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Developing a Systems Architecture Model to Study the Science, Technology and Innovation in International Studies

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Abstract: The international system has changed rapidly in the last thirty years and Science, Technology and Innovation (STI) has become a new critical factor of the world order of the 21st century. The interaction between STI and international affairs has increased, as well as its social and academic interest; however, there is still a lack of new theoretical and methodological approaches that examine this global rising phenomenon. This article is predominantly epistemological and is about how interactions between STI and international relations can be methodologically examined using systems models. This article raises the need for systems science approaches to explaining complex problems in international relations. In this sense, systems science and specifically systemism, offers great potential to study complex issues within a complex social system like the international order. Therefore, the main objective of this research is to develop an original systems framework that provides a comprehensive tool for studying complex topics like STI in the world system. The result is the creation of a Systems Architecture Model that examines the interaction between STI and international affairs from a systemist perspective.

Keywords: social systems; complex systems; systemism; systems architectural framework; science; technology; and innovation; international scientific relations; international studies

1. Introduction

The profound changes occurring in the international system over the past thirty years have resulted in a novel scenario with new rules, trends, patterns and a global structure. In this new international context, one of the most significant issues is the increasing relevance and influence of Science, Technology and Innovation (STI) in international relations.

In recent years, the acceleration and expansion of the technological revolution has rapidly changed the landscape of international relations. New scientific knowledge, emerging technologies and an impressive number of outstanding innovations and developments have increased the complexity of the international system. Reference [1] describes the impact of STI in this new world order as a *turbo change*. The use of drones and artificial intelligence (AI) applied to military operations, hackers manipulating presidential elections, advanced robotics changing the business model, a growing globalized virtual society and new public policies to promote the computerization of manufacturing are some of the new and most influential factors in the current global agenda. At the beginning of the 21st century, STI is an omnipresent participant in the narratives of world politics [2] (p. 662) and is becoming a strategic source of economic development, political influence, military power and social innovation. The post-Cold War international system is experiencing a reconfiguration of its main systemic parameters in which science, technology and innovation have become a critical factor.

Despite the relevance of STI in the international system, there is a reduced number of scholars focusing on this issue in the field of International Studies (IS). As stated by Daniel Deudney [1] (p. 224) the discipline, "*is still poorly equipped to theorize the sources and consequences of turbo change or to offer much in the way of actionable policy advice on this matter.*" However, nowadays it is possible to observe an increasing number of scholars who are making efforts to study the relevance and impact of STI in the international system.

Considering the increasing and complex interconnection between international relations and science, technology and innovation, this manuscript raises the need for systems science approaches to studying complex issues within a complex social system like the international system. Thus, the main objective is to develop a new systems methodology—the Systems Architecture Model (SAM)—to analyse the interaction between STI and IS. Additionally, it encourages scholars to use systems science and especially systemism, as a perspective with great potential for application to IS.

This article is predominantly epistemological and it is about how interactions between IS and STI can be empirically examined using systemist models and demonstrates how principles of systems science are a valuable methodological toolkit to apply to the field of IS. It is crucial to be aware of the breadth and complexity of the subject of study and the empirical, disciplinary and methodological limitations involved in a work of this calibre. The present essay contributions apply to the study of systems science and IS and require new and more complex investigations through developing an original methodological tool.

The essay proceeds in six stages. The second section identifies the empirical, theoretical and methodological needs for new approaches to analysing STI within the international system. Section 3 describes the use of a systems science in IS with special attention to systemism. Section 4 focuses on the selection and application of existing systemist models to examine the reality of STI in the international system. The fifth section develops a new methodological tool, the Systems Architecture Model and shows the application in STI. The final section is a summary of the findings.

2. Need for New Approaches in the Science, Technology and Innovation (STI) System and International Studies

2.1. Empirical Changes

The current international system is under transformation, driven by multiple and profound global processes—the transition from the Cold War to a new global order; changes in the capitalist economic system; a scientific and technological revolution; an increasing globalization process and the erosion of the traditional role of the nation-state. This new global context implies substantial changes in the systemic parameters, which have caused a structural transformation in the configuration of the 21st century world order [3].

The key term STI is defined as "*a set of scientific tasks linked together and with other socioeconomics dimensions within the international system with enormous consequences to actors, interactions, processes, parameters and global configuration of the international system*" [3] (p. 33–34). It is considered a unique and complex empirical phenomenon that has become a key factor within international relations. The scientific and technological transformations and their economic, social, political and cultural implications that have occurred within the international system since the last quarter of the 20th century to present-day are generating the impression of living in one of those key moments in the history of humanity. The speed and depth of the intensive application of new technology to numerous areas of daily life make it difficult to assess the impact that all these changes are generating on a complex society. As stated by Klaus Schwab [4] (p. 2) the international system is transitioning into a new stage called the Fourth Industrial Revolution, "*that will fundamentally alter the way we live, work and relate to one another. In its scale, scope and complexity, the transformation will be unlike anything humankind has experienced before*."

As a result of those changes, the role of STI has become essential in the current international system and the main source of economic development, political influence, military power and social innovation. In this context, Eugene Skolnikoff [5] (p. 44) argued that the interaction between science and technology and political and social factors, "*will be prime factors in determining the winners and losers* *among nations, the very economic viability of some, the forms of national economies and polities, the nature and cost of military conflict, the role and development of international organizations and the world's ability to meet the population, resource, food, health and environment issues we will face."*

Nowadays, the international system is experiencing a transition from an old and simplified bipolar scheme typical of the Cold War towards a new, complex and multipolar post-Cold War international order in which science, technology and innovation have become critical factors in the reconfiguration of the international system.

2.2. Theoretical Debate

All those empirical changes in the international system have generated a theoretical debate on how those changes may affect the main patterns and structure of the 21st century world order. Traditionally, the discipline of IS has primarily focused on topics like security, war, political power and diplomacy but it has paid less attention to issues like science, technology and innovation. However, it could be said that IS always had some sense of the importance of scientific and technological advancements [2] because IS does focus on STI but not explicitly. Instead, STI tends to be built into certain subject matter, like the nuclear issue area (e.g., Manhattan project, nuclear proliferation, International Atomic Energy Agency (IAEA), etc.).

Numerous internationalists (Waltz, Rosenau, Nye, Strange, Keohane, Haass, etc.) from diverse theoretical perspectives approached the phenomenon of STI within the international system but always tied it to issues of security, economy networks or communication systems. Certainly, the study of the role of STI and its impact on the main parameters and configuration of the international system was very limited; just a few researchers have been interested in the intersection between STI and IS from a systemic point of view by reviewing the relevance and consequences of the scientific and technological revolution in the whole international system [1–3,5–9]. This empirical/academic gap is very well described by Charles Weiss [7] (p. 308) when he pointed out, "*the isolation of science and technology from the 'mainstream' of international relations like a curious anomaly in the 21st century."*

The intersection between STI and international affairs opens a new and extended research agenda within IS with topics such as science diplomacy, multi-level governance of knowledge, international cooperation networks, the impact of emerging technologies or the knowledge divide. The relevance of this new area or subfield of study—also called *International Scientific Relations* [3]—is increasing in the last years and becoming an essential point of interest to fully understand the changes in the 21st century world order.

