Modeling the Adoption of Sustainable Practices in the Supply Chain: A Game Theory Approach

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***Abstract*—One goal of the 2030 Agenda for Sustainable Development of the United Nations is strengthening the means of implementing and revitalizing the Global Partnership for Sustainable Development. So, the adoption of sustainable practices into the management and operation of supply chains is a big challenge that companies need to face. However, the research in this area has mainly been qualitative and the developed models do not take into account the social pillar of sustainable development. The aim of this paper is to develop an agent-based model to analyze the factors that mainly influence the interactions among the functional companies of supply chains for the adoption of sustainable practices considering social aspects. First, we develop a conceptual model about the interactions among companies of supply chains based on the pair wise Prisioners Dilemma game and the game-dynamical replicator equations for multiple populations. Then, we implement the model using NetLogo™ software. We design some scenarios varying factors to analyze how the adoption of sustainable practices evolves in time. We prove that the interactions between companies that do not prefer to adopt sustainable practices with those who have already adopted the practices influence the decision to adopting such practices in a positive way. Our results provide a game theoretic model for sustainable supply chains.**

***Index Terms*—supply chain, agent-based modeling, game theory approach, simulation, sustainability, 2030 agenda**

I. Introduction

The 2030 Agenda for Sustainable Development of the United Nations [1] is an action plan for people, planet and prosperity that consists of 17 Sustainable Development Goals, namely: no poverty, zero hunger, good health and well-being, inclusive and equitable quality education, gender equality, clean water and sanitation, affordable and clean energy, sustainable economic growth, full and productive employment and decent work for all, building resilient infrastructure, reducing inequality, making cities sustainable, ensuring sustainable consumption and production patterns, taking urgent action to combat climate change, conservation and sustainably use marine resources, protecting, restoring and encouraging the sustainable use of land ecosystems, promoting peace and inclusive societies for sustainable development, and, last but not least, strengthening the means of implementing and revitalizing the Global Partnership for Sustainable Development. In the case of supply chains, the integration of sustainability issue in its operation and management is a big challenge in the new global business.

From the systemic perspective, the supply chain is a complex system made up by large numbers of adaptive companies at multiple scales that interact in parallel interchanging information, materials and capital. From such interactions arise global patterns of self-organization that let to companies be collaborative and cooperative. Collaboration as a requirement to implementing sustainable management approaches, may contribute to inter organizational dynamics by strengthening the knowledge absorption capacity, structuring solutions, and motivating activities around a commonly defined goal [2] such as the adoption of sustainable best practices in supply chains which are based on economic, environmental and social aspects. Complex systems are distinguished by the extensive use of computer simulation as a research tool. Several scholars have studied supply chain problems based on a complexity approach [3] - [6] but in the case of sustainable supply chain the existing models do not take into account the social aspects [7], [8]. The aim of this paper is to develop an agent-based model to analyze the factors that influence the interactions among companies of supply chains to adopting sustainable practices in their management and operation. The paper relies on standard game theoretic modeling techniques but we make a novel applications in the field of sustainable supply chains where researchers just integrate economic and environmental aspects using traditional theoretical tools.

This paper is prepared as follows: a conceptual model about the interactions among companies of supply chains based on the pair wise Prisioners Dilemma game and the game-dynamical replicator equations for multiple populations is developed in Section 2. An agent-based simulation model about the adoption of sustainable practices is implemented using NetLogo™ software and it is presented in Section 3. The simulation results are analyzed in Section 4. Concluding remarks are drawn in Section 5.

II. Conceptual Model Development

B. Design Formulation

Companies of a supply chain are modeled as agents that interacts each other. The rules of interactions are

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based on the game theory, specifically on the pair wise Prisioners Dilemma game. This kind of game is an abstract formulation of some very common and very interesting situations [9] in which what is best for each agent, in our case study a company individually, leads to mutual defection. While in the situation when every agent or company would have been better is with mutual cooperation. In this study, we consider two populations interacting: companies in population 1(P_1) are those that prefer to adopt sustainable management practices in their operations of the supply chain, while companies in population 2 (P_2) are those that operate based on unsustainable practices. The interesting situation is that companies of P_1 and P_2 interact in a daily basis interchanging material, information and capital flows as part of a supply chain. In order to analyze the evolution in time of the proportions and of companies in populations P_1 andP_2that adopt sustainable practices via the interaction with others of the same supply chain, we propose the game-dynamical replicator equations for multiple populations [10]. According to [11], the game-dynamical replicator equations for two populations P_1 and P_2as in

$$\frac{dp(t)}{dt} = p(t)[1 - p(t)]F\big(p(t), q(t)\big) \tag{1}$$

$$\frac{dq(t)}{dt} = q(t)[1 - q(t)]G(p(t), q(t)) \tag{2}$$

where the functions $F(p(t),q(t))$ and $G(p(t), q(t))$ reflect the interactions among companies in and out of population P_1 and P_2.

