COMPETITIVE DYNAMICS IN EFFLUENT TREATMENT INDUSTRY

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Abstract

As per the Water (Prevention and Control of Pollution) Act, 1974, in India, industries such as textile, leather, paper, etc. are required to treat effluents (wastewater) before disposing it off to the external environment, such as rivers, sea, etc. The Water (PCP) Act, 1974, raises severe concerns regarding the sustainability of small-scale industries (SSIs) as the firms individually lack resources such as adequate capital, manpower, access to land, etc. for establishing their own Independent Effluent Treatment Plants (IETP). Establishing joint wastewater treatment facilities that share the facility among the member-firms, referred to as Common Effluent Treatment Plants (CETP) has evolved as an effective strategy to address these concerns for the firms. Such CETP networks are largely promoted by various government agencies by providing subsidies while defining various operational boundaries. The CETPs are typically preferred by firms over IETPs as scale economies are present in wastewater treatment. Scale economies help in reducing capital expenditure and operational costs for the member firms. On the other hand, empirical evidence suggests that costs associated with the reduction of pollution concentration of the wastewater supplied by the member-firms have diseconomies of scale. Diseconomies of scale increase effluent treatment

costs at the CETP facility. Likewise, a multitude of aspects that exhibit externalities for the participating firms play a significant role in the firms strategic and economic incentives in adopting CETP versus IETP network structure. In this thesis, we build game-theoretic and optimization models to address three critical issues relevant to CETPs.

In the first chapter, we look at the factors which are relevant to the successful adoption and operation of CETPs from a game-theoretic framework. We develop a pre-treatment coordination mechanism to make the CETP effluent treatment process more efficient. Furthermore, we also look at the impact of social network among the CETP member firms on effluent treatment costs post adoption.

In the second chapter, we develop a mixed integer non-linear program for connecting a set of firms to a set of CETPs to minimize the overall cost of installation and treatment of effluents at the cluster level. We solve the problem using a piecewise linearization approach and Bender's partitioning approach. We compare the results obtained by piecewise linearization approach and Bender's partitioning approach with the solution obtained from the monolithic formulation and discuss our results.

In the third chapter, we study collaborative activities among firms in industrial clusters from a CETP perspective. Effective collaboration among firms reduces their production, CETP maintenance and CETP development costs. We depict the collaboration among firms as a network and study it from a strategic network formation and game-theoretic perspective.

Our primary objective in this chapter is to understand the implication of collaboration among firms on supply chains. Our results provide insights into better management and efficient operation of CETPs in industrial clusters. Following are some key insights from the thesis. In the first chapter, the equilibrium profits of firms suggest that the benefit (price/quality-volume) and the cost (pollution/quality-volume) significantly impacts the profits of the firms. We refer to the ratio of benefit and cost as the price/pollution ratio subsequently. We observe that the price/pollution ratio of the firms has a significant impact on the choice of the firms to join a CETP. We observe that firms with similar price to pollution ratio have a greater incentive to become part of the same CETP. We obtain the conditions under which a single CETP is feasible for all the m firms considered. Furthermore, we also observe that in certain cases multiple CETPs may be feasible. Splitting firms into multiple sets each with its own CETP, also changes the equilibrium profits of these firms. Hence, we devise an algorithm which partitions the initial set of m firms into multiple sets such that CETPs become feasible for each set of these firms at equilibria. Furthermore, we devise a pre-treatment mechanism which makes the CETPs more attractive to less-polluting firms. This is because the highly polluting firms which are now part of the same CETP have to reduce the pollution concentration in their effluents before sending it to the CETP for further treatment.

In the second chapter, we observe that popular non-linear commercial solvers are not capable of solving realistic instances of our model. However, our devised Generalized Benders' Partitioning Algorithm performs well with large instances of the problem and is able to give us results in relatively small instances of time. Thus, our model and GBP solution procedure may serve as a way for designing CETPs for upcoming industrial clusters.

In the third chapter, we observe that greater collaboration among downstream firms is beneficial for the upstream firms. However, profits of the upstream firm have a unique minima in the number of links. Thus, benefits of collaboration are realized by the downstream firms only after a certain threshold of collaboration is achieved among them. To facilitate this collaboration Government agencies may want to invest in industrial associations, industry bodies, etc. which can serve as a common platform for downstream players and encourage them to collaborate.

Contents

1 Introduction **14**

1.1 Motivation 14

1.2 Treatment Procedure 16

1.3 CETP Business Model 18

1.4 Research Questions 22

1.4.1 Joint Effluent Treatment (Study 1) 23

1.4.2 CETP Facility Location (Study 2) 24

1.4.3 Sustainable Innovation in Production Clusters (Study 3) 26

2 Joint Effluent Treatment (Study 1) **28**

2.1 Introduction 28

2.2 Literature review 30

2.2.1 Effluent Treatment Costs 30

2.2.2 Collaboration Among Firms For Sustainable Supply Chains 31

2.3 Problem description 32

2.4 Model Building 34
2.4.1 Firm Characteristics 35
2.4.2 Effluent Characteristics & Treatment Costs 39
2.4.3 Game Timeline 43
2.4.4 Utilities 44
2.5 Pre-adoption 45
2.5.1 Feasibility Conditions For CETP Adoption 46
2.6 Impact of Firm Size 55
2.7 Pre-treatment as a Coordination Mechanism 58
2.7.1 Model & Solution Procedure 59
2.7.2 Results 62
2.8 Extensions: Post-Adoption Operational Issues (Network Effects) 66
2.8.1 Network Structure & Efficiency 70
2.9 Conclusion 73

3 CETP Facility Location (Study 2) 77

3.1 Introduction 77
3.2 Literature Review 80
3.2.1 Location-Allocation 80
3.2.2 Effluent Treatment Costs 83
3.3 Problem Description 84
3.4 Mathematical Model 87
3.4.1 Notations 87

3.4.2 MINLP model . . . 89
3.5 Solution Strategy . . . 92
3.5.1 Piece-wise Linear Approximation Solution Approach . . . 92
3.5.2 Bender's Decomposition Based Solution Approach . . . 97
3.6 Computational Analysis . . . 108
3.7 Discussions . . . 112
3.8 Conclusions . . . 113

4 Sustainable Innovation in Production Clusters (Study 3) 115

4.1 Introduction . . . 115
4.1.1 Strategic Network Formation and Stability . . . 118
4.2 Model . . . 121
4.2.1 Firm Characteristics . . . 121
4.2.2 Utilities . . . 124
4.3 Analysis . . . 125
4.4 Optimal Links Among the Downstream Players . . . 129
4.5 Stability . . . 131
4.5.1 Downstream-Stability . . . 131
4.5.2 Downstream Stability Conditions Under Different Network Structures 132
4.5.3 Network Formation & Stability of Local Core-Periphery Structure as Multiple Symmetric/Asymmetric Completely Connected-Stars . . . 136
4.6 Conclusion . . . 142

5 Conclusion & Future Research Directions **144**

5.1 Chapter 1 145

5.2 Chapter 2 147

5.3 Chapter 3 147

5.4 Future Research 149

A Appendix for Chapter 2 **163**

A.1 Pre-Adoption (Proofs) 163

A.2 Pre-treatment (Proofs) 165

A.3 Number of firms (Proofs) 167

B Appendix for Chapter 4 **169**

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