2.3. Methodological Challenges

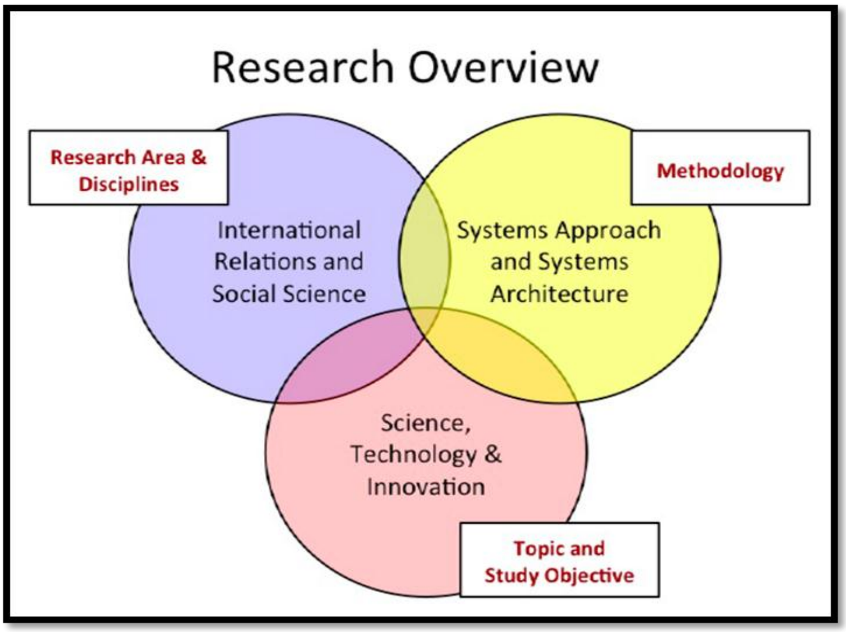
The changes that have taken place in the international system are having important consequences in the field of IS because most of those modifications were not predicted or explained by the discipline. Reference [10] (p. 2) described the new global context as, "*an age of complexity; an age of interconnections, ambiguity, uncertainty and various kinds of revolutions: military, technological, social, political, economic and even philosophical*." In this new international environment, the appearance of new actors, types of interactions, processes and a novel global agenda of topics more complex and interconnected has become outdated the traditional paradigms.

In this context of increasing complexity in a social system like the international system, the traditional scientific analytical approach cannot offer the answers that researchers are looking for. In his book "Open the Social Science" Immanuel Wallerstein recognized the relevance to facing new academic challenges in social science and the need to analyse them in their whole complexity. Wallerstein [11] (p. 80) pointed out, "*major issues within a complex society cannot be solved by decomposing them into small parts that seem easy to manage analytically but rather by attempting to treat these problems in their complexity and interrelations*." As a result, within the IS discipline, some scholars are proposing to go beyond the traditional analytical thinking approach to examine complexity in the international system [10] and a good number of scholars are trying to make the case for embracing complexity [12].

Structural changes in the world order have stimulated the academic debate over the need for new paradigms and approaches that could offer a better understanding of the new complexity within the international system. The lack of suitability and reliability of the traditional academic tools have become more pertinent to the creation of new theoretical and methodological frameworks. Nowadays, the main challenge is to develop original scientific tools to address new international complex problems and build a more useful and reliable interpretation of empirical phenomena. In this new epistemological context, system science can offer new opportunities and solutions to face the increasing complexity of the international system.

2.4. Intersection of Needs

The previous analysis shows the need for new approaches to addressing the challenges that the international system is currently facing. At the same time, it demonstrates the need for new approaches to face complexity in international relations that could offer better explanations and scientific answers about the interactions between STI and international affairs. Those needs can be summarized at the intersection of three main elements: (i) the research area and discipline of international studies; (ii) the use of system science that allows facing complexity; and (iii) topics related to science, technology and innovation within the international agenda. This specific joint point can be found in the intersection between international studies, science, technology and innovation and systems science (Scheme 1).



Scheme 1. Research overview.

3. The Use of a Systems Science in International Studies

3.1. A Long Tradition of a Systems Approach

Many concepts, approaches and models from the systems perspective have been used in several disciplines since General Systems Theory was introduced for the very first time in the late '50 by Bertalanffy [13]. Some of the examples are in Physics (Nicolis and Prigogine, 1977); Biology (Flood and Jackson, 1991); Economy (Wallerstein, 1982); Sociology (Parson, 1951); Political Science (Easton,1953); Communication (Von Foerster, 1979); International Relations (Kaplan, 1957); Education (Bánáthy, 1973); Philosophy (Bunge, 1979); Systems Engineering (Checkland and Scholes, 1990) [14–23].

The tradition of using systems science to analyse international affairs has existed for many decades in the field of IS. Many remarkable scholars have introduced insights from General Systems Theory into IS and systems science has been regularly used by many scholars for analysing international affairs.

Morton Kaplan (1957) was the first scholar in popularizing the systems approach into International Studies [20] and then several academics have been using numerous models of the international system for analysing international relations (e.g., Kaplan, 1957; Braillard, 1977; Waltz, 1979; Wallerstein, 1982; Rosenau, 1990; Jervis, 1997; Wendt, 1999; Braumoeller, 2012, etc.) [20,24–28].

The arrival of the systems approach to IS during the ‘50s and ‘60s had a massive impact within the IS discipline helping to develop a vigorous debate between *traditionalism* versus *scientism* where scholars discussed the need for changes in theoretical and methodological approaches and the need for improvement in methods and techniques as well.

3.2. The Debate Between Macro and Micro-level Approaches

One of the key discussions related to the use of systems science in IS has been the debate between micro and macro-level approaches. The main difference is how to approach international phenomena, whether to study the structure (macro) or focus on the parts (micro). Structural theories (macro) believe that international outcomes result from systemic constraints, meanwhile, micro-level perspectives think those changes come from domestic factors.

During the ‘60s and ‘70s, macro-level theories were very popular in IS and produced a good number of models; for instance, the World System Theory Model (Wallerstein) [16], International System Model (Kaplan) [20], Balance of Power Model (Waltz) [29] and Global Village Model (McLuhan) [30]. These macro-level approaches were used extensively for the study of IS during those decades.

At the end of the ‘80s, the significance and relevance of the systems approach within the IS community decreased due to the lack of explanation offered to describe changes in the international system. According to Albert, Cederman and Wendt [31] (p. 3), "*two empirical changes have called macro-level theorization into question: (i) the end of the Cold War, which no system theory predicted and (ii) the growing importance of non-state actors in the international system*." Consequently, at the end of the ‘90s, more scholars began to subscribe to analytical perspectives rather than to a synthetic or holistic approach and the *strategic choice* approach, based on methods inspired by microeconomics, ascended to a central position in the field of IS. Among many other micro-levels approaches, the agent-based computational model (ABM) based on the general ABM paradigm and computational methodology became one of the most popular approaches in the area of study of International Studies. The ABM model is characterized by facing more complex system like collective systems where processes of emergence occur. Some examples in social science are cities, schools, hospitals, companies, families and temporary communities such as passengers, audiences and telephone networks. The ABM model has been applied in many areas of international relations such as massive migrations, foreign policy or regional conflict [32,33].