C. Model Description

We develop the model to adopting sustainable practices by companies of a supply chain using agent-based modeling (ABM) approach [12]-[24] where interactions among agents are modeled using and 2. The ABM approach works at micro level it means that it uses a bottom-up perspective to understand the interaction rules between elements at local level. From the interactions of the elements emerge new properties of the system in the upper level that cannot be predicted (see Fig. 1). It is important to note that the variation of time in ABM approach is discrete, in steps.

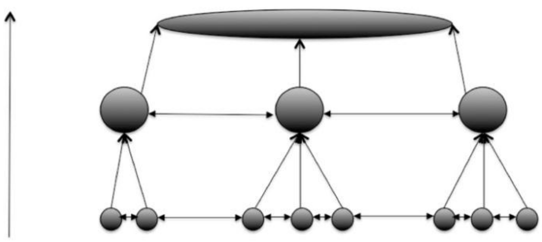

Figure 1. Diagram of the bottom-up perspective.

III. Simulation Model

Nowadays, many different agent-based modeling languages exist but NetLogo™ remains the most widely used [25]. It is an open source language and was designed to be easily readable. Also, NetLogo™ has the big advantage over pseudo-code of being executable, so the user can run and test the programs [25]. We selected Netlogo™(release 5.2) simulation software to implement the conceptual model to adopting sustainable practices by companies of a supply chain as a computerized model.

A. The Layout

Netlogo™ considers a lattice of 20*20 where the agents are allocated (see Fig. 2). The state of one agent depends on the behavior of their neighbors only if there is an interaction among they. The important feature is the global pattern that spontaneously arises from interactions among the agents, and the absence of a centralized coordinator.

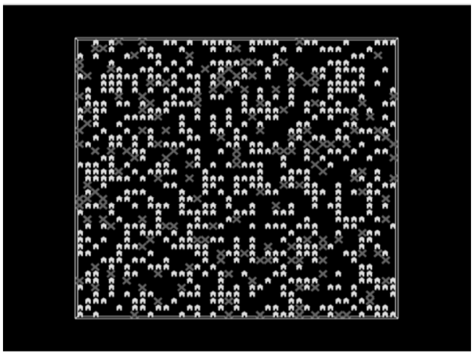

Figure 2. The layout of the ABM model using Netlogo, the white agents represent randomly distributed companies adopting sustainable practices. Running time =70 steps.

B. Parametrization

The first parameter to consider is the dimension of each population P_1 (prefer to adopt sustainable practices) and P_2 (do not prefer to adopt sustainable practices) as the number of groups and the size of each group contained in each population to analyze the impact of the populations dimensions on the decision to adopt sustainable practices. Then, in order to analyze the evolution in time of the proportions $p(t)$ and $q(t)$ of companies in P_1 and P_2, respectively, that adopt sustainable practices via the interaction with others of the same supply chain, we vary the probability (PM) of companies in P_1 and P_2 for meeting companies that have adopted sustainable practices. The benefit to adopting the sustainable practices is fixed and is considered maximum, while the associate cost also is fixed and is considered minimum and the benefit is maximum.

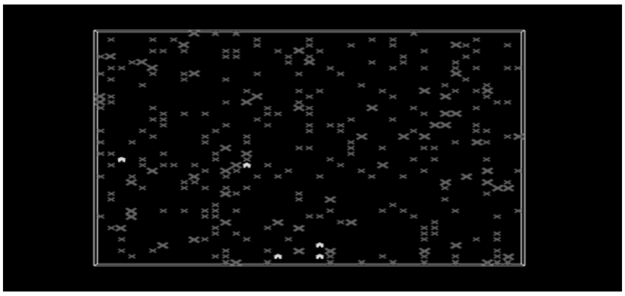

Figure 3. The proportion of companies that adopt sustainable practices is minimum considering $PM\text{-}P_1$=$PM\text{-}P_2$=1, P_1=P_2= 30 groups and group size=10. Running time=70 steps.

