth and lifetime consumption. Dots are shaded on the initial level of wealth, blue meaning in the bottom half of the initial wealth distribution, and orange being for those agents in the top half of the inital wealth distribution. If anything a negative correlation appears to emerge, in particular for the poorer agents, which are more concentrated in their level of wealth. Note that this correlation goes both ways, wealthier agents will be able to consume more, however they will pay more taxes on wealth. At the same time, agents that consume less will be able to save more and then will benefit more from the interest rate. Poorer agents will also receive a subsidy from the tax collected from the wealthier agents.

Another feature that becomes evident here is that consumption is bounded by more than the propensity to consume. Note that there is a finite price on each good, and there is a finite number of connections (bounded at 100 in this case), so in the worst case scenario, the agent buys from the agents with the most expensive goods. In any case this represents a finite amount of expenditure, as in this economy there is no inflation, another potential feature that could be incorporated (indexing the prices to the total amount of nominal wealth available in the economy.)

Regarding the relationship between lifetime wealth and lifetime consumption, illustrated in Fig. 10.4b, the same pattern emerges. This is expectable as again, final wealth and lifetime wealth are expected to be very close thanks to the moving forces in the model, in particular the interest rate and the long time horizon.

Potential alterations to the model could include stochastic factors (like for the interest rate), include higher degrees of heterogeneity (for example different returns on wealth depending on the percentile of wealth, reflecting that wealthier individuals have access to a wider range of investment opportunities), and also the possibility of debt, for example anchoring consumption to the peers, even if that means incurring in debt.

Finally, introducing more demographics variants could also affect the wealth dynamics of the model. For example allowing for multiple generations, whith individuals being born and dying with a probability linked to their age. Also the probability of having child (and thus creating a new agent) which could inheirt the wealth, and a new tax on inheritance can be added. This would require very minor modifications to the *agent* class.

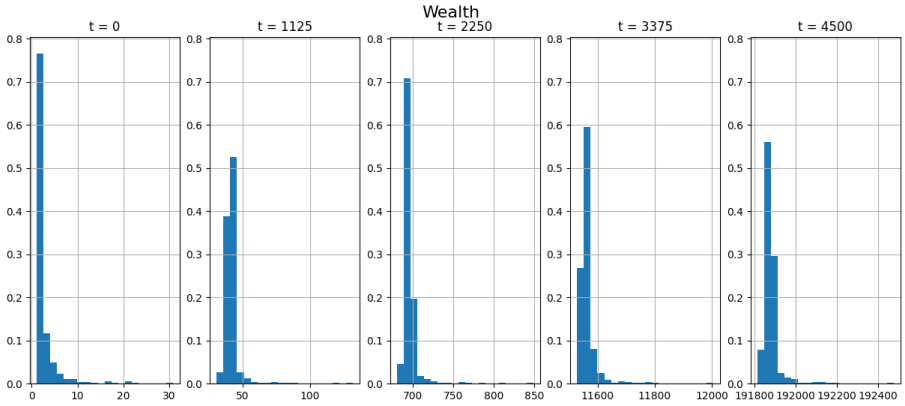
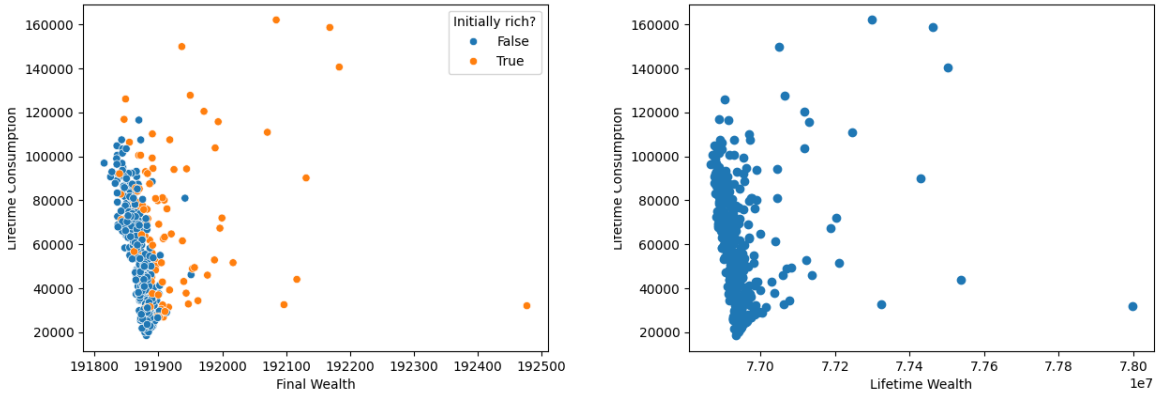


Figure 10.3: Wealth distribution over time.



