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# Extended abstract<sup>1</sup>

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 un-

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der 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.

#### Keywords

Structural change; Institutional change; Nonlinear dynamics; Hidden attractors.

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Title of the session: Nonlinear Economic Dynamics Name of the organizer: Fabio Tramontana

# Credit risk measures and the estimation error in the ASRF model under the Basel II IRB approach

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### Extended abstract<sup>1</sup>

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 [1]. 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 base-line for the derivation of the credit risk measures under the IRB approach [2]. We exploit Monte Carlo simulations to quantify the bias induced by the

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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 ASRF 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 ASRF 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.

#### Keywords

Bank Capital; Regulation; Basel 2; Margin of Conservatism; Value-at-Risk.

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# Ponzi and zombies: the risk of over-indebtness of the private sector

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## Extended abstract <sup>1</sup>

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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.

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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 (incomedebt-hedge, speculative and Ponzi) for financial units, we develop a simple partial equilibium 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' creditwothiness.

### Keywords

Financial instability; Credit worthiness; Agent-based model; Real-financial interactions; Minsky.

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# 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.

 $\begin{aligned} x(t+1) &= x(t) \frac{\exp M_1(t)}{x(t) \exp M_1(t) + (1 - x(t)) \exp M_2(t)} \\ & [] \\ y(t+1) &= y(t) \frac{\exp P_1(t)}{y(t) \exp P_1(t) + (1 - y(t)) \exp P_2(t)} \\ & [] \\ a(t+1) &= \left[ q_D p_D E x(t) + q_{ND} p_{ND} E(1 - x(t)) \right] y(t) + \bar{a} \end{aligned}$ 

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

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.

*Keywords*: defensive medicine; discrete dynamical system; medical malpractice insurance

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# Interdependent preferences and bounded rationality in a dynamical contest model

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### Extended abstract<sup>1</sup>

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  $\omega_i$  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;

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• 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 vincreases, generating endogenously oscillating strategy choices.

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Keywords Contest; Interdependent preferences; Bounded rationality.

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# Hybrid dynamics of multi-species resource exploitation

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## Extended abstract<sup>1</sup>

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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.

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### Keywords

Mathematical Bioeconomics; Heterogeneous agents; Evolutionary Game theory; Hybrid dynamical systems.

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# A duopoly game with robust players and adaptive expectations.

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### Extended abstract<sup>1</sup>

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], [2] and [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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### Keywords

Duopoly games; uncertainty aversion; adaptive expectations; nonlinear dynamics.

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# Oligopoly dynamics with isoelastic demand: the joint effects of market saturation and delegation

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## $\mathbf{Abstract}^1$

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, nonequilibrium 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

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interesting scenario is due to the joint interplay between trigger delegation and market saturation.

### Keywords

oligopoly; delegation; market saturation; nonlinear dynamics;

## An evolutive model with market sentiment

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### Extended abstract<sup>1</sup>

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In [2] we study a financial market populated by heterogeneous agents, whose decisions are driven by "animal spirits". Each agent may have either correct, optimistic or pessimistic beliefs about the fundamental value, which can change from time to time based on an evolutionary mechanism. The evolutionary selection of beliefs depends on a weighted evaluation of the general market sentiment perceived by the agents and on a profitability measure of the existent strategies. As the relevance given to the sentiment index increases, a herding phenomenon in agent behavior may occur and animal spirits can drive the market toward polarized economic regimes, which coexist and are characterized by persistent high or low levels of optimism and

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pessimism. This conduct is detectable from agents polarized shares and beliefs, which in turn influence the price level. Such 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 volatility and multifractality. Moreover, we show that if the sentiment has no or low relevance on belief selection, those stylized facts are abated or are missing from the simulated time series.

We stress that the literature that is closer to the present contribution (see e.g. [1, 3]) provides a "weak form" of animal spirits according to the terminology introduced in [4], 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, in order to retrieve the Keynesian seminal idea in [5].

#### Keywords

Heterogeneous agents; Animal spirits; Behavioral finance; Market sentiment; Herding.

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# A stylized macro-model with interacting real, monetary and stock markets

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## Extended abstract<sup>1</sup>

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.

**Keywords:** Market interactions; Stock market participation; Heterogeneous agents; Nonlinear dynamics.

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# On the asymptotic stability of two spatial models of economic growth

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# Extended abstract<sup>1</sup>

In recent years, models of economic growth have been proposed that accounts for a non-uniform spatial distribution of the main macroeconomic variables. Several of these approaches are concerned with the spatial dynamics of capital, but other papers consider other economic variables too. In this work, we focus on two spatial models of economic growth (hereafter referred to as *Model 1* and *Model 2*) in which the population extends along (the boundary of) the unit circle in the plane and both capital and labor are allowed to move all across space, and we show that asymptotic stability can be proven by applying the theory of abstract parabolic problems [1]. Precisely, the two models are as follows:

*Model 1*: the migration of workers is driven by wage gradients; the migration of capital is driven by gradients of the capital; population grows at a constant rate; saving is exogenous; firms are profit maximizers

*Model* 2: the migration of workers is driven by wage gradients; the migration of capital is driven by returns on investments; population growth follows a law with a unique equilibrium (e.g., a logistic law); saving is exogenous; firms are profit maximizers.

Both models have solutions that are constant all across space: *Model* 1 has a balanced growth path where capital and labor grow at a spatially uniform rate, and *Model* 2 has a flat equilibrium.

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Interesting insights about the (nonlinear) stability of the above spatially uniform solutions can be obtained by applying the theory of abstract parabolic problems [1]. Specifically, we will show that the operators that drive the linearized dynamics in *Model 1* and *Model 2* are sectorial (in a proper function space), with a spectrum of negative eigenvalues (separated by the origin). Then, the spatially uniform solutions are (non-linearly) asymptotically stable to small perturbations.

### Keywords

Spatial growth; capital and labor migration; asymptotic stability; abstract parabolic problem.

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# Stability and Bifurcations in a Bank and Small Enterprise Three-Dimensional Continuous-Time Dynamical System

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# Extended abstract <sup>1</sup>

In this paper, we study a three-dimensional continuous-time Lotka-Volterra dynamical system that describes the role of government in interactions with banks and small enterprises. In Italy, the main objective of government economic intervention during the COVID-19 emergency was to maintain the proper operation of the bank-enterprise system. We review the effectiveness of measures introduced in response to lockdowns for the COVID-19 pandemic in order to avoid a further credit crunch. By applying bifurcation theory to the system we produce evidence of the existence of periodic solutions zero-Hopf bifurcating from a saddle-focus in a special region of the parameter space. A numerical analysis is performed.

### Keywords

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Periodic Solution; Hopf bifurcation; Zero-Hopf bifurcation.

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# Learning equilibria with memory

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### Extended abstract<sup>1</sup>

Several scholars have discussed on the validity of rational expectations over the last past decades. In particular, the hyphothesis 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

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[1] is locally unstable, still persist to cause instabily 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.

### Keywords

Learning equilibria; behavioural learning; overlapping generation models; inflation forecasting; bounded rationality.

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