



NED 2021

Milan, 13-15 September

Program

Book of abstracts

List of Participants

Dipartimento di Matematica per le Scienze Economiche, Finanziarie ed Attuariali

Contents

Welcome Message and Committees	3
Scientific Program	4
Abstract list	
Emiliano Alvarez.....	8
Andrea Bacchiocchi.....	9
Luca Vincenzo Ballestra.....	10
Gian Italo Bischi.....	11
Alessia Cafferata.....	12
Giovanni Campisi.....	13
Andrea Caravaggio.....	14
Simone Casellina.....	15
Fausto Cavalli.....	16
Lorenzo Cerboni Baiardi.....	17
Domenico DeGiovanni.....	18
Roberto Dieci.....	19
Marcello Galeotti.....	20
Germana Giombini.....	21
Luca Gori.....	22
Francesca Grassetti.....	23
Jochen Jungeilges.....	24
Fabio Lamantia.....	25
Simone Landini.....	26
Giulia Livieri.....	27
Stefano Marmi.....	28
Akio Matsumoto.....	29
Kiminori Matsuyama.....	30
Ugo Merlone.....	31
Hiroki Murakami.....	32
Anastasiia Panchuk.....	33
Nicolò Pecora.....	34
Marina Pireddu.....	35
Laura Policardo.....	36
Fabio Privileggi.....	37
Davie Radi.....	38
Lucía Rosich.....	39
J. Barkley Rosser Jr.	40
Edgar J. Sanchez Carrera.....	41
Mauro Sodini.....	42

Serena Sordi.....	43
Iryna Sushko.....	44
Giovanni Villani.....	46
Jan Wenzelburger.....	47
Frank Westerhoff.....	48
Thomas O. Zörner.....	49
Registered Participants	50
Maps	52

Dear Colleagues and Friends,

welcome to the NED 2021 conference!

This conference continues a series of scientific meetings related to nonlinear dynamic modeling in economics and finance initiated in Odense (Denmark, 2002, 2003) and continued in Tokyo (Japan, 2004), Urbino (Italy, 2005), Bielefeld (Germany, 2007), Jönköping (Sweden, 2009), Cartagena (Spain, 2011), Siena (Italy, 2013), Tokyo (Japan, 2015), Pisa (Italy, 2017) and Kyiv (Ukraine, 2019).

The Organizing Committee wishes you a successful and fruitful work. We also hope that you enjoy our social activities and your stay in Milan.

Scientific Committee

- G.I. Bischi (University of Urbino, Italy)
- H. Dawid (Bielefeld University, Germany)
- L. Gardini (University of Urbino, Italy)
- X.-Z. He (University of Sydney, Australia)
- C. Hommes (University of Amsterdam, the Netherlands)
- I. Kubin (University of Wien, Österreich)
- A. Matsumoto (Chuo University of Tokyo, Japan)
- K. Matsuyama (Northwestern University of Chicago, USA)
- J. B. Rosser Jr. (James Madison University, Harrisonburg, USA)
- S. Sordi (University of Siena, Italy)
- I. Sushko (Institute of Mathematics, NASU, and KSE, Ukraine)
- F. Tramontana (Catholic University of Milan, Italy)

Local Organizing Committee

- Alessia Cafferata (University of Turin, Italy)
- Fausto Cavalli (University of Milano-Bicocca, Italy)
- Nicolò Pecora (Catholic University of Piacenza, Italy)
- Marina Pireddu (University of Milano-Bicocca, Italy)
- Fabio Tramontana (Catholic University of Milan, Italy)

NED 2021 – SCIENTIFIC PROGRAM¹

Monday, Sept. 13

8:15 – 8:45 Welcome desk (for participants in presence)

8:45 – 9:00 Opening

9:00 – 11:05 First morning session. Chair: *Frank Westerhoff*

- **Francesca Grasseti*** (with C. Mammanna and E. Michetti): Asset price-GDP cross feedback. The role of dividend policies in a dynamic setting;
- **Giulia Livieri*** (with F. Lillo, S. Marmi, A. Solomko and S. Valenti): Analysis of bank leverage via dynamical systems and deep neural networks;
- **Anastasiia Panchuk** (with E. Michetta and I. Sushko): Interplay between honest and dishonest agents given an endogenous monitoring: bifurcation structure overview;
- **Frank Westerhoff** (with L. Gardini, D. Radi, N. Schmitt and I. Sushko): On the fragility of a stock market's stability;
- **Iryna Sushko*** (with L. Gardini, D. Radi, N. Schmitt and F. Westerhoff): Perception of fundamental values and financial market dynamics: Mathematical insights from a two-dimensional piecewise linear map.

11.05 – 11:30 Coffee-Break

11:30 – 13:10 Second morning session. Chair: *Mauro Sodini*

- **Andrea Caravaggio** (with M. Sodini): Local environmental quality and heterogeneity in an OLG agent-based model with network externalities;
- **Thomas O. Zörner** (with I. Kubin): The green and the brown: Environmental effects in a credit cycle model;
- **Giovanni Villani*** (with M. Biancardi and L. Maddalena): Social norms for the stability of international environmental agreements;
- **Mauro Sodini** (with A. Antoci, S. Borghesi and G. Iannucci): Should I stay or should I go? Carbon leakage and ETS in an evolutionary model.

13:10 – 14:30 Lunch

14:30 – 16:35 First afternoon session. Chair: *Germana Giombini*

- **Pasquale Commendatore** (with I. Kubin and I. Sushko): Spatial and dynamic effects of firms changing perception of their market influence;

¹ Names with an asterisk denote online talks.

- **Laura Policardo** (with G. Calcagnini, S. Pavlinović Mršć and E.J. Sanchez Carrera): The lockdown game;
- **Domenico De Giovanni** (with F. Lamantia and M. Pezzino): Evolutionary dynamics of compliance in a two-population game of auditors and auditees;
- **Luca Gori*** (with P. Manfredi, S. Marsiglio and M. Sodini): COVID-19 epidemic and mitigation policies: Positive and normative analyses in a neoclassical growth model;
- **Germana Giombini** (with F. Grassetti and E.J. Sanchez Carrera): Growth, traps, and cycles driven by productive capacities and inefficiencies.

16:35 – 17:00 Coffee-Break

17:00 – 18:40 Second afternoon session: Chair: *Fabio Tramontana*

- **Andrea Bacchiocchi** (with G.I. Bischi and G. Giombini): Non-performing loans, expectations and banking stability: A dynamic model;
- **Lucía Rosich*** (with J.G. Brida and B. Lanzilotta): Expectations network, centrality and dynamics: Experimental evidence from Uruguay;
- **Emiliano Alvarez***: Self-organization and multifractality in inflation and price systems;
- **Kiminori Matsuyama*** (with P. Ushchev): Destabilizing effects of market size in the dynamics of innovation.

Tuesday, Sept. 14

9:00 – 11:05 First morning session. Chair: *Fabio Privileggi*

- **Hiroki Murakami***: The unique limit cycle in post Keynesian systems;
- **Edgar J. Sanchez Carrera** (with G.I. Bischi and F. Grassetti): Pandemics, labor force and economic growth: Multiple equilibria and traps;
- **Luca Vincenzo Ballestra***: Economic growth with economic driven migration of labor and capital;
- **Akio Matsumoto** (with F. Szidarovszky): The chaotic monopolist revisited with bounded rationality and delay dynamics;
- **Fabio Privileggi** (with D. La Torre, S. Marsiglio and F. Mendivil): Stochastic optimal growth through state-dependent probabilities.

11:05 – 11:30 Coffee-Break

11:30 – 13:10 Second morning session. Chair: *Roberto Dieci*

- **Jan Wenzelburger**: Perfect foresight and learning in two-sector OLG models;

- **Stefano Marmi** (with R. Ceccon and G. Livieri): The Yoccoz-Birkeland livestock population model coupled with random price dynamics;
- **Giovanni Campisi** (with S. Brianzoni and A. Colasante): Nonlinear banking duopoly model with capital regulation: The case of Italy;
- **Roberto Dieci** (with X.-Z. He): Cross-section instability in financial markets: Impatience, extrapolation, and switching.

13:10 – 14:30 Lunch

14:30 – 16:35 Afternoon session. Chair: *Gian Italo Bischi*

- **Ugo Merlone*** (with I. Alfarone): A dynamical model of musicians' career choices;
- **Alessia Cafferata** (with A.K. Naimzada and F. Tramontana): Learning equilibria with memory;
- **John Barkley Rosser Jr.**: The future of complexity economics;
- **Jochen Jungeilges** (with T. Perevalova): Analysis of noise-induced behavioral phenomena;
- **Gian Italo Bischi** (with F. Tramontana): A dynamic adaptive model of consumers with endogenous preferences and non monotonic dependence on past consumption.

