REAL ENVIRONMENTAL OPTIONS: SOME CLASSICS & CHALLENGES

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Abstract

The history of the development of real environmental options shows how long environment externalities concerns have persisted, and what classical (19th and 20th century) authors proposed. Reviews from Jevons (1871) to Pindyck (2002) cover some of the problems identified, models proposed, plausible empirical applications, and shortcomings. In the 21st century there have appeared hundreds of articles on climate deterioration, plausible reversibility, possible abatements, and alternative energy sources (as solutions). This survey concludes with an introductory review of literature surveys of some of the modelling, presenting challenges for the future.

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I INTRODUCTION

The Victorian economist at the University of Manchester, W. Stanley Jevons, was arguably the first[1] to identify real environmental options, based on stochastic models. “In selecting a course of action which depends on uncertain events, as, in fact, does everything in life, I should multiply the quantity of feeling attaching to every future event by the fraction denoting its probability." [2] But beyond this risk adjustment is the real option value. "By far the greater part of what we hold might be allowed to perish at any moment, without harm, if we could have it re-created with equal ease at a future moment, when need of it arises".[3] For instance, transformation of a public park into a housing development based on net present value methods might be justified, were it possible to reverse the action at little cost in the future.

Real option models are required for realistic, sensible environmental economics and policy evaluation. Implementing these methods faces some typical and some unusual problems of real options: defining the underlying focus and social value, mathematical complexity for realistic contexts, and calibrating the current and future value of environmental measures. Furthermore, since the environment usually involves every one of us in varying degrees, there is the “tragedy of the commons”, requiring cooperative games theory rather than strategic game analysis.

Some early publicity for the topic was one page (Dunbar, 1997) in RISK magazine citing an incomplete Paxson paper on Real Environmental Options. “Where do we buy these options to

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[1] Some economists believe Weisbord (1964) was first, see Saphores and Carr (2000), page 255.

[2] Jevons (1871), p. 36.

[3] Ibid., p. 70.

put on our green page? Can we trade the options? Who holds the patent? What do the options cover? Can we create more options?" were some of the typical questions raised.

Some past masters have been concerned with the intergenerational problem: how much should our current generation consume versus what should be left to future generations. Ramsey (1928) argues that the current value of any economic benefits/costs occurring in the future should be discounted at a single social interest rate, for otherwise, under conditions of certainty, individuals could arbitrage along different periods of time. The objective in Solow (1993) is that "a sustainable path for the national economy is one that allows every future generation the option of being as well off as its predecessors". [4]

It is not that there should be no consumption of exhaustible resources, especially if there are substitutes for the future, but the real option value of resources for the future generations should be maintained over time.[5] Also, it is not that there should be no pollution, especially if there are future investments capable of reducing the pollution stock or at least the rate of emissions, but the social cost of the pollution weighted against the real option value for pollution abatement should be balanced over time.

Plausible categories of climate control where real option models might be relevant are:

I Industrial Pollution and Emissions

II Adaptation to Climate Change

III Abatement

IV Carbon Capture and Storage (CCS)

V Alternative Energy Sources

VI Mechanisms for Changing Climate Impacts

VII Using Real Option Games for Climate Conflicts & Cooperation

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[4] Solow (1993), p. 168.

[5] Predictions of the life of exhaustible resources are not always precise, see Jevons (1865) "I see no prospect of any substitute being found for coal, as a source of motive power", page xl.

Of course, there are overlaps among these categories, for instance CCS is a plausible abatement policy, perhaps motivated by mechanisms such as taxes, credits, subsidies or regulation.

II SOME CLASSICAL ARTICLES

I Pollution and Emissions

Arrow and Fisher (1974) note that previous studies of pollution damages treated a stochastic or probabilistic phenomenon as being deterministic. They compare preservation with development, for instance, preserving a virgin redwood forest for wilderness recreation with opening it up to clear-cut logging, where immediate "undevelopment" is hardly possible. They provide a simple two stage model where the benefits from preservation b_p or development b_d costing c_1 in the first period are compared with benefits β_p or from development β_d in the second period costing c_2. The expected values of net benefits from the first period investment are compared with the second period, assuming there is some probability of occurrence of the net benefits, indicating uncertainty. "Given an ability to learn from experience, underinvestment in development can be remedied before the second period, whereas mistaken overinvestment cannot, the consequences persisting in effect for all time", indicating a quasi-option value.[6] Does this sound like real options, echoing Jevons?

