Game Theory to Promote the Sustainable Development of the Pharmaceutical Industry

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This study evaluated the application of game theory in sustainable development strategies in the pharmaceutical industry through a bibliometric analysis. Using databases such as Scopus, Web of Science, and Science Direct, the results indicate a lack of studies focused on applying game theory, specifically in the pharmaceutical industry, especially in sustainability. Gaps were identified in risk management, profitability, decision-making, and competition. It is concluded that game theory can model investment decisions in R&D, competitive scenarios, and sustainable medicine marketing practices, integrating economic, social, and environmental objectives. These insights stimulate future academic research in the area.

Keywords: Game Theory. Pharmaceutical Industry. Sustainable Development. Cooperation. Sustainability. Competition.

The pharmaceutical sector has received increasing attention regarding its contribution to sustainable development. Companies in this segment face multidimensional challenges involving economic, social, and environmental objectives, often with conflicting interests and priorities among stakeholders. The industry's economic vision seeks financial returns through innovations and commercialization of medicines. In contrast, stakeholders in the social vision focus on promoting universal access to treatments, and environmentalists prioritize mitigating adverse environmental impacts [1].

In the pharmaceutical field, social objectives aim to guarantee access to medicines for as many people as possible, regardless of the regional economic context. The economic objectives seek to enable revenues and mitigate costs to create an attractive business model for ongoing investments. Environmental objectives involve implementing practices that minimize the negative externalities of pharmaceutical operations, making production processes more efficient and less polluting [2,3].

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Although sustainability objectives are well-defined, practical implementation faces significant challenges. Economically, the industry faces pressure from affordability, high R&D costs, government regulations, and patent issues that impact innovation. Balancing profitability with social responsibility and equitable access to medicines is a significant challenge.

Environmentally, reducing energy and resource consumption and managing pharmaceutical waste are critical issues. Managing these tensions with decision-support tools that promote cooperation is essential to the long-term sustainable success of the pharmaceutical industry [2].

In this context, game theory emerges as a promising analytical approach to integrate economic, social, and environmental objectives, facilitating conflict resolution and cooperation between interested parties. This approach allows for formal model interactions between industry actors, identifying solutions that maximize mutual benefits and minimize conflicts. The application of game theory can facilitate negotiating and implementing policies that effectively align diverse interests, promoting truly sustainable pharmaceutical development. Furthermore, game theory can help identify Nash equilibria, where no player benefits from changing their strategy unilaterally, creating an environment of stability and predictability [4-7].

This article aimed to understand the current state of application of game theory in sustainable development strategies in the pharmaceutical industry, exploring how this theory has been used in scientific literature. It focuses on identifying existing knowledge gaps and questions the strategies' effectiveness and innovation. We also investigate how these strategies can be improved to integrate economic, social, and environmental objectives.

Materials and Methods

A bibliometric analysis was carried out to achieve its objectives based on scientific literature available in databases. These searches were conducted in the Scopus, Web of Science, and Science Direct databases, focusing on scientific articles and literature reviews. The descriptor was first used: ("game theory") and ("pharmaceutical industry" or "pharmaceutical laboratory"), to understand the profile of scientific research between Game Theory and the pharmaceutical industry or laboratories. Afterward, a second research was carried out with the descriptors ("game theory") and ("sustainable development" or "triple bottom line" or "TBL" or "Sustainable growth"), to understand the profile of scientific research between Game Theory and sustainable development. Next, to understand the development of research between Game Theory, sustainable development, and the pharmaceutical industry, the descriptor ("game theory,") and ("pharmaceutical industry," or "pharmaceutical laboratory ") and ("sustainable development " or "triple bottom line" or "TBL" or "sustainable growth").

Results and Discussion

Initially, we sought to identify the evolution of the number of scientific articles in a comparative way between Game Theory and Sustainable Development, Game Theory and the Pharmaceutical Industry, and the evolution of scientific articles that simultaneously address Game Theory, Sustainable Development, and the Pharmaceutical Industry. Table 1 and Figure 1 show this evolution.

