Mathematical Social Sciences 96 (2018) 10–20

Contents lists available at ScienceDirect

Mathematical Social Sciences

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

Natural cycles and pollution[☆]

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HIGHLIGHTS

- We consider a competitive Ramsey model where a pollution externality impairs a renewable resource.
- A non-separable utility function between consumption and the natural resource is introduced.
- Two steady states can coexist: a welfare and a stability analysis are performed for each steady state.
- Saddle–node, Hopf and Bogdanov–Takens bifurcations can occur.

ARTICLE INFO

Article history:
Received 25 September 2017
Received in revised form 5 August 2018
Accepted 27 August 2018
Available online 31 August 2018

ABSTRACT

In this paper, we study a competitive economy where a pollution externality, coming from production, impairs the renewable resource affecting the consumption demand in turn. A proportional tax, levied on the production level, is introduced to finance public depollution expenditures.

In the long run, two steady states can coexist, the one with a lower resource level, the other with a higher level. Interestingly, a higher green tax rate reduces the natural resource in the low steady state, giving rise to a Green Paradox (Sinn, 2008). Moreover, the green tax can be welfare-improving in the higher steady state but never in the lower one. Therefore, in the second one, it is better to reduce the green tax rate as much as possible. Conversely, the optimal tax rate is positive and unique in the steady state with more natural resource.

In the short run, the two steady states can collide and disappear through a saddle–node bifurcation. Since consumption and natural resource are substitutable goods, a limit cycle can arise around the higher stationary state. To the contrary, this kind of cycles never occurs around the lower steady state, no matter the resource effect on consumption. Finally, focusing on the variety of bifurcations of codimension two, we find a Bogdanov–Takens loop.

1. Introduction

Paleontologists define a mass extinction as a situation in which Earth looses more than three-quarters of its species in a geologically short lapse of time (Barnosky et al., 2011). In the past 540 million years, five mass extinctions occurred and biologists conjecture that a sixth mass extinction (also known as Holocene extinction) is under way (Barnosky et al., 2011). This new extinction comes principally from human activities (deforestation, global warming and climate change: see Ceballos et al., 2015). The strong loss of biodiversity has a large impact on human wellbeing. For instance, as pointed out by Ceballos et al. (2015), this alters crop pollination or water purification. In short, production activities generate pollution promoting global warming and climate change that impair biodiversity and human wellbeing.

The interplay between renewable resource (species, forest,...) and economic activities has already been studied in the theoretical literature. To the best of our knowledge, the first attempt to consider a renewable resource dynamics in a Ramsey framework dates back to the seminal paper by Beltratti et al. (1994). These authors have considered a renewable resource working as a production input and affecting the household's utility. They also contend that a pollution externality, coming from consumption activities, impairs the renewable resource. Assuming that Nature (that is the natural resource) has a small impact on production, they show the existence of a unique stable steady state (saddle-point). Ayong Le Kama (2001) has obtained a comparable result: when pollution comes from production instead of consumption, it is no longer necessary to assume that Nature has a small impact on production in order to ensure the existence of a unique saddle-point stable steady state.

☆ We would like to thank François Salanié and two anonymous referees for their valuable comments and suggestions.

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https://doi.org/10.1016/j.mathsocsci.2018.08.005
0165-4896/

Revisiting the framework in Beltratti et al. (1994) and Ayong Le Kama (2001), Wirl (2004) has proven the existence of two steady states when pollution affects only the household's utility. More precisely, by considering a Pearl–Verhulst logistic function for the reproduction of the natural resource, Wirl (2004) has shown that each branch of the reproduction function possesses a steady state. Interestingly, Wirl (2004) points out the possibility of the emergence of a limit cycle through a Hopf bifurcation around the lower steady state (located along the upward-sloping branch of the reproduction function) and proves the impossibility of this complex dynamics around the higher steady state (along the downward-sloping branch). The existence of endogenous cycles matters from an environmental point of view because it entails the potential emergence of intergenerational inequalities in environmental terms: some generations face a higher level of natural resource while others face a lower level.

All these contributions rest on the hypothesis of a separable utility function between consumption and the natural resource. Nevertheless, intuition suggests that the stock of natural resource affects the marginal utility of consumption and so the consumption demand. Indeed, when Nature increases the consumption demand, consumption and Nature are complements. It is the case when the household likes to consume in a pleasant environment, in presence, namely, of a large biodiversity. Conversely, when Nature lowers the consumption demand, consumption and Nature become substitutes, as happens when the household compensates the utility loss due to a decrease in the natural resource (say a biodiversity loss) by increasing her consumption demand. Both these relevant cases are ruled out in Beltratti et al. (1994), Ayong Le Kama (2001) and Wirl (2004) because of the assumption of separable preferences. One may expect that both these potential effects of Nature on consumption demand matter and may change substantially Wirl's conclusions (2004) on the occurrence of endogenous cycles. In addition, Beltratti et al. (1994), Ayong Le Kama (2001) and Wirl (2004) focus only on the central planner's solution. It is important to understand the short and long-run consequences of the interplay between natural and capital accumulation in the case of pollution externalities. The market representation is pertinent when households face prices without choosing the size of external effects. We aim at addressing all these interesting issues from the perspective of non-separable preferences. In a context of a market economy, the government is allowed to levy a (proportional) tax on production activities to finance depollution expenditures according to a balanced-budget rule.

