Resources Policy 38 (2013) 532–541

Contents lists available at ScienceDirect

Resources Policy

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

Uncertainty in exhaustible natural resource economics: The irreversible sunk costs of Hotelling

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ARTICLE INFO

Article history:
Received 22 August 2013
Received in revised form
10 September 2013
Accepted 10 September 2013
Available online 2 October 2013

Jel classification:
B12
Q32

Keywords:
Hotelling
Sunk cost
Exhaustible resource

ABSTRACT

According to Pindyck (2007) there are three important aspects of uncertainly in environmental economics: (1) the benefits and costs of environmental policy tend to be highly non-linear, (2) environmental policy tends to involve important irreversibilities, where investment in pollution abatement can impose an irreversible, sunk cost on society, and where certain pollutants can stay in the environment forever and build up to cause even more future harm in which case investment in abatement can cause an irreversible, sunk benefit to society, and (3) environmental policy involves long time horizons and yet the discount rate society should use is uncertain for determining the net present value of costs and benefits of pollution abatement. These same uncertainties also affect non-renewable, exhaustible, natural resource economics and in particular the use of the Hotelling rule: (1) the costs, benefits and transversality conditions of using the Hotelling rule can be highly non-linear, (2) the Hotelling rule involves important sunk cost *irreversibilities*, which will be explained here, and (3) the Hotelling rule can involve long time horizons with uncertain discount rates. All three of these problem make it extremely difficult for a market to use in any way the Hotelling rule, yet by the sheer number of articles in non-renewable natural resource economics, one would believe that it is the basis of all resource markets. In this article, we concentrate on the sunk cost *irreversibilities* of using the Hotelling rule. The idea of the Hotelling rule is to optimally store a non-renewable resource, but the optimization is highly dependent on the actual reserves that are available to extract. However, reserves of underground exhaustible resources are often unobservable at the beginning stages of extraction which makes using the Hotelling Rule difficult.

Introduction

An introductory course in non-renewable (exhaustible) natural resource economics is where most students are introduced to the concept of the Hotelling rule. The Hotelling rule states that when a resource is finite, the producers of that resource will try to preserve the resource for the future so that it would not run out too fast merely as a result of profit maximization. Thus markets will automatically maximize the value of that resource for society across all periods of extraction and without any government intervention. See for example Hotelling (1931), Gordon (2009, 1966, 1967), and Devarajan and Fisher (1981). Therefore, it is assumed that the market will work well to maximize society's value of an exhaustible resource. However in the same manner in which Pindyck explains how uncertainties affect environmental economics, so also will uncertainties affect non-renewable natural resource economics, such that the conventional Hotelling rule cannot be used in any meaningful way. This does not imply that markets do not work, or that society should regulate the use of exhaustible natural resources in order to extend their use, rather this article only makes the point that society can never use the Hotelling rule to maximize value without incurring the same kind of sunk cost irreversibilities that Pindyck shows for environmental economics.

As Pindyck notes for environmental economics, the problem is three fold:

1) The benefits and costs of environmental policy are highly non-linear. The costs of imposing small reductions in pollution may be low, but then suddenly those costs can increase substantially as point source reductions are escalated. Likewise pollution may cause no discernible environmental problems for small amounts of emissions, but then after a tipping point, the emissions may cause catastrophic damage. In addition, it is difficult to know how the environment or society will adapt to costs or benefits of pollution policy. This means costs and benefits are extremely uncertain.
2) The costs and benefit of pollution policy have important sunk cost irreversibilities. Since discrete investment in pollution reduction now, including the imposition of emissions fees, causes a reduction

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0301-4207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.resourpol.2013.09.002

in other economic endeavors that could be more valuable to society, then the environmental policy imposes a sunk cost on society that is always lost. Due to the uncertainty of costs and benefits, the sunk costs of lost value cause traditional cost-benefit analysis to be biased toward policy adoption. However, since certain types of pollution can remain in the environment forever and can build up over time, cutting pollution now could have a sunk benefit to society, in which case the irreversibilities of delayed pollution reduction could cause traditional cost benefit analysis to be biased against policy adoption.

3) Since any environmental policy can involve very long time horizons, much longer horizons than businesses deal with, then that can exacerbate the net present value of benefits and costs of current policy, especially since the discount rate that is applicable to environmental policy is extremely uncertain. This makes the uncertainty of the present value of environmental policy very large.