Today, most IS scholars prefer to use a micro-level approach to examine international affairs, which is surprising considering the interconnectedness and interrelatedness of the international system of 21st century, which requires more than ever, a holistic and systemic approach. The world system is more a single *system* than ever before, the structure and dynamics of which only a truly systemic perspective can fully grasp [31] (p. 4).

The current epistemological situation demonstrates a distance between macro-level and micro-level analysis but also the need to build bridges between them in order to provide more adequate and accurate answers. In this context, systemism shows up as a theoretical and methodological approach that can reduce the gap between macro and micro levels and offer new and more reliable findings.

3.3. The Relevance of Systemism for International Studies

The concept of systemism was created by Mario Bunge in the field of philosophy of science. Based on this notion, Bunge [22,34–38] has developed a methodological approach that can be applied to any aspect of social affairs. Specifically, systemism can be considered a good alternative way to make sense of a complex world [39] with great potential for application to IS [40].

In his book "Finding Philosophy in Social Science," Bunge [35] (p. 265) pioneered systemism and defined it as "*an approach rather than a broad theory*." Reference [35] (p. 266–270) postulates that "*everything is a system or a component of one,*" "*every system has peculiar (emergent) properties that its components lack*" and "*systems as entities nested within one another as subsystems, systems and supersystems*." Thus, the international system can be considered as a "*super system*" or "*metasystem*" integrated by multiple subsystems (economic, political, military, cultural, STI, etc.).

Bunge understands systemism is the only cogent and viable alternative to the main two perspectives within social science: *individualism* and *holism*. Following Reference [36] (p. 156–157), "*neither of the two main most influential approaches to the study and management of social affairs is completely adequate. Individualism is deficient because it underrates or even overlooks the bonds among people and holism because it plays down or even enslaves individual action.*" The relevance of systemism is its ability to admit and synthesize both levels: the micro-level of the individualist and the macro-level of the holistic. It seeks a common ground to view the world from a systems perspective, including micro and macro-levels. As suggested by Reference [41] (p. 6) "*systemism allows for linkages operating at macro and micro-levels, along with back and forth between them*."

The application of systemism in IS is not extensive but there are several successful examples in the areas of public policy [39], foreign policy [40] and conflict and peace [41]. These examples make systemism and their models a promissory approach with great potential for application to IS. Patrick James [40] (p. 303) summarizes the potential of systemism, pointing out that "*the studies that exist already are sufficient to reveal the value of systemism with respect to probing the logical consistency of theories, making causal mechanisms explicit, facilitating comparison and identifying priorities for future research*." Considering this potential of systemism's approach to IS, the following section will focus§ on identifying existing systemist models and their application in the area of intersection between STI and IS.

4. Applying Systemist Models to International Studies

According to the systems science tradition [13–30,34–38], system models are a useful and reliable methodological tool for articulating theory and empirical facts through the schematization of a model of reality. Systems models are considered a simplified version of reality that researchers use to examine some aspect of complex reality. Hyunsun Choi [39] (p. 31) defines system models as "*a simpler representation of the real-world problem.*" In recent decades, systems models become more and more popular as a tool for understanding reality and a good number of scholars are developing and applying systems model in different fields of study (e.g., Beer, 1984; Troncale, 2006; Mobus and Kalton, 2014; Rousseau, Billingham, Wilby and Blachfellner, 2016).

In this context, systemism offers a good number of theoretical models that can be applied to IS. In general, systemist models are more consistent and stable than other traditional non-systems models used in IS like Prisoner's Dilemma and Chicken games, because of their goal to analyse the whole and interactions, not just the parts. Based on the extended research work from Mario Bunge, in this section, some of the most popular systemist theoretical models will be selected, revised and applied to facilitate the study of STI within the international system.

4.1. Selection of Systemist Models

Systemism offers a broad variety of theoretical models for analysing reality. After an extensive review, four models have been selected to study the intersection between STI and international affairs: system and subsystems model; CESM model; black-box model; and grey-box model. In Mario Bunge's work there are two models (CESM and Grey Box) where what happens inside the box is studied with the goal of looking for explicit answers and also there are two other models (Systems and Subsystems and Black Box) where what happens inside the box is no-explicit. The selection of these four models from Mario Bunge's work followed the strategy to get a balance between these two kinds of models.

4.1.1. System and Subsystems Model

Figure 1 shows a basic systemist model named system and subsystems model that Bunge has used to describe the interaction between a system and its' subsystems. Essentially, this theoretical representation allows studying the interaction between a given system and the subsystems place on their own. The acquired properties of systems that components do not possess have, in their turn, an influence on the components themselves.

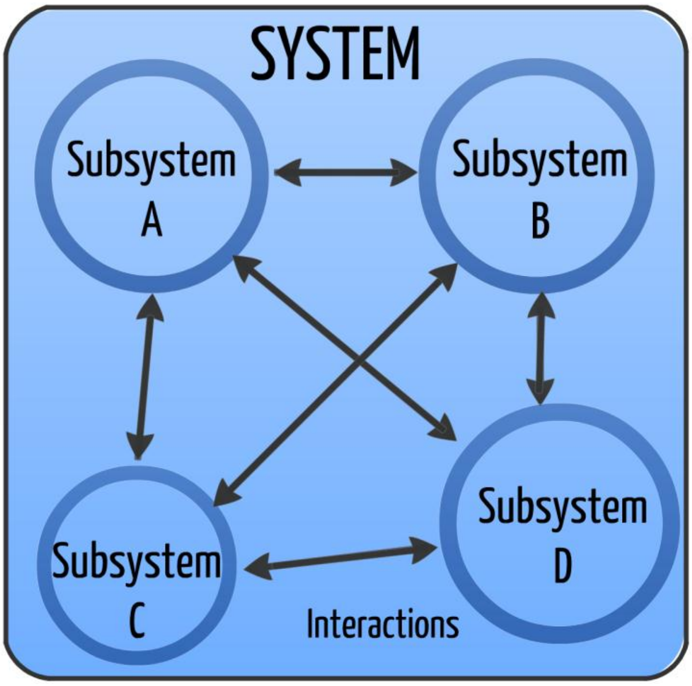


Figure 1. System and Subsystems Model. Source: Elaborated by the author according to Bunge's model [22] (p. 191).

4.1.2. CESM Model

Figure 2 shows each of the elements of a theoretical CESM model, which is a theoretical representation of a given system. Following Reference [37] (p. 35) any system(s) could be modelled like the quadruple:

$\mu(s) = (C(s), E(s), S(s), M(s))$

(1). C(s) = Composition or collection of all the parts of s;
(2). E(s) = Environment or collection of items, other than s, that act on or are acted upon by some or all components of s;
(3). S(s) = Structure or collection of relations, in particular bonds, among components of s or among these and items in its environment;
(4). M(s) = Mechanism or collection of processes in s that make it behaves the way it does.

