Environmental and Cost Synergy in Supply Chain Network Integration in Mergers and Acquisitions

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Abstract: In this paper, we quantify and assess, from a supply chain network perspective, the environmental effects resulting when a merger or acquisition occurs and the resulting synergy from possible strategic gains. We develop a multicriteria decision-making supply chain network framework that captures the economic activities of manufacturing, storage, and distribution pre and post the merger. The models yield the system optima associated with the minimization of the total costs and the total emissions under firm-specific weights. We propose a synergy measure that captures the total generalized cost. We then apply the new mathematical framework to quantify the synergy obtained for specific numerical examples.

Key words: supply chains, variational inequalities, multicriteria decision-making, environmental concerns, system-optimization, mergers and acquisitions, synergy

1. Introduction

Pollution has major adverse consequences including global warming, acid rain, rising oceanic temperatures, smog, and the resulting harmful effects on wildlife and human health. Firms, in turn, are increasingly realizing the importance of their environmental impacts and the return on the bottom line for those actions expended to reduce pollution (Hart and Ahuja (1996)). For example, 3M saved almost $500 million by implementing over 3000 projects that have reduced emissions by over 1 billion pounds since 1975 (Walley and Whitehead (1994)).

The adoption of advanced pollution abatement technologies can be the result of policy instruments or consumer interests. However, it has been noted that firms in the public eye have not only met, but exceeded, the required environmental mandate (Lyon (2003)). In the United States, over 1,200 firms voluntarily participated in the EPA's 33/50 program, agreeing to reduce certain chemical emissions 50% by 1995 (Arora and Cason (1996)). It has been argued that customers and suppliers will also punish polluters in the marketplace that violate environmental rules. As a consequence, polluters may face lower profits, also called a "reputational penalty," which will be manifested in a lower stock price for the company (Klein and Leffler (1981), Klassen and McLaughlin (1996)). For example, Roper Starch Worldwide (1997) noted that more than 75% of the public will switch to a brand associated with the environment when price and quality are equal; and nearly 60% percent of the public favors organizations that support the environment. It has also been argued that sound environmental practices will reduce risk to the firm (Feldman, Soyka, and Ameer (1997)).

Due to the visibility and the number of mergers and acquisitions that have been occurring it is important to understand and study the synergy results for managerial benefits from an environmental standpoint. In the first nine months of 2007 alone, according to Thomson Financial, worldwide merger activity hit $3.6 trillion, surpassing the total from all of 2006 combined (Wong (2007)). Companies merge for various reasons, some of which include such benefits as acquired technologies and greater economies of scale that improve productivity or cut costs (Chatterjee (1986)).

Successful mergers can add tremendous value; however, with a failure rate estimated to be between 74% and 83% (Devero (2004)), it is worthwhile to develop tools to better predict the potential for creating strategic gains in the form of collusive, financial, and operational synergy (Chatterjee (1986)). Specifically, sources of operational synergy include market power (changes in market share (Brush (1996)) or cost savings effects (Chang (1988), Eccles, Lanes, and Wilson (1999)) that can be measured by evaluating the changes in the equity value of production costs of merging firms (Chatterjee (1986)). The ability of a tool to aid in managerial decisions is dependent on its proper use and deployment so that the merger meets the anticipated value. Thus, it should be noted that a successful merger depends on the ability to measure the anticipated synergy of the proposed merger, if any (cf. Chang (1988)). In particular, it has been argued that the supply chain network structure pre and post a merger is crucial in identifying the operational synergy (cf. Nagurney (2009) and the references therein) associated with mergers and acquisitions. Moreover, Chatterjee (2007) recognized that, based on a survey of academic research, interviews and anecdotal evidence that it is much easier to achieve success regarding mergers and acquisitions when the stated goal of a proposed merger is its potential for cost reduction (than its potential to increase revenue). He further emphasized that, regarding horizontal industry consolidations, there is strong academic evidence that such mergers, which are motivated by capacity reduction, are one of the few merger categories that seem to succeed.

