Energy Policy 108 (2017) 624–633

Contents lists available at ScienceDirect

Energy Policy

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

Compliance choice analysis for India's thermal power sector in the market-based energy efficiency regime

Nihar R. Sahoo[a,*], Pratap K.J. Mohapatra[b], Biswajit Mahanty[a]

[a] Indian Institute of Technology Kharagpur, Kharagpur 721302, India
[b] Indian Institute of Technology Bhubaneswar, Bhubaneswar 751013, India

ARTICLE INFO

Keywords:
PAT scheme
Energy efficiency
Decision tree
Investment-decision
Optimal compliance-choice
Indian thermal power plant

ABSTRACT

India has recently introduced a market-based scheme—Perform, Achieve, and Trade—to realize emission reduction by enhancing energy efficiency. In the case of thermal power plants, investment in energy efficiency projects, using clean coal and buying energy saving certificates are the available compliance options for complying with the scheme. These options are associated with specific forms of cash flows that depend on the uncertain price of energy saving certificates and clean coal premium. This paper uses a Monte Carlo-based decision tree approach to find the optimal compliance options for an efficient and a less efficient thermal power plant. The decision tree evaluates different sequences of compliance options in three consecutive PAT cycles by using the discounted cash flows and their associated probabilities. The study shows that investment in energy efficiency is optimal in the first PAT cycle for the inefficient plant only. The threshold certificate price for the efficient plant is substantially higher than the inefficient plant, implying that the real efficiency improvement is likely to take place in the low-efficiency plants. The study also indicates that the investment in high-efficiency plants is not optimal over a wide range of certificate prices and the incremental cost of clean coal.

1. Introduction

India has recently introduced a market-based energy efficiency policy—Perform Achieve Trade—PAT with the primary objective of stimulating investment to enhance energy efficiency in energy-intensive sectors (BEE, 2011; Bhattacharya and Kapoor, 2012). The scheme allows several alternative compliance options in a cost-effective manner. The investment and future cash flows for each compliance option are characteristically different for different industrial units, and the stochastic behavior of market parameters resulting in uncertain compliance cost often stands out as a real challenge for the unit in devising an optimal compliance strategy (Baldursson and Von der Fehr, 2004). In this study, we examine the effect of market uncertainties on compliance choice strategy of Indian thermal power plants obligated under the PAT scheme and suggest a methodology for making an optimal choice for compliance over multiple PAT cycles.

Usually, the compliance options for the PAT-obligated thermal power plants take three forms: (1) investment in energy efficiency projects (Sargent and Lundy, 2009; USDoE, 2010), (2) use of better quality coal at a premium (Khanna and Zilberman, 2001; Zamuda and Sharpe, 2007), and (3) purchasing energy saving certificates (ESC) from the market. In view of uncertainties in certificate price, the incremental price of clean coal (hereafter, we call it *clean coal premium*), and technological output of energy efficiency projects, evaluating the cost-effectiveness of compliance options is difficult. Unfortunately, since PAT is a recently introduced policy, no historical information on the characteristics of PAT-induced uncertainties is readily available, making the task of compliance valuation extremely challenging.

The broad objective of the current research is to find out the optimal compliance options for the thermal power plants over three successive PAT cycles in the face of changing certificate prices and clean coal premiums. The scope of the work is limited to two coal-based thermal power plants—one large and efficient, and the other small and inefficient.

In corporate finance, proper valuation of compliance options are of strategic importance, and traditionally Net Present Value (NPV) with discounted cash flow is used as the criterion for evaluating the alternatives. In the current study, we apply the NPV method in a decision tree framework by leveraging the simplicity of the NPV analysis and the strength of the decision tree approach to make the optimal selection of decision alternatives. The uncertainties are incorporated in Monte-Carlo simulation for risk estimation.

We have considered the case of two thermal power plants obligated

* Corresponding author.
E-mail addresses: nihar54@rediffmail.com (N.R. Sahoo), pkjm@iitbbs.ac.in (P.K.J. Mohapatra).

http://dx.doi.org/10.1016/j.enpol.2017.06.012
Received 7 January 2017; Received in revised form 22 April 2017; Accepted 6 June 2017
0301-4215/

under the PAT scheme (hereafter called the *obligated power plants*) to examine how the threshold of investment in energy efficiency improvement varies with changing values of energy saving certificate (ESC) price and the incremental price for clean coal. We derive the optimal sequence of compliance options over multiple cycles of the compliance period. The results show that the ESC price threshold of investment for energy efficiency (EE) in the case of the less efficient plant is significantly lower than that for the efficient plant, implying that the PAT scheme is likely to stimulate investment in the inefficient plants first. However, for the efficient plant, the investment remains unattractive over a wide range of ESC price and premium to be paid for clean coal.

The remainder of this paper unfolds as follows: Section 2 makes a survey of literature on investment decision under uncertainties in the context of the Indian PAT scheme, and discusses various methods as they are applied to the compliance-choice problem. Section 3 presents the problem background and the compliance-choice dilemma while conceptualising the problem. Section 4 discusses the methodology applied in this study, and Section 5 presents case studies of two thermal power plants, and discusses the implications of the results. Section 6 concludes the paper. The Section 7 discuses the policy implications and indicates the scope for future work in this area.