Publications on Game Theory and Sustainable Development (orange-Figure 1) have grown exponentially in recent years, ranging from 0 to 610 annual publications. In contrast, articles on Game Theory and the Pharmaceutical Industry were sporadic before 2008 but have gradually increased since then, with a peak starting in 2020. The combination of Game Theory, Sustainable Development, and the Pharmaceutical Industry had few publications before 2006 but has seen a slight increase since 2018, reaching 8 articles in 2023. In 2023, 29 articles on Game Theory and the Pharmaceutical Industry and 610 articles on Game Theory and Sustainable Development were published, highlighting a growing academic interest in the association between Game Theory and Sustainable Development, Games and Sustainable Development. The scarcity of publications that combine the three themes reveals an underexplored area with great potential for discoveries and contributions.

When investigating the quality of journals linked to themes, the data in Table 2 is presented. Table 2 reveals the distribution of scientific articles classified by QUALIS for the research descriptors "Game Theory x Pharmaceutical Industry," "Game Theory x Sustainable Development," and "Game Theory x Sustainable Development x Pharmaceutical Industry." It is observed that most articles are published in high-quality journals (A1 and A2), with emphasis on the descriptors "Game Theory x Sustainable Development x Pharmaceutical Industry." In contrast, there are no articles in the A3 and A4 classifications for all descriptors, suggesting that research on these topics is often published in journals of more significant impact and quality. Furthermore, the combination of all descriptors ("Game Theory x Sustainable Development x Pharmaceutical Industry") presents a significantly smaller number of articles (12), with 58.33% of these in A1 journals, indicating an emerging area with

Table 1. Annual evolution of the number of scientific articles published in the research descriptor.

Year	Game Theory x Pharmaceutical Industry	Game Theory x Sustainable Development	Game Theory x Pharmaceutical Industry x Sustainable Development
1986	1		
1987	1		
1988	1	1	
1989			
1990		2	
1991	2	2	
1992	2	1	
1993	3	4	
1994		1	
1995	11	9	
1996	3	2	
1997	2	8	
1998	4	6	
1999	2	5	1
2000	1	7	
2001	2	3	
2002		7	
2003	1	8	
2004	4	9	
2005	2	11	
2006	4	15	1
2007	6	21	
2008	3	16	
2009	1	31	
2010	5	25	
2011	5	30	
2012	6	47	1
2013	7	43	
2014	14	50	1
2015	6	77	1
2016	5	87	1
2017	7	115	4
2018	15	137	2
2019	13	236	4
2020	21	243	7
2021	29	380	3
2022	25	489	3
2023	29	610	8
2024	14	546	5

Figure 1. Annual evolution of the number of scientific articles published according to research descriptor.