(a) Final wealth and lifetime consumption.

(b) Lifetime wealth and consumption.

Figure 10.4: Wealth and consumption.

Connections

As stated, the model relies heavily on the number of connections each agent has. Note that the variables analyzed in the next section are modeled after the characteristics of the agents that traded with each other.

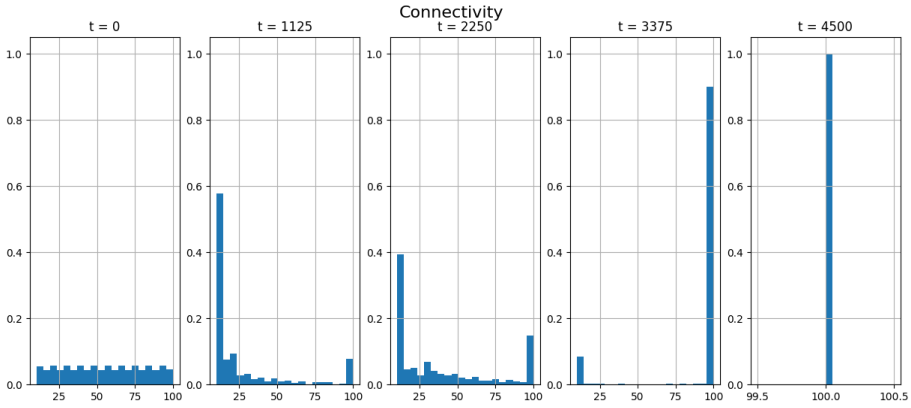


Figure 10.5: Histogram for connectivity

Note in Fig. 10.5 how it starts very uniformly distributed among the individuals, and quickly a high inequality arises to converge to full equality. This is expectable, and is again a result of the driving forces in the model. This can be observed also in Fig. 10.6, where the connectivity time series is drawn for each agent. Of special relevance for this phenomenon are the interest rate and the time horizon. Again, note that the propensity to consume is bounded, and therefore agents are always saving. This savings compounded with the 2.5% interest rate for 4,500 periods makes even the poorer agent very rich in comparison to their initial state. Now considering that the dynamics of the connectivity follows the evolution of personal wealth, we can easily see how this leads to a larger and larger number of connections, in particular when this number is bounded from above.

Depending on the number of periods, a sensible modification to the model could be to adjust the motion law of connections, making it dependent on the wealth of the agent relative to the population. This problem might be less sever if the population is not fixed but growing. However, we leave that for future research. This modification is also relatively simply just modifying the function *update_connectivity(self)* in the agent's code.

Animal Spirits, Political View, and Moral Behavior

The dynamics observed in animal spirits, moral behavior and political view follow a pattern of polarization. By construction, as explained in Gomes, 2024, these dynamics tend to mean reversion and polarization. We observe in the histograms (Fig. 10.7a, Fig. 10.7b, Fig. 10.7c) how agents are more or less uniformly distributed within the range of these variables.[4] Even further, this is more evident when we look at the

[4]Actually the data is generated from a reverse truncated normal distribution, however because of the little observations, the resulting distribution looks quite flat.

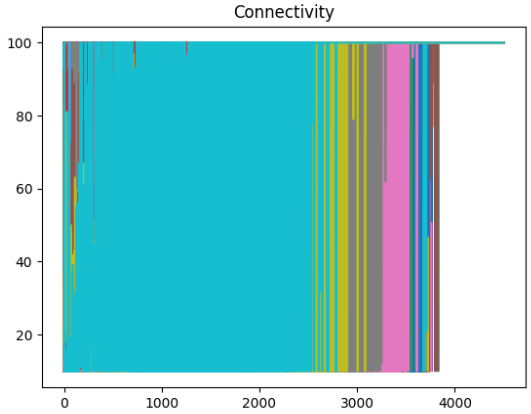


Figure 10.6: Connectivity in time.

group of indiviudal time series, as shown in Fig. 10.8, we see that very early agents are grouped within two groups, and just above the 3,500 periods these groups become even more concentrated around their means (-0.5 and 0.5, *i.e.* on the middle of each side).

