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Investments, Energy, and Green Economy

The current pandemic crisis illustrates that the economy can be strongly affected by factors that are not necessarily economic. This highlights the need for a broad perspective in the analysis of economic dynamics, taking into account the role of different interconnected factors. A new paradigm of growth seems necessary to describe and evaluate economic dynamics and results of decisions and policy interventions. To that end the recent concept of "sustainable development" has been put forward, which provides an integrated development between the economy, society and the environment, capable of understanding the future and managing the growing uncertainty. It is based on the insight that a crucial aspect of future development is the management of natural resources. The new sustainable paradigm addresses topics like decarbonization and energy transition, with the aim to contain future climate change crises. The European Green Deal and part of the Next Generation EU funds have been designed in this direction. They are based on the understanding that investments aimed at the Green Economy can reduce environmental impacts, stimulate growth and also better control sources of environmental and economic uncertainty. Already for a long time contributions to the literature have demonstrated that adopting more sustainable and responsible behavior has the great advantage of reducing future risks. In fact, empirical evidence underlines that economic investors reward the most virtuous companies by recognizing a lower business risk. It therefore seems that the path to growth is traced and, in any case, seems almost inevitable to limit damaging effects of future crises.

Understanding processes of energy transition, buildup of a green economy and decarbonization therefore seem crucial for managing sustainable future development. All these processes are however characterized by strong uncertainty and potentially complex dynamics. Understanding these processes requires studying appropriate economic models. For this reason, different streams of economic literature have been strongly developed in recent years developing and applying suitable methods for studying these issues. In this context, a workshop was held on 26-27 April 2019 at the University of Brescia, Italy, under the patronage of the Fondazione Eni Enrico Mattei (FEEM) and the Italian Association of Environmental and Resource Economists, (IAERE). The workshop was entitled "Investment, Energy and Green Economy" and aimed at bringing together researchers at the forefront of research on economic decisions in dynamic models and in models under uncertainty and irreversibility for discussing new developments and applications in Energy and Green Economy. Papers were presented on theoretical and applied contributions, with an emphasis on microeconomic analysis. The issues addressed were related to reversible and irreversible investment choices in the presence of competing energy (e.g. grey and green) technologies; the diffusion of energy technologies and the role of uncertainty in investment decision problems; the strategic adoption of technologies and switching of energy sources; derivatives on energy markets, weather derivatives; the electricity storage systems, its optimal management and economic impact of green policies.

This special issue brings together some of the best papers from the Brescia workshop and additional papers that have been submitted to the special issue on the themes of "Investment, Energy and Green Economy".

One of the most important problems in environmental economics is the concept of "externalities". It refers to situations where the effect of production or consumption of goods and services imposes costs or benefits on others, which are not reflected in the prices charged for the goods and services being provided. This implies that some costs are not included in the factors affecting choices of economic agents. The result is that production quantities and sales prices are distorted from their optimal values. This in turn implies a misallocation of resources and a typical risk of market failure. The role of institutions to make externalities endogenous is therefore crucial. To reach that aim they can employ instruments like subsidies, taxes or negotiable permits. Their correct adoption can reduce risk, drive investment and stimulate energy transition.

In this context, **Acevedo, Bernales, Flores, Inzunza and Moreno** study the risk in energy generation and demonstrate that environmental policies can decrease this risk for private investors when several renewable technologies are simulta-

neously triggered. This is because diverse renewable technologies can hedge the intermittent generation of other forms of renewable power.

In the same context, **Zwart** analyzes optimal regulation of the gradual investments in energy networks necessary to accommodate the energy transition. By using a real options framework, where costs of new network technology are stochastic and not observable to the regulator, he characterizes the regulatory scheme that optimally balances timely investments with rent extraction in a dynamic agency context. The optimal choice trades off the potential benefits of cheaper expansion with the costs of overcoming information frictions.

Taschini compares abatement technologies and emission permits and proposes a unified framework to rationalise the impact of both investment/divestment lags and irreversibility in relation to the price of emissions permits. Using option pricing concepts, he reformulates the technology adoption problem in terms of the technology's irreversibility and implementation lags and offers a conceptual quantification of the flexibility premium of emissions permits.

Hagspiel Nunes, Oliveira and Portela address the question how uncertainty about future changes in public support policies affects incentives to invest in renewable energy capacity. They consider a real options problem of firm in a setting where an initially active subsidy in a feed-in tariff is retracted with a rate that increases with the time since the introduction of the tariff. A main finding of their analysis is that in light of this policy risk it is optimal for the firm to wait with its investment for the retraction of the subsidy once the subsidy has been in place for too long.

A frequently arising problem is when to adopt an existing technology while taking into account the future arrival of an improved version. **Sendstad and Chronopoulos** study this within the framework of green investments, where decision makers are risk averse, and there are strategic interactions due to competition. Their main result is that risk aversion delays investment, whereas technological uncertainty accelerates the follower's entry, but delays entry of the first investor.

Fontini, Vargiolu, and Zormpas analyze how Reliability Options affect the timing and value of investments in the energy sector and show under what conditions they can be used as investment stimuli. The main result is that Reliability Options can potentially harm the security of supply by delaying the adoption of new capacity and by reducing the value of investing in it.

Picarelli and Vargiolu present a novel technique to solve the problem of managing optimally a pumped hydroelectric storage system. To do so they transform the original constrained problem in an auxiliary unconstrained one in augmented state and control spaces, obtained by introducing an exact penalization of the original state constraints. Then a problem results that can be solved by dynamic programming.

Castellini, Menoncin, Moretto and Vergalli study optimal investment in photovoltaic plants of prosumers who are integrated in a smart grid. The smart grid allows prosumers to cover their energy demand by own production, energy purchases from other prosumers or purchases from the national grid. Assuming that prosumers coordinate their investments and relying on a model calibration using Italian data, it is shown that the possibility to exchange energy among prosumers leads to larger plants compared to a scenario without such a possibility.

Irawan and Okimoto study overinvestment by resource firms, induced by a business cycle and macroeconomic uncertainties. Employing panel data this paper shows that the forestry and paper sector overinvests whereas the alternative energy sector tends to underinvest. For firms in the mining sector a clear result is that the effect of overinvestment on firm performance after three years is positive.

The starting point of the final paper in this special issue by **Antoci, Borghesi, Galeotti and Sondini** is the observation that environmental public goods are progressively substituted by private consumption goods. The authors study an economy consisting of perfectly rational intertemporally optimizing agents, who derive utility from leisure, a public environmental good and private consumption. The authors show that local and global indeterminacy as well as convergence to a Pareto dominated steady state might arise and discuss the implications of the use of green technologies in this context.

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