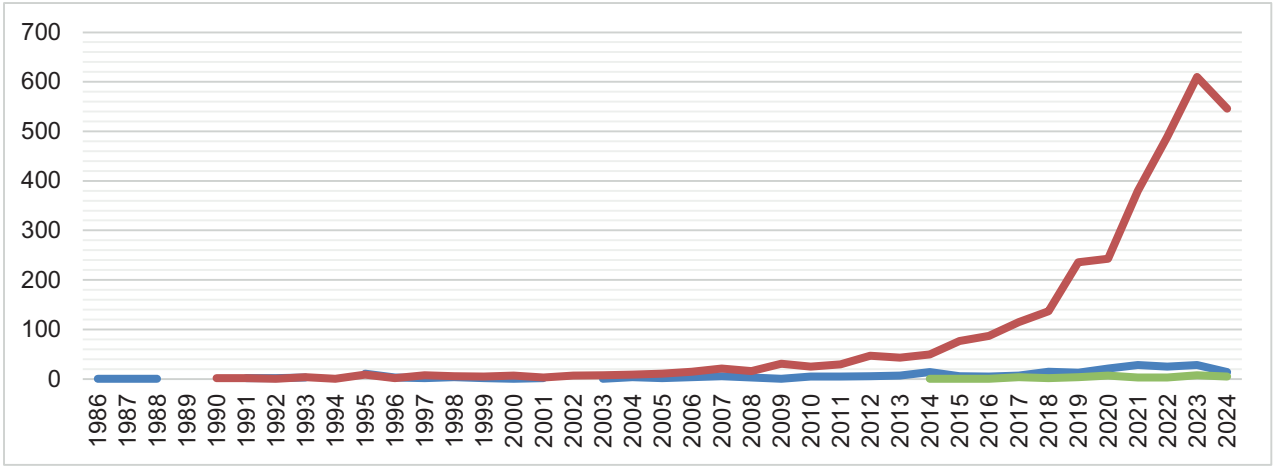


Table 2. Research Descriptor x Qualis.

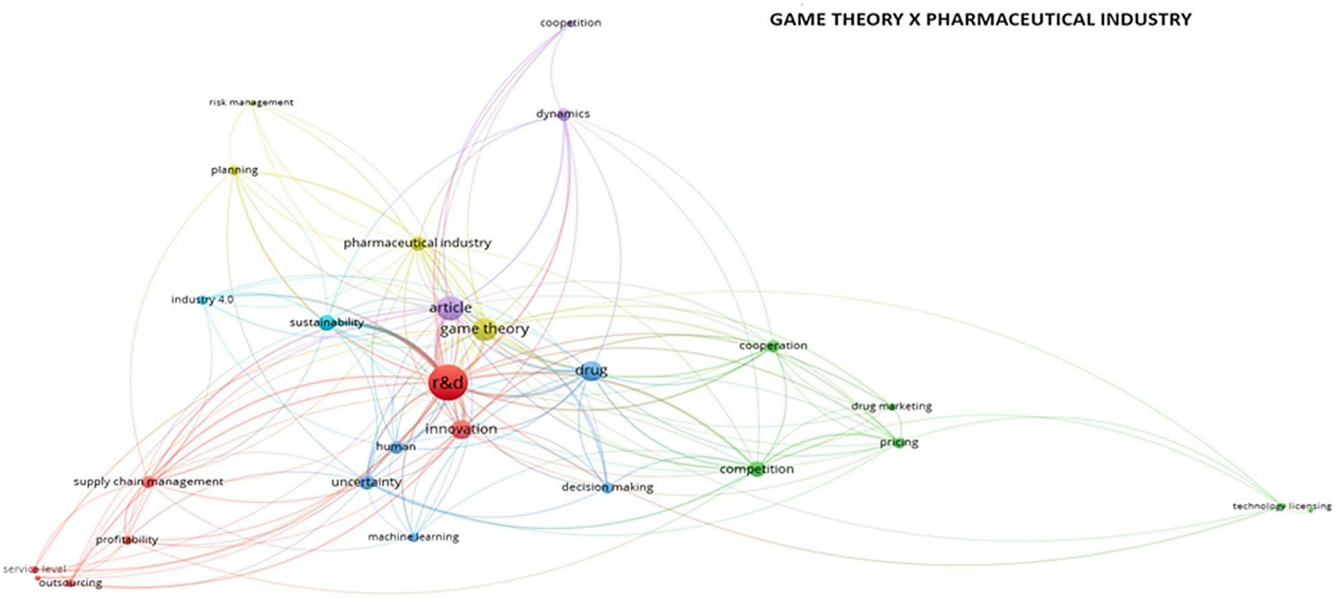
Qualis	Game Theory x Pharmaceutical Industry		Game Theory x Sustainable Development		Game Theory x Pharmaceutical Industry x Sustainable Development	
A1	54	52,43%	1047	57,40%	7	58,33%
A2	3G	37,86%	548	30,04%	3	25,00%
A3		0,00%		0,00%		0,00%
A4		0,00%		0,00%		0,00%
B1	8	7,77%	137	7,51%	1	8,33%
B2		0,00%	50	2,74%		0,00%
B3	1	0,97%	37	2,03%	1	8,33%
B4	1	0,97%	1	0,05%		0,00%
B5		0,00%	4	0,22%		0,00%
Total	103		1824		12	100,00%