2. Literature survey

The optimal choice of compliance to a market-based environmental policy is an investment decision problem in a condition of uncertain project outcome. Investment decision, under uncertainties, is a well-researched subject, and investment decision analysis is usually done using (i) the net present value approach, or (ii) a multi-criteria decision-making approach, or (iii) a real options approach (Chang, 2013).

Traditionally cash flows are discounted to determine the net present value of an investment by discounting the future payoffs over the project life-cycle. This approach has witnessed extensive application to the investment decision problems in various fields. More recently, Testa et al. (2015) approached the problem of choosing between alternative investments in agriculture applying NPV analysis. Similarly, Espinoza and Rojo (2015) used a decoupled NPV approach for valuing the investment for a solar power project. In the NPV approach, the uncertainties in the cash flow are incorporated by appropriately adjusting the discount rate representing the risk profile of the investment (Luehrman, 1998). One drawback of the NPV approach is that the information on uncertainties is embedded in the discount rate that remains constant. However, in reality, the risk profile (volatility) of a project evolves over a period of time, and the decision maker chooses an alternative based on the new information of the project environment. This aspect is addressed by Laurikka and Koljonen (2006), who extended the discounted cash flow approach to take into account two real options that adjust the discount rate, for an investment decision problem under emission trading scheme.

Some of the limitations of the discounted cash flow approach in representing risk and valuing managerial flexibility are addressed in decision tree Analysis (Smith and Nau, 1995; Brandão et al., 2005a, 2005b). Decision tree determines the present value of the project with the risk-adjusted discount rate. For example, Herbelot (1994a, 1994b) formulated a compliance-choice problem of Sulphur-dioxide control in the *1990 Clean Air Act Amendment* as a Real Option problem, and solved it numerically, applying binomial decision tree.

However, in the decision tree, the future cash flows are discounted at the same risk-adjusted discount rate. It is argued that use of the same discount rate through all the time periods is not an appropriate representation of managerial flexibility, because, as the future unfolds, the uncertainties resolved, and the decision making is recalibrated, the risk profile of the project does not remain the same (Copeland and Antikarov, 2001). The real options approach, however, overcomes this problem, as the option value derived at different time period represent risk profile at corresponding time periods. On the other hand, the discount rate in option valuation method is derived from a from a perfectly correlated replicating portfolio (Dixit and Pindyck, 1994). However, in reality, it is extremely difficult to obtain a perfectly correlated replicating portfolio.

An alternative to the risk-adjusted discount method is the risk-neutral probability method. In this method, the probability of the outcome is adjusted to the volatility, and the present value is obtained by discounting the future cash flows with the risk-free discount rate (Dixit and Pindyck, 1994; Smith and Nau, 1995; Copeland and Antikarov, 2001). The valuation problem using risk-neutral probability approach can be conveniently represented in a decision tree (Smith and Nau, 1995; Brandão et al., 2005a, 2005b; Smith, 2005), which can be solved using the decision tree software. Smith and Nau (1995) have shown that, if the market opportunities are included and the risk and time preferences are captured, the results of the decision tree are consistent with the results of real options methods. More recently Tan et al. (2009, 2010) have demonstrated that the decision tree may be preferred over real options method, if the risk profile of the project is not highly sensitive to the risk-adjusted discount rate.

For a decision tree formulation, prior determination of the future consequences and their likelihood is a necessity. Although, the uncertain future can be modelled as a as general Brownian motion, considering the limitation of an immature ESC market and the resulting incomplete market information on the stochastic process, the future state of the PAT market can be modelled applying the Monte-Carlo simulation instead (Copeland and Antikarov, 2001; Tan et al., 2009).

Traditionally uncertainties in decision trees are modelled by assigning probabilities to each branch leaving the chance node, or assigning risk neutral probability measures derived from the market data (Tan et al., 2010). Each source of uncertainty can be represented through separate chance node. In the case when sufficient market data is not readily available construction of decision tree has to rely on simulation for assigning probabilities of each source of uncertainty.

Instead of representing each uncertainty as separate chance node, Monte Carlo simulation can be applied to report distribution of uncertainty at each chance node. The advantage of Monte Carlo simulation is that, multiple uncertainties can be represented through a single variable, thus simplifies the decision tree construction to a great extent.

A properly calibrated simulation data can be used in the decision tree of the investment problem. Clarity in modelling, sensitivity analysis and the ability to evaluate sophisticated decision rules are recognized as the advantages of this approach.

3. Problem description

3.1. The PAT scheme

The PAT scheme mandates improvement in specific energy consumption by each obligated plants with reference to a set target within a period of three years (referred to as *one compliance cycle*, or *one PAT cycle*). In a thermal power plant, the specific energy consumption is measured in terms of ‘Heat Rate’, which is defined as the energy required by a power plant to generate one unit of electricity, and is expressed in kcal/kW h (Abbi, 2011). The PAT scheme sets unit-wise targets to reduce the heat rate within a PAT cycle, and the plants, which exceed their targets, earn energy saving certificates. The plants which fail to achieve their targets have to either compensate their shortfalls by purchasing equivalent amounts of ESCs from the firms in the PAT market, or pay penalty. The process of re-setting the targets and improving heat rate continues till the plants operate at a heat rate equal to the design heat rate.

Empirical studies have shown that, by using clean coal, the