17:45 Visit at the Cenacolo Vinciano

20:00 Social dinner at Bebel restaurant

Wednesday, Sept. 15

9:00 – 11:05 First morning session (AMASES Session). Chair: *Fausto Cavalli*

- **Serena Sordi** (with M.J. Dávila-Fernández): The difficult task of changing while growing;
- **Simone Casellina*** (with S. Landini and M. Uberti): Credit risk measures and the estimation error in the ASRF model under the Basel II IRB approach;
- **Simone Landini** (with A. Cafferata, S. Casellina and M. Uberti): Ponzi and zombies: The risk of over-indebtedness of the private sector;
- **Marcello Galeotti** (with A. Antoci, G. Rabitti and P. Russu): A coevolution model of defensive medicine, litigation and medical malpractice insurance;
- **Fausto Cavalli** (with M. Gilli and A.K. Naimzada): Interdependent preferences and bounded rationality in a dynamical contest model.

11:05 – 11:30 Coffee-Break

11:30 – 13:35 Second morning session (AMASES Session). Chair: *Marina Pireddu*

- **Fabio Lamantia*** (with D. Radi and T. Tichý): Hybrid dynamics of multi-species resource exploitation;
- **Davide Radi** (with L. Gardini): A duopoly game with robust players and adaptive expectations;
- **Lorenzo Cerboni Baiardi** (with F. Lamantia): Oligopoly dynamics with isoelastic demand: The joint effects of market saturation and delegation;
- **Marina Pireddu** (with F. Cavalli, A.K. Naimzada and N. Pecora): An evolutive model with market sentiment;
- **Nicolò Pecora** (with F. Cavalli and A.K. Naimzada): A stylized macro-model with interacting real, monetary and stock markets.

13:35 – 14:30 Closing and Lunch

SELF-ORGANIZATION AND MULTIFRACTALITY IN INFLATION AND PRICE SYSTEMS

Emiliano Alvarez¹

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The analysis of price systems as complex systems is of utmost importance to understand the allocation of resources in the economy based on the interactions between agents. In this paper, the price system of the Uruguayan economy is analyzed using the consumer price index disaggregated at the product level and the general index as inputs. From the analysis of the distribution of the price variations in each period and the general price variations and performing a multifractal analysis, we obtain robust and consistent results in the sense of understanding the price variations as coming from complex systems. Main results indicate that the hypothesis of a power-law as the distribution of the analyzed series is not rejected, as well as the persistent behavior of price variations is modified by large fluctuations in the system.

NON-PERFORMING LOANS, EXPECTATIONS AND BANKING STABILITY: A DYNAMIC MODEL

Andrea Bacchiocchi¹

Gian Italo Bischi¹

Germana Giombini¹

¹*Department of Economics, Society and Politics, Università di Urbino Carlo Bo, Italy*

This paper proposes and compares dynamic oligopolistic models to describe heterogeneous banks that compete in the loan market. Two boundedly rational banks adopt an adaptive behavior to increase their profits under different assumptions of (limited) information and computational ability in the presence of a share of credits that might not be reimbursed (i.e. non-performing loans). Each equilibrium point of the dynamic adjustments proposed is a Nash equilibrium, i.e. coincides with the corresponding perfect competition outcome obtained under assumptions of complete information and rational (profit maximizing) banks. Thus, in the dynamic framework considered, the repeated strategic interactions between banks may converge to a rational equilibrium according to the parameters' values and the initial conditions considered. As a case study, we assume an isoelastic demand and linear costs, as proposed by Puu in [1] in a general oligopoly setting, and we study the influence of the economic parameters on the local stability of the unique equilibrium as well as the kinds of attractors that characterize the long-run behavior of the banks. Moreover, we analyze the global structure of the basins of attraction and we compare the degrees of stability of the Nash equilibrium under the different dynamic adjustments proposed. The dynamic models analyzed offer interesting policy insights on how different risk factors and activities interact in producing concrete situations of banking stress and fragility, which is a highly important issue to the goal of increase banks' resilience to adverse shocks. Different monetary policies set by the Central Bank produce a variety of behaviors affecting banking stability.

[1] T. Puu, *Chaos in business cycles*. *Chaos Solitons & Fractals* **1**(5), 457–473 (1991).

ECONOMIC GROWTH WITH ECONOMIC DRIVEN MIGRATION OF LABOR AND CAPITAL

Luca Vincenzo Ballestra¹

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The world economy has become more and more competitive and global, and we continuously see massive flows of labor and capital that move across space in search of better earnings and investment opportunities. Generally speaking, the migration of workers and capital has a strong impact on the economic growth of nations, and poses several research challenges. In particular, the relevant question arises whether, in a world characterized by competition and profit maximization, economic driven migration contributes to reducing inequalities, or if, instead, it tends to produce clusters of wealth and poverty. This work tries to address this issue on a rigorous theoretical basis, by developing and analyzing a spatial model of economic growth with economic driven migration of workers and capital. Specifically, we consider an economy in which labor and capital can freely move across space in search of better gains, and we model the dependence of the flows of labor and capital on wages and returns on investments, which in turns are fully endogenized by assuming no friction and profit maximization on the labor, capital and production markets. From the analytical standpoint, the propose model is constituted by a set of two fully non-linear and coupled partial differential equations. Precisely, let L and k denote the labor force and the capital per workers, respectively. The model developed is as follows:

$$\left\{ \begin{array}{l} \frac{\partial L(\theta, t)}{\partial t} = b \frac{\partial}{\partial \theta} \left(k f''(k(\theta, t)) \frac{\partial k(\theta, t)}{\partial t} \right) + \eta(L(\theta, t)) \\ \frac{\partial k(\theta, t)}{\partial t} = -a \frac{\partial}{\partial \theta} \left(f''(k(\theta, t)) \frac{\partial k(\theta, t)}{\partial t} \right) - \frac{bk(\theta, t)}{L(\theta, t)} \frac{\partial}{\partial \theta} \left(k(\theta, t) f''(k(\theta, t)) \frac{\partial k(\theta, t)}{\partial \theta} \right) \\ \quad - \frac{k(\theta, t)}{L(\theta, t)} \eta(L(\theta, t)) + sf(k(\theta, t)) - \delta k(\theta, t) \\ k(0, t) = k(2\pi, t), \quad \frac{\partial k(\theta, t)}{\partial \theta} \Big|_{(0, t)} = \frac{\partial k(\theta, t)}{\partial \theta} \Big|_{(2\pi, t)} \\ L(\theta, 0) = L_0(\theta), \quad k(\theta, 0) = k_0(\theta) \end{array} \right. \quad (1)$$

where θ is the spatial location, f is the production function, a, b, δ, s are constant parameters (δ and s are the capital depreciation rate and the saving rate, respectively), η is the natural rate of population growth and L_0 and k_0 are the initial spatial distributions of labor force and capital per workers, respectively. We perform an analytical investigation of the spatial model (1), based on the theory of non-linear abstract parabolic problems. In particular, by considering a rather general setting in which the knowledge of the exact form of the production function is not required, we find an asymptotically stable spatially homogeneous equilibrium. That is, in the presence of economic driven migration of labor and capital, inequalities are reduced in the long run, and clusters of wealth and poverty are not created. Finally, we also present numerical simulations that highlight role of the migration of workers in accelerating the process of salary re-distribution.

A DYNAMIC ADAPTIVE MODEL OF CONSUMERS WITH ENDOGENOUS PREFERENCES AND NON MONOTONIC DEPENDENCE ON PAST CONSUMPTION

Gian Italo Bischi¹

Fabio Tramontana²

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²*DiMSEFA, Catholic University of the Sacred Heart*

We re-consider the discrete time dynamic model proposed by D’Orlando e Rodano [1] to describe the choices of boundedly rational consumers with preferences that vary endogenously according to past consumption. The properties of the basins of attraction of the same model has been analyzed by Bischi and Tramontana [2], where some particular structures are evidenced due to the presence of a vanishing denominator, as well as a focal point, in the two-dimensional invertible map representing the model. In these papers consumer’s preferences for a given good is positively influenced by past consumption. However, excessive past consumption of a good may cause saturation and hence a decrease of preference. In this paper we consider a non monotonic function to mimic this saturation effect. The main mathematical consequence is that the twodimensional map becomes noninvertible. This implies, for the set of parameters for which different attractors coexist (the map can have up to three equilibrium points), that new structures of the basins and global bifurcations are obtained due to the contacts of focal point and prefocal set with the critical lines.

- [1] F. D’Orlando and G. Rodano, *Fondamenti teorici dell’ipotesi di razionalità: il ruolo dell’esperienza*. *Economia Politica* **XXIII**, 421–448 (2006).
- [2] G.I. Bischi and F. Tramontana, *Basins of attraction in an evolutionary model of boundedly rational consumers*. *Pure Mathematics and Applications* **16**(4), 345–363 (2006).

LEARNING EQUILIBRIA WITH MEMORY

Alessia Cafferata¹

Fabio Tramontana²

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Several scholars have discussed on the validity of rational expectations over the last past decades. In particular, the hypothesis that individuals are able to precisely elaborate information and to make precise forecasts has been perceived as unrealistic. On the other hand, boundedly rational agents use their experience and their perception to make inferences about inflation, asset pricing and other economic phenomena. To this end [1] in an overlapping generation model where households predict future inflation rates by running a least squares regression on prices, shows that endogenous business cycles may emerge when agents are modeled as econometricians.