IV. Simulation Model Analysis

A. Designing Simulation Scenarios

We design six scenarios to analyze the impact of two factors: *PM* and the dimensions of populations P_1 and P_2 with two possible values, on the evolution of the proportions $p(t)$ and $q(t)$ of companies in P_1 and P_2that adopt sustainable practices (see Table I). Results are showed from Fig. 4 to Fig. 9.

TABLE I. Simulation Scenarios

Scenario	Value of simulation parameters		
	Probability and proportion	Group size	Number of groups
1	$PM\text{-}P_1=PM\text{-}P_2=0.5$ $P_1=P_2=0.5$	20	20
2	$PM\text{-}P_1=PM\text{-}P_2=0.5$ $P_1=P_2=0.5$	20	40
3	$PM\text{-}P_1=PM\text{-}P_2=1$, $P_1=0.8 P_2=0.2$	20	20
4	$PM\text{-}P_1=PM\text{-}P_2=1$, $P_1=0.8 P_2=0.2$	20	40
5	$PM\text{-}P_1=1$, $PM\text{-}P_2=0.5$ $P_1=P_2=0.5$	20	20
6	$PM\text{-}P_1=1$, $PM\text{-}P_2=0.5$ $P_1=P_2=0.5$	20	40

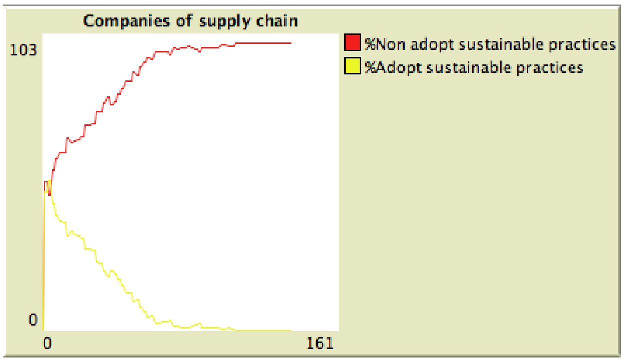

Figure 4. Scenario 1:PM-P_1=PM-P_2 =0.5, 20 groups of size 20, $P_1=P_2=0.5$, 70 steps.

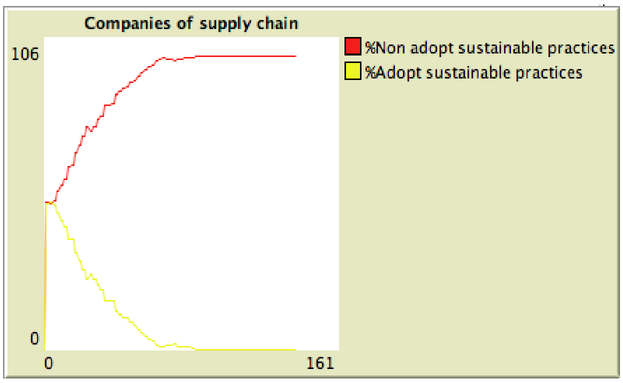

Figure 5. Scenario 2:PM-P_1=PM-P_2 =0.5, 40 groups of size 20, $P_1=P_2=0.5$, 70 steps.

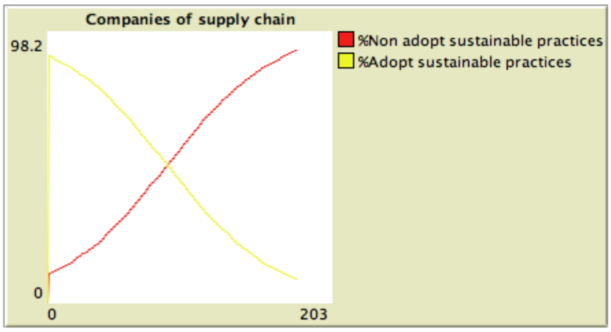

Figure 6. Scenario 3:PM-P_1=PM-P_2 =1, 20 groups of size 20, $P_1=0.8$,$P_2=0.2$, 70 steps.

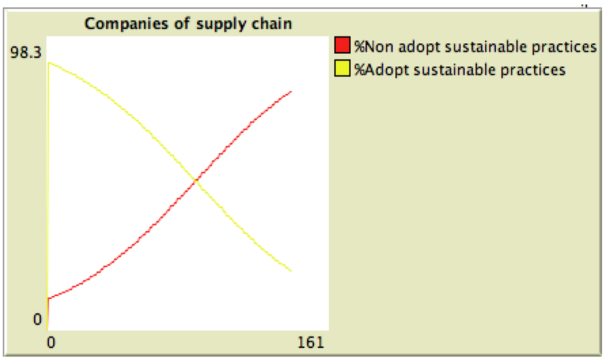

Figure 7. Scenario 4:*PM-* P_1=*PM-*P_2= 1, 40 groups of size 20, $P_1=0.8$,$P_2=0.2$, 70 steps.

