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# Essays on Networks, Information Economics, and Dynamic Games of Populism and Conflict

PhD Dissertation Summary

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# Essays on Networks, Information Economics, and Dynamic Games of Populism and Conflicts <sup>\*</sup>

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**JEL Classification:** D7 (Analysis of Collective Decision-Making), D81 (Criteria for Decision-Making under Risk and Uncertainty), D82 (Asymmetric and Private Information; Mechanism Design), D83 (Search; Learning; Information and Knowledge; Communication; Belief; Unawareness), D85 (Network Formation and Analysis: Theory), C73 (Stochastic and Dynamic Games, Evolutionary Games, Repeated Games), C63 (Computational Techniques, Simulation Modeling)

## 1. Purpose and objectives of research

This dissertation consists of three applied theory papers. The overarching goal is to develop tools and models for studying strategic interactions among agents in dynamic games. The first chapter studies strategic interactions among agents in Markovian differential games. Markovian differential games provide the analytical framework for studying strategic interactions in setups where agents are forward-looking and take into account their future strategic interactions. The second and third chapter connects strategic interactions under incomplete information in a dynamic network formation process. The second and third

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chapter demonstrate a tool/method for connecting strategic actions with the evolution of a network structure. The third chapter extends this method in order to pursue a policy-prescription goal. It studies network-manager strategies that can lead to welfare-improving network evolution under incomplete information (think of an internet social-media platform manager).

The first Chapter studies Markovian differential games. Markovian differential have various economic applications, such as corruption, capital flights, pollution and etc. The models appearing in the literature mostly use very special utility functions that also require parametric assumptions in order to find closed-form solutions. Such parametric assumptions usually demonstrate the high level of complexity of these games. Studying such games requires knowledge such as dynamic programming, functional analysis, metric space analysis, etc., for characterizing Markovian strategies. The purpose of the first chapter is to develop an exact formula, which can serve as a guide for finding interior closed-form Markovian strategies. The objectives of this research are: (1) To find a characterization for Markovian strategy with general utility functions of players. When the reproduction of a common-property resource is linear. Such theoretical games of commons are useful for the analysis of sustainability. This is accomplished by showing that the Hamilton-Jacobi-Bellman equation of a player's dynamic problem can be transformed into the Lagrange d'Alembert differential equation. This differential equation has an exact interior solution when the integration constant is equal to zero. In this case, which characterizes the prime Markovian strategies, the Markovian strategies consist of an indefinite integral of the inverse function of marginal utility. (2) To prove, that if the utility function is analytic, then these particular Markovian strategies are analytic, too.

The second Chapter seeks to understand the impact of social networks on the economics

of conflict, populism, political segregation, radicalism, religious fanaticism, etc. During our times, political indicators throughout the globe indicate the rise of populism and of separatist trends. One of the ways to view populism is the tendency of people to define themselves within exclusive groups that seek enemies outside a group. The roots of populism have two main ingredients, each defining a theoretical goal. The first ingredient is the network interactions of people in society. Now that internet connections are rapid and smartphones allow people to exchange enormous amounts of information, pictures, videos, etc., at very low cost, the interactions of people who tend to organize themselves into subgroups are more intense. Online Social networks are now very popular in spreading information. Therefore, the objective is to build an equilibrium model that addresses whether available information technologies affect information flows, beliefs and decision-making in societies. The second ingredient leading to populism is incomplete information. With incomplete information, people in networks need to verify the limited information they receive, and they are challenged in distinguishing between facts and “fake news”. Therefore, a key theoretical goal is to model a workable belief mechanism that evolves within networks.

The third Chapter intends to shed light on the populism problem addressed by chapter two, by developing a mechanism that can lead to welfare-improving network evolution under incomplete information. This chapter aims to identify if a social planner (e.g., a manager of a social-media platform), can manipulate network dynamics so as to bring agents’ actions closer to fundamental knowledge about unknown parameters behind their actions. The objective of this research is to build an evolutionary network where a social planner introduces network members to other members they are not connected with, but lets them free to choose whether they will become network friends with the suggested people or not. I study which strategies of the Social Planner and what knowledge of the Social Planner indeed increases social

welfare of network members and why. The increase in welfare stems from helping agents make more informed decisions through meeting other informed agents (e.g., on what are good selling/buying prices for houses or other assets).

