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Sustainable economic development and the environment: Theory and evidence

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ABSTRACT

The relationship between growth and pollution is studied through a vintage capital model, where new technologies are more environmentally friendly. We find that once the optimal scrapping age of technologies is reached, an economy may achieve two possible cases of sustainable development, one in which pollution falls and another in which it stabilizes, or a catastrophic outcome, where environmental quality reaches its lower bound. The outcome will depend on countries' investment path and their propensity to innovate in environmentally clean technologies, both of which are likely to differ across economies. Empirical results using long time series for a number of developed and developing countries indeed confirm heterogenous experiences in the pollution-output relationship.

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1. Introduction

Since the seminal paper by Grossman and Krueger (1995) there has been considerable academic interest in the relationship between economic development and environmental pollution. Importantly the authors have shown empirically that the link between these follows an inverted U-shaped pattern, now commonly referred to as the Environmental Kuznets Curve (EKC). This suggests that lower income regions are 'too poor to be green', but as countries become richer they will naturally reduce their generation of pollution, either through reducing production (the so-called scale effect), or by switching to cleaner technologies (referred to as the technique effect) or finally by switching to cleaner sectors (i.e. the composition effect). Several recent studies, however, have put the existence and the exact shape of an EKC into question (Stern, 2004). In view of the recent policy developments, resolving this issue seems of particular importance. More precisely, the recent Kyoto Protocol has set reduction targets for pollutant emissions to which developed countries are expected to commit themselves to, but from which developing countries are at the first instance exempt. This would suggest that policymakers are of the view that wealth on its own does not result in a – possibly sufficient – reduction in pollution, a stance which as of date has not yet been substantiated in the academic literature.

Arguably one of the main reasons for the lack of consensus on the existence of an EKC can be attributed to the fact that the number of theoretical underpinnings is relatively sparse and hence that the mechanisms underlying the link between pollution and development are probably not yet well understood (Dasgupta et al., 2002). The existing papers have borrowed from a broad range of theoretical frameworks to demonstrate the existence of the EKC. For example, Selden and Song (1995) show an inverted U-shaped relationship between pollution and output in a strictly neo-classical framework. Similarly, Brock and Taylor (2010) demonstrate by adding abatements to the standard Solow model that there will be an EKC. John and Pecchenino (1994) and John et al. (1995), in contrast, use overlapping generation models to highlight the same result. In their models, environmental quality declines when consumption levels are low, but given sufficient returns to environmental maintenance, environmental quality eventually improves. Building also on an overlapping generations political ecnomy framework, Jones and Manuelli (2001) have characterized the logistics of the EKC by modeling pollution as an externality where citizens choose between different policy instruments to limit it. Arguably the use of endogenous growth models may be particulary relevant to the understanding of the pollution-output link, since it allows one to lay down the conditions of sustainable economic development. Notably in this regard, Stokey (1998) uses an *Ak* model in order to introduce pollution in an endogenous growth framework and finds that inevitably

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an EKC will arise. Importantly, however, all of the existing models do not consider the decision of when to replace obsolete with newer technologies and how this may affect the pollution output relationship, but instead consider technological adoption to be exogenous. Clearly though, if one assumes, as would be more realistic in most cases, that older technologies are more environmentally unfriendly, then the decision when to scrap these is likely to be an important determinant of the extent of pollution generation.

In the current paper we thus explicitly model how the decision to scrap obsolete technologies affects the relationship between economic development and pollution, thus capturing the technique and scale effect referred to above.[2] In order to do so we build on the Schumpeterian framework of Boucekkine et al. (1997) by introducing a vintage capital structure with exogenous technological progress, which allows us to develop explicit short run trajectory dynamics. The law of motion of environmental quality will depend on the pollution flow and some upper limit on environmental quality that takes into account the exhaustibility of resources.[3] In this context, we diverge from the existing literature on the pollution-output relationship by making the explicit distinction between environmental quality and pollution. Arguably it is important to do so since the very notion of sustainable development refers to some self regeneration capacity of ecosystems, as originally defined by Daly (1990, 1991) and now commonly used by the World Bank (1991a, 1991b). Finally, we explicitly assume that new technologies are more environmentally friendly, allowing us to shed light on the mechanisms through which the environmental quality affects growth performance following technological adoption.