potential for future growth. The smaller presence of articles in lower QUALIS (B2, B3, B4, B5) reinforces the tendency for publication in more prestigious journals.

Some findings can be identified when conducting a semantic network analysis of the research using the specified descriptors (Figure 2). The figure shows the semantic network of the descriptor "game theory" in combination with "pharmaceutical industry" or "pharmaceutical laboratory."

It is evident in this semantic network that Research and Development (R&D) occupies a central position, connecting to several other terms. This highlights its importance at the intersection between game theory and the pharmaceutical industry, which is in the same cluster as innovation, profitability, outsourcing, service

Figure 2. Semantic Network: Game Theory x Pharmaceutical Industry.



quality, level), Supply Chain Management, and Product Recall. This grouping suggests that game theory can be used to model investment decisions in R&D, considering competition and the need for innovation to maintain competitiveness.

Additionally, game theory can help determine the best strategies for increasing profitability by optimizing processes such as outsourcing and supply chain management. It can also be applied to improve interaction between different parts of the supply chain and to improve risk management, evidenced by the emphasis on product recalls, which must be managed effectively to minimize negative impacts on the company's reputation and finances. The proximity in the semantic network of cooperation, competition, pricing, and drug marketing suggests that these areas are closely related and often studied together in the context of game theory and the pharmaceutical industry. This indicates that medicine marketing strategies are influenced by both cooperation and competition between companies, reflecting the complexity of marketing decisions, where it is necessary to balance market rivalry and strategic partnerships to improve efficiency and innovation. To be more specific, Figure 3 shows the semantic network of Game Theory and the Pharmaceutical Industry, focusing on the word "cooperation." Several connections can be identified through this semantic network that represent knowledge gaps and research opportunities.

Figure 3 identifies knowledge gaps (highlighted in red) related to research on Game Theory, the Pharmaceutical Industry, and Cooperation: risk management, competition, profitability, and decision-making. These gaps represent opportunities to explore how game theory, through cooperation, can model risk scenarios and develop effective mitigation strategies, improving operational resilience. Furthermore, it allows us to understand the balance between competition and cooperation, facilitating strategic partnerships that promote innovation. Pricing and operations optimization models based on game theory, linked to cooperation, can maximize profitability, while advanced modeling tools can improve strategic decision-making. These insights can guide the pharmaceutical industry to implement more effective and sustainable strategies and better adapt to complex market dynamics. Figure 4 highlights the semantic network of Game Theory x Pharmaceutical Industry x sustainability:

When relating Game Theory, the Pharmaceutical Industry, and Sustainability, some research gaps highlighted in red are identified: risk management,

Figure 3. Semantic Network: Game Theory x Pharmaceutical Industry: cooperation.

