Economic Modelling 54 (2016) 439–449

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

Environmental pollution, sustained growth, and sufficient conditions for sustainable development[☆,☆☆]

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ARTICLE INFO

Article history:
Accepted 21 January 2016
Available online xxxx

Keywords:
Catastrophe
Climate change
Environment
Externalities
Global warming
Optimal growth
Sustainability

ABSTRACT

Sustainability and optimality are the two main issues discussed in environmental economics and economic growth theory. This paper studies economic growth in the presence of two environmental externalities. The first one is local and gives account of the marginal damage from the emissions flow. The second one is aggregate, or global, and relates to the extreme damage which may happen if the accumulated stock of pollutants is on the threshold of a worldwide catastrophe. In this context, the decentralized equilibrium is inefficient and economic growth unsustainable. However, we find and completely characterize the socially optimal equilibrium, which shows that sustained growth is feasible along the balanced path. Efficiency alone is not sufficient for sustainability, but Pareto optimality is necessary to produce sustainable outcomes. According to our results, the sustainability of the optimal sustained long-run growth depends on environmental constraints, production and abatement technologies, individual preferences, and population dynamics. This means that government has a clear incentive for intervention by means of direct and indirect policies. These ones cover the usual Pigouvian taxes and subsidies, the setting of emission standards, and the public provision of abatement. Moreover, the government can promote eco-efficiency in the use of materials, implement information campaigns that influence social preferences for environmental conservation, or even put into action population controls and other measures that encourage the demographic transition.

1. Introduction

Economic growth has implications for emissions and, hence, for environment and sustainability, but also economic growth may be affected by environmental deterioration. If pollution increases with economic growth, it may happen that growth ceases when the stock of accumulated pollutants reaches a certain upper bound. Moreover, long-run growth sustainability depends not only on the emissions flow but also on the assimilative capacity of the environment. Indeed, as López (1994) points out, the world's capacity to absorb pollution is bounded and, once pollution stock approaches the absolute tolerable limit, economic growth would not be feasible anymore because the economy would fall into an extreme situation of catastrophic state. Hence, it is of great relevance to ask whether there are limits to growth. Of course, the global economic collapse is more likely to arise in an economy following a sustained long-run growth path if pollution emissions appear positively related to the economic activity as a by-product. Modern economies satisfy human needs through the consumption of goods and services, which requires obtaining raw materials from the elements of Earth, the production of intermediate and final goods, transport of passengers and merchandise, as well as the provision of all kinds of services. All these productive activities call for both energy consumption and land use. Energy used in economic activity, fundamentally thermal energy (heat) and electricity (alternating and direct current), is obtained from the chemical reactions of oxidation (combustion), from generators activated by steam, wind, or water (electromagnetism), and from the photovoltaic panels (solar). The land used in different productive processes represents a transformation of the soil and subsoil that causes deforestation and forest degradation, and whose quantitative impact determines the ecological footprint. The amount of energy and land required is greater the more widespread agriculture, forestry, animal farming, grazing, and mining is, but also depends on the intensity of

☆ The authors acknowledge the support of the Belgian research programs ARC on Sustainability as well as the financial support from the Spanish Ministerio de Ciencia e Innovación, Projects SEJ-2004-04579/ECON, SEJ-2007-65552/ECON, ECO2010-17943, and ECO2013-48884-C3-1-P. Ruiz-Tamarit also acknowledges Grants PR2006-0294 and PR2009-0125 from the Secretaría Gral. de Universidades, Ministerio de Educación, Gobierno de España, and Grant BEST/2011/139 from the Dirección Gral. de Política Científica, Conselleria d'Educació, Generalitat Valenciana.
☆☆ The helpful comments of two anonymous reviewers and the editor S. Mallick are gratefully acknowledged because they have contributed to improve this paper.
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http://dx.doi.org/10.1016/j.econmod.2016.01.017
0264-9993/

industrialization and urbanization processes, which bring with them the need for residential construction, the need for construction for industrial and tertiary use, as well as the corresponding infrastructures.

In all the stages of economic activity in which there are (i) chemical reactions associated with the transformation of materials or the combustion of biomass and fossil fuels, and (ii) changes in the Earth's surface that alter and destroy the ecosystems, we find anthropic waste and emissions. For the most part they are pollutant flows that have negative effects, both locally and globally, on either the environment or the economic system. We have in mind radioactive and other material wastes, as well as released emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrogen sulfide (H_2S), chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), sulfur hexafluoride (SF_6), nitrogen oxides (NO_x), sulfur oxides (SO_x), and carbon monoxide (CO).[1] All these polluting anthropic emissions are closely related to economic activity (production, transport, and consumption) as a by-product, and all of them are undesirable, inevitable, but dimmable.