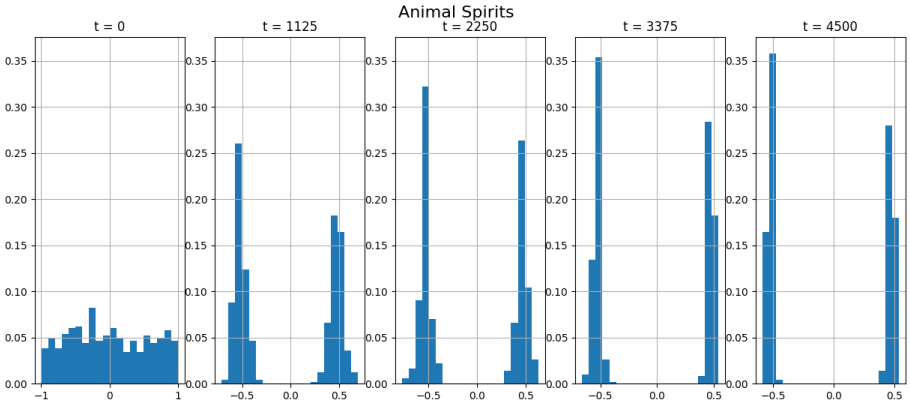
Particularly political view has a huge impact on the evolution of the tax, which stays slightly below 50%, indicating that on average, for this run, agents tend to the right, as the extreme left implies a tax of 100%, and an extreme right view, in our model, would imply a tax of 0%. In Fig. 10.9 we observe that the average political view stays consistently, although very slightly, below 0 (slightly to the left), and consequently the tax remains above 50% for the whole sample of periods.

Even though the observed dynamics might suggest a certain correlation in moral behavior, political view, and animal spirits, this is not the case. Computing correlation coefficients between them we obtain numbers very close to zero (-0.01, or -0.04), and if a scatter plot is made between any of these variables, considering their lifetime average, for all the agents, we obtain essentially four dots with coordinates +0.5 and -0.5.[5] This is consistent with the dynamics of the model, as there is no particular underlying mechanism driving these forces in parallel, as one is to expect in real life.

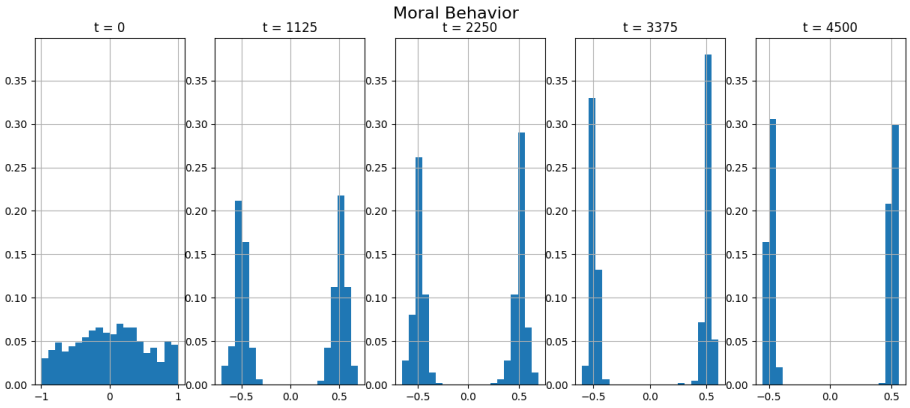
10.3.3 Representativeness of the results

An important question is how representative a single run of the experiment might be, as moral behavior, political views, and animal spirits are consistently around zero. To answer this we ran the simulation, with the base parameters, 200 times, allowing us to obtain confidence intervals and a distribution of the metrics of interest. The simulation took around 972 minutes or over 16 hours. We find that with 95% confidence the average tax is not different from 50%, and that all the runs seem to be closely distributed around 50%, as show in Fig. 10.9. Also, we measure the Gini index for inequality for initial and final wealth. We find that average initial Gini is 11.11%, while final Gini is 4.06%. This confirms our conclusion that the system under our initial parameters converges to a more egalitarian society as show in Figure 6 and Figure 7.