## 1.1 Research Questions

The key questions of our research are the following:<sup>3</sup>

1. Can we develop an exact formula that can serve a guide for developing well-grounded numerical solutions to Markovian differential games, and generalize these parametric examples in order to take the models to data through numerical simulations?
2. Why have agents been gradually downgrading expert opinion in opinion polls in past few decades?
3. Can a social planner manipulate network dynamics so as to bring agents' actions closer to fundamentals, making actions more pragmatist?

## 2. Literature review

There is a large literature, both theoretical and empirical, on the subject of strategic interaction among agents in dynamic games. This thesis builds bridges among the following literatures: differential games, social and economic networks, global games, the literature on political economy, mechanism design.

The first chapter of this PhD thesis contributes to the literature of Markovian differential games. This literature is the specific part of game theory that uses differential equations in order to analyze problems such as corruption, rent-seeking, pollution, etc. Markovian

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<sup>3</sup> The enumeration of research questions follows Chapter numbers.

differential games with linear constraints, focusing on how strategic interactions influence the growth rate of common property resource, have been developed by Tornell and Valasco (1992), Lane and Tornell (1996,1997), Sorger (2005), and Long and Sorger (2006). This literature was surveyed and explained in Clemhout and Wan (1994), Basar and Olsder (1999), Dockner et al. (2000), and Long (2010). The latest paper extending Tornell and Valasco (1992), is Kunieda and Nishimura (2018). They introduce financial constraints and uncertainty in the model. Contrary to Kunieda and Nishimura (2018), our paper is deterministic, without uncertainty in financial markets, but our results can be used for extending Kunieda and Nishimura (2018) using a general utility function. As I mention before the most of literature use specific utility functions (more often a quadratic utility function), and the existence of Markovian strategies in closed form depends mostly on parametric constraints. Our contribution in the literature is developing an exact solution for Markovian differential game, which can serve as a guide for finding interior Markovian strategies for different types of utility functions. Our model generalizes the results of Tsutsui and Mino (1990) and Dockner and Long (1993) for a general utility function. The scope of the first paper is to characterize the interior solution, but our exact interior solution can be used for finding also corner solutions using a homotopy approach.

The second and the third chapters of this PhD thesis build bridges among the literatures of social and economic networks, global games, the political economy literature, mechanism design, and literatures developed in computer science. The papers link to four strands of literature: (1) *The literature on quadratic games* (for the definition of such class of games, see Jackson (2008)). Both papers are an extended version of the workhorse paradigms in Morris and Shin (2002), Golub and Morris (2017), who use quadratic utility functions, combined with “beauty contest” elements. The utility function developed in Chapter 2 is closer to

this of Golub and Morris (2017), Dewan and Myatt (2012), Myatt and Wallace (2012), Bonfiglioli and Gancia (2013), Llosa and Venkateswaran (2012), Pavan (2014) papers, with the following differences (1) assimilation bias in the agents utility functions, (2) evolutionary dynamics with the endogenizing weights on signals and biases. The utility function for the third chapter is mostly closer to Morris and Shin (2002). Agents' utility functions depend not only on actions of agents to whom they are connected, but also on actions of non-friends in the network. Comparing the third chapter with Morris and Shin (2002), there are three differences: (i) network structure, (ii) evolutionary dynamics, with endogenized weights, (iii) assimilation/confirmation bias in preferences. The closest paper using quadratic games with asymmetric agents is Myatt and Wallace (2019), who use two types of asymmetry: (a) asymmetry in conformity (coordination motive), and (b) different weights for friends (with whom agents coordinate). Compared to Myatt and Wallace (2019), our paper adds also asymmetry in assimilation bias, weight for non-friends, and dynamics in the model.

(2) *The literature on games on networks, focusing on centrality, key players, degree centrality.* Examples of this literature are Jackson (2008), Currarini et al. (2009), Kossinets and Watts (2009), Golub and Jackson (2012a,b), Bramouille et al. (2012), Jackson and Lopez-Pintado (2013), Centola (2013), Lobel and Sadler (2015), Currarini and Mengel (2016), and Halberstam and Knight (2016). The second chapter contributes to this literature showing the vicious circle between biases and network homophily. The third chapter focuses on analyzing who are the key players, and how we can improve social welfare combining indegree and outdegree links.

(3) *The literature on strategic disclosure or information manipulation, fake news.* The literature developed on information manipulation, such as Edmond (2013) and Edmond and Lu (2017), use biased signals, of social planners trying to manipulate other agents' actions.