In a so featured modern economy which we shall conveniently describe by means of a model of endogenous growth, if pollution tolerance is bounded sooner or later the state of ecological catastrophe will be attained, which represents an effective and absolute limit to growth. This problem, however, may be mitigated when it is possible for economic agents to undertake emissions abatement activities or to control for the degree of pollution associated with production technologies (Byrne, 1997). Pollution stocks can be diminished not only by increasing the regenerative capacity or by reducing the level of polluting activities, but also by means of pollution abatement actions. These contribute to determining the degree of dirtiness associated with technology as well as the net flow of pollutants discharged to the environment. Consequently, improving environmental quality requires abatement expenditures that leave less resources available for growth-oriented investment activities. Hence, the model used to describe a representative economy in such a context must be able to show a trade-off between production growth and environmental quality. Moreover, in the presence of environmental externalities, lower rates of growth for output and pollution is expected to be found when pollution is optimally controlled than when it is competitively managed in a decentralized economy.[2] On the other hand, the opportunity for pollution abatement appears as a mechanism that may act as a limit to growth, even though it is less dramatic than the limit which arises from a catastrophic event.

Environmental literature has long dealt with modeling catastrophes and its impact on the economy. Cropper (1976); Clarke and Reed (1994); Tsur and Withagen (2011) study the role of catastrophic thresholds in changing utility and agent's behavior when pollution stock exceeds some critical level. They study uncertainty by introducing the likelihood of collapse but they do not consider externalities at all and, in fact, none of them studies the feasibility of sustainable long-run growth. Our approach is closer to Aronsson et al. (1998) which focuses on the study of catastrophes within the theory of economic growth, but we are more interested in global environmental catastrophes like the climate change associated with global warming, a phenomenon attributed to the increase in anthropogenic greenhouse emissions. Accordingly, the important question for us is whether economic growth and environmental protection are reconcilable. That is, whether optimal sustained growth is compatible with ecological sustainability of the economy as a whole. Moreover, the query on whether environmental concern will eventually limit growth has to be answered looking at two different issues: first, the effects of pollution abatement on the long-run rate of growth; and second, the evolution of the stock of pollutants with respect to the ecologically catastrophic level.

All these issues will be analyzed more accurately in this paper in a simple model of endogenous growth with optimizing behavior with respect to consumption and pollution. Given that we are not directly interested in how technological change has been originated, but in conditions under which sustained endogenous growth and ecological sustainability are compatible, our benchmark model will be the traditional Rebelo's (1991) one-sector *AK* model to which we incorporate variables representing pollution and the environment. In spite of having no transitional dynamics, this model is suitable for our goal due to its simplicity and ease of use, which allows us to focus on the performance of developed economies and their outcomes in the long term, i.e., the period in which sustainability appears to be a relevant issue. An alternative approach to the study of the relationship between pollution and economic growth may be found in Brock and Taylor (2010), which builds upon the Solow model taking as given the savings rate, but introduces the constituent elements that define the environmental problem. The nature of their model with diminishing returns to capital produces short-run transitional dynamics, allowing them to study one of the key empirical issues in environmental economics: the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis, popularized with the work of Grossman and Kreuger (1995), suggests a U-shaped curve relating per capita income levels to environmental quality. Finally, the approach of Brock and Taylor also refers to the problem of choosing less or more abatement, which is subject to technological progress in line with Bovenberg and Smulders (1995). Instead, we adopt here the approach of Stokey (1998) who doesn't consider technological progress in abatement and refers to the decision problem as one of choosing between dirty or clean technologies. However, as we shall see below, our assumptions on the emissions function allow us to go beyond her result of incompatibility between sustained long-run growth and non-catastrophic sustainability.

In our model welfare depends not only on consumption but also on the quality of the environment where agents consume. We assume that pollution arises from production as a flow that enters the consumer's utility function playing the role of a negative *local externality*. There is an externality because of the existence of numerous households who take into account the local effect that *pollution flow* exerts on their respective utilities, without having any influence on the generating process which mainly depends on firms. Moreover, one central aspect of the analysis below is the explicit consideration of abatement activities, which are costly because they absorb resources, reducing investment and consumption possibilities. In this setting, however, households show environmental concern but they do not decide on abatement, whereas firms bear the cost of such an activity but do not receive the corresponding benefits.[3]

Our model considers another externality which arises from the fact that, even if the local negative effect from pollution is not present or has been internalized, households and firms are not aware of the global negative effect from an eventual ecological catastrophe. This is an *aggregate externality* because individual agents decide on the emissions flow but do not control for the accumulated *stock of pollutants*. However, the aggregate stock will eventually have a severe effect on the environment

[1] The case of carbon monoxide is paradigmatic since it combines the effects of toxicity, local pollution, and global warming. In origin it is lethal by inhalation, locally it contributes to harmful pollution concentrations of the ambient air (Photochemical Smog) depending on weather conditions, and when it is dispersed into the atmosphere it has global consequences enhancing the greenhouse effect. Carbon monoxide (CO) reacts with oxygen molecules ($2O_2$) producing carbon dioxide (CO_2) and tropospheric ozone (O_3).

[2] Things could be different if a pollution externality on the side of production is considered as in Ewijk and Wijnbergen (1995). In such a case, environmental quality changes production opportunities by affecting the economy's productivity, and an increase in environmental care may boost growth.

[3] We ignore here any other local externality associated with the flow of pollution, which could play a significant role by affecting the productivity of factors via the health of workers or the quality of inputs.