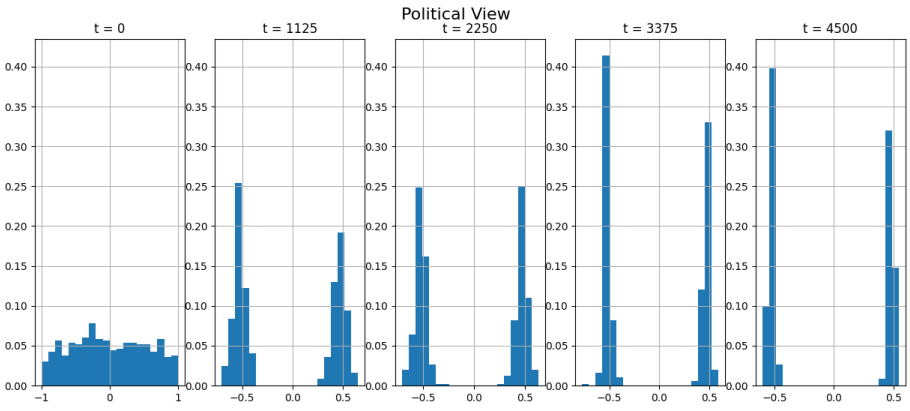
[5]Given the large amount of plots, the authors have decided to spare the reader this time.



(a) Animal Spirits.

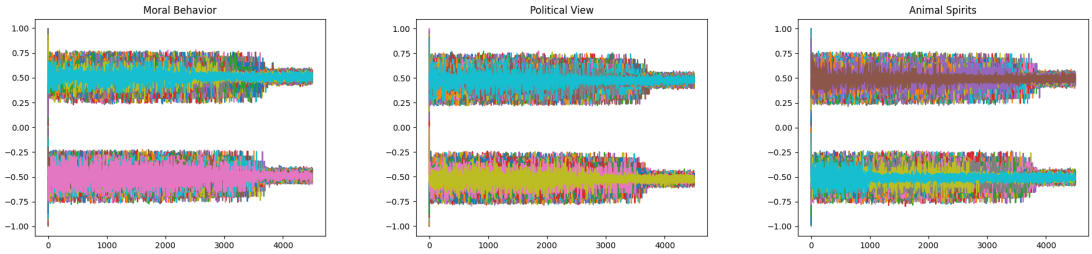


(b) Moral Behavior.



(c) Political View.

Figure 10.7: Distribution of Animal Spirits, Moral Behavior, Political View over time.



(a) Moral Behavior over time. (b) Political View over time. (c) Political View over time.

Figure 10.8: Moral, political view, and animal spirits over time.

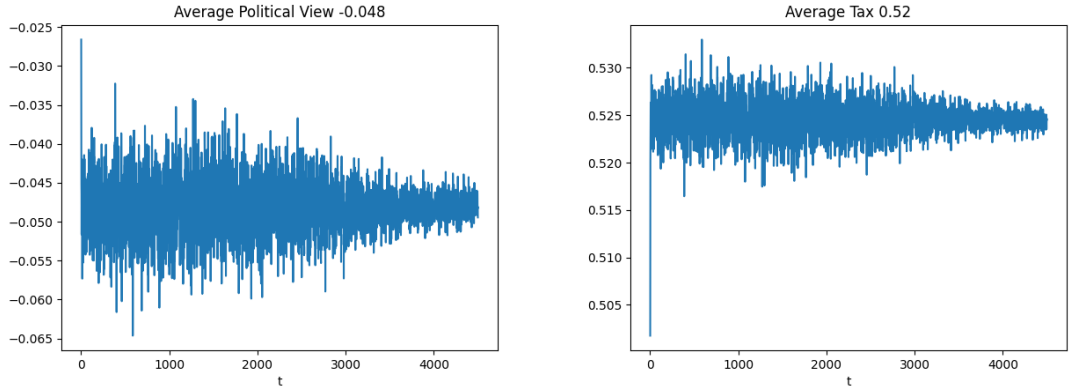


Figure 10.9: Political View and Tax evolution.

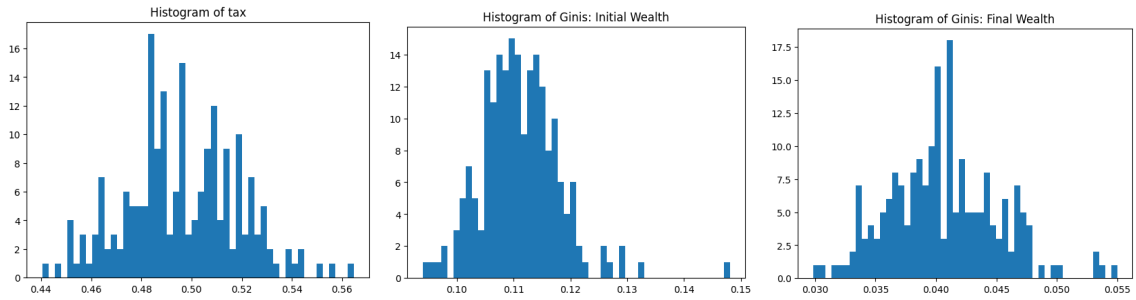


Figure 10.10: Several runs, histograms for Gini coefficient and average tax, initial wealth's gini, and final wealth's gini.

