SSM
Scuola Superiore Meridionale

MERC PhD Project Proposal 2024/2025

Title of the research project:

A multifaceted study of stochastic control for complex systems and networks, motivated by financial and economic applications.

Keywords (up to five)

optimal control, network control, stochastic differential equations, agent-based models, financial markets

Supervisors (at least two from two different areas):

Supervisor 1
Francesco Lo Iudice, francesco.loiudice2@unina.it,
https://www.docenti.unina.it/francesco.loiudice2, Control theory, agent based modelling.

Supervisor 2
Tiziano de Angelis, tiziano.deangelis@unito.it,
https://sites.google.com/site/tizianodeangelis/home, stochastic differential equations, financial markets.

Project description (max 5000 characters)

Economic and financial markets are a paradigmatic example of complex systems, their dynamics being determined by the interdependent investment and trading decisions of the agents populating the market and by the policies enforced by regulating bodies, such as the market maker, central banks, and monetary authorities in the case of stock markets. Furthermore, these dynamics are affected by numerous external disturbances, such as news on geopolitical developments, changes in the fundamentals of the firms or assets traded in the market and so on. At a higher level of abstraction, we are thus looking at a complex multi-agent system, where feedback loops are closed at different time scales, based on different information, and most importantly by pursuing different goals. To make things even more interesting, these feedback mechanisms are affected by several sources of uncertainty whose stochastic description can be highly heterogeneous. While indeed differences induced by agent heterogeneity and information mismatches might be suitably modelled as white noise processes with relatively low variance, geopolitical developments such as the start of a new war, or a substantial variation in the fundamentals of a firm, are less frequent but induce large shocks in the market dynamics, thus requiring substantially different stochastic modelling.

Not surprisingly, different approaches have been proposed for market modelling, both at the microscopic scale exploiting game theory [1,5] and/or agent-based models [2,3], and at the macroscopic scale, based for instance on time series analysis [4]. In this project, we take a multidisciplinary approach and attempt to go beyond our current understanding of the dynamics of economic and financial markets by exploiting tools from network science (to model agent interactions), optimal control and game theory (to model agent decision making across different scales) and stochastic differential equations. This makes for a challenging multidisciplinary project whose payoff would be the ability to gain a profound understanding of market dynamics that can be exploited at the investors level to take more profitable decisions, while at the market maker, and

more generally at the policy maker, level to mitigate risks associated to undesired effects generated by the adopted policies.

The project is expected to be structured into three ORs.

WP1 Centralized and distributed optimal control of complex systems:
Economic and financial markets are characterized by the quest for optimal decision making. Hence, the first part of this project will be devoted to studying optimal control problems over complex networks. Both centralized and decentralized approaches will be considered, so to mimic the standpoint of a regulating entity and of an agent of the market respectively. These optimal control problems will be initially studied in the ideal case where the network dynamics is perfectly known and deterministic.

WP2 Stochastic optimal control of complex systems:

In the second part of the project, we will relax the assumptions made in OR1, so to understand the role of stochasticity and of imperfect knowledge of the network dynamics in our optimal control problems. This will require exploiting tools such as stochastic differential equations and model free techniques for optimal control so to cope with the presence of uncertainty and with the case where the dynamics of the multi-agent system are not completely known.

WP3 Application to economic and financial markets

This work package entails the application of the modeling and control tools developed in WP1 and WP2 to open problems in the area of economic and financial markets. The developed decentralized optimal control strategies will be exploited to model decision making at the agent level while the centralized tools will serve to model the role of market makers. The theory of stochastic differential equations will serve instead to take into account the effects of uncertainty and unpredictable exogenous signals on the market dynamics in continuous time.

Relevance to the MERC PhD Program (max 2000 characters)

The project is perfectly aligned with both areas of the MERC program, namely risk and complexity. Indeed, as detailed in the project description, economic and financial markets are a paradigmatic example of complex systems and consistently, several tools from complexity theories will be exploited throughout the project. We envision that our results will come in handy for market makers and for policy makers in general, to quantitatively assess the risks associated to different alternative policies and regulations.

Key references

[1] Allen, Franklin, and Stephen Morris. "Game theory models in finance." Game theory and business applications. Boston, MA: Springer US, 2013. 17-41.
[2] Mizuta, Takanobu. "An agent-based model for designing a financial market that works well." 2020 IEEE symposium series on computational intelligence (SSCI). IEEE, 2020.
[3] Axtell, Robert L., and J. Doyne Farmer. "Agent-based modeling in economics and finance: Past, present, and future." Journal of Economic Literature 14 (2022).
[4] Idrees, Sheikh Mohammad, M. Afshar Alam, and Parul Agarwal. "A prediction approach for stock market volatility based on time series data." IEEE Access 7 (2019): 17287-17298.

[5] De Angelis, Tiziano, Peter Tankov, and Olivier David Zerbib. "Climate impact investing." Management Science 69.12 (2023): 7669-7692.

Joint supervision arrangements

Weekly in person meetings with F. Lo Iudice. Monthly meetings with both supervisors.

Location and length of the study period abroad (min 12 months)

Possible hosts for the period abroad are
Prof. Claudio Altafini, Linkoping University, Linkoping
Prof. Peter Tankov, ENSAE Paris
Prof. René Aid, Paris Dauphine

Francesco Lo Iudice has ongoing collaborations with Claudio Altafini, while Tiziano De Angelis has ongoing collaborations with both Peter Tankov and Renè Aid.

Any other useful information