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Market Price Minimization of Tradable Pollution Permits to Reduce Pollution

KEYWORDS: tradable pollution permits; Joint Implementation; Clean Development Mechanism; transaction costs; price determination

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ABSTRACT *Market price of tradable pollution permits needs to be minimized to increase the transparency of the price information. This contributes to the increase in the volume of trade in the market by reducing the transaction cost in trading. The trading programme thus becomes more effective in reducing pollution by increase in the volume of trade. Scarce and unpriced resources are efficiently allocated using permit trading technique. Tradable Pollution Permits followed the "Command-and-Control" Approach which was initially used to control pollution. The tradable pollution permits on the other hand, are an instrument which can be used to reduce pollution and at the same time can be traded in the market to gain revenue (Tietenberg, 1985). Tradable Pollution Permits is essentially nothing but "Market mechanism". An efficient distribution of the right to pollute takes place. It was used in US in the Acid rain Programme, Lead Reduction Programme in Gasoline and RECLAIM. The Kyoto Protocol was adopted in 1997 and it came into existence in 2005. Measurement of transaction cost and its impact on the market price in tradable pollution permits is discussed using optimization techniques. The first case is that of a single company social planner and the next case is that of two firms when the information available is asymmetric.*

1.0 INTRODUCTION:

Today, the globe is facing a challenge of Global Warming and pronounced Greenhouse effect and resultant unfavourable Climate change. Increasing amount of carbon dioxide and other greenhouse gases due to pollution from industrial activity are the reasons for global warming and climate change. Tradable pollution permits are an instrument to effectively reduce pollution. Like any other financial instrument, it is traded in markets and the market mechanism works to reduce pollution. Pollution abatement is more effective if the number of instruments traded in the market is high. A proper price signal in the market will ensure that the number of transactions in the market is high. An optimized price can give the price signal in the market which can be achieved by reduction of transaction costs.

Emission trading is used as a technique to efficiently allocate scarce and unpriced resources. The concept of Tradable Pollution Permits was suggested as an alternative to the "Command-and-Control" Approach. The "Command-and-Control" approach simply places a limit on the amount of pollution caused by an entity. The tradable pollution permits on the other hand, are an unconventional instrument which can be used to reduce pollution and at the same time can be traded in the market to gain income (Tietenberg, 1985).

2.0 TRADABLE POLLUTION PERMITS

The concept of Tradable Pollution Permits is based on the "Market mechanism". The right to pollute is efficiently distributed. The Government gives quotas for all the entities to pollute. So, the overall emissions-limit is maintained. Supposing that it costs more to an entity to reduce its emissions and it costs comparatively less for another entity to reduce its emissions. The latter entity can thus reduce its emissions and trade its remaining quotas with the first entity that needs the quotas. The first entity needs quotas because it costs more to reduce its emissions and so it can use those purchased quotas to emit. Thus the right to pollute is efficiently distributed.

This concept has been used over the years in a few programs in US like the Acid rain Programme, RECLAIM and Lead Reduction Programme in Gasoline and also in New Zealand Fisheries License Trading. After initially using them to control industrial air pollution in 1975 in the United States, it is now being used in land-use policies, biodiversity protection, water quality improvement, water quantity trading and so on (Hansjürgens, Antes and Strunz, 2011). The Hydrofluorocarbon phase-out programme adopted by US EPA (Environmental Protection Agency) is expected to slow down global warming by a decade (Tietenberg and Lewis, 2012). The target reductions defined in terms of different greenhouse gases and not just carbon dioxide has caused reduction in compliance costs by around 22 percent (Tietenberg and Lewis, 2012). India started a particulate matter emissions trading system in 2011 which was started as a pilot scheme in three of its states namely – Tamilnadu, Gujarat and Maharashtra. The particulate matter emission trading is actually expected to start during 2013-2014.

The Kyoto protocol is an international agreement linked to the UNFCCC (United Nations Framework Convention on Climate Change) entered into by several nations, mostly the developed ones along with a few countries of Central Europe with a commitment to reduce greenhouse gases in the atmosphere.