With respect to the Gini coefficient, we run a single simulation with the base parameters, for 5,000 periods, and find that the model tends to equality, i.e. a Gini coefficient of 0, as shown in Fig. 10.10.

10.4 Conclusion

In this chapter we have implemented a canonical Agent-based model of the economy, which incorporates behavioral and political features, along the more traditional macroeconomic variables.

Simulations were ran over thousands of periods, allowing us to illustrate clearly what is the long run state and in which directions the variables are diverging, assisting whomever uses the model to callibrate the number of periods for which to run the model.

We have made suggestions on potential alterations to the model, for the implementation of a diverse set of possible applications, and from the results of our simulation, a notion on how heavy to run it might turn out to be. Furthermore, a notion on the optimal number of periods to utilize.

The model offers many degrees of customization depending on the intention of the researcher. We established that introducing multiple generations and taxes on inheritance could be a valuable addition. Also, introducing inflation seems reasonable, as the wealth and how it is generated is clearly a nominal phenomenon.

Controlling the boundaries of consumption, and allowing for debt would make more realistic the effect of the interest rate in inequality, as well as the connectivity dynamics depending on the wealth level relative to the population instead of its absolute level, in particular as in the long run it always increases.

Something that was not modelled here, although perfectly possible, is a higher degree of heterogeneity in the parameters. For example some agents might be more influenced by its peers than another. This, for example, could be modelled by generating random parameters from some predefined distribution, and if an overlapping generations model is being used, these parameters could be influenced by the parent's. This approach could be extended to the initial values of the variables like political views, moral behavior, and animal spirits, and these agents might even share partially the set of "contacts" from their parents.

In sum, this model is, as stated, a canonical model with a plethora of reasonable adjustments that can make it suitable for a wide set of applications.

