

Applications of Dynamic Systems to Economic Growth with Environment

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Abstracts of Presentations
(in alphabetical order with the speaker in bold)

Probabilistic Okun's Law

Serguei KANIOVSKI

The paper estimates a parametric model of the co-movement of the real GDP growth and the unemployment rate using a bivariate Gaussian copula with the generalized logistic marginal distributions. Parameters of the model are estimated using the maximum likelihood method. Unlike the regression analysis, a copula model recovers the joint probability distribution of the two variables, which can then be used to numerically compute the conditional probability of a decrease in the rate of unemployment given a certain growth rate of the real GDP. The model is estimated and tested using quarterly data for fifteen European countries the USA.

Modeling Optimal Trajectories of Economic Growth under Exhausting Energy Resources

Andrey KRASOVSKII and Alexander Tarasyev

The research deals with the model of economic growth based on the real time series. The methodology for analysis of a country's macroeconomic parameters is proposed. A distinguishing feature of the approach is that real data is analyzed not by direct statistical approximations but through formalization of the process in terms of optimal control theory. The econometric analysis is used only at the stage of calibration of initial parameters of the model. This feature helps to analyze the dynamism in growth of economic factors which drive the economic growth. The study is focused on the gross domestic product (GDP) of a country. There are three production factors in the model: capital, labor and useful work. Several production functions (Cobb-Douglas, modifications of LINEX) are implemented in the model to express the relationship between factors of production and the quantity of output produced. The problem of investments optimization is solved using the version of the Pontryagin maximum principle, elements of the qualitative theory of differential equations and methods of differential games. Numerical algorithm is proposed for constructing synthetic trajectories of economic growth. Numerical experiments are fulfilled via elaborated software. The comparison of optimal trajectories and real trends are presented. Based on the model simulations scenarios of future growth are discussed. For verification of the proposed approach several model modifications and case studies are presented. They are based on data for economies of the UK, US and Japan.

Equilibrium Growth Dynamics in Market Environment

Arkady KRYAZHIMSKIY

We construct optimal (equilibrium) trajectories for simplified models of selfish heterogeneous economic agents. The agents produce products, bring these products to market and consume the products purchased on market. Each agent aims at maximizing his/her integrated consumption index. Key results stated using the mathematical theory of optimal control are the following.

1. The agents' optimal capital saving rates are insensitive to the market prices and can be planned in advance. Moreover, the agents' optimal capital saving rates do not change over time and are determined by the agents' productivity coefficients and the discount coefficients in the agents' integrated consumption indices.
2. The prices regulate only the quantities of the products purchased in market for consumption.

A Dynamic Model of Oligopoly with Capital Accumulation and Pollution Externalities

Davide Dragone, **Luca LAMBERTINI** and Arsen Palestini

We model a differential Cournot game where the production of the final good requires the accumulation of productive capacity and pollutes the environment. Firms are myopic as to the production of pollution, which instead appears in the objective functional of the benevolent planner. In view of this, there is an incentive for the planner to reduce the total amount of industry output as compared to the Cournot-Nash outcome. This of course translates into a reduction in consumer surplus via an increase in prices, as this is more than compensated by the reduction in the amount of pollution and by the increase in total profits. Conversely, if the golden rule of capital accumulation prevails under both regimes, the conflict between social and private incentives disappears.

Environmental Mortality and Long-Run Growth

Ulla LEHMIJOKI and Elena Rovenskaya

There is emerging evidence that environmental degradation increases human mortality. This paper provides a long-run consumer optimization model in which mortality is endogenous to emissions generated by production. There is a trade-off between consumption and mortality as large consumption calls for large production and leads to more numerous deaths. Emissions abatement efforts thus help to avoid several deaths. Yet, in the optimum, some deaths are accepted as an exchange for consumption. The model is calibrated for the European outdoor air pollution data.

Growth, Innovation and Environmental Policy: Clean vs. Dirty Technical Change

Maria A. Cunha-e-Sa, **Alexandra LEITAO** and Ana Balcao Reis

This paper focuses on a two sector endogenous growth model with environmental quality. Endogenous technological change creates either clean or dirty innovations, depending on relative profitability. The decentralized equilibrium doesn't attain neither optimal growth nor the optimal emissions rate. We show that R&D subsidies should be combined with a pollution tax to increase the rate of innovation and promote research towards cleaner technologies. The reduction of emissions intensity of aggregate output is achieved by changing the dirty-bias of technology in the economy. We study both first and second-best policies. We claim that pricing only emissions might not be enough, as the price required to give incentive, for instance, to low carbon technologies is too high, compromising growth.