2.0.1 Kyoto Protocol

The parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol in 1997 and it entered into force in 2005. Countries of European Union, certain western and central European countries, USA, Russia, Japan, Greenland, Australia and New Zealand agreed to binding targets for emission reductions in two commitment periods. The first commitment period was between 2008 and 2012 and the second commitment period is between 2013 and 2020. This Kyoto Protocol was entered into agreement as a result of an immediate requirement to reduce the amount of greenhouse

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gas emissions in the atmosphere. This agreement was reached keeping in mind the "Common-but-differentiated" responsibilities of nations which holds the developed nations more responsible for the increased pollution levels of greenhouse gases. The six main greenhouse gases in the atmosphere identified by the protocol are: Carbon-dioxide, Methane, Nitrous-oxide, Hydrofluorocarbons, Perfluorocarbons and Sulphur-hexafluoride (United Nations, 1998, *Kyoto Protocol To The United Nations Framework Convention On Climate Change)*. These greenhouse gases are converted into carbon-dioxide equivalents for trading. Four implementation mechanisms are considered under the Kyoto protocol: Bubbles, International Emissions trading (IET), Joint implementation (JI) and Clean development mechanism (CDM). The Annex B parties to the provision in the Kyoto protocol can trade assigned amounts of permits among themselves. From this provision, there emerge three kinds of trading: Trading among countries with domestic emissions trading systems, Trading among countries without domestic emissions trading systems and Trading among countries with and without domestic emissions trading systems.

More countries may ratify the protocol as reaching the goals of the protocol becomes easy and this increases their compliance. It causes across-the-border cost-sharing because it separates the one who pays for control and one who implements control. Thus it is an important instrument for both developing countries and the countries of eastern European under transition. Also, Tradable Pollution Permits help us to involve private capital to reduce pollution. The idea of the use of private capital is critical because there is a common feeling that there is insufficient public capital. It is also an unconventional technique to curb pollution which can reduce the long-term costs by a great measure. A small amount charged on each entitlement could cover the administrative expenses and the revenue obtained through this could also be used to finance cleaner technologies.

2.0.2 Lessons from Previous Trading Programmes

Previous trading programmes give us important lessons to keep in mind while designing national and international trading systems. These become especially important as nations strive to meet their national and international standards. Their design also becomes critical as that determines the transaction costs and the risks and uncertainties involved in trading transactions.

Systems should not become a means of evading international agreements rather than complying with them. For this, sufficient administrative procedures need to be in place. Banking of permits is a feature which gives the entities flexibility. Banking is a feature which allows entities to save their unused permits for future, for instance, the next compliance period, when there is a need for a big investment. The banked permits can then be traded to get some income to contribute to the investment.

The lessons learnt from the past emissions trading programmes show that continuous high-quality monitoring is required for the trading. Some programmes also require that the monitoring systems be frequently tested to ensure reliability. High-quality monitoring is to be done and the results obtained through monitoring are also to be publicized.

Reporting is one of the essential activities which are part of compliance. Many countries are required to report their emissions of pollutants every month. Continuous emissions monitoring makes reporting once in every 15 minutes possible. The structure of allowance trading programme is such that it ensures that the allowances are authentic and also defines a cap for them. Thus it does not require explicit certification. But almost all credit trading programmes require explicit certification.

2.0.3 Monitoring and Verification

Two things have to be monitored: emissions and trading of permits. The national reporting systems of all the parties to the United Nations Framework Convention on Climate Change (UNFCCC) have the responsibilities of monitoring both the above mentioned activities. Each party to the convention would be responsible on its own to track the emissions of greenhouse gases in the same format as prescribed by the conference of the parties. If a party has delegated its authority in trading to private entities, then the list should be mentioned separately in the inventories. All the parties would also report the permit transfers and would verify the ownership of the traded permits. Each party would send its report in the standard format prescribed by the conference of parties to compare the actual emissions with the amount of emissions prescribed by the convention. Then, these are compared with the reports of the different parties to the convention. This reporting is usually done once in a year, even though it could be done more frequently as well if the conference of the parties found it necessary.

An international agency would perform the following functions: (1) Initial acceptance of a country's monitoring system, which authorizes it to participate in the emissions trading. (2) Receipt and review of the reports from the parties to the convention that will have to provide the agency with trustworthy data on their monitoring methods and the results obtained from their monitoring. (3) Regular inspections to make sure that the parties comply with the requirements and they function properly.