10.5 Appendix

10.5.1 Agent's code

```
import mesa
import numpy as np
import random
from scipy.stats import pareto, truncnorm

class agent(mesa.Agent):

    def __init__(self, unique_id, model):

        super().__init__(unique_id, model)

        ###################
        ### Parameters ###
        ###################

        # Wealth distribution parameter: The higher, the higher the inequality
        inequality_wealth = model.data['inequality_wealth']

        # Skills distribution parameter: The higher, the higher the inequality
        inequality_skills = model.data['inequality_skills']
        weight_gen_skills = model.data['weight_gen_skills'] # theta in the paper

        # Qualities and varieties parameters
        self.qualities = model.data['qualities'] # Q in the paper
        varieties = model.data['varieties'] # J in the paper

        # Own good pricing parameters
        a = model.data['a']
        alpha = model.data['alpha']

        # Connectivity limits, parameters
        self.min_connectivity = model.data['min_connectivity']
        self.max_connectivity = model.data['max_connectivity']

        # Propensity to consume parameters
        self.pc_a = model.data['pc_a']
        self.pc_c_l = model.data['pc_c_l']
        self.pc_c_h = model.data['pc_c_h']

        # Connectivity update parameters
        self.connect_w = model.data['connect_w']
        self.connect_b = model.data['connect_b']
```

```
# Animal spirits parameters
self.as_gamma = model.data['as_gamma']
self.as_g = model.data['as_g']

# Moral behavior parameters
self.mb_z = model.data['mb_z']
self.mb_zeta = model.data['mb_zeta']

# Political view parameters
self.pv_x = model.data['pv_x']
self.pv_omega = model.data['pv_omega']

##################
### Vars Init ###
##################

self.wealth = pareto.rvs(inequality_wealth)

self.gen_skills =
    (self.wealth * (1 - weight_gen_skills) +
    pareto.rvs(inequality_skills) * weight_gen_skills)

self.sp_skills =
    np.round(np.random.default_rng().uniform(0.5 , varieties + 0.5) , 0)

self.pref_low =
    np.round(np.random.default_rng().uniform(0.5 , varieties + 0.5) , 0)

self.pref_high =
    np.round(
        np.random.default_rng().uniform(0.5 + self.pref_low , varieties + 0.5) , 0)

# Connectivity will be updated later, once everyone has already gotten their wealth
self.connectivity = -1

self.animal_spirits = truncnorm.rvs(-1,1)

self.moral_behavior = truncnorm.rvs(-1,1)

self.political_view = truncnorm.rvs(-1,1)

self.price = a * self.gen_skills ** alpha

######################
### Auxiliary Vars ###
```

```
        ######################

        self.past_wealth = 0

        self.max_consumption = 0
        self.consumed = 0

        self.revenue = 0

        self.my_friends = [] # list of contacts

    def get_friends(self):

        aux_agents = [a for a in self.model.schedule.agents]
        aux_agents.remove(self)
        random.shuffle(aux_agents)

        return aux_agents[0 : min(int(self.connectivity), self.max_connectivity)]

    def propensity_to_consume(self):
        c_l = self.pc_c_l # paper's c_l
        c_h = self.pc_c_h # paper's c_h

        a = self.pc_a # a in the paper

        return 0.5 *
            ((c_h + c_l) + (c_h - c_l) *
            (np.arctan(a / 2 * self.animal_spirits)) / (np.arctan(a / 2)))

    def update_connectivity(self):

        self.connectivity +=
            np.round(
                (self.connect_w * (self.wealth - self.past_wealth) +
                self.connect_b * self.moral_behavior ) * self.connectivity)

        self.connectivity =
            max(min(self.connectivity, self.max_connectivity), self.min_connectivity)

    def update_animal_spirits(self, friends):

        def gamma(x):
            ga = self.as_gamma # gamma constant in the paper
            if x < 0:
                return -ga * (1+x)
            elif x == 0 :
```

```
            return 0
        else:
            return ga * (1-x)

    g = self.as_g # g constant in the paper

    Am_temp = []

    for a in friends:
        Am_temp.append(a.animal_spirits)

    Am = np.mean(Am_temp)

    self.animal_spirits =
        self.animal_spirits + g * (Am - self.animal_spirits) + gamma(self.animal_spirits)

def update_moral_behavior(self, friends):

    z = self.mb_z

    def zeta(x):
        zet = self.mb_zeta # constant greek zeta in the paper

        if x < 0 :
            return -zet * (1+x)
        elif x == 0:
            return 0
        else:
            return zet * (1-x)

    Bm = np.mean([a.moral_behavior for a in friends])

    self.moral_behavior =
        self.moral_behavior + z * (Bm - self.moral_behavior) + zeta(self.moral_behavior)

def update_political_view(self, friends):

    x = self.pv_x # constant x in the paper

    def omega(x):
        ome = self.pv_omega # constant omega in the paper
        if x == 0:
            return 0
        if x < 0:
            return - ome * (1+x)
        else:
```

```
                return ome * (1-x)

        Xm_temp = []

        for a in friends:
            Xm_temp.append(a.political_view)

        Xm = np.mean(Xm_temp)

        self.political_view =
            self.political_view + x*(Xm-self.political_view) + omega(self.political_view)

    def update_wealth(self):
        new_wealth =
            self.revenue +
            self.wealth * (1 + self.model.interest_rate)
            - self.consumed
        self.past_wealth = self.wealth
        self.wealth = new_wealth

##########################################################################
    ##### Actually the move of the agents, crucial for the order ####
##########################################################################

    def step(self):

        self.my_friends = self.get_friends()

        self.my_friends.sort(key = lambda x: x.connectivity, reverse = True)

        self.max_consumption = self.propensity_to_consume() * self.wealth

        for a in self.my_friends:
            if (self.max_consumption - self.consumed > a.price)
                and (a.sp_skills >= self.pref_low)
                and (a.sp_skills <= self.pref_high):
                self.consumed += a.price
                a.revenue += a.price
```