Starting from the formalization of [1], we propose an overlapping generation model in which periodic learning equilibria coexist. By introducing a “memory” component, we allow agents to weight their past price observations with a decreasing parameter: people tend to forget quickly, and last information have more relevance in inflation forecasting. With fading memory, the parameters configurations for which the monetary steady state of [1] is locally unstable, still persist to cause instability and, in addition, the monetary steady state becomes easily locally unstable. We also find out values of the parameters originating instability only in the fading memory case.

Our results go in the same direction of [2]. Numerical simulations confirm that a source of instability (and creation of learning equilibria) are the different elements through which the past prices realizations are observed, giving more relevance to the last observations.

[1] J. B. Bullard, *Learning Equilibria*. Journal of Economic Theory **64**(2), 468-485 (1994).

[2] J. Tuinstra and F. O. Wagener, *On learning equilibria*. Journal of Economic Theory **30**, 493-513 (2007).

NONLINEAR BANKING DUOPOLY MODEL WITH CAPITAL REGULATION: THE CASE OF ITALY

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We develop a nonlinear banking duopoly model with capital regulation and asymmetric costs. We follow the literature on banking and capital regulation, focusing on Italian banks. We start from the model of Brianzoni and Campisi [2] which considers a banking duopoly model, but we introduce nonlinearity both in the cost function [1] and in the demand function [3], [5]. We proceed in two parts. First, we concentrate on the analysis of the local stability of the model. Given the high number of parameters and the complex analytical form of our system, we support the analytical study with several numerical simulations. In the second part, we focus on the conditions under which small banks are more efficient than large banks. For this purpose, we study the evolutionary dynamics of loans when different parameters vary simultaneously. Our results confirm the Empirical evidence that small banks play a central role in supporting local firms and families more than large banks [4].

- [1] H. N. Agiza and A. A. Elsadany, *Nonlinear dynamics in the cournot duopoly game with heterogeneous players*. *Physica A: Statistical Mechanics and its Applications* **320**, 512–524 (2003).
- [2] S. Brianzoni and G. Campisi, *Dynamical analysis of a banking duopoly model with capital regulation and asymmetric costs*. *Discrete & Continuous Dynamical Systems-B*, In press. (2021).
- [3] T. Puu, *Chaos in duopoly pricing*. *Chaos, Solitons & Fractals* **1**(6), 573–581 (1991).
- [4] M. L. Stefani, V. Vacca, D. Coin, S. Del Prete, C. Demma, M. Galardo, I. Garri, S. Mocetti, and D. Pellegrino, *Le banche locali e il finanziamento dei territori: evidenze per l'Italia (2007-2014)*. Number 324. Banca d'Italia (2016).
- [5] F. Tramontana, *Heterogeneous duopoly with isoelastic demand function*. *Economic Modelling* **27**(1), 350–357 (2010).

LOCAL ENVIRONMENTAL QUALITY AND HETEROGENEITY IN AN OLG AGENT-BASED MODEL WITH NETWORK EXTERNALITIES

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Most of the theoretical contributions on the relationship between economy and environment assumes the environment as a good distributed homogeneously among the agents. The aim of this work is to weaken this hypothesis and to consider that the environment can have a local character even if conditioned through externalities by the choices made at global level. In particular, adapting the classical framework introduced by John and Pecchenino in [3] to analyze the dynamic relationship between environment and economic process, in this paper we propose an OLG agent-based model where each agent perceives its own level of environmental quality determined by her own decisions, and by the decisions of those living around her. What emerges is that, despite the attention devoted to local environmental aspects, the network externalities (determined through the scheme of Moore neighbourhoods) play a fundamental role in defining environmental dynamics and they may induce the emergence of cyclical dynamics. Specifically, we investigate how the interplay between the efficiency of the technology behind defensive expenditures and the environmental impact of private production affects the local environmental dynamics. In addition, we analyse the role of environmental awareness of agents, both in a context of homogeneous and heterogeneous preferences.

- [1] A. Antoci, M. Galeotti, and P. Russu, *Undesirable economic growth via agents' self-protection against environmental degradation*. Journal of The Franklin Institute **344**(5), 377–390 (2007).
- [2] B. Desmarchelier, F. Djellal, and F. Gallouj, *Environmental policies and eco-innovations by service firms: An agent-based model*. Technological Forecasting and Social Change **80**(7), 1395–1408 (2013).
- [3] A. John and R. Pecchenino, *An overlapping generations model of growth and the environment*. The Economic Journal **104**(427), 1393–1410 (1994).
- [4] D. La Torre, D. Liuzzi, and S. Marsiglio, *Transboundary pollution externalities: Think globally, act locally?* Journal of Mathematical Economics 102511 (2021).
- [5] L. Marchiori and I. Schumacher, *When nature rebels: international migration, climate change, and inequality*. Journal of Population Economics **24**(2), 569–600 (2011).
- [6] J. Zhang, *Environmental sustainability, nonlinear dynamics and chaos*. Economic Theory **14**(2), 489–500 (1999).

CREDIT RISK MEASURES AND THE ESTIMATION ERROR IN THE ASRF MODEL UNDER THE BASEL II IRB APPROACH

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In many standard derivation and presentations of risk measures like the Value-at-Risk or the Expected Shortfall, it is assumed that all the model's parameters are known. In practice, however, the parameters must be estimated and this introduces an additional source of uncertainty that is usually not accounted for. The Prudential Regulation have formally raised the issue of errors stemming from the internal model estimation process in the context of credit risk, calling for margins of conservatism to cover possible underestimation in capital. Notwithstanding this requirement, to date, a solution shared by banks and regulators/supervisors has not yet been found. In this paper, we investigate the effect of the estimation error in the framework of the Asymptotic Single Risk Factor (ASRF) model that represents the baseline for the derivation of the credit risk measures under the IRB approach. We exploit Monte Carlo simulations to quantify the bias induced by the estimation error and we explore an approach to correct for this bias. Our approach involves only the estimation of the long run average probability of default and not the estimation of the asset correlation given that, in practice, banks are not allowed to modify this parameter. We study the stochastic characteristics of the probability of default estimator that can be derived from the Asymptotic Single Risk Factor framework and we show how to introduce a correction to control for the estimation error. Our approach does not require introducing additional elements in the Asymptotic Single Risk Factor model like the prior distributions or other parameters which, having to be estimated, would introduce other sources of estimation error. This simple and easily implemented correction ensures that the probability of observing an exception (i.e. a default rate higher than the estimated quantile of the default rate distribution) is equal to the desired confidence level. We show a practical application of our approach relying on real data.

INTERDEPENDENT PREFERENCES AND BOUNDED RATIONALITY IN A DYNAMICAL CONTEST MODEL

Fausto Cavalli¹

Mario Gilli¹

Ahmad Naimzada¹

¹*University of Milano-Bicocca, Department of Economics, Management and Statistics.*

It is well-known that in contests experiments [1,3] players commonly overbid with respect to the equilibrium strategy that is theoretically predicted by the standard Nash equilibrium. In this work we propose a model for a classic lottery contest [2] with two players $i = 1, 2$ competing for a prize v . The goal is to investigate, through a theoretical dynamical approach, whether bounded rationality and preference interdependence can provide an explanation of the above-mentioned experimental phenomena. We consider a setting in which two agents have an expected utility with interdependent preferences. Each agent's utility consists of a linear combination of his own profits and those of his competitor, evaluated by a negative, null or positive weight ω_i respectively accounting for a spiteful, selfish or altruistic behavior of agent i . Decisions are taken at each discrete time t in a setting in which

- Agents' strategic behavior is influenced by their interdependent preferences, and dynamically evolves on the basis of a best response mechanism with static expectations;
- Agents' preferences are in turn influenced by the behavior of the other agents, inferred observing their competitors past choices or realized profits.

The model is represented by a four dimensional dynamical system, whose possible steady states, their stability and dynamical behavior are both analytically and numerically investigated. In particular, we focus on two specific agent's behavior, consisting of a tit-for-tat strategic behavior and an inequality aversion behavior. We show that for all the possible combinations of agent's behavior, Nash equilibria larger than that predicted in the classic self-interested framework can emerge, and that can become unstable as v increases, generating endogenously oscillating strategy choices.

- [1] R. M. Sheremeta, *Overbidding and heterogeneous behavior in contest experiments*. Journal of Economic Surveys **27**, 491–514 (2013).
- [2] G. Tullock, *Efficient rent seeking*. In: Buchanan J. M., Tollison, R.D. and Tullock G. (eds) *Toward a theory of the Rent-Seeking Society*, Texas A&M University Press, College Station, TX, 97–112 (1980).
- [3] K. Wärneýrd, *Chaotic dynamics in contests*. Economic Inquiry **56**, 1486–1491 (2018).

