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Innovation and the dynamics of global warming

Ralph A. Winter

Sauder School of Business, UBC, Canada

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ABSTRACT

Global warming and the carbon cycle are a dynamic system with positive feedbacks. Fossil fuels are exhaustible resources. These two facts mean that innovation in clean energy technology, rather than mitigating global warming, can lead to a permanently higher temperature path. This paper explores the impact of innovation in the simplest model linking the economic theory of exhaustible resources with positive feedback dynamics in the carbon cycle.

Introduction

The green paradox literature shows that seemingly obvious propositions about climate change policy are often wrong. Commitment to future green policies, whether these policies are carbon pricing or subsidies to the innovation of clean energy technology, tends to *raise* current carbon emissions. The logic of the paradox is familiar: the anticipation of green policies lowers the expected returns from the future sale of fossil fuels and therefore lowers the opportunity cost of selling the fossil fuel today. This reduces fossil fuel prices, increasing the consumption of fossil fuels. Carbon emissions therefore rise instead of falling.

The green paradox is generally framed in terms of the unintended impact of policies.[1] But the idea extends directly to the impact of innovation, whether innovation is influenced by policy or not (Hoel, 2008; van der Ploeg and Withagen, 2012). Consider, for example, a market for energy produced from oil in which the current price is 100 dollar per barrel and extraction costs are low. Suppose that a clean, inexhaustible energy substitute is discovered and becomes immediately available at a cost equivalent to 60 dollars per barrel of oil. The owner of any conventional fuel deposit would prefer to sell at 59.99 or less rather than share the energy market with the substitute. Oil from these deposits will be sold at a lower price and exhausted before clean energy captures any market share at all. With the drop in price, oil will thus be extracted more intensively and exhausted at an earlier date. The current flow of carbon emissions rises as a result of innovation as does the near-term stock of atmospheric green house gases.

E-mail address: ralph.winter@sauder.ubc.ca

[1] Van der Werf and Di Maria (2012) review more than 20 papers about the climate change policy and the green paradox. These authors identify four different policy approaches that may induce a green paradox.

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In the central framework of the green paradox literature, however, innovation in the clean backstop must help the battle against global warming in the long run. The framework includes a market for exhaustible resources with heterogenous extraction costs for fossil and a clean backstop technology. van der Ploeg and Withagen (2012) offer the most in-depth analysis. The discovery of a clean energy substitute at a cost equivalent of 60 dollars per barrel in the van der Ploeg–Withagen model would mean that any fossil fuel with extraction cost greater than this amount would be left in the ground instead of being extracted. While cumulative emissions rise in the short run with innovation because of the decline in oil prices, cumulative emissions necessarily fall in the long run. If the growth in atmospheric green house gases equals cumulative emissions, as it does in the van der Ploeg–Withagen model, innovation must eventually reduce atmospheric green house gases.[2] The message from the green paradox literature, in short, is that the paradox disappears in the long run.

This is far too optimistic a conclusion about the impact of clean-energy innovation. This paper shows that innovation – and any government policy that increases the rate of innovation – can not only raise temperatures in the short run but also set us on a *permanently* higher temperature path.

The proposition is not merely a point of disagreement between theoretical models. As carbon pricing has proved politically impossible in many countries (the U.S., in particular), innovation and development of clean energy sources such as wind and solar energy are emerging as the key strategies in the battle against global warming. The strategy has been supported in the U.S. across a wide range of the political spectrum.[3] The green paradox literature supports this pro-innovation strategy in the sense that it predicts a long run benefit from clean-energy innovation. But in reality, clean-energy innovation – as a naked policy instrument, unsupported by carbon pricing – can lead to runaway global warming.

The argument is simple. I integrate the economic theory of exhaustible resource extraction with the simplest climate dynamics incorporating a fundamental feature of the carbon cycle: positive feedback effects. In reality, as greater atmospheric carbon raises the global temperature, reflective ice-field melt and methane gas is released from melting permafrost (to take just two examples), resulting in a higher *rate* of flow of carbon from the surface to the atmosphere. On the economic side, energy is produced with either carbon-emitting fossil fuels (of heterogenous extraction costs) or perfectly clean energy. Innovation in the model consists of an exogenous shift in the per unit cost of clean energy from b_0 to $b_1 < b_0$. Innovation occurs once and for all, and the probability of innovation in a small time interval dt is $\rho\, dt$, where ρ is an exogenous probability rate. The date of innovation is the only random variable.

These dynamics yield two possible stable steady-state levels of atmospheric carbon and temperature, with an intermediate tipping point. Exceeding the tipping point leads inexorably to the higher steady state temperature, interpreted as “runaway global warming.” Clean energy innovation accelerates carbon emissions through the green paradox effect, which can take the stock of atmospheric carbon above the tipping point. In this model, the long run impact of innovation depends on the innovation date.

The two main results of the theory are illustrated with the aid of Fig. 1. First, the set of innovation dates that lead to runaway global warming is in general not connected. If innovation is realized sufficiently late, in $\Psi_2 \equiv \{t | t \geq t_2\}$ in Fig. 1, then (for the parameter values underlying the figure) low-cost clean energy does not displace enough fossil fuel to avoid atmospheric carbon and temperature crossing the tipping point. Long run temperature converges to the higher steady state value. If innovation is realized early, in $\Psi_1 \equiv \{t | t \leq t_1\}$, then a large stock of remaining fossil fuel and *in situ* carbon is subject to the green paradox effect of lower prices and accelerated emissions. The rapid build up of carbon pushes the atmospheric temperature past the tipping point and again runaway global warming results. The effect of early *realized* innovation I label the ex post long run green paradox. In the intermediate range $t \in (t_1, t_2)$, innovation is late enough that most of the low-cost fossil fuel has already been extracted. The post-innovation price (which must cover extraction costs) therefore remains high and the green paradox effect is weak. Yet enough additional fossil fuel is displaced by the low-cost clean energy that the innovation has the effect of eliminating runaway global warming.

Our second main result is that for a sufficiently low probability rate ρ of innovation, the set Ψ_1 remains, but Ψ_2 can *disappear*. This result captures an ex ante green paradox. The non-empty Ψ_2 at higher values of ρ reflects the lower fossil fuel price that results from the *threat* of innovation. In short, either the early realization of innovation or the mere threat of innovation can lead to runaway global warming.

This is not an anti-clean-energy paper. The possibility of perverse effects of innovation does not mean that optimal policy should limit innovation. The potential negative social impact of innovation, through either the ex post or ex ante green paradox effect, is eliminated through the adjustment of optimal carbon pricing if carbon pricing is adopted. The policy message of this paper is that carbon taxes and innovation subsidies are not *substitute* instruments to battle global warming as is generally assumed. Instead, carbon pricing is even more important with innovation than without. The policy instruments are *complementary*: with carbon taxes, innovation is always valuable whereas without carbon taxes it may or may not be.

[2] The positive long run benefit of innovation in the van der Ploeg–Withagen model clearly generalizes to a more standard assumption of the literature: that green house gas dynamics are described by $\dot{g}^A = e - a g^A$, where g^A is the stock of atmospheric green house gases, e is emissions, and $a > 0$ is the rate of reabsorbtion of gases to the earth's surface.

[3] Consider, for example, the recent joint call by the Brookings Institute and the American Enterprise Institute (a liberal think tank and conservative think tank, respectively) for an increase in clean energy investment from 4 billion to 25 billion annually (Hayward et al., 2010). In the popular press as well, clean energy subsidies have been touted as a superior instrument to carbon taxes (e.g., David Leonhardt, 2010. A climate proposal beyond cap and trade. New York Times, October 12).