The next two articles illustrate the complexity of attempting to model environmental options without necessarily a host of impractical assumptions. Cortazar, Schwartz and Salinas (1998) provide 14 parameter values for modelling the option to estimate the threshold copper price for extending the output rate of a copper smelter, with pollution constraints (modified by environmental investments). Based on a two-factor input (X=concentrate) and output (S=refined copper) model, the value of the firm must satisfy a partial differential equation (PDE). Assuming $X=(1-\lambda)S$ (λ is a constant spread, thus not looking at a smelter as a variable spread operator), there are six value matching equations and six unknowns (including five option coefficients and the S

[6] Arrow and Fisher (1974), page 317.

threshold justifying a specified extension), with an unspecified[7] "numerical" simultaneous solution for six nonlinear equations. The real option S* is over 3.5 times the net present value solution.

Saphores and Carr (2000) "analyze a model of an environmental pollutant that decays at an exogenous but stochastic rate, and causes social costs that are incurred at a rate that increases quadratically in the level of the pollutant. They show that a small level of uncertainty in the decay process may either advance or delay the timing of an investment that will reduce the pollution rate; however, when the uncertainty is sufficiently high the expected environmental costs become the dominant consideration and it becomes optimal to reduce emissions immediately. Interestingly, the optimal policy when the uncertainty is small is quite different from the deterministic case (when it is zero)."[8]

III Abatement

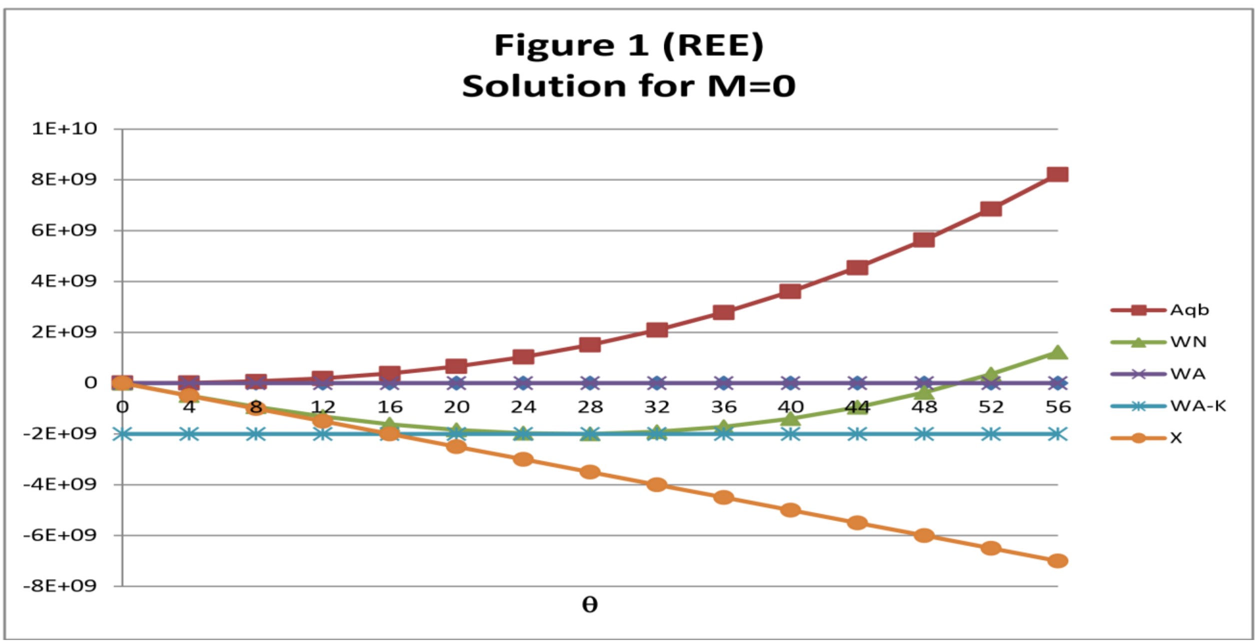
Dixit and Pindyck (1994) (D&P) Chapter 12.2 cite the Herbelot (1992) thesis as the source of their first abatement option model. The US Clean Air Act 1990 required utilities to limit SO_2 per BTU of fuel burnt. Shortfalls in emissions could be sold, excess allowances purchased, or alternatively low-sulfur coal used, or instead the utility could invest in "scrubbers" for high sulfur coal. The price of an allowance and also the spread between high and low sulfur coal are assumed to follow geometric Brownian processes, possibly correlated. There is a PDE for each action. While Herbelot uses a binomial numerical method, D&P suggest an "Exercise for the Reader" ignoring the low value switching option, assuming an infinite life plant, and using a basic one factor model to determine the level of the (traded) emission allowance that would justify installing scrubbers. Edleson and Reinhardt (1995) consider a similar problem and also provide a basic binomial model.