OLIGOPOLY DYNAMICS WITH ISOELASTIC DEMAND: THE JOINT EFFECT OF MARKET SATURATION AND DELEGATION

Lorenzo Cerboni Baiardi¹

Fabio Lamantia¹

¹*Department of Economics, Statistics and Finance, University of Calabria*

In the framework of a Cournot oligopoly game with isoelastic demand, the simultaneous presence of both market saturation and strategic delegation are here considered. Although this two (realistic) aspects have already been considered in the literature each on its own, we aim at deepening their joint interactions when matched together in oligopolistic competition. Indeed, delegation activities actuated by firms to weaken or even exclude competitors from the market can be interrupted by successful players, which thus regaining their pure profit maximizer behavior (trigger delegation strategy). In this context, a limited market saturation level (positively) influences the effectiveness of delegation strategies and, at the same time, can sustain equilibrium configurations for the winning (monopolistic) firm even under the isoelastic market structure. Through local stability analysis, we show how the combination of strategic delegation with market saturation contributes to determine the equilibrium number of active players and the local asymptotic stability of the (economically relevant) fixed point. Moreover, non-equilibrium dynamics observed in numerical simulations performed for the duopoly case reveal the presence of periodic cycles along which a firm is active while its competitor alternatively exits and enters the market. This interesting scenario is due to the joint interplay between trigger delegation and market saturation.

EVOLUTIONARY DYNAMICS OF COMPLIANCE IN A TWO-POPULATION GAME OF AUDITORS AND AUDITEES

Domenico De Giovanni¹

Fabio Lamantia¹

Mario Pezzino²

¹*Department of Economics, Statistics and Finance, University of Calabria (Italy)*

²*School of Social Sciences, University of Manchester (UK)*

The paper studies the dynamics of compliance in a population of agents that can decide whether to comply with a prescribed behavior or not. These agents are subject to controls by auditors who might also be honest and truthfully report a fraudulent behavior of an auditee or be corrupt and get a bribe for not reporting the unlawful behavior of the auditee. Applied to the example of tax evasion, we study the case in which the level of evasion by the auditees is obtained by expected utility maximization. We then investigate the rich dynamic scenarios that may arise through the interaction of auditors and auditees.

CROSS-SECTION INSTABILITY IN FINANCIAL MARKETS: IMPATIENCE, EXTRAPOLATION, AND SWITCHING

Roberto Dieci¹
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This paper presents a stylized model of interaction among boundedly rational heterogeneous agents in a multi-asset financial market to examine how agents' impatience, extrapolation, and switching behaviors can affect cross-section market stability. Besides extrapolation and performance-based switching between fundamental and extrapolative trading, we show that a high degree of "impatience" of agents who are ready to switch to a more profitable trading strategy in the short run provides a further cross-section destabilizing mechanism. Though the "fundamental" steady state values, which reflect the standard present-value of the dividends, represent an unbiased equilibrium market outcome in the long run to a certain extent, the price deviation from the fundamental price in one asset can spill-over to other assets, resulting in cross section instability. Based on a (Neimark-Sacker) bifurcation analysis, we provide explicit conditions on how agents' impatience, extrapolation, and switching can destabilize the market and result in a variety of short and long-run patterns for the cross-section asset price dynamics.

A COEVOLUTION MODEL OF DEFENSIVE MEDICINE, LITIGATION AND MEDICAL MALPRACTICE INSURANCE

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We model the interactions between physicians and patients, subject to clinical and legal risks, by means of an evolutionary game. In each instant of time, there are a large number of random pairwise encounters between members of the two populations. In each encounter, a physician heals a patient. The outcome of the healing process is uncertain and may result in patient harm; if that happens, the patient may sue the physician for medical malpractice. Physicians have to choose between two alternative treatments, with different levels of benefits and risks. The safer treatment is also the less effective; therefore its provision corresponds to practicing negative defensive medicine.

Physicians prevent, at least partially, negligence charges by buying medical malpractice insurance. This transfers the risk of litigation from the physician to the insurer.

The dynamics we analyze are determined by the discrete-time dynamic system:

$$x(t+1) = x(t) \frac{\exp M_1(t)}{x(t) \exp M_1(t) + (1-x(t)) \exp M_2(t)}$$

$$y(t+1) = y(t) \frac{\exp P_1(t)}{y(t) \exp P_1(t) + (1-y(t)) \exp P_2(t)}$$

$$a(t+1) = [q_{DPD} E x(t) + q_{NDPND} E (1-x(t))] y(t) + \bar{a}$$

where x and y are, respectively, the shares of defensive physicians and litigious patients, while a represents the insurance premium, M_1, M_2 are physicians' and P_1, P_2 are patients' expected payoffs.

In such a context, we study the role played by model's parameters related to the accuracy of the judicial system and legal reforms in shaping the coevolution between healthcare providers' and patients' choices and price dynamics of medical malpractice insurance.

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GROWTH, TRAPS, AND CYCLES DRIVEN BY PRODUCTIVE CAPACITIES AND INEFFICIENCIES

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We develop a growth model to explain economic fluctuations mainly affected by productive capacities (i.e. capacity utilization driven by innovations and know-how) and inefficiencies. Our methodology consists in the combination of a neoclassical-inspired (Solow-Swan) growth model with Schumpeterian notions, namely the depiction of economic evolution according to a production function that takes into consideration the effect of productive capacities and inefficiencies. We show that economies may experience economic growth, poverty traps, or fluctuations (i.e. cycles) and chaotic behaviors. Economic growth is reached when an economy experiences both a low level of inefficiencies and a high level of productive capacities while an economy falls into a poverty trap when there is a high level of inefficiencies in production. Instead, the economy gets in cycles when there is a large level of the lack of know-how, and low levels of productive capacity. We conclude that more capital per capita (greater savings and investment) and greater productive capacity (with less lack of know-how) are the economic policy keys for an economy being on the path of sustained economic growth.

COVID-19 EPIDEMIC AND MITIGATION POLICIES: POSITIVE AND NORMATIVE ANALYSES IN A NEOCLASSICAL GROWTH MODEL

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The COVID-19 pandemic is still ravaging the planet but its diverse effects on health, economy and society are far from being understood in the short, medium, and long terms. This article investigates the potential impact of a deadly epidemic and its main non-pharmaceutical control interventions (social distancing versus testing-tracing-isolation, TTI) on capital accumulation at different time scales. This is done by integrating an epidemiological SIR model with a Solow-type growth model including public expenditure, as a parsimonious setting to offer insights on the trade-off between protecting human lives and the economy and society as a whole. The work clarifies (i) the long-term interactions amongst a deadly infection, demography and capital accumulation, (ii) the lack of viability of persistent social distancing measures, even through an analytical characterisation, and the risk of policy-enhanced COVID-19 endemicity, (iii) the potentially high return on investments in TTI activities to avoid future lockdowns and related capital disruption. It also quantifies the welfare effects of a range of policies, confirming a counterintuitive role for tax-funded preventive investments aimed to strengthen TTI as more desirable interventions than generalised lockdowns.

ASSET PRICE-GDP CROSS FEEDBACK. THE ROLE OF DIVIDEND POLICIES IN A DYNAMIC SETTING

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[3] affirmed the irrelevance of dividends basing on the hypothesis of a frictionless capital market. Recent literature demonstrated that the market is imperfect as well as that dividend policies affect the value of the firms and their asset prices. Decisions and announcements over dividend payouts modify information asymmetry and may affect investor preferences. Moreover, dividend policy and dividend volatility are ambiguously connected to stock price movements. Dividends move capital generated in real economy to financial markets, affecting the resources (retained earnings) allocated for investments in fixed capital that, in its turn, influences economic growth. In this view, the decision over dividend payments is crucial and the twofold effect of dividend payout on real economy and financial markets needs to be investigated (see [1]). Basing on [2] and [4], we study the discrete time evolution of a simplified economy in which physical capital and asset price evolves depending on the dividend payments decided by managers, the expectations of individuals regarding future cum-dividend prices and the return of a risk free bond. We found that the dividend payout ratio produces a twofold effect: an excessively high dividend payout ratio erodes the economy, while in the opposite case instability and fluctuations arise. Additionally, positive returns for government bonds leads to instability. This counterintuitive idea reflects empirical evidences. In this view, our findings relate the instability of capital and asset price to the return of risk free bond suggesting that, if all the others parameters would allow stability, a negative sign for bond return would be needed in order to reach an the equilibrium, in which capital and asset price do not change over time. Moreover, we showed that unfulfilled expectations might have a twofold effect: an expectation of lower dividends tends to rise the asset price after dividends are realised, conversely an expectation of higher dividends lowers the asset price in the long run.

- [1] J. H. Cochrane (ed), *Financial Markets and the Real Economy*, International Library of Critical Writings in Financial Economics, vol 18. Edward Elgar (2006).
- [2] D. De La Croix and P. Michel, *A Theory of Economic Growth. Dynamics and Policy in Overlapping Generations*. Cambridge University Press, Cambridge (2004).
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ANALYSIS OF NOISE-INDUCED BEHAVIORAL PHENOMENA

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Our analysis of behavioral change in the context of a *stochastic, non-linear consumption model* with interdependent agents focuses on potential transitions occurring between four coexisting attractors (4-cycle, 5-cycle, and 2 fixed points) of the deterministic skeleton. Relying on the indirect approach to the analysis of a stochastic dynamic system, we describe the potentially existing transition scenarios, and identify conditions in terms of behavioral and environmental parameters under which such transitions are likely to occur.

In a first step, we clarify the genesis as well as the structure of the (immediate) basins associated with each of the four attractors. The subsequent stochastic analysis applies the stochastic sensitivity function technique (SSF) due to [1]. Using the SSF technique confidence sets for attractors can be devised. To understand the relation between these confidence sets and immediate basins of the respective attractors is crucial for the understanding of transition phenomena.

