A STUDY OF ENVIRONMENTAL EFFICIENCY IN A MULTI-LEVEL PRODUCTION SYSTEM USING DATA ENVELOPMENT ANALYSIS

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Abstract

Environmental pollution has resulted in global warming, extreme weather conditions, and degradation of ecological balance. National leaders across the globe started to realize that ecological difficulties are transboundary when nations that are affected by serious environmental crises are far away from the source of the problem. However, the growing number of international agreements and treaties testifies that the outlook on the environmental crises is changing. But, the free-rider incentives of non-compliance or participation and disagreement among the nations lead to the failure of the final ratification of the protocols. The divergence of opinions arises mostly in operational details and in the rules for measuring the country's efforts.

Such structural deficiencies can be attributed to a number of serious complications. The policies would have implications for a wide range of stakeholders starting with regulatory bodies, national leadership, firms, and the citizens. Therefore, we take a holistic approach to study socioeconomic problem of such a huge macro-level impact. The environmental efficiency evaluation technique is developed for the individual firm level. The second issue pertaining to the abatement process to reduce the pollution, emission permits are allocated among the firms in a particular industry or nation based on their environmental performance. With the allotted permits, the tendency of the firms to pool the emission permits to generate higher profit is studied using cooperative game theory concepts. A fair evaluation of the efficiency of the production is developed that takes into account the intensity of the external factors affecting the pollution. An ex-post evaluation framework of environmental efficiency that accounts for uncontrollable external factors is developed to provide reliable efficiency scores.

The developed framework in my thesis addresses the issue of measuring and controlling emissions at different levels. The models do not presume any *predefined* functional form of the production systems. Thus, the use of Data Envelopment Analysis (DEA) allows the production frontier to be driven entirely by the existing production mixes. In addition, the underlying principles of linear programming problems in DEA such as duality theorem, shadow price comparison, and sensitivity analysis enable the decision-makers to generate more reliable and robust results. The four essays in this thesis are briefly discussed below.

In the first essay, we have developed an *emission-oriented* production planning mechanism that focuses on emission reduction only, in contrast to the conventional input-oriented approach. The study has also incorporated a two-stage firm structure, which is often the case with the complex corporate and industrial sectors. The overall environmental efficiency is decomposed into stage level efficiencies without sacrificing any of the implications for the overall system. We have shown that technical efficiency and environmental efficiency are complementary only for inefficient firms. The shadow prices of the input and output factors help to assess and compare the respective emission abatement costs to draft the least costly emission reduction plan.

Reduction of the present levels of emission is needed to mitigate environmental degradation. However, the major discontents in international agreements stem from the perceived *inequality* of sharing the responsibility of emission reduction among the signatories. The existing allocation scheme (i.e., grandfathering principle) is primarily based on historical data and may result in worse environmental performance. In order to balance environmental protection, and economic development, we have developed a *reward-based* allocation scheme that credit firms for their effort to curb emission, in the second essay. The proposed model assigns a sufficient number of permits to continue the current production only at the optimal levels of operations. At the same time, the model accounts for the ecological responsibilities e.g., waste disposal, recycling used products, etc., to influence the allocated permits. Therefore, firms can maximize their production either by deploying less-polluting inputs and practices or by diverting their existing resources to augment abatement technologies.

As the emission ceilings are prescribed using the allotted permits, the economies of the signatory countries are feared to shrink. There are also rippling effects of the emission ceilings on capital flow and terms of trade. The third essay investigates a probable *cooperative* coalition among the participating countries. We have assumed that the current state of production in the countries are facing binding abatement targets. We have shown that the game has a *core*. The allocation of the surplus is also based on two aspects of the production system: Resource (emission permits) and Capability (technical efficiency).

In the last essay, we evaluate the production units' *relative* efforts in environmental protection. As long as the permits are generated based on the current state of production technology, the inefficiency in the

production system continues to underplay the abatement targets. Hence imposition of agreements by target setting and compliance do not necessarily ensure emission reduction. If commensurable improvement on emission standards is to be achieved, the leading units need to set the benchmark for the poor performers to follow. However, units face different external factors e.g., politico-economic, socio-cultural differences. Therefore, comparing the outcome of the efforts of a unit that is in a disadvantaged position with that of a unit in a comparably favorable position undermines the performance of the former. Hence, we propose an evaluation system that compares units only within the same range of favorable external settings. In order to account for the unfairness caused by human judgment, linguistic ambiguity, and vagueness, the categorized evaluation is extended to include a fuzzy optimization framework. The results show that several countries register higher performance scores merely due to positive *externalities* and not for superior operational excellence.

The applicability of the developed models is demonstrated using data from production systems of varying scale. Environmental efficiency decomposition is studied by analyzing firm-level data on agricultural products (crops and livestock) and the resultant emission in European countries published by Farm Accountancy Data Network (FADN). Examination of the economic and environmental performance of region-wise Chinese transportation authorities illustrates the usefulness of a reward-based allocation scheme of emission permits that generates *three-fourths* of total profit by emitting only *one-fourth* of the emission as compared to a profit-oriented approach. Existing literature shows that amount of emission is influenced by the level of urbanization. Chinese regional energy efficiency is measured considering urbanization level as a negative externality.