In the third chapter the social planner does not use any biased or unbiased signals, but manipulates the set of possible invitations for friend-making or exposes annoyances, leaving, however, agents to make a decision with whom to create or delete network ties. Both the second and third chapters do not have direct links to the fake news literature. Yet, the main results of the second chapter show that fake news is not the complete explanation of polarization/populistic behavior in networks. The insights of the second paper show an avenue for mitigating polarization in networks. Exploiting this avenue, the third chapter is different from standard sender/receiver games such as Crawford and Sobel (1982) and Kartik (2009). In our model, senders and receivers have a conflict of interest, that Crawford and Sobel (1982) characterize as the “Babbling equilibrium”. In such a game there is no information transmission. Therefore, in the third chapter I demonstrate a mechanism for solving the coordination problem without directly sending information.

(4) *The literature on social policy.* The third paper can also be interesting to researchers who study social-policy through social-welfare improvements. The most relevant research on this topics are Dyckman (1966), Cavallo (2008), and Bernheim (1989).

### **3. Research methodology and structure**

The dissertation consists of three applied theory papers.

The first paper is titled “Symmetric Markovian Games of Commons with Potentially Sustainable Endogenous Growth”. It is a joint work with Christos Koulovatianos. The research question addressed in this paper is the following: “Can we develop the exact formula that can serve as guides for developing well-grounded numerical solutions to Markovian differential games, generalizing these parametric examples in order to bring models closer to the data?” We answer this research question in two steps. First, we develop an exact formula

for finding the interior solution of symmetric Markovian games with linear accumulation constraints of a common resource. Second, we characterize the general solution, which can be used as a guideline for finding corner solutions, using a homotopy approach. For achieving the first step, of finding an exact solution, we show that the Hamilton-Jacobi-Bellman equation of a player's dynamic problem can be transformed into a Lagrange d'Alembert differential equation. We show that this differential equation has an exact interior solution when the integration constant is equal to zero. In this case, the Markovian strategy is equal to the indefinite integral of the inverse function of marginal utility. For achieving the second step, of characterizing the solution, we prove the analyticity of Markovian strategies, if the utility function of players is analytic. Analyticity is crucial for proving the existence of approximate numerical solutions. We further demonstrate our findings by characterizing some closed-form interior solutions, which are well-known in the literature, as well as demonstrating some new examples admitting closed form solutions that are new to the literature.

The second chapter titled "Populism and Polarization in Social Media Without Fake News: the Vicious Circle of Biases, Beliefs and Network Homophily", is also joint work with Christos Koulovatianos. We develop a model/method using evolutionary games on networks in order to provide a partial explanation that fake news is not the sole or dominant explanation to the observed growing polarization and populist behavior in the past few decades. We use an extended version of the information-seeking "beauty-contest" game with higher-order beliefs, which was developed by Morris and Shin (2002) and Golub and Morris (2017). Compared to the standard beauty-contest model of Morris and Shin (2002), we introduce "biased assimilation" in agents' utility functions. Biased assimilation is a structural (perhaps education-based) inclination to push facts slightly away from reality. At the same time, agents try to align their actions closer to the actions of their friends

(“belongingness” in agents’ preferences). We introduce a search-and-matching mechanism for creating and deleting links, and we study the evolutionary dynamics of network structure. In equilibrium the network structure is characterized by more homophily, and homophily brings peer-induced amplification to structural biases, contributing to gradually downgrading expert opinions over time, as observed in the data.

The third chapter, titled “Can a social planner manipulate network dynamics and solve coordination problems?”, is a single-authored paper. This paper recommends a way to solve the polarization problem in social networks arising from the mechanism explained in the second Chapter. In this chapter I also develop an evolutionary dynamic model/method, that introduces a “Liberal Social planner” who has no bias in his preferences. This social planner manipulates network dynamics in order to make agents’ actions more pragmatist, closer to fundamentals. The research questions in this chapter are: “Can a social planner increase social welfare, by manipulating the set of possible invitations sent to network members for making new friends, or by manipulating the set of annoyances among friends that are exposed, without directly changing the network structure by obliging people to make friends or cut ties with existing friends?”, “What are the main drivers behind welfare increases?”, “How do the results change if the social planner has incomplete information or wrong priors about the fundamentals?”. Crucially, this chapter focuses on developing a liberal manipulation strategy by a social planner, such as a network manager of a social-media platform, who does not directly affect agents’ signals or actions.