In the course of our analysis of transitions, we (i) aim at identifying noise induced chaos via Lyapunov exponents (ii) determine noise levels for which a complex repeller of the deterministic skeleton surfaces (becomes visible) and (iii) propose a confidence set for such a repeller is developed based on the concept of an absorbing region.

In the discussion section, an economic interpretation of our findings concerning complex transitions between the coexisting meta-stable consumption attractors is given.

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HYBRID DYNAMICS OF MULTI-SPECIES RESOURCE EXPLOITATION

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In this work, we analyze a bio-economic model of exploitation of renewable commercial resources. To take into account the typically continuous-time modeling of biological species and, instead, of the specialized harvesting activities, which by its nature cannot change continuously, the resulting dynamic system is of the hybrid type, i.e. continuous for biological variables and discrete for the economic ones. Through a discretization of the continuous variables, the problem is then reformulated by means of a three-dimensional map. We study in [1] the dynamic properties of this map to understand how economic parameters influence the long-run availability of resources.

- [1] D. Radi, F. Lamantia, and T. Tichý, *Hybrid dynamics of multi-species resource exploitation*. *Decisions in Economics and Finance*, 1–19 (2021).

PONZI AND ZOMBIES: THE RISK OF OVER-INDEBTNESS OF THE PRIVATE SECTOR

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Financial and economic crises are not always the same, and only some of them have a radical and persistent impact on the economic system and on the well-being of the community. For this reason it is important to understand why only some episodes of crisis generate prolonged and systemic recessions. In this respect, [2,3] has introduced the idea that in periods of stability, financial actors tend to increase their risk exposure, moving from a stable hedge-dominated structure to an unstable one characterised by speculative financial position and Ponzi: stability would be destabilising.

As a response of the Great Recession and of the most recent Covid-19 economic crisis, several central banks opted for a liquidity injection as a stimulus for the economy and to prevent systemic collapse. However, although not with the same intensity, these non-conventional expansive monetary policies had been pursued also during the period of “tranquility” between 2014 and the beginning of 2020, facilitating the access to credit over a wide spectrum of solvability degrees.

Starting from the three different relationships presented by Minsky (income-debt-hedge, speculative and Ponzi) for financial units, we develop a simple partial equilibrium agent-based model in which firms, the banking sector, the real and the financial side of the economy interact. This theoretical framework allows to extend the migratory microsimulation models based on the E(ntry)-S(tay)-L(eave) scheme of [1] by considering the economic system, the business cycle and by simulating the heterogeneity in firms’ creditworthiness.

- [1] S. Landini, M. Uberti, and S. Casellina, *Credit risk migration rates modelling as open systems II: A simulation model and IFRS9-baseline principles*. Structural Change and Economic Dynamics **50**, 175–189 (2019).
- [2] H. P. Minsky, *John Maynard Keynes*. Columbia University Press, New York (1975).
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ANALYSIS OF BANK LEVERAGE VIA DYNAMICAL SYSTEMS AND DEEP NEURAL NETWORKS

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We consider a model of a simple financial system consisting of a leveraged investor that invests in a risky asset and manages risk by using Value-at-Risk (VaR). The VaR is estimated by using past data via an adaptive expectation scheme. We show that the leverage dynamics can be described by a dynamical system of slow-fast type associated with a unimodal map on $[0, 1]$ with an additive heteroscedastic noise whose variance is related to the portfolio rebalancing frequency to target leverage. In absence of noise the model is purely deterministic and the parameter space splits in two regions: (i) a region with a globally attracting fixed point or a 2-cycle; (ii) a dynamical core region, where the map could exhibit chaotic behavior. Whenever the model is randomly perturbed, we prove the existence of a unique stationary density with bounded variation, the stochastic stability of the process and the almost certain existence and continuity of the Lyapunov exponent for the stationary measure. We then use deep neural networks to estimate map parameters from a short time series. Using this method, we estimate the model in a large dataset of US commercial banks over the period 2001–2014. We find that the parameters of a substantial fraction of banks lie in the dynamical core, and their leverage time series are consistent with chaotic behavior. We also present evidence that the time series of the leverage of large banks tend to exhibit chaoticity more frequently than those of small banks.

THE YOCOZ-BIRKELAND LIVESTOCK POPULATION MODEL COUPLED WITH RANDOM PRICE DYNAMICS

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We study the discretization of a random version of the population-market model proposed by Arlot, Marmi and Papini in [1]. This model is based on the Yoccoz-Birkeland integral equation and describes a time evolution of livestock commodities prices which exhibits endogenous deterministic stochastic behaviour.

We introduce a stochastic component into the price equation, inspired from the Black-Scholes market model. We prove the existence of a random attractor and of a random invariant measure, as well as the convergence of the random system to the deterministic one as the volatility in the market equation tends to zero.

We also investigate the properties of a time-discretized model. The similarities between the discretized system and the original one are studied by implementing the Sinkhorn distance, following a work by M. Cuturi [2]. This is a discrete and penalized version of the Optimal Transport Distance between two measures, given a transport cost matrix.

[1] S. Arlot, S. Marmi, and D. Papini, *Coupling the YoccozBirkeland population model with price dynamics: chaotic livestock commodities market cycles*. *Nonlinearity* **32**(7), 2564–2592 (2019).

[2] M. Cuturi, *Sinkhorn distances: Lightspeed computation of optimal transport*. *Advances in Neural Information Processing Systems* **26**, 2292–2300 (2013).

THE CHAOTIC MONOPOLIST REVISITED WITH BOUNDED RATIONALITY AND DELAY DYNAMICS

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Two types of boundedly rational monopolists are studied when the marginal revenue is not necessarily negative sloping. Knowledgeably monopolists (k -monopolists) know the analytic form of the price function but are unable to compute the profit-maximizing output level. Limited monopolists (ℓ -monopolists) know only the price and output values in two previous time periods. It is assumed that k -monopolists adjust their output levels according to the usual gradient process, while ℓ -monopolists approximate the marginal profit with a two-point finite difference formula. Discrete and continuous time scales are examined. A single-delay model is considered for k -monopolists, however for ℓ -monopolists a two-delay model is constructed. In the discrete case the stability condition is the same for the two models and requires a sufficiently small speed of adjustments. However, there are differences in the two dynamics. In the continuous case the discrete models are transformed into continuous models via Berezowski transformation. In the one delay case the critical values of the delays are computed and the directions of stability switching determined. In the two-delay case the stability switching curves are analytically found and the directions of stability switchings are characterized by computing the stability index for each point of the curves. The analytical results are verified and illustrated via numerical studies, when sensitivity analysis is performed showing that an increase in the adjustment coefficient shrinks the stability region, while it is extended by increasing the inertia coefficient.

DESTABILIZING EFFECTS OF MARKET SIZE IN THE DYNAMICS OF INNOVATION

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In existing models of endogenous innovation cycles, market size alters the amplitude of fluctuations without changing the nature of fluctuations. This is due to the ubiquitous assumption of CES homothetic demand system, implying that monopolistically competitive firms sell their products at an exogenous markup rate in spite of the empirical evidence for the procompetitive effect of entry and market size. We extend a model of endogenous innovation cycles to allow for the procompetitive effect, using a more general homothetic demand system. We show that a larger market size and/or a smaller innovation cost, which causes the markup rate to decline through the procompetitive effect, has destabilizing effects on the dynamics of innovation under two complementary sets of sufficient conditions; i) when the price elasticity function is log-concave; and ii) when the demand systems belong to parametric families of “generalized translog” or “constant pass-through.”

A DYNAMICAL MODEL OF MUSICIANS' CAREER CHOICES

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The music labor market is a highly competitive one, characterized by an oversupply of professionals in relation to the demand for artistic performance or other related activities, and several forms of temporary employment [4, 5]. We propose a simple career choice model in which musicians can switch from a musical to a non-musical career and vice versa. An interesting formalization of cultural output taking into account the appreciation of cultural goods in a generic city, and the reservation utility level of musicians was proposed by Borowiecki in [2]. We extend his model considering musicians' career choices in a population by introducing their propensity to switch career. The dynamic model we obtain is a binary choice with externalities model [6] in which musicians can decide whether to pursue a musical career or choose another in a non-artistic sector. Following [1], the dynamic model we obtain is analyzed and the equilibria and their stability are interpreted in terms of the sustainability of musicians' career choices.

- [1] G. I. Bischi, L. Gardini, and U. Merlone, *Periodic cycles and bifurcation curves for one-dimensional maps with two discontinuities*. *Journal of Dynamical Systems & Geometric Theories* **7**(2), 101–123 (2009).
- [2] K. J. Borowiecki, *Agglomeration economies in classical music*. *Papers in Regional Science* **94**(3), 443–468 (2015).
- [3] D. Chafe and L. Kaida, *Harmonic dissonance: Coping with employment precarity among professional musicians in St Johns, Canada*. *Work, Employment and Society* **34**(3), 407–423 (2020).
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THE UNIQUE LIMIT CYCLE IN POST KEYNESIAN SYSTEMS

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The existence and uniqueness of a limit cycle (persistent growth cycles) was established in Murakami's [1] post Keynesian model, which emphasizes the effect of expectations on investment. It was found in Murakami [1] that the existence and uniqueness of a limit cycle is obtained under reasonable assumptions if investment (or the rate of capital formation) is highly elastic to the expected rate of profit and the latter is frequently revised in response to the realized rate of profit. In particular, the uniqueness (as well as existence) of a limit cycle is the distinguished contribution of this paper because it has rarely been explored until the recent studies by Murakami [1–3] due to technical difficulty. In Murakami [1], however, the existence and uniqueness of a limit cycle was only confirmed but the convergence of solution paths, which describe the states of the macroeconomic system, to the unique limit cycle was not discussed.