D&P Chapter 12.3, based on an unpublished Pindyck paper, assumes there is a stock of an environmental pollutant M (for instance GHG concentration or the acidity of a lake) which

[7] There are no disclosed numerical results for these coefficients, only the thresholds.
[8] Brennan and Trigeorgis (2000), page 7.

follows a kind of birth[9] and death deterministic process[10]: $dM/dt = \beta E(t) - \delta M(t)$, where β is the absorption degree and δ is the natural decay or dissipation of M over time. The social cost (negative benefit) of M is $B(M, \theta) = -\theta M$, where θ follows a geometric Brownian motion: $d\theta/\theta = \alpha\, dt + \sigma\, dz$. θ is a "variable that shifts over time to reflect changes in taste and technologies, like shifts in new agricultural techniques that reduce the cost of a higher M, or, alternatively, demographic changes that raise the cost". Why does θ follow a gBm, and who measures its constant volatility? This two-factor model $W^N(\theta,M)$ denotes the no-adopt region, and $W^A(\theta,M)$ the adopt region, where by investing K, E is reduced to zero [while there is still a social cost for the existing pollutant stock].

Then the PDEs are subject to the usual boundary conditions, value matching and smooth pasting, and curiously $W^N(0,M)=0$ [if the social cost of the stock of pollutant is nil, there will be no further environmental concerns with this particular pollutant?]. So, the solution takes the usual form where W^N consists of the option to eliminate emissions $A\theta^\beta$ less the perpetual social cost of the pollutant stock less the perpetual social cost of original rate of emissions (see Figure 1).

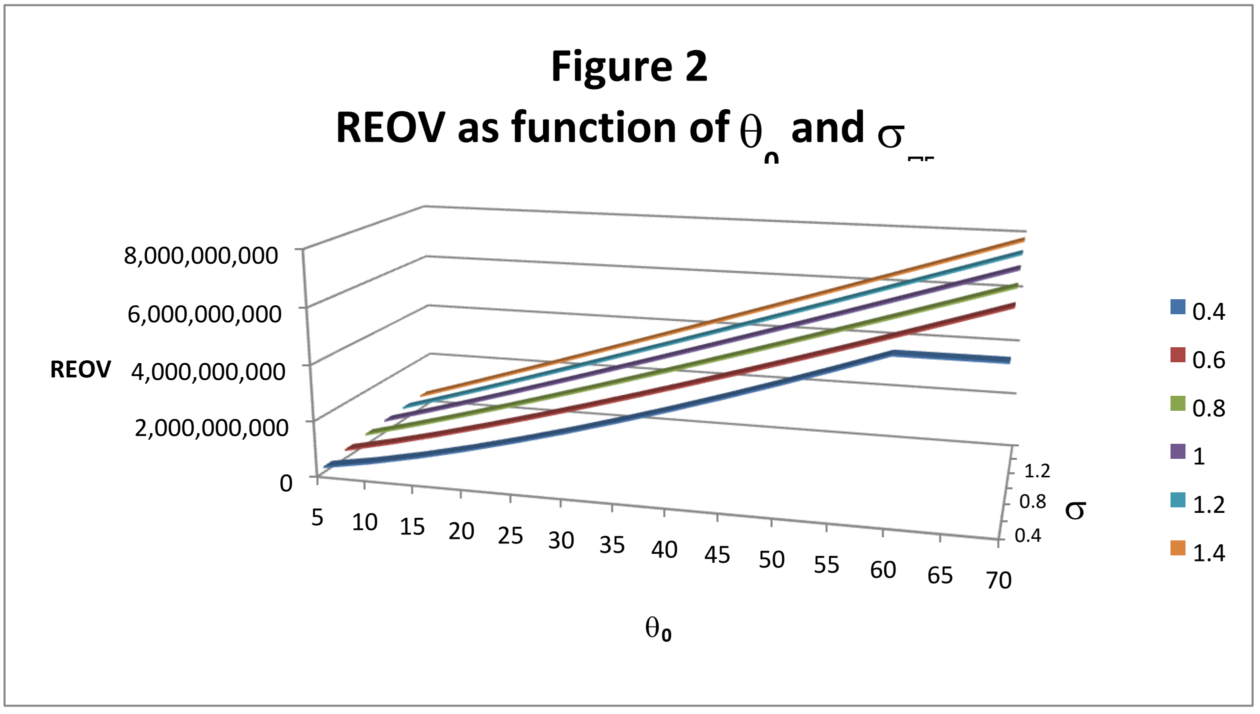


[9] But the rate of emissions E is not dependent on M.

[10] Using the notation of Pindyck (2000), who notes that Hendricks (1992) develops a similar continuous-time model.

[X is the social cost of emissions, since the cost of the pollutant stock appears in both W^N and W^A. Also. in this illustration M=0, so W^A is also nil and not affected by changes in θ.] W^N initially declines as θ increases, since although the option value increases with θ, the social cost of the emissions which are subtracted from the option value also increases].

There is a closed-form solution for θ* ($27 in this figure) which is where W^N=W^A-K. The option to invest in eliminating the rate of emissions is a positive function of θ, and of σ_θ as shown in Figure 2.



