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Dynamic optimal control of pollution abatement under emissions permit banking

Shoude Li [*]

Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai 200052, China

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ABSTRACT

In a recent work, Dragone et al. (2010) modeled an optimal control model of pollution abatement, and investigated the adoption of a tax levied on the firm's instantaneous contribution to the accumulation of pollution. In this paper, we extend the work of Dragone et al. (2010) by providing a dynamic optimal control model of pollution abatement with emissions permits banking, where the firm is allowed to purchase, sell and bank emissions permits given a finite planning horizon of length. Our objective is to find the optimal levels of the production, the pollution abatement investment and the quantity of emissions permits bought or sold in continuous time through the use of optimal control theory. We illustrate the results with a numerical example.

1. Introduction

It is widely recognized that tradable emissions permits provide a flexible mechanism for reducing the cost of achieving a wide range of environmental targets. In particular, three features of permit schemes have been highlighted as providing potential cost savings-emissions trading between firms; emissions averaging between firms within firms; and emissions trading through time. In an emissions permits program, the regulatory authority issues a certain number of emissions permits for firms; each firm can legally emit only the level of emissions corresponding to the number of emissions permits it holds. Firms can then buy and sell these emissions permits with one another, creating a market for the emissions permits; firms can also reallocate these emissions permits among different emissions sources within the firm itself. Emissions permit trading usually refers to trade across space in the same period of time, but it can also refer to trade through time, typically by banking, i.e., the possibility of carrying over unused permits from one period for use in a later period. Firms can bank unused emissions permits for use in a future period, or borrow against future emissions permits for use in the present period. Banking and borrowing provide the firms with intertemporal flexibility in meeting their abatement responsibilities.

In recent times, emissions permit banking is becoming an increasingly important feature of emissions trading schemes in practice. For example, in the USA, banking was first allowed under the EPA's emissions trading program in 1979, although initial uptake was slow (Hahn and Hester (1989) reported that fewer than 120 banking transactions had occurred by 1986). More recently, the Acid Rain Program (established under Title IV of the 1990 Clean Air Act Amendments) included a provision for the banking of SO_2 permits and during the first two years of the program's life the number of permits saved for later use has been significantly greater than the number traded intratemporally. At the state level, California's Low-Emission Vehicle Program allows firms to bank permits from 1 year to the next at a 50% discount (Kling and Rubin, 1997). US fuel economy regulations allow automobile producers to save or borrow permits for up to three years (Leiby and Rubin, 2001). A potentially important motive for a firm to bank emissions permits is that it has unexpectedly low emissions in one particular period because the firm has unexpectedly low production or unexpectedly superior equipment performance. Conversely, firms may want to borrow permits from the future when they have unexpectedly high emissions. At an aggregate (market-wide or emissions basin) level, actual emissions can also be unexpectedly low or high. Such uncertainty can lead to excess demand or excess supply for current-period emissions permits that, in the absence of intertemporal trading opportunities, can necessarily yield regulatory violations and an associated enforcement action that is costly to both the government and regulated firms.

Emissions permit banking is implicit in the cumulative emissions permit system described by Tietenberg (1985) where all permits are issued at the start of the planning horizon and then used up gradually over time. More recently, there were a small number of papers that have looked specifically at the efficiency of permit banking. Rubin and Kling (1993) presented an empirical model of emissions trading and banking, quantifying the cost savings from a banking program. The

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[*] Tel.: +86 21 52301194; fax: +86 21 62932982.
E-mail address: sdli@sjtu.edu.cn.

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conclusions from these papers on the desirability of allowing permit banking are mixed. Using a discrete time model, Cronshaw and Kruse (1996) presented a discrete time model of regulated firms in a competitive market for bankable emissions permits, showing that with a competitive market for transferable and bankable emissions permits, the time path (or trajectory) of emissions minimized the present value of total abatement costs for achieving a cumulative emissions target. The cost efficiency of permit banking was confirmed by Rubin (1996) who generalized the result to a continuous time framework, and derived explicit time trajectories for emissions and for permit prices. The results from Cronshaw and Kruse (1996) and Rubin (1996) suggested that a target level of emissions over time can be reached at the lowest present value of cost by allowing banking. This is an intuitive result since allowing banking simply gives firms a greater number of options to use in meeting emissions standards. Kling and Rubin (1997) considered the effects of intertemporal trading on both abatement costs and damages from pollution. The authors described the first best solution to their model and state conditions under which a permit market with completely fungible permits attains this solution. An important implication of their work was that a simple one for one trade may not be the preferred structure for intertemporal permit trading. However, when Kling and Rubin (1997) extended the analysis to consider specifically the welfare efficiency of permit banking, the authors found that in many cases the market equilibrium does not coincide with the socially optimal solution, i.e. the timing of emissions does matter. In order to correct for this divergence, they proposed a modified banking system, under which permits “borrowed” from the future were discounted. Godby et al. (1997) and Mestelman et al. (1999) presented the results of experiments which suggested that banking under uncertainty provides benefits in terms of smoother functioning permit markets. Requate (1998) provided a model of emissions trading under uncertainty that addressed the optimality of banking. The author argued that banking in a world of certainty cannot improve welfare if it was assumed that the regulator has initially allocated the optimal total number of permits per time period according to a social damage function. Yates and Cronshaw (2001) considered the problem of determining the permit discount rate in pollution permit markets in which permits may be traded over time and polluting firms have better information about their abatement costs than does the regulator. The author showed that the preferred permit discount rate may be greater than or less than the money discount rate. Cronshaw and Kruse (1999) designed experiments to study the features of the permit market initiated under the 1990 US Clean Air Act, and found that subjects were able to achieve about two-thirds of the gains theoretically available from banking alone and an additional 39–78% of the potential gains when trading was allowed.

