Resource and Energy Economics 30 (2008) 540–554

Contents lists available at ScienceDirect

Resource and Energy Economics

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

Stochastic technical change, non-renewable resource and optimal sustainable growth

Gilles Lafforgue

Toulouse School of Economics (INRA-LERNA), 21 allée de Brienne, 31000 Toulouse, France

ARTICLE INFO

Article history:
Received 19 March 2007
Received in revised form 24 June 2008
Accepted 30 July 2008
Available online 8 August 2008

Keywords:
Non-renewable resource
Drastic innovations
Sustainability
Poisson uncertainty
Mean-preserving spread

JEL Classification:
Q30
Q32
C61
O30

ABSTRACT

We develop a stochastic endogenous growth model involving a non-renewable resource, in which innovation arrivals are governed by a non-stationary Poisson process. Using a CRRA analytical example, we characterize the optimal trajectories of the model and analyze the effects of uncertainty in the sense of Rothschild and Stiglitz by computing a mean-preserving spread. We show that increased variability in the innovation process always implies a smaller optimal R&D effort, since this leads to a reduced marginal rate of return. Effects on the other variables of the model may also be unambiguously identified depending upon the relative risk aversion of agents, the social discount rate and the marginal arrival rate of innovations. Finally, we investigate the conditions under which, on average, the economy reaches a sustainable growth path.

1. Introduction

This paper explores two main issues. Firstly, we aim to demonstrate how optimal research and development effort, by improving total factor productivity with an uncertain rate of return, can help avoiding the limits to growth stemming from scarcity of nonrenewable resources. Secondly, we investigate the impact of technological uncertainty on the resource extraction rule, the R&D policy and the consumption trajectory at the optimum.

At least since the series of seminal papers published in the Review of Economic Studies (Symposium on the Economics of Exhaustible Resources, 1974), it is now generally accepted that the

E-mail address: glafforg@toulouse.inra.fr.

0928-7655/$ – see front matter
doi:10.1016/j.reseneeco.2008.07.001

limited supply of non-renewable resources does not necessarily imply a limit to growth (for example, see Dasgupta and Heal, 1974; Stiglitz, 1974; Solow, 1974). In particular, the neoclassical theory gives rise to three main possibilities: (i) substitution of the resource by other inputs such as capital, (ii) improvement of the resource efficiency and (iii) development of backstop technologies. However, without any technical change, none of these outcomes could balance the resource exhaustion and continue to sustain some positive growth in the long run. First, as pointed out by Smulders (2003), resource substitution for capital is limited in the long run because of the law of diminishing returns, which decreases the capital productivity with increasing scarcity of the resource.[1] Second, the improvement in efficiency may be the result of some accumulation of specific knowledge (or learning by doing). Third, alternative production processes would not be able to take place without a technological breakthrough.

Most of the literature on non-renewable resources and technical advance considers that technological improvement takes place essentially through the development of a single backstop technology. Once it has been put in place, at a time that is generally endogenous, the backstop renders the exhaustible resource obsolete by producing a non-exhaustible perfect substitute (Dasgupta and Heal, 1974; Dasgupta and Stiglitz, 1981; Kamien and Schwartz, 1978). Another approach consists in considering a flow of innovations instead of a single backstop. In such a case, the resource remains a necessary input, but its productivity can be gradually improved by technical change since the flow of innovations allows for the accumulation of a specific knowledge asset that drives up the input productivity levels (Robson, 1980).[2] According to this approach, innovation arrival can be either continuous or discontinuous. Usually, new endogenous growth models consider a smoothed arrival of innovations over time, while the innovation itself can be seen as a time-continuous production function linking R&D effort positively with knowledge accumulation. Such innovations are called non-drastic innovations. However, the most significant, or drastic, innovations occur discontinuously, i.e. by "fits and starts". In this case, technological progress should be viewed as a discontinuous incremental process. Helpman (1998) defines these drastic innovations as general purpose technologies (GPTs), and justifies their discontinuities by the fact that "a GPT has the potential to affect the entire economic system and can lead to far-reaching changes in such social factors as working hours and constraints on family life". The present study is concerned with such drastic innovations in a non-renewable resource context, like for instance nuclear fusion process or hybrid motor vehicles.

A second important aspect is that, when undertaking R&D activities, the economic agents do not know when and how many innovations will be developed. In reality, technical progress is far from predictable, hence uncertainty should be taken account since it is a determining factor in the drafting of research policy. When these two aspects are combined together, the jump process driving innovation arrivals becomes stochastic and is usually modelled by a Poisson process. While the literature on economic growth and Poison uncertainty is very extensive (e.g. Aghion and Howitt, 1998; Turnovsky, 1995, part IV, Steger, 2005; Wälde, 1999, 2002), there are much fewer studies addressing both technological uncertainty and resource exhaustion issues. For instance, Just et al. (2005) investigate the impact on the depletion rate of an exogenous Poisson uncertainty in successive technology discoveries. They show that uncertainty causes the resource to be depleted more rapidly, due to the existence of sunk costs in the adoption of a new technology that create an incentive – an option value – to always delay current investments.

The objective of this paper is twofold: (i) to investigate the effect of technological uncertainty on the optimal trajectories of the economy and (ii) to determine under which conditions an optimal growth path is sustainable. As in many neoclassical growth models with environmental considerations, sustainable growth is here defined as the way of achieving an unbounded growth

[1] Dasgupta and Heal (1974) show that, with a CRS Cobb–Douglas technology using capital and resource as inputs, positive discounting keeps optimal consumption from being sustained at a strictly positive level in the long run, even if the resource is non-essential to production. If the social discount rate or the elasticity of marginal utility is low, it will delay the decline of the economy but cannot prevent it. However, consumption can eventually grow in the short run.

[2] The two approaches are complementary since economic growth requires a permanent technological improvement while awaiting the occurrence of a backstop.