The purpose of this paper is to generalize the conclusion on the existence and uniqueness of a limit cycle verifying that, if the revision speed of the expected rate of profit is high enough, every solution path, except for the one starting at the long-run equilibrium, converges to the unique limit cycle, regardless its initial condition. By so doing, we shall demonstrate the inevitability of persistent business cycles in capitalist economies.

- [1] H. Murakami, *Existence and uniqueness of growth cycles in post Keynesian systems*. *Economic Modelling* **75**, 293-304 (2018).
- [2] H. Murakami, *A note on the “unique” business cycle in the Keynesian theory*. *Metroeconomica* **70**(3), 384-404 (2019).
- [3] H. Murakami, *Monetary policy in the unique growth cycle of post Keynesian systems*. *Structural Change and Economic Dynamics* **52**, 39-49 (2020).

INTERPLAY BETWEEN HONEST AND DISHONEST AGENTS GIVEN AN ENDOGENOUS MONITORING: BIFURCATION STRUCTURE OVERVIEW

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The process of public procurement includes many corruption risks due to certain advantages of dishonest behavior (e. g., avoiding taxes increases the revenue). Recently, investigations concerning such non-compliant behavior have got widespread among researchers due to high relevance of this phenomenon. The present model considers an evolutionary process with honest and dishonest agents whose behavior is chosen according to the type of company they encounter and the rewards involved. The agents are allowed to change their attitude joining the opposite party. Following [1], an honest firm may turn “bad” if it obtains better benefit from such an action and vice versa. On the other hand, following [2], we assume that the agents are more inclined to honesty (the honesty propensity assumption). That is, a dishonest firm meeting an honest one will always change type if the honest behavior is more beneficial. However, not every honest firm meeting a dishonest one will change type even if a higher expected utility can be reached. Finally, the state monitoring is introduced endogenously, namely, the audit efforts are intensified if the dishonesty level increases.

Such a setup leads to a two dimensional piecewise smooth map, describing the evolution of the dishonest firm fraction and of monitoring level by the state. In the earlier work by Coppier et al. [3], the effectiveness of economic policies has been studied so that to reduce or eliminate non-compliant behavior. It was found that the social stigma plays a fundamental role. That is, increasing the “inner attitude toward honesty” can reduce dishonesty level and help to avoid the dishonesty trap (an equilibrium state with all firms being fraudulent). The current research aims at providing deeper mathematical analysis of more complex asymptotic dynamics and review possible bifurcation structures in the parameter space.

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- [2] S. Brianzoni, R. Coppier, and E. Michetti, *Evolutionary effects of non-compliant behavior in public procurement*. *Structural Change and Economic Dynamics* **51**, 106–118 (2019). doi: 10.1016/j.strueco.2019.08.008
- [3] R. Coppier, F. Grassetti, and E. Michetti, *Non-compliant behaviour in public procurement: an evolutionary model with endogenous monitoring*. *Decisions in Economic and Finance* **44**, 459–483 (2021). <https://doi.org/10.1007/s10203-021-00317-y>

A STYLIZED MACRO-MODEL WITH INTERACTING REAL, MONETARY AND STOCK MARKETS

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We propose a model-economy consisting of interdependent real, monetary and stock markets. The money market is influenced by the real one through a standard LM equation. Private expenditures depend on stock prices, which in turn are affected by interest rates and real profits, as these contribute to determine the participation level in the stock market. An evolutionary mechanism regulates agents' participation in the stock market on the basis of a fitness measure that depends on the comparison between the stock return and the interest rate. Relying on analytical investigations complemented by numerical simulations, we study the economically relevant static and dynamic properties of the equilibrium, identifying the possible sources of instabilities and the channels through which they spread across markets. We aim at understanding what micro and macro factors affect the dynamics and, at the same time, how the dynamics of asset prices, which are ultimately influenced by the money market, behave over the business cycle. Starting from isolated markets, we show the effect of increasing the market interdependence on the national income, the stock price and the share of agents that participate in the stock market at the equilibrium. Moreover, we investigate the stabilizing/destabilizing role of market integration and the possible emergence of out-of-equilibrium dynamics.

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- [2] J. M. Keynes, *The general theory of employment, interest and money*. Palgrave Macmillan, London (1936).
- [3] M. Lengnick and H. W. Wohltmann, *Agent-based financial markets and New Keynesian macroeconomics: a synthesis*. Journal of Economic Interaction and Coordination **8**(1), 1–32 (2013).
- [4] W. Semmler, *Asset prices, booms and recessions: financial economics from a dynamic perspective*. Springer Science & Business Media (2011).

AN EVOLUTIVE MODEL WITH MARKET SENTIMENT

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We study a financial market populated by heterogeneous agents, whose decisions are driven by “animal spirits”, being not only based on an individual evaluation of the market performances, but taking into account also a form of market sentiment. Each agent may have either correct, optimistic or pessimistic beliefs about the fundamental value, that can be changed from time to time on the basis of an evolutionary mechanism. More precisely, the evolutionary selection of beliefs depends on a combination of the average mood perceived by the agents about the status of the market, that we call sentiment index, and of a precise evaluation of the profits associated with the existing strategies. In this way, the psychological and emotional components become a constitutive part of the decision process. As the relevance given to the sentiment index increases, a herding phenomenon in agents behavior may take place and the animal spirits can drive the market toward polarized economic regimes, which coexist and that are characterized by persistent high or low levels of optimism and pessimism. This conduct is detectable from agents polarized shares and beliefs, which in turn influence the price level. The polarized regimes can consist in stable steady states or can be characterized by endogenous dynamics, generating persistent alternating waves of optimism and pessimism, as well as return distributions displaying the typical features of financial time series, such as fat tails, excess of volatility and multifractality. Moreover, we show that, if the sentiment has no or low relevance on the selection of beliefs, those stylized facts are abated or are missing at all from the simulated time series.

We stress that the literature that is closer to the present contribution (see e.g. [1,2]) provides a “weak form” of animal spirits according to the terminology introduced in [3], since changes in the psychological and emotional perception of the market were only consequences of the agents choices, without being part of the process on which decisions are taken. Conversely, our work provides a “strong form” of animal spirits modeling, which exists if agents also rush toward an attitude simply because it is being applied by the majority of agents.

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THE LOCKDOWN GAME

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During these unpredictable and unexpected months of pandemics, Governments have largely been found unprepared to manage this emergency. However, some of them have been able to limit the spread of the infection at manageable levels without imposing their citizens dramatic policies of lockdown. Others, on the contrary, despite prolonged restrictive measures and serious economic losses, still register high levels of infections, which does not appear to slow down as one would expect. In this paper, we offer an explanation for this evidence, by analyzing the strategic foundations between citizens and politicians in an evolutionary game approach. In our setup, politicians choosing between a hard or soft lockdown policy, and so facing the difficult task of managing the pandemic successfully, while citizens, on their side, may accept the policy enforced by policymakers and obey, or not. In line with the recent behavioural and medical literature, we introduce the psychological benefits driven by peer effects for those citizens who do not obey, which positively increase their utility as a function of other non-obeying citizens, and we prove that, under our hypothesis, different scenarios may arise.

STOCHASTIC OPTIMAL GROWTH THROUGH STATE-DEPENDENT PROBABILITIES

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We extend the classical discrete time stochastic one-sector optimal growth model with logarithmic utility and Cobb-Douglas production à-la Brock and Mirman [1] to allow probabilities to be state-dependent. In this setting the probability of occurrence of a given shock depends on the capital stock, thus as the economy accumulates more capital the probability of occurrence of different shocks changes over time. We explicitly determine the optimal policy and its relation with state-dependent probabilities in two alternative scenarios in which the probability function, assumed to take a logarithmic form, is either decreasing or increasing with capital. We show that, by affecting the optimal policy, state-dependent probabilities act as an engine of capital accumulation, which, through its effects on the probability of shocks realization, impacts the evolution of economic inequality. In particular, whenever the probability is decreasing (increasing) in the capital stock the probability of the most (least) favorable shock increases, and this incentivizes the planner to increase (decrease) his capital investment, which in turn will generate a widening (reduction) in economic inequalities over time. We then show that the optimal solution can be converted into an affine iterated function system with affine state-dependent probabilities which converges to an invariant self-similar measure supported on a compact (eventually fractal) attractor. We also characterize the properties of such an invariant self-similar measure in terms of singularity and absolute continuity with respect to the Lebesgue measure, which ultimately depends on the magnitude of the capital share.