The monitoring systems are mostly based on self-reporting. The entities that pollute can themselves provide information on their emissions of pollutants, which could form part of the monitoring activities. This reporting could be done at a lower cost, instead of the case of having a separate monitoring system. Almost every national and international agency for monitoring works on the principle of self-reporting, which is both politically and economically feasible. The primary level of reporting is at the level of the parties to the convention. National level monitoring has been found to be the most effective system so far. The international agency mentioned above could be an agency subsidiary to the conference of the parties.

Different layers of veracity checks help to identify discrepancies in monitored data. The concept of self-reporting presents opportunities for deception, even though some of the critics of self-reporting may overstate it. To ensure integrity, veracity checks are performed at different levels; more frequently at national level and also occasionally at the international level.

Environmental NGOs (Non-governmental organizations) could also play their role as a part of the above mentioned international agency or even in monitoring activities mentioned above. The capacity of the NGOs and these NGOs' access to publicly available information, play a key part in deciding on their role in such activities.

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The collected data through monitoring should be made widely available to promote transparency and ensure integrity. Veracity-checking is much simpler if we have data from multiple sources. A good database is definitely useful when private monitors take part. The allowance tracking model in the Acid rain programme in the US is an example for a free-flowing and transparent reporting. This reporting is openly visible to the public and contributes to effective compliance. Transparency can also be ensured by selling permits in auctions.

2.0.4 Certification and Verification

The credits under Joint Implementation (JI) and Clean Development Mechanism (CDM) require scrutiny and approval before they are traded which results in increased transaction costs according to many popular experts in tradable permits. Hence certification is one way to ensure the authenticity of the transactions and to ensure that the trading activity runs smoothly. The Conference of the Parties acts as the ultimate authority in Certification. It delegates the day-to-day activity of certification of each transaction to a sub-ordinate body.

This certification authority could also be delegated to Government agencies provided they meet the following conditions: 1. Organizational capacity and willingness to take up the certification activity 2. Enabling legislation to ensure the unit is able to take up the responsibility and achieve its goals 3. Ability and willingness to use the standard certification criteria

All the procedures should be designed to accommodate future expansion. The expansion could be in terms of new gases, new parties and different commitment periods.

Certification is followed by verification to assure that the transaction has actually taken place. Certification guarantees in advance that a transaction could take place. Verification actually confirms that a transaction has actually taken place. Whereas certification is ex ante, verification is ex post.

2.0.5 Compliance and Enforcement

The enforcement of compliance is achieved through declaration of non-compliant parties as ineligible for trading and also reducing their assigned quotas in ensuing commitment periods. Enforcement can also be done at the domestic level as well. The effectiveness of enforcements depend on the financial capability, will of the political leaders and legal constraints on the punishments that could be imposed for non-compliance. The main problem with enforcement is found be –deterrence, which is not just the exact opposite of compliance. Transparency can be a tool used to ensure compliance. Self-reporting is the main policy adopted to ensure transparency. Accounting is the remaining aspect that is to be taken care of. Accounting is to be as per the standards and formats required by the convention of the parties.

3.0 PRICE MODEL IN TRADABLE POLLUTION MARKETS USING OPTIMIZATION TECHNIQUES:

3.0.1 Measurement of Transaction Costs:

While our discussion so far has been based on the following premise that JI and CDM transactions could have high transaction costs because they require high-quality monitoring and enforcement through-out their operation along with certification (Tietenberg, 1992), some researchers are not exactly of the same view. They say that the credit transactions in JI and CDM need not necessarily have high transaction costs compared to permit transactions in IET (Woerdman, 2001).

IET is an instrument in which emission reductions are measured top-down. According to Woerdman (2001), the principles, modalities, rules and guidelines for IET are not very clearly defined in the Kyoto protocol. On the other hand, JI and CDM are bottom-up instruments which are flexible and are measured for each project from a baseline (Gaast and Woerdman, 1997). A baseline is a standard. The baseline for a project is the pollution level that would be present in the absence of the project. Additionality is the amount of excess pollution reduction achieved by the project compared to the existing alternative. According to Hahn and Hester (1989), Grubb et al. (1998), Heller (1999), transaction costs are very important to ensure the success of an emissions trading system. According to Arrow (1969), for any case of resource allocation in general, the identification of transaction costs is essential.