Among environmental economists, there has been a consensus that an ETS is an efficient environmental management system to achieve environmental targets. One important criterion for the evaluation of performance of ETS is their effects on environmental investment. The primary objective of environmental regulation is to correct negative externalities. Jaffe et al. (2002) provided theoretical analysis of the effects of environmental policy on technological change. Many papers were motivated by this to examine the investment effects of ETS (Jung et al., 1996; Millman and Prince, 1989; Montero, 1999; Requate and Unold, 2003).

What has not yet been examined is the effect that allowing the permit banking will have on the incentive to invest in, or adopt, improved pollution abatement technology. Orr (1976) and Kneese and Schultze (1978) suggested that the most important criterion in judging policy tools for controlling pollution emissions is the incentives that they provide for the investment in, or adoption of, new abatement technology. A large literature has developed examining this question for the various static-time pollution control instruments, with the results generally in favor of economic-incentive based methods. Phaneuf and Requater (2002) examined the incentives that firms have to invest in cleaner abatement technology when the banking of permits is allowed in emissions permit trading schemes. The authors showed that under certainty, permit banking can distort incentives for investment and lead to a sub-optimal amount of investment spending. Under imperfect information, aggregate abatement cost uncertainty and investment irreversibility provided arguments for allowing banking. Phaneuf and Requater (2002) provided a two-stage optimization model. The authors' finding was that the banking system unambiguously reduces abatement investment. Without the banking system, the only feasible strategy to reduce future abatement cost would be an investment in cost-reducing abatement technology. However, by allowing banking permits, the firm would be able to use banked permits for future compliance and this reduces environmental incentives. Zhao (2003) presented a real option model to compare the effectiveness of emissions trading scheme (ETS) and the emissions charge system on environmental investment. The author showed that uncertainty on abatement cost reduces firms' investment incentives under both ETS and the emissions charge system, but incentive is less aggravated under ETS. Hojeong (2012) analyzed the investment effects of ETS when emission permits are bankable and there is technological uncertainty with regard to the abatement cost. A real option model was employed to accommodate irreversibility of investment and cost uncertainty. The author argued that in the absence of abatement cost uncertainty, a bankable ETS reduces a firm's incentive for environmental investment. However, when cost uncertainty is prevalent, investment may reduce the opportunity cost of irreversible investment under the banking system, thereby increasing a firm's investment incentive.

In this paper, following the analytical framework of Dragone et al. (2010), we present a dynamic optimal control model of pollution abatement with emissions permit banking. Our objective is to apply optimal control theory to find the optimal levels of the production, the pollution abatement investment and the quantity of emission permits bought or sold such that the firm's monetary payoff is maximized. We illustrate the results of the paper with a numerical example.

The remainder of the paper is structured as follows. The model is laid out in Section 2. The solution of the model is in Section 3. In Section 4 we illustrate the results of the paper with a numerical example. Conclusions are in Section 5.

2. The basic model

We consider a monopolistic single-product firm facing the instantaneous demand function $p(t) = a - q(t)$, where $a > 0$ is the reservation price and $q(t) \in [0, a-c]$ is the output level. The production cost is linear in $q(t)$ with unit cost $c \in (0,a)$. Following Dragone et al. (2010), the production process involves a negative environmental externality $S(t)$ that accumulates according to the dynamics

$$\dot{S}(t) = b(t)q(t) - \delta S(t) \tag{1}$$

where $\delta > 0$ is a constant decay rate. The coefficient $b(t)$ measures the marginal contribution to the stock of pollution that the production of the firm entails. $S(0) = S_0$ and $b(0) = b_0$ are the initial conditions. According to Dragone et al. (2010), the coefficient $b(t)$ is thus a further state variable which has the following form:

$$\dot{b}(t) = -k(t) + \eta b(t) \tag{2}$$

where $\eta > 0$, and $b(t)$ is decreasing in $k(t) \geq 0$, which is the instantaneous R&D effort carried out by the firm. A plausible economic interpretation of $b(t)$ is to see it as the environmental obsolescence rate of technology, measuring the growth rate of the external damage involved by the use of technologies that become increasingly more polluting as time goes by. Let us assume that $\eta < \rho$, here $\rho \geq 0$ is the constant discount rate.