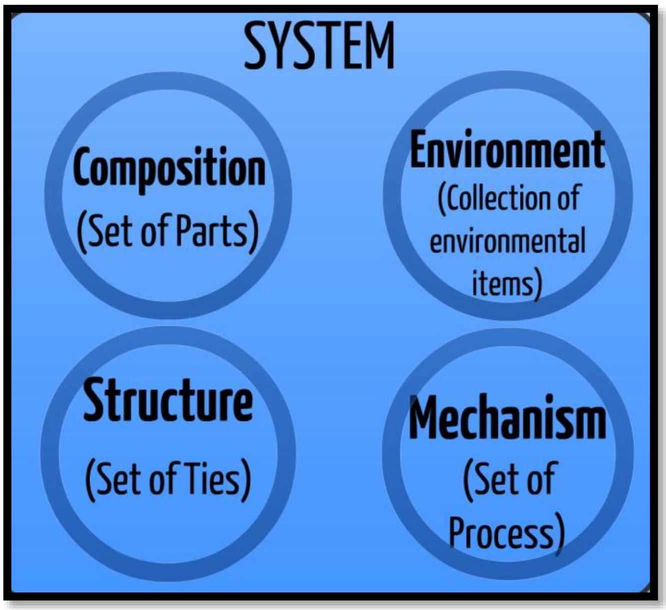


Figure 2. Composition Environment Structure Mechanism (CESM) Model. Source: Elaborated by the author according to Bunge's CESM Model [37] (p. 35).

4.1.3. Black-Box Model

Figure 3 shows one of the simplest but also more popular theoretical systemist models used to analyse social reality. The black-box is a visualization of a concrete system which can be analysed considering its inputs and output reactions. According to Bunge [22] (p. 253), "*the constitution and structure of the box are altogether irrelevant to the approach under consideration, which is purely external or phenomenological.*" *It is considered black because it has no structure or we do not care to disclose it.*" In this model, it is also possible to identify the double-loop. In a single-loop the system is expected to be controlled by regulating the input as a function of the output, whereas in a double-loop the system is expected to redesign the rules and not just to apply them; so, the system is changing along the time. This is also called second-order cybernetics or cybernetics of cybernetics [19,42]. The black box model is very helpful for studying the interactions of a given system with their environment and examining how the system/subsystem reacts to external inputs.

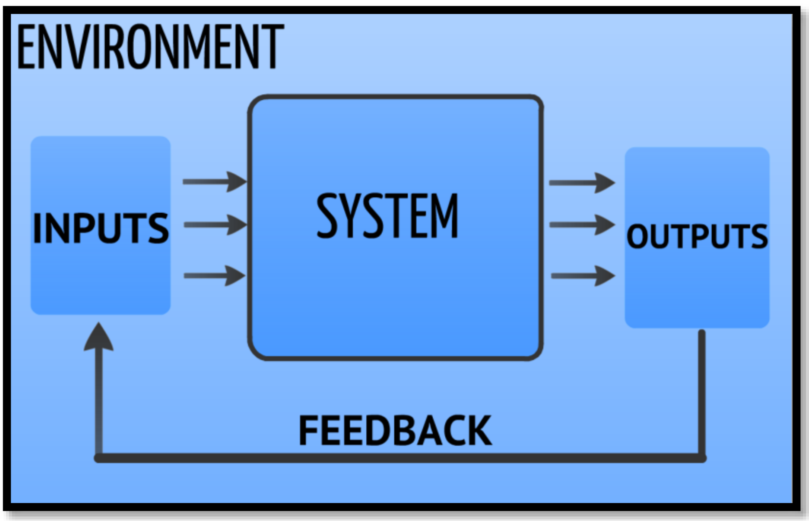


Figure 3. Black Box Model. Source: Elaborated by the author according to Bunge's Black-Box Model [22] (p. 253–257).

4.1.4. Grey-Box Model

Finally, Figure 4 shows a theoretical representation that allows knowing what happens inside the box through the identification of the main dimension and variables and their interactions. The grey-box model is considered the opposite of a black-box model because it is a system where the internal constitution and structure can be observed. The analysis of the internal processes (box) allows identifying several types of causal and multicausal relations (positives, negatives, complex, etc.). In this Grey Box Model, it is possible to observe and analyse inputs, outputs, internal processes and feedback but it is not described the emergence process yet.

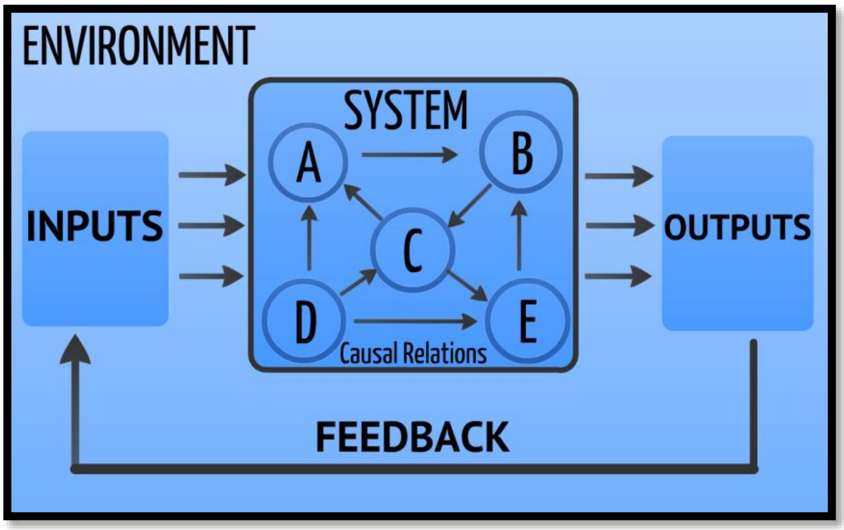


Figure 4. Grey Box Model. Source: Elaborated by the author according to Bunge's Grey-Box Model [22] (p. 262–263).

These four systemist models (system and subsystems; CESM, black-box and grey-box models) are generic representations to be applied to real cases. Those models were identified and selected because they were traditionally considered by Mario Bunge's research work as having easy usability in social science, allowing good predictive capability. Therefore, the next step is to model interactions between STI and international relations.

4.2. Systemist Models Applied

The next methodological step is the application of those four theoretical systemist models to the reality of STI within the international system. The following are the preliminary results applying each of the systemist models individually to analyse the relevance and role of STI within the international system.

4.2.1. System and Subsystems Model Applied

Figure 5 shows the systems and subsystems model applied to the reality of science, technology and innovation within the international system. The structure of this model should be considered as a network where it will be observed how many subsystems (Social, Political, Economic, etc.) interact with each other in multiple ways within the international system and, in particular, how those subsystems interact with the STI subsystem. The international system and their subsystems contain and condition the STI subsystem but at the same time, the international system and the subsystems will be conditioned by the internal dynamic of the STI subsystem.