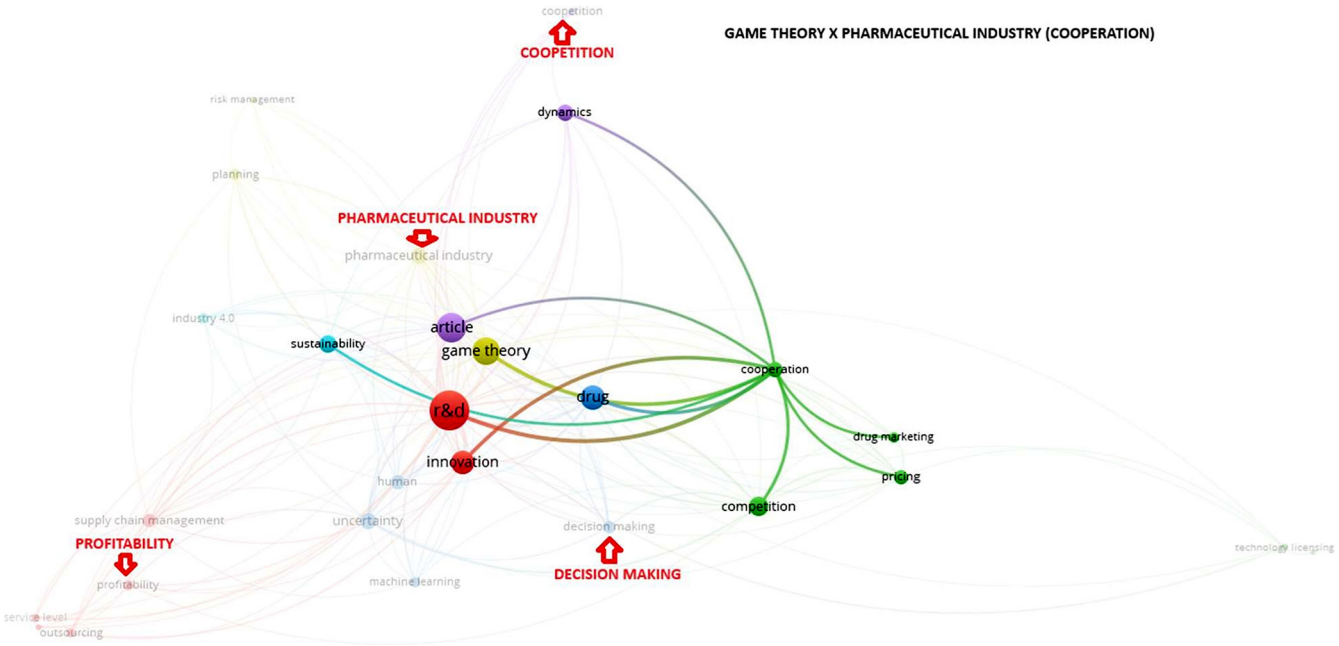
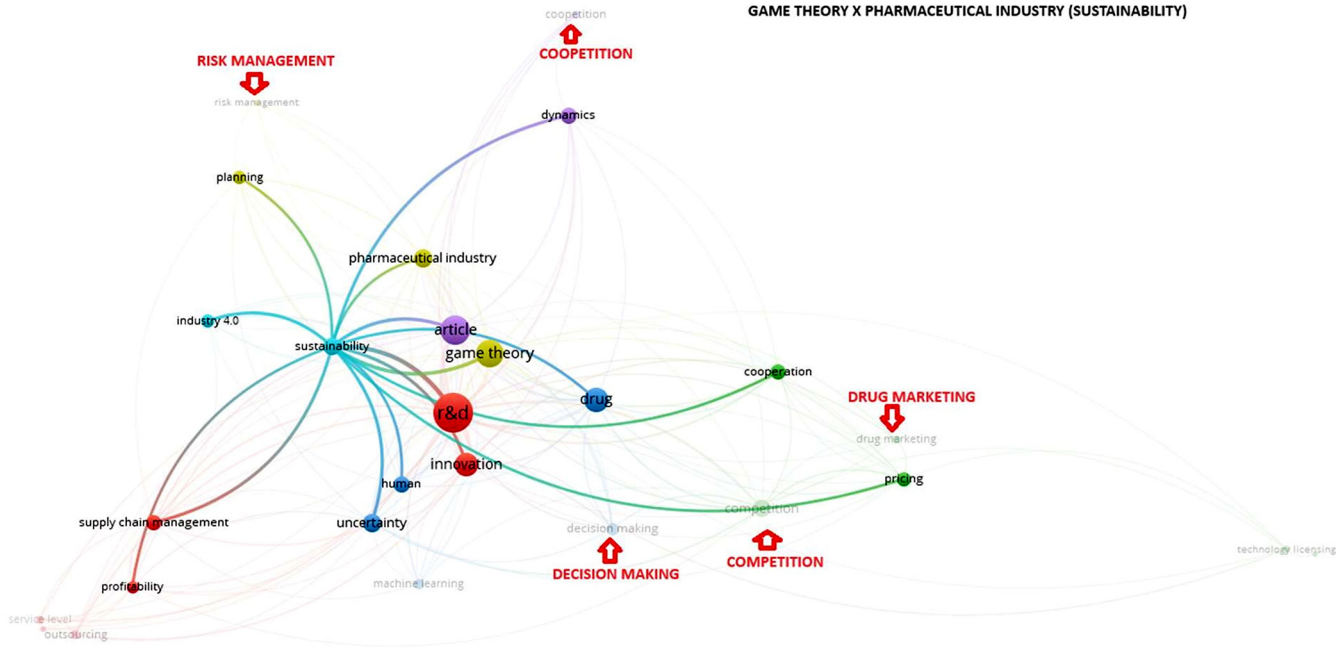