10.5.2 Model's code

```
from agents import agent
import numpy as np
import mesa

class model(mesa.Model):
```

```
    def __init__(self, data):

        super().__init__(self, data)

        self.data = data

        self.interest_rate = data['interest_rate'] # r in the paper

        self.tax = 0
        self.av_pol_view = 0
        self.av_wealth = 0

        self.num_agents = data['agents']
        self.schedule = mesa.time.RandomActivation(self)

        self.first_step = True

############ BEGIN DATA COLLECTOR ##################

        self.datacollector = mesa.DataCollector(
            model_reporters = {
                "n_agents": lambda m: m.schedule.get_agent_count(),
                "tax" : "tax"
             },
            agent_reporters = {
                "wealth" : "wealth",
                "moral_behavior" : "moral_behavior",
                "connectivity" : "connectivity",
                "animal_spirits" : "animal_spirits",
                "political_view" : "political_view",
                "consumption" : "consumed",
                "max_consumption" : "max_consumption",
                "past_wealth" : "past_wealth",
                "gen_skills" : "gen_skills",
                "revenue" : 'revenue'
            }
        )

############ END DATA COLLECTOR ##################

        gen_skills = []
        wealths = []

        for i in range(int(self.num_agents)):
            a = agent(i, self)
```

```
            gen_skills.append(a.gen_skills)
            wealths.append(a.wealth)
            self.schedule.add(a)

        max_g_skills = max(gen_skills)

        wealths = sorted(wealths)

        def gen_connect(w, ws, min, max):
            from scipy.stats import percentileofscore

            ps = percentileofscore(ws, w, kind = 'weak')

            bins = range(max - min)
            return min + int(len(bins)*ps/100)


        for a in self.schedule.agents:
            a.gen_skills =
                np.round(a.gen_skills / max_g_skills * (a.qualities - 1) + 1)
            a.connectivity =
                gen_connect(a.wealth, wealths, a.min_connectivity, a.max_connectivity)

    def step(self):

        ## get initial data ##
        if self.first_step:
            self.datacollector.collect(self)
            self.first_step = False

        ########################
        ### Now agents move! ###
        ########################

        # reset intra period variables for all
        for a in self.schedule.agents:
            a.revenue = 0
            a.consumed = 0

        self.schedule.step()

        ########################
        ########################

        # Update wealth levels with consumption and revenue
```

```
        for a in self.schedule.agents:
            a.update_wealth()
            a.update_connectivity()

        # Get average wealth and political views
        # to compute tax
        self.av_pol_view = np.mean([a.political_view for a in self.schedule.agents])
        self.av_wealth = np.mean([a.wealth for a in self.schedule.agents])

        # Compute tax
        u = 0.5
        self.tax = 0.5 * (1 - (np.arctan(u / 2 * self.av_pol_view)) / (np.arctan(u / 2)))

        # Redistribute
        for a in self.schedule.agents:
            a.wealth = a.wealth + self.tax * (self.av_wealth - a.wealth)

        for a in self.schedule.agents:
            a.update_animal_spirits(a.my_friends)
            a.update_moral_behavior(a.my_friends)
            a.update_political_view(a.my_friends)

        self.datacollector.collect(self)
```

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Chapter 11

Epilogue: Agent-based Transdisciplinarity

Orlando Gomes

Summary
The study of human behavior crosses a large spectrum of scientific fields. Every social science tries to understand specific issues regarding how people choose, act, and interact. Although scientific specialization is many times required to attain a deep perception of the matters at hand, one can only aspire to truly grasp the intricacies of human behavior and human interaction through an integrated perspective. In this last chapter, we advocate that such integrated view is closely intertwined with the notion of transdisciplinarity. This notion underlies most of the analysis in the book and, particularly, it serves as the inspiration for the proposed agent-based model that was characterized and explored in the previous chapters. The agent ID model might be classified as a transdisciplinary agent-based model.
Keywords: Transdisciplinarity, Human behavior, Agent-based models, Worldly philosophers, Soft science.

Agent-based transdisciplinary models. In Rezaei and Seyedpour, 2022, p.4, the concept of transdisciplinarity is defined in the following terms:

> Transdisciplinarity is a problem-oriented method that combines, integrates, and synthesize knowledge across disciplinary boundaries to generate a comprehensive solution.
>
> Transdisciplinarity research focuses on a complex problem that cannot be solved by methods, concepts, theories, and knowledge produced by a single or even multiple disciplines. It requires another fundamental component, society.

The mentioned authors interpret transdisciplinarity as a step forward relatively to the notions of interdisciplinarity and multidisciplinarity. Multidisciplinarity is defined as the process through which scientists of different disciplines collaborate to approach a given problem; it is an additive strategy that does not impose any type of integration across fields of knowledge. Instead, interdisciplinarity suggests some degree of integration between sciences, but they preserve their autonomy and independence. Transdisciplinarity goes further and deeper; it involves a process through which concepts, methodologies, and theories of different disciplines merge to explore new and more comprehensive answers and solutions to the complex problems that nature and society pose.

The transdisciplinary perspective is pervasive across this book. When people make decisions, select courses of action, interact with third parties, or are influenced or inspired by others, all of this has

holistic repercussions, that cannot be strictly separated into economic, social, psychological, or political compartments. Hence, by approaching human behavior, we have been concerned with the overarching consequences of such behavior, which manifests itself in the ways people choose, learn, innovate, interact, cooperate, and compete in all dimensions of society.