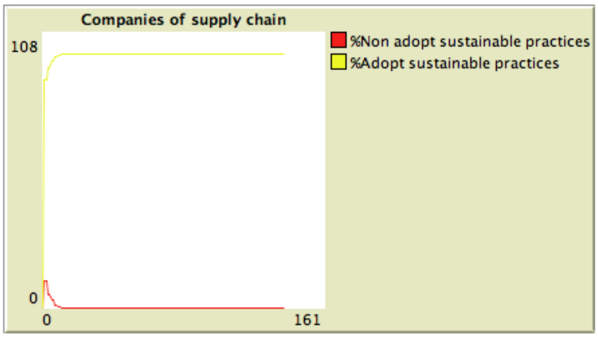

Figure 8. Scenario 5:*PM-*P_1*=1, PM-*P_2=0.5, 20 groups of size 20, $P_1=0.7$,$P_2=0.3$, 70 steps.

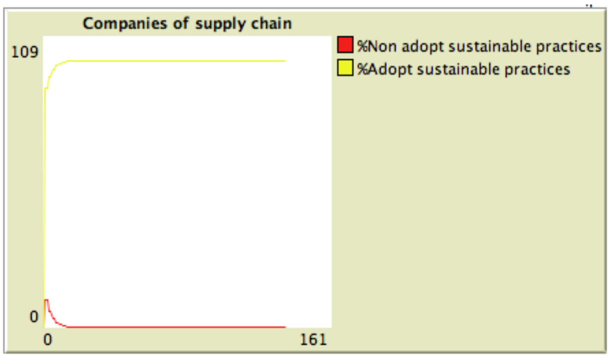

Figure 9. Scenario 6:*PM-*P_1*=1, PM-*P_2=0.5, 40 groups of size 20, $P_1=0.7$, $P_2=0.3$, 70 steps.

B. Main Results

The main two factors that impact directly on the decision of companies of a supply chain to adopt or not sustainable practices is the percentage of companies of P_2, which prefer not to adopt such practices and the probability to meeting companies of P_1. In scenarios 3 and 4, the percentage of companies in P_2 was decreased so at the beginning companies tend to adopt the sustainable practices but along time, they change their decision and reject the sustainable practices first adopted. In scenarios 5 and 6, companies adopt sustainable practices when the probability of companies in P_1 to meeting companies that have already adopted the practices is 1. The number of groups and the group size do not influence the making decision about adopting sustainable practices when the proportions of P_1 and P_2remains unchanged.

V. Conclusions

In this paper, we developed an agent-based model to analyze the factors that influence the interactions among the actors of supply chains for the adoption of sustainable practices. We proposed a conceptual model about the interactions among actors of supply chains based on the pair wise Prisioners Dilemma game and considering two populations: P_1 (companies that prefer to adopt sustainable practices) and P_2(companies that do not prefer to adopt sustainable practices). Then, we implemented in computer the conceptual model using NetLogo™ software. We designed six simulation scenarios varying factors such as the group number, the dimensions of groups, the probability to meeting other companies that have adopted sustainable practices and the proportion of P_1 and P_2. From the simulation results we concluded that the interactions (meeting) between companies that do not prefer to adopt sustainable practices with whose that have already adopted the practices impact directly on the decision of others companies to adopting such practices. When the percentage of companies of P_2 decreases, at the beginning companies tend to adopt the sustainable practices but along the time, they change their decision and reject the sustainable practices first adopted.

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References

[1] United Nations, *Transforming Our World: the 2030 Agenda for Sustainable Development* (Resolution A/RES/70/1).

[2] B. Hoof and M. Thiell, “Collaboration capacity for sustainable supply chain management: small and medium-sized enterprises in Mexico,” *Journal of Cleaner Production*, vol. 67, pp. 239-248, 2014.

[3] T. Choi, K. Dooley, and M. Rungtusanatha, “Supply networks and complex adaptive systems: Control versus emergence,” *Journal of Operations Management*, vol. 19, pp. 351-366, 2001.

[4] J. Dunne, U. Brose, and R. Williams. “Modeling food-web dynamics: Complexity-stability implications,” SFI working paper 2004-07-021, 2004.