Optimal Control Problems with State and Control Delays and Applications to Growth Processes

Helmut MAURER, Laurenz Goellmann and Daniela Kern

We study optimal control problems with delays in control and state variables. The control process is subject to mixed control--state constraints. The retarded optimal control problem can be transformed to a standard optimal control problem by suitably augmenting the state dimension. This allows us to derive a Pontryagin type Minimum Principle for retarded optimal control problems. We discuss numerical methods which are based on discretisation and optimization techniques. These methods also provide the adjoint function that satisfies an advanced differential equation. Theory and numerics are illustrated by two challenging problems which model growth processes in a chemical engineering and biomedicine: (1) control of a continuous stirred tank reactor (CSTR); (2) computation of optimal multi-drug protocols in a generic model of the innate immune response.

A Controlled Model of the Development of Transport Infrastructure

Sabine Fuss, Michael Obersteiner, **Benjamin ORTIZ**, Denis Pivovartchuk and Jana Szolgayova

A model is developed, taking into account the mutual interactions of transport infrastructure on economic growth from the point of view of their dynamic behavior. In this model, a variable threshold curve is introduced in order to show the distinct qualitative behavior of the vector field describing the dynamics of the system. A brief look at historical data shows that for some developed countries, the relation between transport infrastructure and GDP is fairly linear. An optimal control problem, which involves road length and GDP as phase variables, is formulated and solved with the aid

of Pontryagin's Maximum Principle. A case study involving real data is shown, in which some trajectories are calculated. The results show that the calculated trajectories approximately correspond to the behavior of real data.

International Emission Policy with Lobbying and Technological Change

Tapio PALOKANGAS

In this study, I examine the implementation of emission policy in a union of countries. The production of goods in any country incurs emissions that pollute over the union, but efficiency in production can be improved by research and development (R&D) which has a random outcome. I compare four cases: no emission policy, Pareto optimal policy, lobbying with emission quotas and lobbying with emission trade. The main findings are the following. Lobbying with emission quotas yields the same growth rate and the same emissions intensity Pareto optimal policy. Lobbying with emission trade produces even a lower growth rate than no emission policy.

On Overtaking Optimal Solutions of Infinite Horizon Optimal Control Problems

Sabine PICKENHAIN

Still at the beginning of the previous century the optimal control problems with infinite horizon became very important with regards to applications in economics, where an infinite horizon seems to be a very natural phenomenon. These problems were treated by many authors and various necessary, sufficient as well as transversality conditions were obtained. The problem we consider in this talk is formulated as follows. Minimize the functional

$$J(x, u) = \int_0^{\infty} r(t, x(t), u(t)) \tilde{\nu}(t) dt$$

subject to all pairs

$$(x, u) \in W_p^{1,n}(\mathbb{R}^+, \nu) \times L_p^r(\mathbb{R}^+),$$

satisfying state equations, control restrictions and initial conditions. The integral in the functional J is understood in Lebesgue sense. The remarkable on this statement is the choice of the weighted Sobolev- and weighted Lebesgue spaces as state and control spaces respectively. We call functions and weights. These considerations give us the possibility to extend the admissible set and simultaneously to be sure that the adjoint variable belongs to a reflexive Banach space. For a resource allocation model with infinite horizon we find the solution by proving sufficiency conditions. At the same time we construct the finite horizon model for which overtaking optimality is preserved.

Consistency between Long–Term Target and Short–Term Policy

Denis PIVOVARCHUK

Sometimes it is not possible to elaborate actions, that provide achieving a given target, over a whole time period, especially, if a target is defined for a long period of time. In this case, it is reasonable to postpone choosing a final policy and initially design actions for a short–term time period only, taking into account current possibilities and information. However, achieving a long–term target anyway must be a major factor in designing these short–term actions so that the short–term actions keep the possibility to meet the target. In this presentation we propose an approach to examine if a long– term target and short–term actions are consistent and estimate which long–term actions needed to meet a target depending on a chosen short–term policy. In illustration of the approach, we carry out analysis of the consistency for the DICE–94 model that is an model describing the relation between economic growth and climate change.

Natural Hazards, Growth and Risk-Transfer: An Empirical Comparison between Risk-Transfer-Mechanisms in Europe and the USA

Paul RASCHKY

An analysis of the effects of natural hazards on society does not solely depend on a region's topographic or climatic exposure, but the region's institutional resilience to natural processes that ultimately determines whether these processes result in a natural hazard or not. The purpose of this paper is to provide an institutional comparison between different societal risk-transfer mechanisms against floods in Europe and the USA. In the short run, a major flood event in a European region reduces the regional GDP by 0.4-0.6%-points; an average flood event in the USA reduces the personal income by 0.3-0.4%-points. In addition, the results for the U.S. sample suggest that counties participating in the NFIP follow a less volatile growth path in subsequent years. Appropriate ex-ante risk-transfer policies can largely mitigate these effects, while ex-post governmental disaster relief tends to even enlarge the negative impact of natural hazards on income. These results provide useful implications for adaptation strategies against the adverse effects of climate change.