#### **4. Conclusion: Main findings and contribution**

In the first chapter, “Symmetric Markovian Games of Commons with Potentially Sustainable Endogenous Growth”, we develop an exact formula for finding the exact interior solution for

Markovian differential games with linear accumulation constraints of a common resource. Second, we characterize the general solution, which can be used as a guide for finding corner solutions numerically, using a homotopy approach.

In the second chapter, “Populism and Polarization in Social Media Without Fake News: the Vicious Circle of Biases, Beliefs and Network Homophily”, the cheap way of making internet friends increases the speed of finding friends with similar biases, which increases homophily. In turn, homophily affects the weight that each agent places on their bias, while taking action, and this leads to more homophily. This vicious circle of biases, beliefs, and homophily, increases the peer-induced weight of their pre-existing structural biases that agents put on their actions. Crucially, agents gradually ignore expert opinions (unbiased signal) more and more, which matches the trend measured by opinion polls in the past few decades.

In the third chapter, “Can a social planner manipulate network dynamics and solve coordination problems?”, I introduce a “Liberal Social Planner” and find that, indeed, the social planner can indirectly manipulate network dynamics in order to bring agents’ actions closer to fundamentals. I find that the key mechanism behind increasing social welfare is to increase the number of indegree nodes of central agents. This happens because agents can substitute expert information with private information from central nodes and make more informed decisions. Social planners who are more confident (or even sure, even if biased) about the fundamentals (e.g., of pricing houses for buying/selling) achieve better results. These results have potential applications to the management of social media platforms by the owners of these platforms. Platforms can develop robots that can help their users in becoming more informed and more satisfied about real-life issues, such as housing prices, etc.

## 5. Dissertation validation

1. The 27th Jerusalem School in Economic Theory, The Theory of Networks June 27-July 6, 2016, title of poster “Information manipulation and protests” (earlier version of the third chapter, which was re-named as “Can a social planner manipulate network dynamics and solve coordination problems?”).

2. The 29th Jerusalem School in Economic Theory, Industrial Organization June 26-July 5, 2018 title of poster “Information losses in coordination game” (earlier version of the third chapter, which was re-named as “Can a social planner manipulate network dynamics and solve coordination problems?”).

3. NES-HCEO Summer School on Socioeconomic Inequality (SSSI Moscow) August 28-September 2, 2017, poster session “Can a social planner manipulate network dynamics and solve coordination problems?”.

4. XIX April International Academic Conference on Economic and Social Development, HSE Moscow, Section Theoretical Economics, April 10-13, 2018. Title “Information learning in social networks, and coordination game”.

5. XXI April International Academic Conference on Economic and Social Development, April 6-10, 2020, Section Theoretical Economics, title “Populism and polarization in social media without fake news: the vicious circle of biases, beliefs and network homophily” (by zoom platform).

6. 11th Workshop on Dynamic Games in Management Science October 24-25, 2019, title “Populism and polarization in social media without fake news: the vicious circle of biases, beliefs and network homophily” (presented by co-author).

Also paper has passed the selection bar for the following conferences, which were postponed because of COVID-19.

1. The Fourteenth International Conference on Game Theory and Management (GTM2020) St. Petersburg University, postponed till September, title: “Populism and polarization in social media without fake news: the vicious circle of biases, beliefs and network homophily”
2. The sixth Annual Conference on Network Science and Economics, Chicago March 27-29. Title: “Populism and polarization in social media without fake news: the vicious circle of biases, beliefs and network homophily”.

## **6. List of author’s original articles**

Key outcomes of the dissertation have been published in 3 papers, 9 editor’s sheets in total; the author’s personal input comes to 6.4 editor’s sheets.

1. Symmetric Markovian Games of Commons with Potentially Sustainable Endogenous Growth joint work with Christos Koulovatianos. CFS (Center for Financial Studies) No. 638 in 2019 and is forthcoming Dynamic Games and Applications, in 2020 (personal input – 1.4 ed. sheet from 2.8)
2. Populism and Polarization in Social Media Without Fake News: the Vicious Circle of Biases, Beliefs and Network Homophily is a joint work with Christos Koulovatianos. CFS Working paper, No 629 in 2019, and Higher School of Economics Research Paper No. WP BRP 227/EC/2020 (personal input – 1.2 ed. sheet from 2.4)
3. Can a social planner manipulate network dynamics and solve coordination problems? Higher School of Economics Research Paper No. WP BRP 229/EC/2020. (personal input – 3,8 ed. sheet).

The structure of the PhD thesis is the following: introduction, three chapters and appendices after each chapter, conclusion and references.