3.0.2 Reduction of Transaction costs:

Reduction of transaction costs can be achieved by first measuring it. Something that is measured can be managed. Hence, our discussion focuses on measurement of transaction costs. Dudek and Wiener (1996) define transaction costs as consisting of search costs, negotiation costs, approval costs, monitoring costs, enforcement costs and insurance costs. The Government usually handles monitoring and enforcement costs. There are several other definitions of transaction costs by authors like direct and indirect costs, and fixed and variable costs. Trade tends to be profitable if the price of the permit less the permit value is greater than the transaction cost (Hinchy et al., 1998). Transaction costs tend to reduce when the number of transactions and the transactions from a source increase and vice versa (Stavins, 1995).

Measurement of transaction costs could be ex post or ex ante, that is some of them could be measured before and others could be measured after the transactions take place. If decision-making is yet to be done, then ex ante is more suitable. On the other hand, if an alternative has been already chosen, then ex post measurement is more suitable (McCann et al., 2004).

According to Thompson (1999) and McCann and Easter (1999), transaction costs associated with public policies include the following: (1) research and information costs (2) enactment or litigation costs (3) design and implementation costs (4) support and administration costs (5) contracting costs (6) monitoring or detection costs (7) prosecution or enforcement costs

Hypothesis H: The typology, chronology and measurement methods of transaction costs have been verified in the Exhibits 2, 4 and 5 for the Indian markets.

The typology was verified for the CDM trades at the Indian carbon exchange based on a sample of 37 respondents at Mumbai through convenience sampling using Chi square analysis. The results of this analysis are presented here:

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Exhibit1:

	Chi square	Degrees of freedom	Significance
Research and Information costs incurred by Legislature and Courts	20.162	2	0.000
Research and Information costs incurred by Agencies	23.081	2	0.000
Research and Information costs incurred by Stakeholders	19.676	2	0.000
Enactment or Litigation costs incurred by Legislature and Courts	16.919	2	0.000
Enactment or Litigation costs incurred by Agencies	13.838	2	0.001
Enactment or Litigation costs incurred by Stakeholders	19.514	2	0.000
Design and Implementation costs incurred by Legislature and Courts	29.892	2	0.000
Design and Implementation costs incurred by Agencies	16.919	2	0.000
Design and Implementation costs incurred by Stakeholders	26.811	2	0.000
Support and Administration costs incurred by Legislature and Courts	24.703	2	0.000
Support and Administration costs incurred by Agencies	20.162	2	0.000
Support and Administration costs incurred by Stakeholders	23.730	2	0.000
Contracting costs incurred by Legislature and Courts	16.432	2	0.000
Contracting costs incurred by Agencies	30.216	2	0.000
Contracting costs incurred by Stakeholders	17.568	2	0.000
Monitoring and Detection costs incurred by Legislature and Courts	20.973	2	0.000
Monitoring and Detection costs incurred by Agencies	26.162	2	0.000
Monitoring and Detection costs incurred by Stakeholders	23.543	2	0.000
Prosecution and Enforcement costs incurred by Legislature and Courts	22.108	2	0.000
Prosecution and Enforcement costs incurred by Agencies	16.919	2	0.000
Prosecution and Enforcement costs incurred by Stakeholders	20.973	2	0.000

From the tables above, it is clear that all of them have Chi Square values with significance of less than 0.05. Hence we can say that different actors (agents) incur different amount of costs in each type of transaction cost. The amount of costs they incur: negligible, low or high can be found out from the tables below.

The different costs and who incurs them is given in the following exhibit:

Exhibit2:

Type of transaction cost	Incurred by various actors		
	Legislature/ courts	Agencies	Stakeholders
Research and information	Low	High	Low
Enactment or litigation	High	Low	High
Design and implementation	Negligible	High	Low
Support and administration	Negligible	High	Low
Contracting	Negligible	Low	High
Monitoring/ detection	Negligible	High	Low
Prosecution/ enforcement	Low	High	Low

The above categories of transaction costs are distributed across different stages of the life-cycle of a policy (McCann et al., 2004). McCann et al. also discuss when the transaction costs should be measured, that is ex ante or ex post. The first stage in the life-cycle of a policy is the baseline period, when a lot of awareness about the policy is generated, but the policy is not actually proposed to be implemented. The next stage is the development stage, in which policies are formally proposed, several people speak for it and against it, lobbyists try to work their way and so on. The third stage is the early implementation stage, wherein the administrative rules are designed and staff inducted. The policy is implemented on a short-term basis. The reactions of the people are found, conflicts resolved. In the fourth stage that is full implementation, policies are actually implemented. Markets are formed and trading activity starts to take place. In the final established stage, full-fledged trading takes place. The life-cycle of a policy and when the transaction costs are to be measured for each stage are indicated in the diagram below:

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Exhibit3:
The Chi Square Analysis is presented here:

	Chi Square	Degrees of Freedom	Significance
Research and Information costs incurred during Baseline stage	9.757	1	0.003
Research and Information costs incurred during Baseline stage	19.703	1	0.000
Research and Information costs incurred during Baseline stage	22.730	1	0.000
Research and Information costs incurred during Baseline stage	9.757	1	0.003
Research and Information costs incurred during Baseline stage	11.919	1	0.001
Enactment or Litigation costs incurred during Baseline stage	22.730	1	0.000
Enactment or Litigation costs incurred during Development stage	11.919	1	0.001
Enactment or Litigation costs incurred during Early Implementation stage	9.757	1	0.003
Enactment or Litigation costs incurred during Full Implementation stage	6.081	1	0.020
Enactment or Litigation costs incurred during Established Programme stage	19.703	1	0.000
Design and Implementation costs incurred during Baseline stage	25.973	1	0.000
Design and Implementation costs incurred during Development stage	16.892	1	0.000
Design and Implementation costs incurred during Early Implementation stage	11.919	1	0.001
Design and Implementation costs incurred during Late Implementation stage	22.730	1	0.000
Design and Implementation costs incurred during Established Programme stage	9.757	1	0.003
Support and Administration costs incurred during Baseline stage	9.757	1	0.003
Support and Administration costs incurred during Development stage	14.297	1	0.000
Support and Administration costs incurred during Early Implementation stage	16.892	1	0.000
Support and Administration costs incurred during Full Implementation stage	22.730	1	0.000
Support and Administration costs incurred during Established Programme stage	11.919	1	0.001
Contracting costs incurred during Baseline stage	19.703	1	0.000
Contracting costs incurred during Development stage	14.297	1	0.000
Contracting costs incurred during Early Implementation stage	9.757	1	0.003
Contracting costs incurred during Full Implementation stage	11.919	1	0.001
Contracting costs incurred during Established Programme stage	22.730	1	0.000
Monitoring and Detection costs incurred during Baseline stage	16.892	1	0.000
Monitoring and Detection costs incurred during Development stage	9.757	1	0.003
Monitoring and Detection costs incurred during Early Implementation stage	7.811	1	0.008
Monitoring and Detection costs incurred during Full Implementation stage	22.730	1	0.000
Monitoring and Detection costs incurred during Established Programme stage	11.919	1	0.001
Prosecution and Enforcement costs incurred during Baseline stage	7.811	1	0.008
Prosecution and Enforcement costs incurred during Development stage	19.703	1	0.000
Prosecution and Enforcement costs incurred during Early Implementation stage	11.919	1	0.001
Prosecution and Enforcement costs incurred during Full Implementation stage	16.892	1	0.000
Prosecution and Enforcement costs incurred during Established Programme stage	25.973	1	0.000

As with *Exhibit1*, all the Chi Square values have significance level less than 0.05 (i.e. 5 % Significance level).

The results of the analysis are presented here in *Exhibit4*:

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Exhibit4:

Type of cost	Baseli-ne	Devel-opme-nt	Early Imple-menta-tion	Full Imple-mentat-ion	Establ-ished Progr-am
Resear-ch and informa-tion	yes	yes	yes	yes	yes
Enactm-ent or litigati-on		yes	yes	yes	yes
Design and imple-mentat-ion		yes	yes	yes	
Support and adminis-tration			yes	yes	yes
Contrac-ting				yes	yes
Monito-ring/ detecti-on				yes	yes
Prosecution/ enforce-ment				yes	yes
Transaction cost measure-ement activity	Ex ante measu-rement	Data Collec-tion	Data Collec-tion	Data collect-ion and prelim-nary ex post estimate-es	Finali-zed ex post estima-tes

The results in the above *Exhibits 3 and 4* have been verified with the same respondents as in *Exhibit1* and *Exhibit2*.

According to Williamson (1993), measurement of transaction costs done through indirect methods is generally not complete. Various transaction costs and their measurement techniques have been mentioned. Implicit costs are the costs of opportunity, whereas costs actually spent are explicit costs.