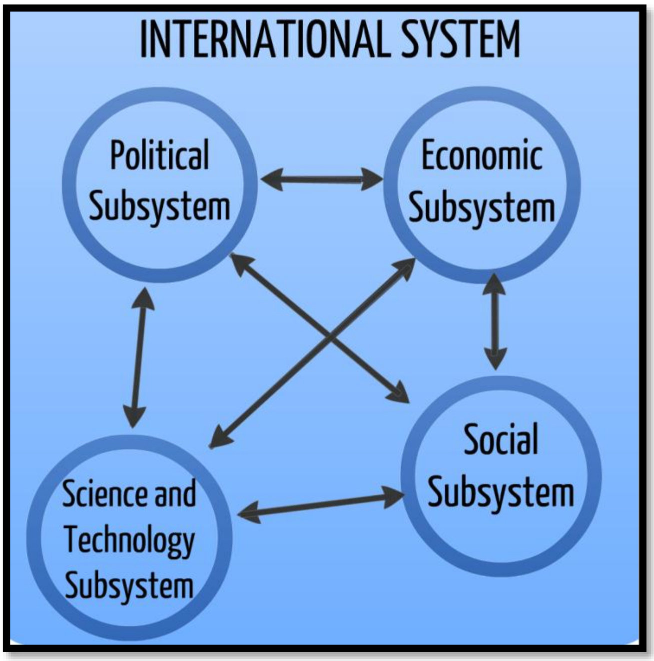


Figure 5. System and Subsystems Model Applied. Source: Elaborated by the author.

4.2.2. CESM Model Applied

Figure 6 shows the application of the CESM model to the STI subsystem within the international system. This applied CESM model describes the main internal elements of an STI subsystem—the component or stakeholders that participated in the STI subsystem (states, companies, universities, NGOs, etc.); the structure or type of interaction between the international actors (cooperation, conflict, competence and subordination); the mechanism or dynamics of the scientific knowledge that are created inside the STI subsystem (production, transfer, distribution, application and governance): and, finally, the emerging properties that appear in the subsystem as a result of the interactions of the actors (multi-level governance, knowledge gaps and utility of knowledge, etc.).

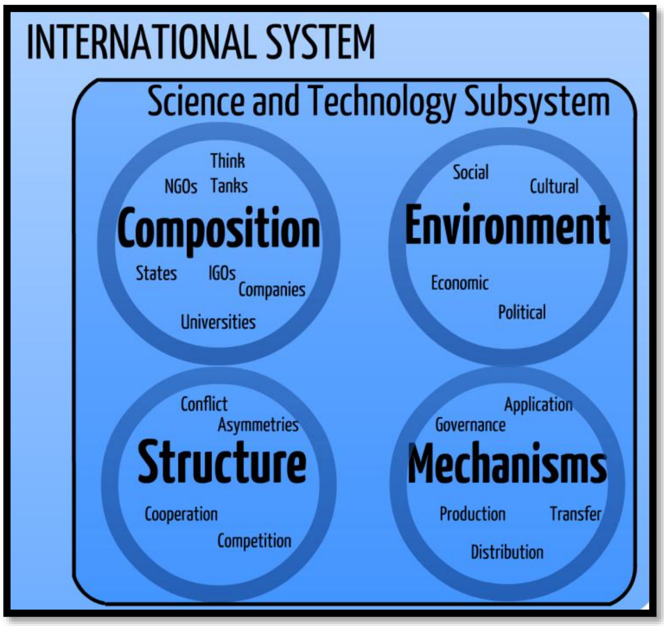


Figure 6. CESM Model Applied. Source: Elaborated by the author.

4.2.3. Black-Box Model Applied

Figure 7 shows the application of the black-box model to the interactions between STI subsystem and the international system. It is possible to understand this scheme as a global overview of the interaction between all the subsystems integrated into the international system with the STI subsystem. The relevance of this applied model is the description of the most important elements within the international systems; the interaction between different subsystems; and particularly, the connection between the international system (and each of the subsystems) and the STI subsystem.

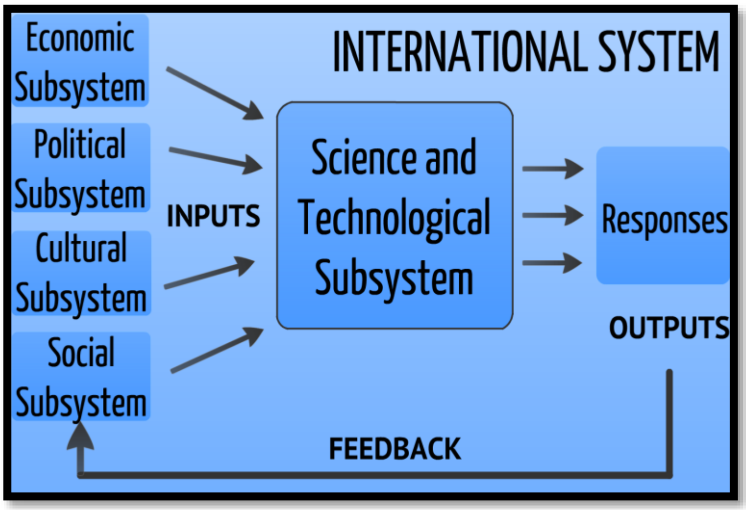


Figure 7. Black Box Model Applied. Source: Elaborated by the author.

4.2.4. Grey-Box Model Applied

To conclude the application of existing theoretical systemist models to the reality of STI it will be necessary to apply the grey-box model. Contrary to the black-box model, in this case, the model focuses on what is happening inside the STI subsystem and not only in the interactions with the rest of the subsystems. In general, this model examines the internal operation and dynamics of a given system/subsystem and describes the main dimensions, variables and potential multi-causal relations.

According to Bunge, to apply the grey-box model, first, it is necessary to identify and select the main dimensions, variables and indicators related to the phenomenon that will be analysed. In any systems model the role of the observer should be considered. This role implies selecting issues, scalarity and priorities and giving meanings to them. In Table 1, the observer has identified and selected the main elements (dimensions, variables and indicators) within the STI subsystem in order to do an internal study. Each dimension could be considered as a subsystem where variables and indicators that characterized the subsystem could be found it.

It is important to consider that all these dimensions and variables of STI are part of interrelated and interconnected processes that create a complex system. As a result, each dimension receives inputs from other processes and, at the same time, generates outputs and feedback that impact the other dimensions. Thus, these processes within the STI subsystem should be defined as multi-causal procedures that generate feedback loops.

Table 1. Defining Dimensions, Variables and Indicators. Source: Elaborated by the author based on his previous research work.

Dimensions	Variables	Indicators
Production	*Modes of production*	-Number of Actors -Number of Places -Number of Interactions -Methodologies applied
	Factors of production	-Investment on R&D -Investment on Researchers -Investment on Facilities -Number of Publications and Patents
Intermediation	*Transmission* via *formal education*	-Number of Publications -Investment on Higher Education -Number of Online courses -Number of Academic Programs
	Transferences	-Number of Public-Private agreements -Number of Clusters -Number of Scientific parks -Number of Patents, Spin-Off
	Diffusion	-Mass Media cover -Social Media cover
	Mobility	-Number of Highly Skilled Workers -Number of Scientific Diasporas
Distribution	*Geographical*	-Investment in R&D and Researchers by countries. -Number of Publications by countries -Number of Patents by countries -Number of World-Class Universities by countries
Application	*Type of Research*	-Basic Research -Applied Research -Experimental Development
	Field of Study	-Natural Science -Engineering and Tech -Health and Medical Science -Agriculture Science -Social Science and Humanities
	Socioeconomic impact	-Defense -Economic Development -Health and Environment -Education and social programs
Governance	*Subnational*	-Number ofLocal Policy Plans
	National	-Number of Public Policy Plans -Number of Research Projects
	Regional	-Participation in regional processes -Number of regional agreement
	International	-Number of international agreements

After defining dimensions, variables, indicators and determining complex multi-causal relations within the STI subsystem, practitioners are ready to apply the grey-box model to STI.