Figure 4. Game Theory Semantic Network x Pharmaceutical Industry: sustainability.



coopetition, and competition, decision-making) and drug marketing. These gaps deserve investigation as they can explore how game theory can be used to model environmental risk scenarios in the pharmaceutical industry and develop effective mitigation strategies, promoting operational resilience. Additionally, competition analysis can identify ways to balance competition and cooperation between pharmaceutical companies to foster innovation and sustainability. Game theory can also help optimize strategic decision-making, such as investments in research and development and marketing strategies, maximizing profitability, and minimizing environmental impacts. These

investigations can provide valuable insights into integrating economic, social, and environmental objectives, creating a more sustainable model for the pharmaceutical industry.

Conclusion

This study used a bibliometric analysis to understand the current state of the application of game theory in sustainable development strategies in the pharmaceutical industry. The research identified that, despite the great academic interest in integrating game theory with sustainable development, there is a scarcity of studies focused on applying game theory specifically in the pharmaceutical industry and even less in the context of sustainable development in this industry. When examining the intersection between game theory and the pharmaceutical industry, emphasizing cooperative practices, important knowledge gaps were identified that integrate these practices with risk management, profitability, decision-making, and competition, for example. That game theory can be modeled using the logic of cooperative games, building the design of strategic alliances in R&D, where companies collaborate to share costs and benefits, focused on developing new medicines with less environmental impact in a faster and cheaper way. Furthermore, competitive Scenarios can be modeled, where pharmaceutical companies and public laboratories can collaborate in areas of basic research and innovation while competing in the commercialization of products, avoiding oligopolies.

This research is also identified as a knowledge gap, research on the use of game theory in the pharmaceutical industry with a focus on sustainability in which medicine marketing, cooperative practices, coopetition, risk management, and competition are articulated. In this case, game theory can model sustainable medicine marketing practices that are environmentally responsible, competitive, and cooperative.

This research, therefore, brought insights that allowed us to raise several questions, such as: How can game theory be used to develop sustainable marketing strategies in the pharmaceutical industry? How can game theory balance cooperation and competition (coopetition) between pharmaceutical companies to promote sustainable innovation? How can game theory be used to model sustainable R&D resource allocation? How can game theory help prioritize economic, social, and environmental goals?

Both these questions and the knowledge that came to light in this article address the complexity and interdependence of economic, social, and environmental objectives in the pharmaceutical industry, which can find answers in Game Theory, providing a solid basis for future academic research, which can stimulate new research that also leads to exponential growth in academic interest in the theme of Game Theory to promote the sustainable development of the pharmaceutical industry.

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