Exhibit5:

Type of cost	Ex ante		Ex post	
	Impl-icit	Expli-cit	Impl-icit	Expli-cit
Research and information	1,2	5	1	1,3,4,5
Enactment or litigation	1,2		1	1,3,4,5
Design and implementati-on	1,2	5	1	1,3,4,5
Support and administrati-on	1,2		1	1,3,4,5
Contracting	1,2	5	1	1,3,4,5
Monitoring/ detection	1,2	5	1	1,3,4,5
Prosecution/ enforcement	1,2	5	1	1,3,4,5

Surveys or interviews of Government personnel and stakeholders

- **ex post results from other studies**
- **Government reports**
- **financial accounts**
- **proposed budgets**

As with *Exhibit2* and *Exhibit 4*, the *Exhibit5 has* also been verified for the Indian markets, even though the chi square analysis values and significance values are not presented here.

Hence, **Hypothesis H** is verified.

Measurement of these costs as mentioned before enables us to manage and reduce them effectively.

3.0.3 Price determination model:
This final section is a review of few works in this area. Initially, the case of a single company: social planner is considered and then the case is extended to the case of two firms under the condition of asymmetric information.

The case of a representative company or a social planner trading:

Let δ_0 be the total number of permits with a company at the initial time. Then,

$\delta_0 = N + X_0$,

Where N is the number of permits allocated to the company and X_0 is the number of permits bought by the company or sold by the company at time 0.

Chesney and Taschini (2011) assume that a firm continuously emits gases according to a stochastic exogenous process over the period [0, T] and so the process follows a geometric Brownian motion. The pollution level 'Q_t' at time 't' is thus given by:

$$(dQ_t / Q_t) = \mu\, dt + \sigma\, dW_t \qquad \text{----------(1)}$$

where μ and σ are respectively the instantaneously constant drift term (trend) and constant volatility term (uncertainty) of the pollution process.

The solution to this differential equation is given by

$$Q_t = Q_0 \exp(\mu - (\sigma^2 / 2)\, t + \sigma W_t)$$

where Q_0 denotes the initial pollution level.

A negative μ implies a lower rate of accumulation of pollution level.

A non-decreasing function that measures the accumulated pollution is needed. Hence, the geometric Brownian motion can be assumed. Hence, we want .

The firm's final cost during the period [0, T] is given by,

$$\text{Max}\{0, (-\delta_0)\} \cdot P \qquad \text{----------(2)}$$

where P is the penalty.

Thus, according to the above equation (2), emission allow-

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ances are similar to option contracts.

The permit spot price is given by

$S0 = k \cdot \exp(-\eta T). [P \cdot \varphi (d\_)],$

where, k is a fraction between 0 and 1 which indicates the effect of transaction cost on the market price, η is the discount rate, P is the penalty rate.

$d\_ = (\ln (Q0 \cdot \Delta t / \boldsymbol{\delta}_0) + (\mu - (\sigma^2/2)). \Delta t)/ (\sigma \cdot \sqrt{\Delta t}),$

where $\varphi (x)$ is the standard cumulative distributive function.

The results are similarly extended for two firms' case under information asymmetry. That is a lag is assumed in getting the other company's permits price information:

The differential equation for the pollution level is given by

$(dQ_{i,t} / Q_{i,t}) = \mu_i \, dt + \sigma_i \, dW_{i,t}$

$\delta_{1,t} + \delta_{2,t} = N$

According to Chesney and Taschini (2011), the price of emission permits for company 1 at time 'T – Δt' is given by:

$S_{T-\Delta t} = k \cdot \exp(-\eta \Delta t) \cdot P \cdot [1 - P^1_{T-\Delta t}],$

Where

$$P^1_{T-\Delta t} = \begin{cases} 0, \text{ if } \geq \delta_{1,T-\Delta t} \text{ or } \geq \delta_{2,T-\Delta t} \\ \varphi (-d_{1,T-\Delta t}) \cdot \varphi (-d^{lag}_{2,T-\Delta t}) \text{ , else} \end{cases}$$

Similarly, expression for company 2 can also be derived.

4.0 CONCLUSION:

Tradable pollution permits are already used by many developed countries to reduce pollution and to distribute scarce resources in general, even though these instruments are in the beginning stages of implementation in few less developed countries. This paper reviews a few studies on transaction costs, and also discusses the importance of measuring transaction costs and managing them in order to reduce them. It also reviews price models using optimization techniques after initially reviewing the fundamentals. More studies in these areas would benefit researchers further.

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