Using our model we show that a reduction in environmental pollution during the industrialization process is only possible when the optimal rate of technological adoption has been reached. However, reaching this point will not necessarily guarantee that pollution decreases. Rather, we identify the three possible outcomes concerning the relationship between pollution and economic development, where these depend on the rate of growth of investment relative to the rate of growth of environmental friendliness of technological improvement. First, there is the case that we term *weak sustainable development* where investment, consumption, and output increase at a constant rate, the level of pollution stabilizes, but environmental quality improves. Second an economy may achieve *strong sustainable development*, where investment, consumption, and output improve at a constant, but lower rate than under the former scenario, while pollution is decreasing. This latter case is what constitutes the EKC. Finally, there may be the case where pollution increases unboundedly and environmental quality reaches its lower bound in finite time, which we refer to as the *catastrophic development*.

Our theoretical predictions have potentially important empirical implications in terms of seeking evidence for the EKC. For one, they suggest that there could be considerable heterogeneity across countries in their pollution–output relationship experience, depending on their relative investment growth rates and the rate at which the environmental friendliness of their technology improves. More precisely, countries may not only differ in the rate and when they reach the point along their development path at which they could potentially reduce their pollutant emissions, but this reduction is not guaranteed. Thus, the shape of the pollution–output relationship can differ widely across countries, so that the use of cross-country panel data sets to seek evidence for the existence of an EKC – a now common practice in the literature – may be flawed. Instead it may be more insightful to study the pollution-outcome link by examining countries individually. Additionally, if one wants to capture the full pattern of how industrialization affects environmental quality in individual countries, one is likely to require long time series data, in order to contemplate our results for the transition period with confidence. As a first attempt in this direction, we thus here use individual long time series on carbon dioxide emissions and an indicator of economic development for a number of developed and developing countries and rely on a nonparametric kernel regression estimator, which places little restriction on the functional form of the relationship between pollution and output. Our results do indeed provide evidence of heterogeneous experiences across the countries examined.

The rest of the paper is organized as follows. A vintage capital model is presented in Section 2. In particular, we proof the existence of a balanced growth path, and show that it can be reached in finite time. In Section 3, the long time series data, the empirical framework, and the econometric results are displayed. A general discussion and conclusions are provided in Section 4.

2. The model

In this section, we first present a standard central planner's vintage capital model,[4] where we add an equation of motion representing environmental quality. We then derive the transition dynamics and the conditions under which a balanced growth path exists. In particular, we are able to fully characterize the optimal scrapping path, which is usually not the case in these types of models.

2.1. A vintage capital structure

Consider an economy with a constant population level, where the labor market is perfectly competitive, and the production sector produces only one final good, which can be assigned to consumption or investment and plays the role of the numeraire.

2.1.1. Production sector

At time $t>0$, per capita output $y(t)$ is assumed to follow a vintage capital rule

$$y(t) = \int_{t-T(t)}^{t} i(z)dz. \tag{1}$$

where $0<T(t)<\infty$ represents the vintage of the oldest machine in use,[5] and $i(z)$ is per capita investment in a machine of age z. Define the life expectancy of a machine as $J(t)=T(t+J(t))$, i.e., the expected life of a machine at time t is equal to the scrapping time $T(\cdot)$, evaluated at $t+J(t)$, which corresponds to the time when this new machine will be scrapped in the future. Furthermore, we assume that $T(0)$ is initial scrapping age and exogenously given.

As can be seen from Eq. (1), we, in contrast to Stokey (1998),[6] do not consider the level of pollution as an input in the production sector. Instead, we allow pollution to enter consumers' utility function. Thus we are assuming that although the firm has the right to pollute, consumers also have the right to refuse buying goods from 'dirty' industries. Consequently, if a good is produced in such an industry, returns to capital will decrease with the employed technology. Hence, the firm is forced to scrap the old dirty machines and replace

[2] Note that given there is only one sector in our macro-model, we cannot capture the composition effect.

[3] The use of vintage capital models, which were launched in the early 1960s' formalize Schumpeter's idea of "creative destruction", have become increasingly popular in the economics literature, see for example, Benhabib and Rustichini (1991), Boucekkine et al. (1997, 1998, 2002), Chari and Hopenhayn (1991), Cooper et al. (1999) and so on, just to mention a few.

[4] The reason we use a vintage capital model lies in the fact that it provides short run trajectory dynamics, while standard aggregate growth models usually do not allow to determine explicit conditions of scrapping rules.

[5] We assume that if one machine is scrapped, it cannot be used again in some other later dates.

[6] We follow Stokey's exogenous technology growth. However, the main difference is that new technology is embodied in new machines. Thus, investment in machines is boils down to invest in a new technology, which is exogenously given. Furthermore, we explicitly determine when it is optimal to scrap old machines, which is impossible within Stokey's framework.

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