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A DUOPOLY GAME WITH ROBUST PLAYERS AND ADAPTIVE EXPECTATIONS

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The paper considers a simple duopoly game, as in [4], where firms are uncertain about the values of the parameters of the demand function. Adopting a robust approach to uncertainty, see, e.g., [1–3], firms decide the next-period production by maximizing the maximum-guaranteed payoff. Assuming adaptive expectations on competitors' next-period output and assuming that production decisions are updated at regular intervals of time, the production of the duopoly evolves over time according to a discrete-time (piecewise-linear) dynamical system. The investigation reveals that cyclical and chaotic dynamics can emerge as the consequence of the worst-case approach to uncertainty that introduces further nonlinearities in the payoff functions of firms.

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EXPECTATIONS NETWORK, CENTRALITY AND DYNAMICS: EXPERIMENTAL EVIDENCE FROM URUGUAY

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This study empirically explores the dynamics of expectations of the Uruguayan manufacturing firms about economic growth. Data from the Monthly Industrial Survey of the Chamber of Industries of Uruguay (CIU) for the period January 2003-June 2008 are examined. The paper introduces a notion of distance between the paths of the agent's expectations, to perform comparisons. We construct Minimal Spanning Trees (MST) and a Hierarchical Trees (HT) to detect groups of firms that share similar performance on expectations. The methodology enables to identify the vertexes of the MST, that play crucial roles in the expectation process formation, and also clusters that can be interpreted as groups of affinity in expectations. The most pessimistic firms seem to form clubs in an extended way than the most optimistic ones. Besides, the study uses time-windows to analyze the dynamics of the network, including the one of these clusters. The evolution of the network shows a possible link between changes in the structure of the firms and macroeconomic uncertainty. During periods of large uncertainty, the total distance of the network increases but the average distance between two firms reduce, indicating that firms locate closer to those that have a similar opinion and further to those that have different ones. At the same time, the group's composition and central firms seem to change facing uncertainty peaks. The majority of the companies in central positions belong to activity branches highly linked with international competition.

THE FUTURE OF COMPLEXITY ECONOMICS

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This paper considers how complexity theory is influencing the future of economics. It considers the broad pattern of the evolution of economics, a broad view of the nature of complexity, what cutting edge complexity economics research is, how this is changing research methods, how this affects macroeconomic research particularly, what are implications for public policy, and the paradox arising from economics itself being a complex adaptive system. What is seen as a move from rationality, greed, and equilibrium to one of purposeful behavior, enlightened self-interest, and sustainability.

PANDEMICS, LABOR FORCE AND ECONOMIC GROWTH: MULTIPLE EQUILIBRIA AND TRAPS

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Economic crises plunge economies into recession in the short, medium and long term. For example, the last major global financial crisis of 2008-09 was responsible for lower growth in total factor productivity, the labor force, and corporate fixed investment (i.e. determinants of potential GDP). Without a doubt, the COVID-19 pandemic can have similar impacts (such as an economic crisis in the short, medium and long term) on the main determinants of economic growth. Recent estimates indicate that the real potential real GDP level for 2020 was 5-8 % lower compared to the projections made before such a Global Financial Crisis. So we wonder how workers are affected by the pandemic. One implication is the net reduction in the supply of labor. Along these lines, the purpose of this study is to investigate the dynamic effects of suppression policies (i.e. quarantines and lockdowns) to face the pandemic on the labor force and capital accumulation (Solow economic growth modeling). Therefore, we analyze a nonlinear dynamic system of labor and capital accumulation to describe the evolution of the economy in pandemic times, focusing on the long-term effect of government policies that strings production (lockdown measures). We show the existence of multiple equilibria driven by the rate of the suppression policy or lockdown measures and by the severity of the disease. Furthermore, we show that the dynamic stability properties of the equilibria are mainly determined by i) the pandemic suppression policies, ii) the proportion of infected workers, and iii) the recovery rate of workers. Hence, economies can fall into the equilibrium of the poverty trap if the economic policies that reduce the spread of infection are severe enough and there are high levels of infection and with a sufficiently low recovery rate. Otherwise, if suppression policies are efficient such that infection levels are low and recovery rates are high, then the economy converges to the high-level equilibrium of economic growth with capital accumulation. Numerical simulations corroborate our results.

SHOULD I STAY OR SHOULD I GO? CARBON LEAKAGE AND ETS IN AN EVOLUTIONARY MODEL

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Emissions trading is gaining increasing importance around the world as a suitable instrument to address climate change. In the absence of a global carbon market, however, unilateral carbon policies may end up causing carbon leakage effects, the more so if carbon prices are to increase in the future to achieve more ambitious emissions abatement targets. This paper intends to explore the possible delocalization effects of an Emissions Trading System (ETS) by proposing an evolutionary theoretical model in which regulated firms decide whether to stay (keep their production activities in the domestic country) or leave (move production abroad where no ETS is in place) imitating what other firms do. We investigate how this decision is affected by some key ETS design features, such as the emissions cap, the number of allowances granted for free to ETS firms, the level of a floor price for allowances. Numerical simulations show that the firms' decision on whether to stay or relocate abroad, and on how many allowances to purchase (and/or emissions to abate) for those that stay, are more sensitive to policies that reduce the cost of green technologies than to changes in specific features of the ETS design such as the emissions cap, the floor price and the number of permits granted for free.

THE DIFFICULT TASK OF CHANGING WHILE GROWING

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Institutions are a key feature in the analysis of how agents deal with uncertainty. While there is a wide acceptance that innovative change demands a set of institutional adjustments, questions such as how, or even whether, badly performing economies may be able to design and implement “good” institutions remain open. This article is an attempt to provide some answers under the evolutionary premise that, even though they might appear as exogenous to the individual agent, institutions are essentially endogenous to the economic system [1,2]. By means of a small-scale agent-based model, where we differentiate between changers, neutrals, and deniers, we show that, as the productive structure evolves, the institutional framework is transformed reinforcing technological change in a cumulative way.

The 3-dimension nonlinear dynamic system of the model is compatible with a weak representation of hysteresis. As we increase the intensity of choice, which captures the degree of interaction between agents, a bi-modal distribution with two different basins of attraction emerges: one around an equilibrium with the majority of the population supporting innovative change, and another with most agents being suspicious to innovation. Neutral agents play an important role as an element of resilience. A numerical investigation of the basins of attraction reveals that the separatrix between the two solutions is a function of the sensitivity of agents to growth, and under certain conditions we might have the birth of a hidden periodic attractor [3].

The economic interpretation of both hidden and standard persistent fluctuations is similar. They consist in a dynamic representation of long-run processes of cumulative causation. Nonetheless, there is an extra flavour in our story. A hidden cycle of structural and institutional change may coexist with locally stable fixed points. Over the past decades, historians have given important insights on this phenomenon. To the best of our knowledge, we are the first to develop a formal representation of it. The empirical literature on institutional economics is heavily grounded on the idea that different attractors might even coexist but should be locally stable. By demonstrating the presence of a hidden orbit, our model suggests that we should be careful in the interpretation of standard econometric techniques.

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PERCEPTION OF FUNDAMENTAL VALUES AND FINANCIAL MARKET DYNAMICS: MATHEMATICAL INSIGHTS FROM A TWO-DIMENSIONAL PIECEWISE LINEAR MAP

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We develop a simple financial market model in which a market maker adjusts prices with respect to the order flow of chartists and fundamentalists. Based on [1, 2], and motivated by [3]–[6], we assume that fundamentalists optimistically (pessimistically) believe in a relatively high (low) fundamental value when the financial market is rising (falling). Our model is rather stylized and we may regard it as a speculative financial market model for stocks, commodities or currencies. However, a novel feature of our model is that fundamentalists (optimistically) pessimistically believe in a relatively high (low) fundamental value when the financial market is increasing (decreasing). The dynamics of our model is driven by a two-dimensional piecewise linear discontinuous map G defined as follows:

$$\begin{cases} P_{t+1} = \begin{cases} (1 + b - c)P_t - bX_t + d & \text{if } P_t > X_t \\ (1 + b - c)P_t - bX_t & \text{if } P_t = X_t \\ (1 + b - c)P_t - bX_t - d & \text{if } P_t < X_t \end{cases} \\ X_{t+1} = P_t \end{cases}$$

Here P_t is the log of the price of the financial market at time period t , $X_t = P_{t-1}$, and parameters are $b > 0$ (aggressiveness of chartists), $c > 0$ (aggressiveness of fundamentalists) and $d > 0$ (fundamentalists' optimism and pessimism with respect to the fundamental condition; it is symmetric with respect to the true fundamental value). We provide an in-depth analytical and numerical investigation of the dynamics of map G . In particular, we investigate bifurcation structure of the (b, c) -parameter plane, characterized by infinitely many periodicity regions associated with attracting cycles. Close to the Neimark-Sacker bifurcation value, $b = 1$, these regions are organized in a period adding structure well described for one-dimensional piecewise increasing maps (see, e.g., [7]). However, our map is two-dimensional, and as a result the observed period adding structure is not standard: decreasing b several regions become overlapping, leading to multistability. Using symbolic representation of attracting cycles, we obtain analytically the boundaries of the main periodicity regions, present examples of basins of coexisting attracting cycles and propose some economic interpretations of the obtained results.