The implication of Pindyck is that it is often better to not undertake any environmental policy other than to cut current pollution that has a current cost-benefit outcome, which is quantifiable and positive to society. These same problems of uncertainty that affect the environment are just as problematic for the Hotelling rule as they are for environmental policy:

1) The benefits and costs of the Hotelling rule are highly non-linear. For example the expected demand for an exhaustible resource, or the expected cost of extracting the resource, may not follow an easily tractable, differentiable function. Costs of extraction may be very low at first, only to become very high after a certain critical point, or *vise versa*, i.e. that extraction can be quite costly at first, only to become very cheap later. The demand for a resource may be volatile and change over time. The backstop technology as Solow (1974) and Simon (1990) suggest may in fact turn out to be at higher or lower cost than expected. Plus any strategy to save or use up a resource is subject to a future adaptation strategy or substitution strategy for society which is unknowable.
2) There are important irreversibilities in using the Hotelling principle as we shall discuss in this article. A particularly problematic scenario is how much reserves there are in the first place. This creates a catch -22 problem: it costs money to quantify reserves of the natural resource, but why pay to quantify reserves that you will not be using for years?
3) The Hotelling rule can involve a very long time horizon much longer than most business time horizons. If the social discount rate that best maximizes a resource value is uncertain, then that can leverage the future values, costs and transversality conditions of extracting the non-renewable resource.

One can argue that uncertainty is always a part of business, and yet businesses seem to overcome that uncertainty and invest anyway, therefore it should be possible for businesses and markets to use the Hotelling rule to some degree and make appropriate investments while taking account of the uncertainties. However, the uncertainties involved with Hotelling are magnitudes greater than what businesses normally deal with and therefore the ability to use Hotelling in any meaningful sense is limited. For example Gordon (1966) shows that changing the interest rate to a perceived (more accurate) low social rate of discount has no discernible effect on saving or using up the reserve and does nothing to increase societies value of the exhaustible resources. Here in this article, we actually go one step further and assume that it is best not to use Hotelling at all or in other words to assume an infinite discount rate and use all exhaustible natural resources as fast as possible.

Note, this does not mean produce a resource as fast as physically possible since certain resources such as oil and natural gas are subject to reserves destruction if the resource is extracted too quickly. See for example Nystad (1988, 1987). It only means produce the resource to maximize value without regard to saving the resource for the future because of the high uncertainty of future costs, values and transversality conditions.

In this article, we will not look at the non-linearity problem of any Hotelling analysis, nor at the uncertainty of the discount rate, but we will concentrate instead on the sunk cost irreversibilities of using Hotelling in regard to the uncertainty of the reserve. In particular the irreversibility of using a resource when the quantity of reserves is uncertain and how that would cause firms not to use the Hotelling rule at all will be looked at. First the literature on Hotelling will be explored, then the nature of what is called the mineral economy based on Ricardo's corn and hardtack economies will be explained. Then an example of how sunk cost irreversibilities in a Ricardo mineral economy model can cause the use of Hotelling to harm society will be shown. Then we will show other example models for using the Hotelling rule in a mineral economy model and finally give some concluding remarks.

The literature review

Devarajan and Fisher (1981) give a 50 year overview of the literature surrounding Hotelling where they suggest that one of the most important characteristics implied by Hotelling and David Ricardo is the idea that non-renewable resources are used up based on costs. It is assumed, especially in Barnett and Morse (1963), that cheap resources are used up first and more expensive resources are used up later. Hotelling suggests as a mine goes deeper, its costs increase. Pindyck (1978) creates a stochastic exploration process based on this concept and shows how mineral prices can first decline and then increase.

However, according to Knight (1921) there is a difference between risk and uncertainty. Risk is like gambling on a roulette wheel, where all the probabilities are known and quantifiable. Uncertainty is where the probabilities of failure or loss are unquantifiable and therefore, you have no idea what to expect. The risks of business are so unknown, that it is impossible to plan for them. Whenever business is conducted, you are dealing with uncertainty rather than risk. This is why business requires such high profits to succeed, and why if there are only small profits, then no one would ever invest. Consider then how the difference between risk and uncertainty play a role in exploration and development of exhaustible resources as well.

When we consider mining, the depth of the mine is not a good proxy for costs. A wide range of factors determine costs of mining such as the richness of the ore, the thickness of the ore's vein, the strength or weakness of the ores surrounding geologic structure, the above ground access to the mine site, the excess quantities of, or lack of, ground and surface water, and environmental considerations. Therefore, mining has the same or more Knightian uncertainty for costs as any business, and there is no way to quantify the costs or risks of mining.

Uhler (1976) goes even further and suggests that there are information effects whereby early exploration effort creates knowledge about where new reserves could be located. However, before the knowledge is created, much effort, and expense, must be exerted to find that knowledge, usually through efforts to find any small reserves of the natural resource. It is this information effect that can help exploration to a degree, but it is also this information effect, i.e. the lack of information, that can make early exploration and extraction very costly. Yet, even today after so much knowledge of the Earth has been gained, nevertheless, there is still much uncertainty about how much gold the world holds.