The idea of transdiciplinarity is also present in the conceived model, the agent-ID profile model, according to which every individual is endowed with a series of idiosyncratic features. These features are associated with economic capabilities, but also with the ability to choose, and with a wide array of preferences, not only over goods but also pertaining to ethics, ideology, and behavior in collective environments. The devised model can be classified as an agent-based model, because it considers a large number of agents, endowed with basic features, which interact following simple rules. The emergent result is a complex macro result that is shaped by a multiplicity of characteristics of the individuals and of the interaction processes.

Because of the bottom-up essence of the advanced model, and because this framework encloses many aspects of human behavior, specially those attached to social and economic connectivity, one can classify the setup as an agent-based transdisciplinary model (ABTM). The thought experiments that ABTMs allow for can be extremely precious for science and for the understanding of socio-economic relations. The proposed model offers a step in such direction.

The transdisciplinary nature of economics. Although the explored ideas and frameworks in the preceding chapters crossed many disciplines and areas of knowledge, the analysis and discussion throughout the book placed a special emphasis on economic choices and economic processes. Hence, an important question is whether the economic science is a promoter of transdisciplinarity or, on the contrary, if it tends to be an isolated scientific field that does not actively search for collaboration with other areas of knowledge.

At this respect, we close the book with a brief mention to two important reflections on the role of economics in the wider panorama of scientific knowledge. The first study we would like to highlight is R. Shiller and V. Shiller, 2011. These authors argue that there are fundamental differences between how we approach economic phenomena in current times and how we approached them in the early days of this science, namely in the eighteenth and nineteenth centuries. Economics became highly specialized and a field that is eminently technical. This contrasts with the contributions of Adam Smith, David Ricardo, John Stuart Mill, and many other classical economists, who interpreted economics as being inseparable from philosophy and other humanities.

The overspecialization of economics is advantageous in acquiring detailed insights about many relevant facts and ideas. However, the narrow focus can also be detrimental, leading to a loss of perception of the 'big picture,' *i.e.*, a loss in the capacity to reflect upon the economy as a whole and in an integrated perspective. There are too few contemporaneous economists revealing a wide understanding of the surrounding world and the capacity to convey an overarching perspective on the subjects that worry all of the citizens of this planet. In the words of R. Shiller and V. Shiller, 2011 we lack today the same kind of 'worldly philosophers' that were capable of launching a new science more than two hundred and fifty years ago.

A prototypical example of what a worldly philosopher is, is precisely the founder of economics as a science, Adam Smith. At the same time Adam Smith enunciated the principles governing market efficiency and the accumulation of wealth, he also reflected on the organization of work, moral sentiments, and social ties. Another great worldly philosopher, who offered an incisive and insightful view of the economy, is John Maynard Keynes. To explain the economy, Keynes explored the psychological and sociological underpinnings of human behavior. He has also reflected on the political organization of societies and on the philosophical and moral implications of living in prosper economies.

In the view of the mentioned authors, economics should revert the tendency for overspecialization. Economics needs to be closer to other scientific fields and to be on the forefront of the effort to foster interdisciplinarity and transdisciplinarity. In their own words (R. Shiller and V. Shiller, 2011, p.175), "The real imperative for researchers is that efforts need to be redoubled to encourage cross-fertilization and broad-spectrum thinking, driven by the broad moral purpose of improving human welfare."

In Akerlof, 2020, attention is called for the fact that economics evolved to be a hard science, resorting to methods similar to those employed in physics and mathematics. This does not leave much room for economics to mingle with other social sciences, which have a reputation of being essentially soft sciences. The distinction between hard and soft is associated with the degree of precision of the results that research can obtain. Precision and accuracy are, no doubt, important, but there are many subjects pertaining to social relations that cannot be scientifically approached with the rigor of mathematical methods and models.

Therefore, the effort to become more precise, rigorous, and quantifiable, led economics to go astray relatively to their closest scientific cousins, like sociology or political science. This hardness bias is today an obstacle to scientific development, promoting the perpetuation of existing paradigms, encouraging overspecialization, and making it difficult for new ideas to emerge and thrive. In the context of our discussion, we could say that the hardness bias did not work in favor of transdisciplinarity.

The above arguments suggest that, when it comes to science, flexibility is the key term. Scientists in different areas of knowledge must keep an open mind and understand that all existing fields, approaches, and techniques have potential merit and virtues. The quest for their correct use and combination is essential to arrive to the desired holistic perspective on human behavior and interaction.

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