Figure 8 shows a STI subsystem receiving inputs from the international system and internally processing those inputs through complex interactions where the main dimensions (production, intermediation, distribution, application and governance of scientific knowledge) take place in multi-causal relations.

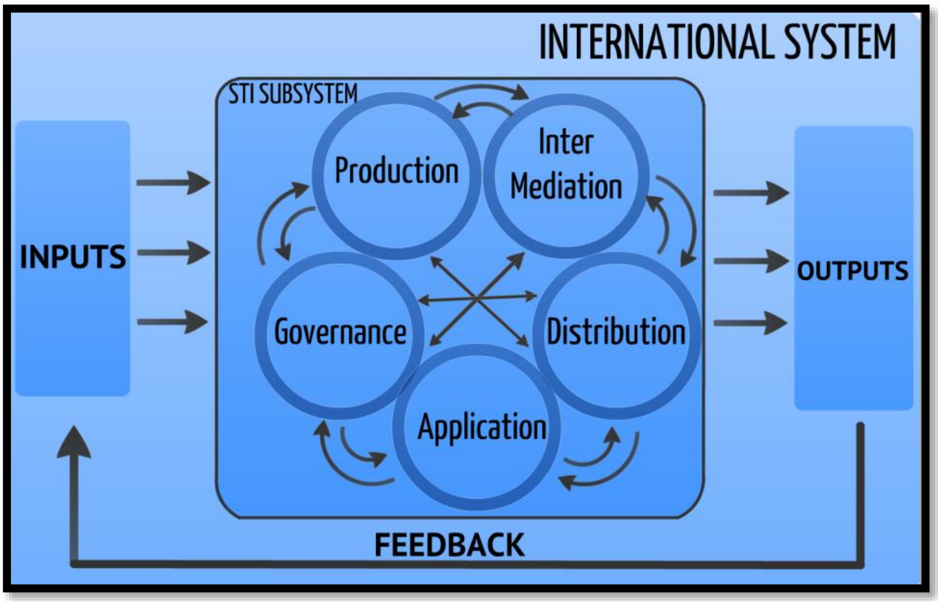
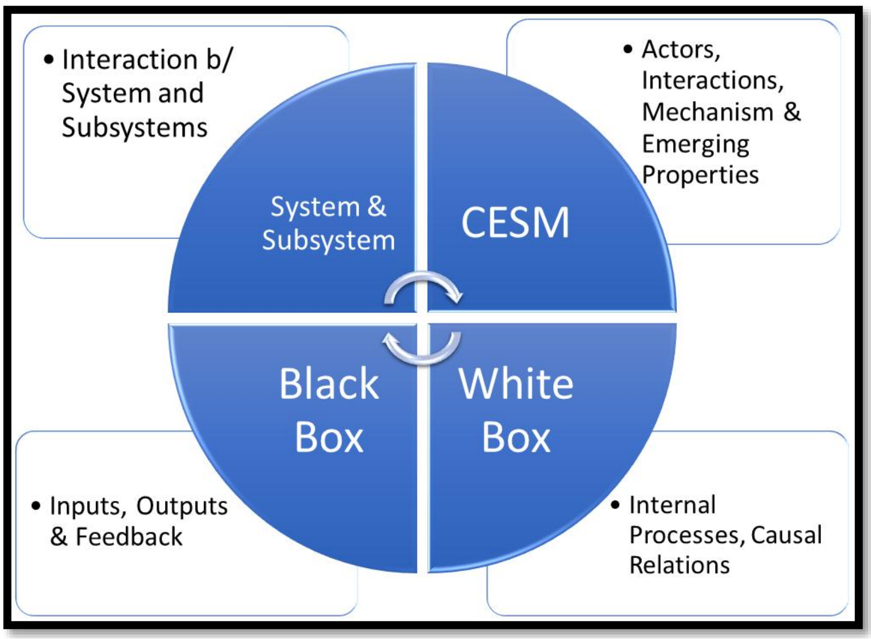


Figure 8. Grey Box Model Applied. Source: Elaborated by the author.

4.3. The Contribution of the Existing Systemist Models

Each of the existing systemist models applied to the reality of STI within the international system offers different perspectives on the same phenomenon. The system and subsystem model gives an interesting view of the interaction between a system and the subsystems within them. The CESM model allows analysing, within a specific subsystem, actors, interactions, internal mechanism and emerging properties. The black-box model studies the interactions between a given subsystem and the greater system identifying inputs, outputs and feedback. Finally, the grey-box model allows understanding the main internal mechanism of a subsystem throughout identifying the main dimensions, variables and multi-causal relations. As shown in Scheme 2, each of those models covers some aspect of reality but none of them offer a global, holistic and comprehensive overview of the phenomenon.



Scheme 2. The Contribution of Each Systemist Model. Source: Elaborated by the author.

5. Creating a System Architectural Model (SAM)

5.1. Need for SAM

The preliminary analysis allows the understanding that those existing systemist models are useful for capturing part of the reality but they are not enough to have a comprehensive systemic overview of the phenomenon of STI in the international system. For that reason, the present research is proposing a new, broader and more systemic methodological framework. Borrowing the concept from the field of Engineering, the Systems Architecture Model, responds to the conceptual and practical difficulties of the description and the study of complex systems like the international system [43]. The developing of a SAM offers a high-level point of view seeing issues related to STI (STI subsystem) as being part of an overall greater system (international system), in interaction with other subsystems (political, military, economic, etc.) and its environment, therefore, understanding the complexity of multicausal relations among actors.

5.2. Creating a Theoretical SAM

The proposal creates one single model to use as a systemic methodological tool blending those four systemist models with the objective that they can function in a complementary way. The combination of these four systemist models (system and subsystem, CESM, black-box and grey-box models) creates a new theoretical framework named the Systems Architecture Model (Figure 9) that can be used as a methodological instrument to examine, study and analyse in-depth a subsystem within a system and can be applied to all types of systems, at all levels and in all fields of research.