In the long run, we find that the economy experiences multiple steady states depending upon the environmental impact of production. In particular, the economy has no steady state when the impact is excessive while two steady states arise under a low impact along the branches of the renewable resource reproduction function. The first one is characterized by a lower natural level while the second one, by a higher level. We observe that the effect of a higher green tax rate depends on the steady state. In particular, the rate lowers the natural resource in the lower steady state. Such counter-intuitive negative effect suggests that a greener policy can exacerbate the environmental damage. This case is very close to the Green Paradox pointed out by Sinn (2012) in a resource extraction context.

In the environmental literature, a Green Paradox is a situation where a green tax increases the environmental damages instead of mitigating them. To understand the mechanism, consider an owner of fossil fuel maximizing the profit and a government announcing that a green tax will be introduced tomorrow. The owner rationally expects higher extraction costs tomorrow and, then, speeds up the extraction today causing more environmental damages at the end. According to a recent survey by Jensen et al. (2015), this paradox takes place in various contexts and, in particular, when agents behave strategically in the resource markets (Gerlagh and Liski, 2011), when resource and capital markets interact (Van der Meijden et al., 2015), when future policies are uncertain (Hoel, 2010). Even if the Green Paradox refers historically to a specific dynamic effect concerning the resource extraction, it makes sense to adopt a broader definition by considering any case where a heavier green taxation impairs the environmental quality. In this respect, a negative relation between the green tax and the natural resource, obtained in our paper along the increasing branch of the reproduction function (at the steady state), gives rise to a new category of Green Paradox which differs from the traditional one in two respects: (1) the relation is static rather than dynamic and (2) has nothing to do with the resource extraction. Recently, Bosi and Desmarchelier (2017, 2018) have pointed out the possibility of static Green Paradox in a Ramsey model with pollution but without the natural resource. In this sense, this Green Paradox seems to be a robust property of Ramsey economies. Finally, we prove that the green tax may be welfare-improving in the higher steady state but never in the lower one, and that a unique optimal green tax rate exists for the higher steady state while, for the lower one, the optimal policy consists in reducing as much as possible this rate.

In the short run, we find that the lower stationary state is always unstable while a limit cycle can emerge near the higher steady state because consumption and Nature are substitutes. This result is quite surprising, since Wirl (2004) shows that limit cycles occur only near the lower steady state in a centralized economy. Moreover, we prove that the two steady states can collide and disappear through a saddle–node bifurcation when the environmental impact of production is large enough. Eventually, we find a parameter region where, at the saddle–node bifurcation point, the lower steady state coalesces with the limit cycle surrounding the higher steady state.[1] Our contribution adds a value to the existing literature by detecting a Bogdanov–Takens bifurcation in an (environmental) growth model à la Ramsey. Limit cycles are quite interesting from an environmental perspective. The existence of limit cycles means that the pollution level experiences stable oscillations around the higher steady state and that, in social terms, some generations suffer from a lower natural quality while others enjoy a healthier environment.[2] A Bogdanov–Takens bifurcation is a way by which the higher steady state becomes unstable, and arises when the conditions for a saddle–node and a Hopf bifurcation meet together. Even in the case of a Bogdanov–Takens bifurcation, the existence of limit cycles near the critical point implies the intergenerational inequalities in terms of environmental quality.

The remainder of the paper is organized as follows. In Section 2, we introduce the model. Sections 3–5 are devoted respectively to the equilibrium system, the steady state and the optimal taxation. Section 6 studies the local dynamics, while Section 7 provides some numerical illustrations. Section 8 concludes. All the mathematical proofs are gathered in the Appendix.

2. Model

We consider a model in the spirit of Wirl (2004), but with three main differences: (1) a market economy instead of a social planner, (2) a non-separable utility function between consumption and the natural resource, (3) a proportional tax on production.

[1] In this case, the dynamic system undergoes a so-called Bogdanov–Takens bifurcation. This kind of bifurcation has been rarely studied in a general equilibrium context. The interested reader is referred to Barnett and Ghosh (2013) and Benhabib et al. (2001) among others.

[2] It is known that a Ramsey economy is equivalent to an overlapping generations model with altruism à la Barro (1974). In this respect, it makes sense to reinterpret the limit cycles in terms of intergenerational inequalities. Moreover, many OLG economies exhibit limit cycles (see Schumacher and Zou, 2008 among others).