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SOCIAL NORMS FOR THE STABILITY OF INTERNATIONAL ENVIRONMENTAL AGREEMENTS

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This paper is devoted to study the stability of international environmental agreements (IEAs) in a pollution abatement context. Countries can decide to cooperate or to defect. Defector countries decide on their abatement levels by minimizing their own total cost whereas, signatory countries decide on their abatement levels by minimizing the aggregate of all co-operators. In the model, all countries have the same environmental damage instead, respect to the non-environmental cost, we assume that each signatory country has to punish a non-signatory for its behaviour, at some cost to itself (see [3]). We propose two different cases in which we have that punishment is directly proportional to the level of pollution (see [2]) or not (see [1]). Punishments can be in the form of trade sanctions or import tariffs, as a measure to encourage cooperation. We model a differential game in order to determine both the optimal path of the abatement levels and stock pollutant as results of feedback Nash equilibria. Stability conditions, such as internal and external stability, are applied showing that different answers about the size of a stable IEA can be obtained.

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PERFECT FORESIGHT AND LEARNING IN TWO-SECTOR OLG MODELS

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This paper develops an overlapping generations model with two-sectors. Starting from the classical approach in [1], it is demonstrated that a perfect-foresight dynamics is not well defined for a large set of parameter values for which the perfect foresight steady state is unstable. Building on [2], the classical approach is extended to a dynamical system with expectations feedback in which agents may have perfect foresight locally around a perfect-foresight steady state but not globally in the state space of the economy. By means of simulations it is shown that for a robust parameter set, there exists stable cycles which are not entirely located inside the region with perfect foresight. Hence agents have perfect foresight only for a distinct subset of states which constitute the cycle.

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ON THE FRAGILITY OF A STOCK MARKET'S STABILITY

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We develop a simple behavioral stock market model in which a market maker adjusts stock prices with respect to the orders of chartists, fundamentalists and sentimental traders. We show that the mere presence of sentimental traders, i.e. traders who optimistically buy stocks in rising markets and pessimistically sell stocks in falling markets, may compromise the stability of stock markets. Instead of converging towards its fundamental value, stock prices may display endogenous oscillatory dynamics with significant amplitudes when sentimental traders are present - an observation that challenges standard stability claims offered in the pertinent literature.

THE GREEN AND THE BROWN: ENVIRONMENTAL EFFECTS IN A CREDIT CYCLE MODEL

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We propose an augmented variant of the credit cycle model introduced by [2] to analyse the linkages between the environment and financial markets. The environmental quality of our economy depends on the pollution emitted by different investment projects and may be enhanced by an endogenously determined abatement technology. In an overlapping generations setting agents choose a utility maximising allocation of their net worth to Green or Brown projects, which ultimately differ in their general equilibrium effects and in their impact on the environment. While Green projects generate pecuniary spillovers to the next generation and provide a positive environmental externality, Brown projects fail to do so. Following [1], the externality is modelled by a learning-by-producing abatement technology that (partially) offsets the emitted pollution. Green projects generate a certain return equal to the marginal product of capital without demand for external finance, while Brown projects are assumed to yield higher returns but need to be financed by credit. Thus, agents who want to start Brown projects need to borrow from the competitive capital market and have to pledge their expected return as collateral. The Browns' contribution and their exposure to environmental risks may diminish the value of the projects' return such that the collateral is subject to an environmental haircut. In our setting, a regulator observes the environmental quality and sets the haircut accordingly. Hence, the regulated credit flow into Brown projects impacts the pollution emitted and therefore links the environmental quality to the financial market.

This setting allows us to explore the general equilibrium effects and the dynamic impacts of an environmental regulation via financial markets and financing conditions. Due to the intergenerational and environmental spillovers generated by the heterogeneous investment projects and the potentially regulated credit flow, complex dynamics emerge and provide interesting insights of the stability of credit and environmental dynamics. The first results point towards an ambiguous effect of financial restrictions of Brown projects for both the environmental quality and the aggregated output of the economy.

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ROUTE FROM LARGO GEMELLI TO CENACOLO VINCIANO

A Largo Agostino Gemelli, 1, 20123 Milano MI, Italy

Walk north-west on Piazza Sant'Ambrogio towards

Largo Caduti Milanesi per la Patria

85 m

↙ Turn left towards Piazza Sant'Ambrogio

76 m

↗ Turn right onto Piazza Sant'Ambrogio

7 m

↙ Turn left onto Galleria Giuseppe Borella

52 m

Continue onto Via Giacomo Mellerio

112 m

↗ Turn right onto Via Aristide de Togni

167 m

↙ Turn left onto Corso Magenta

268 m

↗ Turn right towards Piazza di Santa Maria delle Grazie

46 m

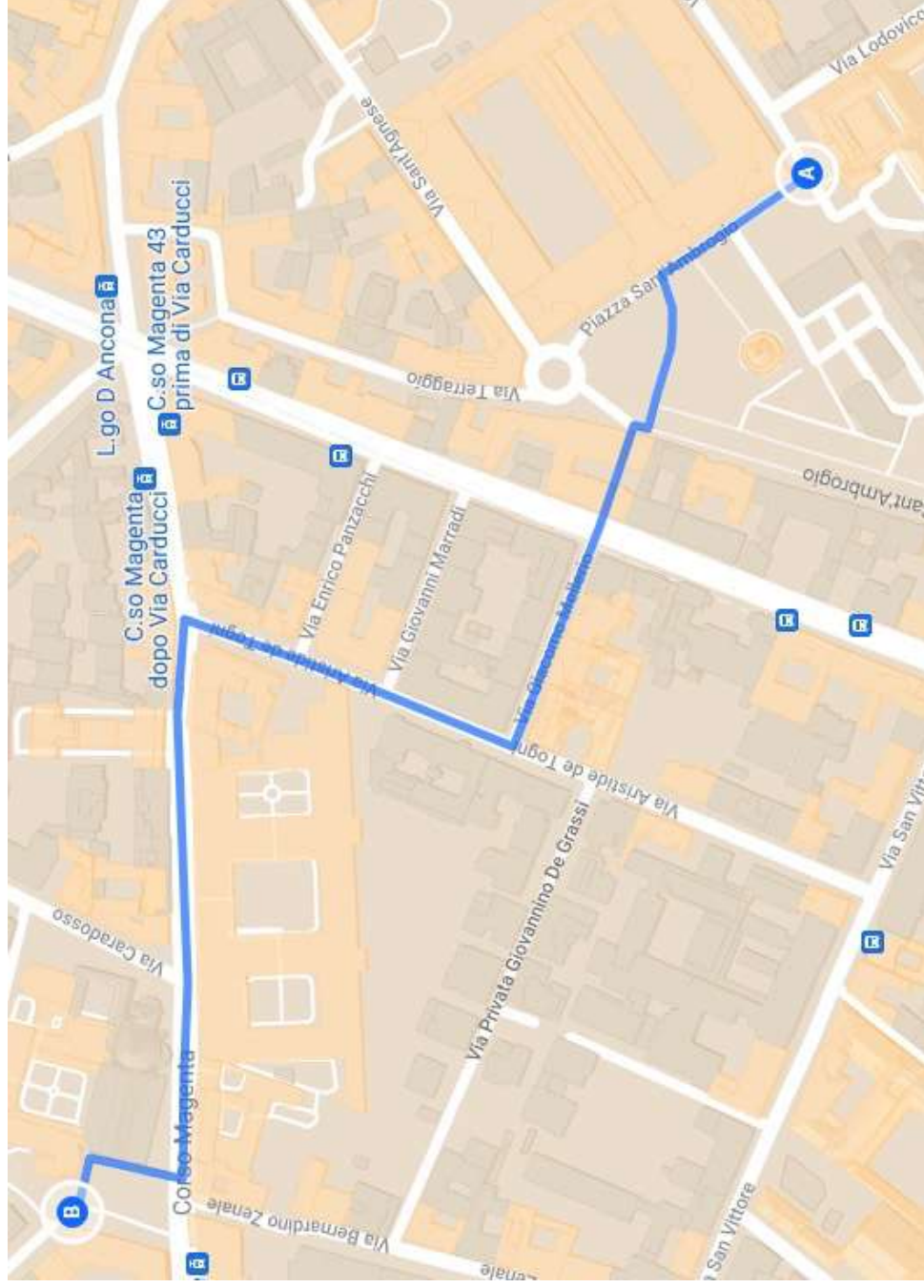
↙ Turn left towards Piazza di Santa Maria delle Grazie

26 m

↗ Turn right onto Piazza di Santa Maria delle Grazie

14 m

B Via Fratelli Ruffini, 1, 20123 Milano MI, Italy



ROUTE FROM LARGO GEMELLI TO "BEBEL" RESTAURANT

- A** Largo Agostino Gemelli, 1, 20123 Milano MI, Italy
 - Walk north-west on Piazza Sant'Ambrogio
 - Turn left
 - Turn right towards Via San Vittore
 - Turn left towards Via San Vittore
 - Turn right onto Via San Vittore Destination will be on the left
- B** Via San Vittore, 3, 20123 Milano MI, Italy