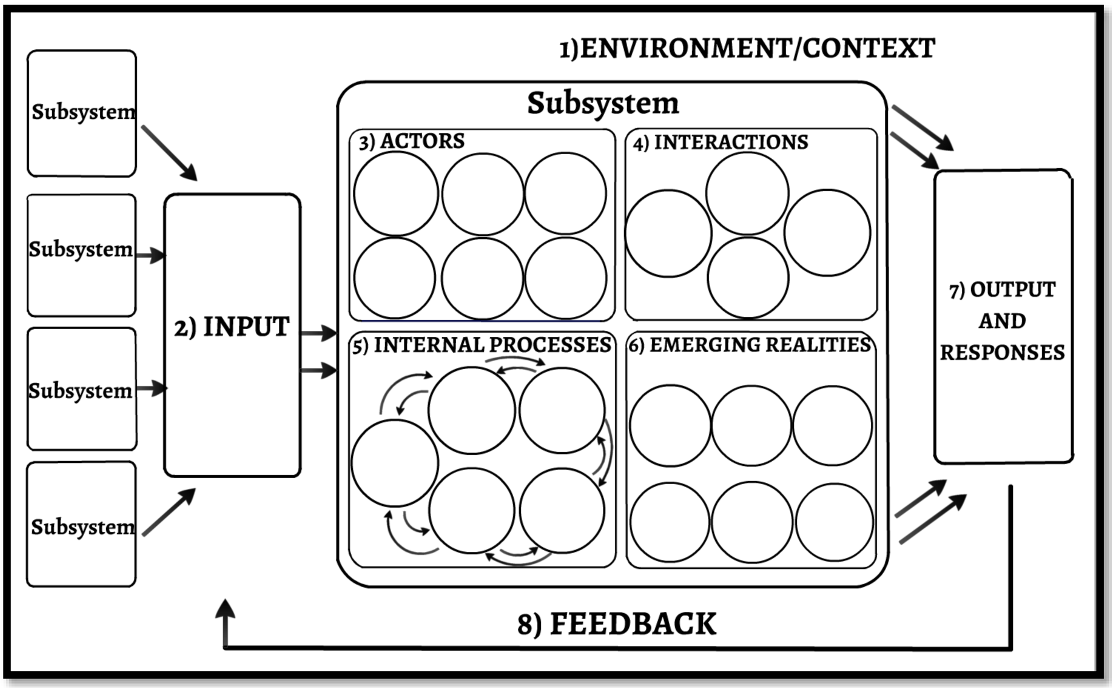


Figure 9. Theoretical Systems Architecture Model. Source: Elaborated by the author.

The theoretical Systems Architecture Model includes the following elements:

1. *Environment*: The international system could be understood as the environment or context where the rest of the subsystems interact [22] (p. 205) and it is defined as the systems' context that generates input, demand or support to the subsystems. The international system is the greater system or supersystem that contains all the subsystems: political subsystem, economic subsystem, social subsystem, cultural subsystem, military subsystem, STI subsystem, and so forth.

2. *Inputs*: From the environment of the system, there are demands, information, actions and many other factors that have an impact into the subsystems.
3. *Actors*: Anyone that has relevance in the international relations and the international agenda and influence over the strategies of other actors will be considered an international actor. The systemist analysis focusses on the most relevant actors, identifying their main characteristics, power, goals and strategies. The main international actors are nation-states, companies, international organizations, intergovernmental organizations, non-governmental organizations, and so forth.
4. *Interactions/Relations*: Relationships among the most relevant actors within the system/subsystem. In this sense, the international reality could be defined as a vast network of interactions among international actors that can be identified, analysed and characterized. According to Reference [44] interactions among actors occur in a short-term period so it is very useful to understand the international situation at a particular moment. On the other hand, relations refer to the same actions when they are sustained in the medium and/or long term.
5. *Internal Processes*: Operational mechanisms that occur within any system or subsystem. The systemist analysis identifies, describe and explain the main internal mechanism that makes the system/subsystem works.
6. *Emerging Properties*: One of the main features of a system/subsystem is that it has global or emergent properties that its components do not possess. Bunge [28] defines emerging properties as "*qualitative novelty*," the appearance of novel characteristics is exhibited on the level of the whole ensemble but not by the components in isolation.
7. *Output/Responses*: The elements that exist in the system due to the processing of the inputs by the subsystem. Usually, the main outputs/responses are decisions, support and actions.
8. *Feedback*: It is a process where an effect could have, directly or indirectly, impact on the cause as part of a chain of cause-and-effect that forms a loop. Systems and subsystems generate two types of feedback: i) negative or tendencies of continuity that maintain the status quo of the system, and/or ii) positive or tendencies of change that modify the status quo of the system.

5.3. SAM Applied to Science, Technology and Innovation

The Systems Architecture Model (SAM) is a methodological tool that is useful for examining and analysing issues within the international system. Even though a theoretical SAM can be applied to all systems, at all levels and in all fields of study, this essay pursues to apply this new instrument to the study of interactions between STI and IS. Figure 10 shows the SAM applied to STI in the international system. Within this epistemological instrument it is possible to identify three main parts of the model: (i) the STI subsystem within the international system and its relations with other subsystems (political, economic, military and social); (ii) The main features of the STI subsystem (actors, interactions, internal processes and emerging realities); and (iii) The main outputs, responses and feedback to the international system and each of the subsystems.

The use of the SAM will require following a precise methodological pathway in order to apply the instrument successfully.

Figure 11 shows the way in which the Systems Architecture Model should be applied. The starting point is to define the research parameters, which includes explanations about the research problem, main goals and case study. Second, a preliminary approach to the subject of study should be done through a literature review. Third, it will be necessary to determine systemist methodological definitions: (i) identify the main system and subsystems, (ii) define actors (considering their power, goals and impact in the system), (iii) detect the most important interactions (conflict, cooperation, competition, etc.) and (iv) determine the internal processes (defining dimensions, variables and indicators). Fourth, it will be the data collection process gathering and measuring information on dimensions and variables of interest (using interviews, surveys, focus group, statistics or any other recollection techniques). Fifth, the data analysis through the creation of a database, comparing and classifying information and providing a narrative. Sixth, apply the Systems Architecture Model itself which will consist of five steps: (i) identify inputs from the main subsystems and the entire environment; (ii) analyse actors, interactions and internal process; (iii) find out main emerging realities; (iv) recognize output and response; (v) examine feedback, changes and impact on the global system and in each of the subsystems. Finally, findings will be presented by creating a systemist visualization and summarizing the main results by writing a report or creating a table.