Now this makes real environmental options easy. Scientists measure M, E, and the rate of emission absorption plus the natural pollutant decay rate. Then psychologists, social scientists, philosophers and other experts measure the current level of the social costs per unit of M, its drift over time and its expected constant volatility. As they observe θ approaching θ* and identify the required K, governments and world environmental advisors (EPA, EU, UN, ICPP] are notified, and environmental abatement investments are initiated. D&P emphasize this is a simple model just illustrating how option value can arise in public policy problems. For realism, they suggest specifying B(M,θ) as a convex function of M, and also specifying K as a convex function of E.

Pindyck (2000) starts off with the same model, then taking his own earlier advice, considers convex costs and partial reduction in emissions $K= k_1(E_0 - E_1)+k_2(E_0 - E_1)^2$, and also a convex benefit function $B(M,\theta)=-\theta M^2$ so that a higher amount of the pollutant stock even for the same social cost per unit M implies a lower value of θ at which it is optimal to reduce emissions. Also considered are gradual emission reductions; instead of single reduction opportunities, there are multiple investment or reinvestment opportunities.

The major innovation is considering that θ is fixed, but M follows an arithmetic Brownian motion process: $dM = (\beta E - \theta M)dt + \sigma dz$. Pindyck also considers gBm $dM = (\beta E - \delta M)dt + \sigma M dz$, so M could not become negative (but notice the problem of the drift term), but relies on W^A reaching its maximum at M=0, with a convex benefit function. The solution under these assumptions is that the option value is $Be^{\phi M}$ based on value matching and smooth pasting conditions. He concludes that relaxing the assumption of complete irreversibility could be relevant.

Pindyck (JEDC,2002) allows for such a partial reversibility in a simple model and a partial reduction in emissions, but then innovates through a two stochastic factor continuous time model with M (aBm)[11] and θ (gBm). There are two smooth pasting conditions and so uses four equations with four unknowns to solve for θ*(M), that is the social cost per a specific level of stock pollutant that justifies emission reduction investments. For further research, repeated emission-reduction investments should be considered, along with partially reversible investments, and appropriate alternative stochastic processes for M, so a non-zero decay rate could be included in the solution.

Real Environment Option Challenges

There are many additional features (and indeed corrections to the solutions) which have been added to these basic models. There are many other environmental option models such as a

[11] He conveniently assumes M and θ are not correlated, and for a solution that δ=0, and rejects gBm for M, since there is "little empirical support for this…one would expect that unpredictable increases or decreases in M are due largely to under-or over-predictions of emissions levels from various sources, and thus should not depend on the overall level of the pollutant stock", pages 21-22.

plausible pollution abatement mechanism like carbon capture and storage (CCS) (**IV**), where CO2 from coal plants is injected deep into the earth.

There are few (if any) articles on calibrating the current level, drift and volatility of θ, the social cost measure. Availability of any stochastic price and quantity series, such as marketable pollution permits or emissions (if fair trades), would be a suitable basis for calculating the convenience yield and volatilities and correlations. In the past, the available date is infrequent and based on opinions (surveys) or other soft data. Perhaps some observed environmental investments could be used, with some assumed models, to infer implied social cost parameter values, but this would be a joint factor of the particular real option model and the available data.

What is the progress over the 150 years since Jevons? Real environmental option methodology is required for sensible economic policies regarding climate change, clean air, soil and water. We expect specific policy recommendations and specific threshold action indications. We expect estimates on whether the environmental options left to future generations justify our current consumption and environmental policies. Perhaps there is an ambitious research agenda, involving combinations of environmental scientists and philosophers.

III RECENT LITERATURE SURVEYS

There is now a cottage industry of providing surveys of the real options literature, including articles focused on renewable energy and carbon controls, adaptation and emissions. Azevedo and Paxson (2014) survey almost 60 real option game articles, some of which might be appropriate for real environment options where there is competition or cooperation **VII**, both at the macro-level (certain developed countries climate control versus other countries) and micro-level, investments in climate control, adaptation, restitution, GHG absorption for particular industries. Trigeorgis and Tsekrekos (2018) survey the real option publication just in a select group of operational research journals, including many previously presented at various Real Option Group conferences over the years. Agaton (2021) looks at 67 articles on the real options of carbon capture and storage **IV**. Notably seven out of the top eight authors with the greatest number of publications were from China. Nadarajah and Secomandi (2022) survey the operations literature on real option in energy, including some 24 articles on renewables **V**. Naturally, one would expect similar surveys of such articles presented at the Real Option Group conferences over the past decades.

Surely there will be soon (or are) similar surveys of **II** adapting to climate change, and **VI** evaluating the effectiveness of the wide variety of mechanisms, including taxes, credits, allowances, traded emission certificates, funding and broad regulations.

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