Economic Growth and Global Warming: A Model of Multiple Equilibria and Thresholds

Alfred Greiner and Willi SEMMLER

This paper studies the dynamics of an economic growth model with global warming. Recent research on climate change suggests that a change in global surface temperature affects the capacity of the earth to reflect radiation. Our paper takes into account that the ratio of reflected to incident radiation of the earth, i.e. the albedo, negatively depends on the average surface temperature. We presume a simple model

of endogenous growth where economic growth is affected by global warming and analyze the dynamics of economic growth and global warming from both the perspective of a market economy and the social planner's perspective. Our regulatory instrument is an emission tax rate. We demonstrate that for certain values of the emission tax the market economy exhibits multiple equilibria and a threshold may exist which separates the domains of attraction for the growth paths. There exist paths to high growth rates and low temperature and low growth rates and high temperature, separated by a threshold. For the planner's problem the long-run equilibrium is unique unless the damage of global warming is very small.

High Order Precision Estimates in Algorithms for Solving Problems of Economic Growth

Andrey Krasovskii and **Alexander TARASYEV**

The research is devoted to analysis of optimal control problems arising in models of economic growth. The Pontryagin maximum principle is applied for analysis of the optimal investment problem. Specifically, the research is based on existence results and necessary conditions of optimality in problems with infinite horizon. Properties of Hamiltonian systems are examined for different regimes of optimal control. The existence and uniqueness result is proved for a steady state of the Hamiltonian system. Analysis of properties of eigenvalues and eigenvectors is completed for the linearized system in a neighborhood of the steady state. Description of behavior of the nonlinear Hamiltonian system is provided on the basis of results of the qualitative theory of differential equations. This analysis allows us to outline proportions of the main economic factors and trends of optimal growth in the model. A numerical algorithm for construction of optimal trajectories of economic growth is elaborated on the basis of constructions of backward procedures and conjugation of an approximation linear dynamics with the nonlinear Hamiltonian dynamics. High order precision estimates are obtained for the proposed algorithm. These estimates establish connection between precision parameters in the phase space and precision parameters for functional indices. The results of numerical experiments illustrating algorithm's constructions are given for real data of US and Japan economies.

Capital growth in an endogenously changing environment

Vladimir VELIOV

The study is motivated by the issue of global warming, which is influenced by the economic activities and, on the other hand, affects both the efficiency of production and the utility. We consider a global decision maker maximizing the social objective based on an explicit model of the dynamics of the economy and that of the environment. In addition we define three types of policies of a representative firm (or country) that does not relay on the environmental component of the model: "business as usual", "successive econometric adjustment", and "perfect foresight with free riding". We define these policies in a formal and unified way and prove that under appropriate (some times restrictive) conditions they exist. We compare the

results obtained within the above four scenarios for the evolution of the world's economy and average temperature in the next 100 years.

Open Innovation in a Post-oil Society

Chihiro WATANABE

Despite many handicaps, Japan accomplished sustainable growth using technology substitution for scarce resources as labor in the 1960s and energy in the 1970s, which in turn induced further innovation. Thus, Japan constructed a sophisticated co-evolutionary dynamism between innovation and institutional systems by transforming external crises to a springboard for new innovation.

Although Japan's dynamism moved in the opposite direction in the 1990s due to a systems conflict with a new paradigm shift from an industrial society to an information society, a swell of reactivation emerged in the early 2000s. This can largely be attributed to hybrid management fusing the "East" (indigenous strength developed in an industrial society) and the "West" (learning from global best practice in an information society).

This strategy corresponds to a new stream of innovation which depends on functionality development in the diffusion process. Japan's leading R&D and profitable firms have constructed an explicit hybrid management system which effectively utilizes indigenous strength in domesticating external technology from rivals as well as markets, thereby attaining enhanced functionality development leading to construction of a co-evolutionary dynamism between innovation and institutional systems.

While the global environmental consequences of CO₂ discharge resulting from energy use are causing mounting concern regarding the sustainability of future development, it has been broadly postulated that the recent dramatic increase in oil prices may signal the possibility of a new paradigm shift from an oil dependent society to a post-oil society.

Given Japan's notable accomplishments in overcoming historical crises subsequent to a paradigm change, an attempt to elucidate this dynamism is conducted.