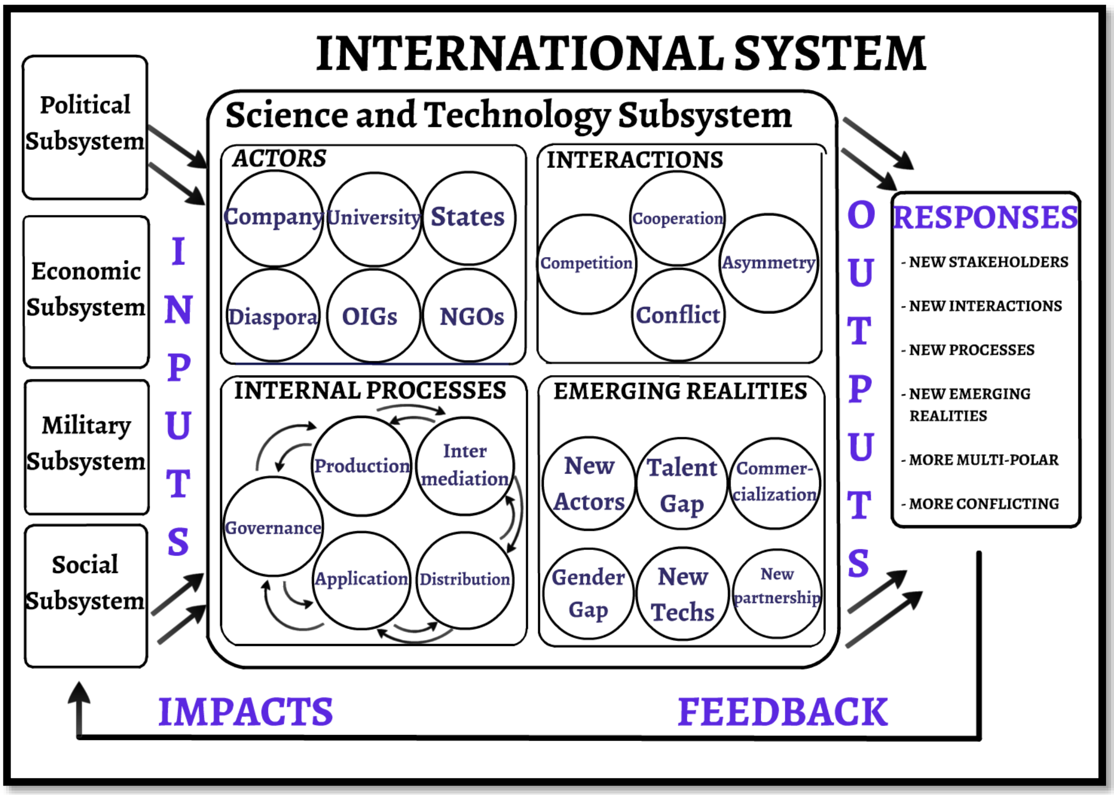


Figure 10. Systems Architecture Model (SAM) Applied to Science, Technology and Innovation (STI). Source: Elaborated by the author.

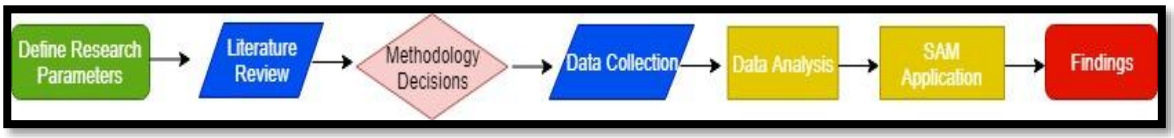


Figure 11. Methodological Path Source: Elaborated by the author.

Following this methodological pathway to apply the SAM allows us to address any case study related to STI and its impact on the international system using a systems tool. The use of the SAM offers a good number of expected findings that include—identifying the main input from other subsystems and the greater system; recognizing the main stakeholders involved; detecting the most relevant interactions; identifying and classifying the internal mechanism of any STI processes (production, transmission, distribution, application and governance of scientific knowledge); precisely capture the emerging realities of the STI subsystem; and finally, pinpoint the outputs and responses generated in the STI subsystem and how it will affect the rest of the subsystems and the entire international system.

SAM has been successfully applied in case studies that combine STI and international relations. Under the research project "Complex International Science Technology and Innovation Partnerships"—founded by the NSF and in partnership between Johns Hopkins University and the Massachusetts Institute of Technology (MIT)—SAM was applied to analysis of space technology programs in four countries in South East Asia. After conducting interviews with key informants, data was used to apply SAM and obtain unique findings. For instance, SAM allowed the recognition of the strategic domestic and international public and private stakeholders involved in the developing of national space programs; identified the kind of interactions that actors have developed in order to improve their technological programs; recognized the main international inputs and demands that each space program received and in how those space programs have responded by adopting specific policies. Also, SAM was applied in the context of the research project "Clinical Trials Systems" founded by the Bloomberg Foundation and in partnership with MIT Collaborative Initiatives and the Systems Institute at Johns Hopkins University. In this case, SAM was required to do a comparative study about the effectiveness of the clinical trial system in the United States and to compare it with other national clinical trials systems around the world. This application allowed the discovery of key actors, interactions and processes involved in the development of a new drug and analysed the main weaknesses of the American clinical trial system. The findings of both projects are expected to be published.

In conclusion, it could be said that the Systems Architecture Model has been designed to represent reality in such a way that identifies, describes and analyses patterns, behaviours, properties and the structure of the STI subsystem within the larger international system.

6. Conclusions

The international system has changed rapidly in the last thirty years and science, technology and innovation has become a new critical factor of the world order of the 21st century. The interactions between STI and international affairs have increased rapidly, as well as social and academic interest in them. On the contrary, there is still a lack of new theoretical and methodological approaches that examine this rising phenomenon. This essay has raised the theoretical and methodological need for new approaches to studying complex social systems like the international system and has demonstrated the great potential of systems science to provide reliable answers in the field of IS.

There is a long tradition within the IS discipline of applying systems science to analysing international affairs. Today, most IS scholars prefer to use a micro-level approach to examine the international reality, which is surprising considering the interconnectedness and interrelatedness of the international system of the 21st century, which requires, more than ever, a systemic approach. The current epistemological situation within IS demonstrates a gap between macro-level and micro-level analysis but also the need to build bridges between them to provide more adequate answers. In this context, systemism shows up as a theoretical and methodological approach that can reduce the distance and overcome the traditional disconnection between macro and micro-level approaches within IS.

The application of existing systemist models (system and subsystems, CESM, black-box and grey-box models) has shown the relevance and utility of systemism but has also proved the lack of response of those models to analysing in-depth and systematically the interaction between STI and international affairs. For that reason, this article introduces a new systems methodological tool—the Systems Architecture Model—with the precise goal of improving what the existing systemist models can offer.

This systemist approach studies empirical issues like STI based on interactions between the micro and macro-level and offers a high-level point of view for analysing international relations as a complex system. The Systems Architecture Model does identify, describe and analyse the patterns, behaviours, actors, interactions, processes, emerging properties and structure of the STI subsystem within the larger international system. The application and uses of the Systems Architecture Model allow the examination of several pieces between the interaction between STI and international relations—describe certain aspects of the system (actors, interactions, internal processes, etc.); examine the effects of changes to a system/subsystem (input, output/response, feedback); explain multi-causal relations (internal processes); and identify emerging realities from the system/subsystem (emerging properties). Additionally, it can be applied to all types of systems, at all levels and in all fields of research.

The creation of a Systems Architecture Model can be understood as an epistemological effort to improve the methodological framework in the field of IS and as a response to the conceptual and practical difficulties of the description and analysis of complex social systems like the international order and complex topics on the global agenda like STI. Also, this methodological effort should be considered part of a bigger enterprise within Systems Science where currently a big number of scholars are developing systems models within whose conceptual vein the SAM uses different structures to convey similar ideas. For instance, a good example of similar approaches are the neural network architectures, a very popular tool in machine learning.

The Systems Architecture Model will be part of the Visualization International Relations Project in the School of International Relations at the University of Southern California. This new research project looks for new applications in the field of international studies using the systemist perspective to analyse complex issues in the international system. Additionally, SAM will be used by graduate students in their research project within the MA Program in Global and International Studies, specialization in Science, Technology and International Relations at the University of Salamanca.

Finally, advances in the application of the Systems Architecture Model can include multiple sectors, stakeholders and purposes. It is expected that several applications in the field of systems science and international studies may contribute to finding new academic explanations, helping to design public policies and supporting planning strategies for the private sector.

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