[5] L. Bettencourta, A. Cintrón-Arias, D. Kaiser, and C. Castillo-Chávez, “The power of a good idea: Quantitative modelling of the spread of ideas from epidemiological models,” *Physica A.*, vol. 364, pp. 513-536, 2006.

[6] S. Kimbrough, D. Wu, and F. Zhong, “Computers play the beer game: can artificial agents manage supply chains,” *Decision Support Systems*, vol. 33, pp. 323-333, 2002.

[7] S. Seuring, “A review of modelling approaches for sustainable supply chain management,” *Decision Support Systems*, vol. 54, pp. 1513-1520, 2013.

[8] M. Brandenburg, K. Govindan, J. Sarkis, and S. Seuring, “Quantitative models for sustainable chain management: Developments and directions,” *European Journal of Operational Research*, vol. 233, pp. 299-312, 2014.

[9] R. Axelrod, *The Evolution of Cooperation*, New York: Basic Books, Inc., Publishers, 1984.

[10] P. Schuster and K. Sigmund, “Replicator dynamics,” *Journal of Theoretical Biology*, vol. 100, pp. 533-538, 1983.

[11] D. Helbing and A. Johansson, “Cooperation, norms, and revolutions: A unified game-theoretical approach,” *PLoS ONE*, vol. 5,2010.

[12] C. Iglesias, M. Garijo, J. C. González, and J. R. Velazco, *Analisis and design of multiagent systems using MAS-CommonKADS*, in Singh, M., Rao, A. S., Wooldridge, M. (Eds), Intelligent Agent IV, Lecture Notes in Computer Science 1365, pp. 312-328, 1997.

[13] M. Wooldridge, N. R. Jennings, and D. Kinny, “The Gaia methodology for agent-oriented analysis and design,” *Journal of Autonomous Agents and Multi Agent Systems*, vol. 3, pp. 285-312, 2000.

[14] T. Juan, A. Pearce, and L. Sterling, “ROADMAP: Extending the Gaia methodology for complex open systems,” in *Proc. First International Conference on Autonomous Agents and Multi-Agent systems-AAMAS’ 02*, 2002, pp. 3-10.

[15] L. Padgham and M. Winikoff, “Prometheus: A methodology for developing intelligent agents,” in *Proc. First International Conference on Autonomous Agents and Multi-agent Systems-AAMAS’ 02*, 2002, pp. 135-146.

[16] S. De Loach, M. Wood, and C. Sparkman, “Multiagent systems engineering,” *International Journal of Software Engineering and Knowledge Engineering*, vol. 11, pp. 231-258, 2001.

[17] G. Wagner, “The agent-object-relationship metamodel: towards a unified view of state and behavior,” *Information Systems*, vol. 22, pp. 401-422, 2003.

[18] A. Sturm, D. Dori, and O. Shehory, “Single-model method for specifying multi-agent systems,” in *Proc. Second International Conference on Autonomous Agents and Multi-Agent Systems-AAMAS’ 03*, 2003, pp. 121-128.

[19] J. Lind, *Iterative Software Engineering for Multiagent Systems, the MASSIVE Method*; New York: Springer, 2002.

[20] J. Gómez-Sanz, and J. Pavón, “Agent oriented software engineering with INGENIAS,” in *Proc. Third Central and Eastern Europe Conference on Multiagent Systems*, Lectures notes in Computer Science 2691, 2003, pp. 394-403.

[21] P. Bresciani, A. Perini, P. Giorgini, F. Giunchiglia, and J. Mylopoulos, “A knowledge level software engineering methodology for agent oriented programming,” in *Proc. Fifth International Conference on Autonomous Agents*, 2001, pp. 648-655.

[22] F. Brazier, C. Jonker, and J. Treur, “Principles of component-based design of intelligent agents,” *Data and Knowledge Engineering*, vol. 41, pp. 1-28, 2002.

[23] F. Giunchiglia, J. Mylopoulos, and A. Perini, “The tropos software development methodology: processes, models and diagrams,” in *Proc. Agent-Oriented software engineering (AOSE-2002)*, 2002, pp. 63-74.

[24] V. Grimm, and S. F. Railsback, *Individual-based Modeling and Ecology*; New Jersey: Princeton University Press, 2005.

[25] U. Wilensky and W. Rand, *An Introduction to Agent-Based Modeling*, 1st ed. Cambridge: The MIT Press, 2015.

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