However, with the growing investment and industrialization in developing nations, it is also important to evaluate the overall impact of merger activities at not only the operational level, but also as related to environmental impacts. There is enormous potential for developing countries to adopt cleaner production, given current technologies as well as the levels of private capital investments. For example, between 1988-1995, multinational corporations invested nearly $422 billion worth of new factories, supplies, and equipment in these countries (World Resources Institute (1998)). Through globalization, firms of industrialized nations can acquire those firms in developing nations that offer lower production costs; however, more than not, combined with inferior environmental concerns. As a result of the industrialization of developing countries, the actions taken today will greatly influence the future scale of environmental and health problems.

Farrell and Shapiro (1990) used a Cournot oligopoly model to demonstrate that when synergistic gains are possible through post-merger economies of scale, it is in consumer interests that price does not increase (also see Stennek (2003)). However, Spector (2003) showed that the failure to generate synergies from any profitable Cournot merger must raise prices, even if large-scale entry or the avoidance of a fixed cost is possible. Farrel and Shapiro (2001) also studied synergy effects related to cost savings related to economies of scale, competition, and consumer welfare that could only be obtained post-merger. They specifically claimed that direct competition has an impact on merger-specific synergies. Soylu et al. (2006) analyzed synergy among different energy systems using a multi-period, discrete-continuous mixed integer linear program (see also Xu (2007)). Lambertini and Mantovani (2007) concluded that horizontal mergers can contribute to reduce negative externalities related to the environment. Moreover, according to Stanwick and Stanwick (2002), if environmental issues are ignored the value of the proposed merger can be greatly compromised.

Nevertheless, there is virtually no literature to-date that discusses the relationship between post-merger operational synergy and the effects on the environment and, thus, ultimately, society. We attempt to address this issue from a quantitative perspective in this paper. This paper, towards that end, develops a multicriteria decision-making optimization framework that not only minimizes costs but also minimizes emissions. Multicriteria decision-making has been recently much-explored as related to the transportation network equilibrium problem. For example, Nagurney, Dong, and Mokhtarian (2002) included the weighting of travel time, travel cost, and the emissions generated. For general references on transportation networks and multicriteria decision-making, see Nagurney and Dong (2002). Multicriteria decision-making within a supply chain has assisted in the production and delivery of products by focusing on factors such as cost, quality, and lead times (Talluri and Baker (2002)). Thus, Dong, Zhang, and Nagurney (2002) proposed a supply chain network that included multicriteria decision-makers at each tier of the supply chain, including the manufacturing tier, the retailer tier, and the demand markets.

The proponents for a system view structure of the supply chain, which we utilize in this paper, include the fostering of relationships, coordination, integration, and management in order to achieve greater consumer satisfaction and service reliability, which is necessary to be competitive in the current economic environment (Zsidisin and Siferd (2001)). Sarkis (2003) demonstrated that environmental supply chain management, also referred to as the green supply chain, is necessary to address environmental concerns. For example, the Ford Motor company demanded that all of its 5000 worldwide suppliers with manufacturing plants obtain a third party certification of environmental management system (EMS) by 2003 (Rao (2002)). Thus, in this paper, we provide a system-optimization perspective for supply chains, a term originally coined by Dafermos and Sparrow (1969) in the context of transportation networks and corresponding to Wardrop's second principle of travel behavior with user-optimization corresponding to the first principle (Wardrop (1952)). Nagurney (2006a), subsequently, proved that supply chain network equilibrium problems, in which there is competition among decision-makers within a tier, but cooperation between tiers, can be reformulated and solved as transportation network equilibrium problems.

This paper is built on the recent work of Nagurney (2009) who developed a system-optimization perspective for supply chain network integration in the case of horizontal mergers. In this paper, we also focus on the case of horizontal mergers (or acquisitions) and we extend the contributions in Nagurney (2009) to include multicriteria decision-making and environmental concerns. In particular, in this paper, we analyze the synergy effects associated with a merger, in terms of the operational synergy, that is, the reduction, if any, in the cost of production, storage, and distribution, as well as the environmental benefits in terms of the reduction of associated emissions (if any). This has not been done before in the literature. This paper is organized as follows: the pre-merger supply chain network model is developed in Section 2 (consider, for example, such production chains as Perdue Farms vs. Tyson Foods). Section 2 also includes the horizontally merged (or acquired) supply chain model (see also Rice Jr. and Hoppe (2001)). The method of quantification of the synergistic gains, if any, is provided in Section 3. In Section 4 we present numerical examples and we conclude the paper with Section 5.

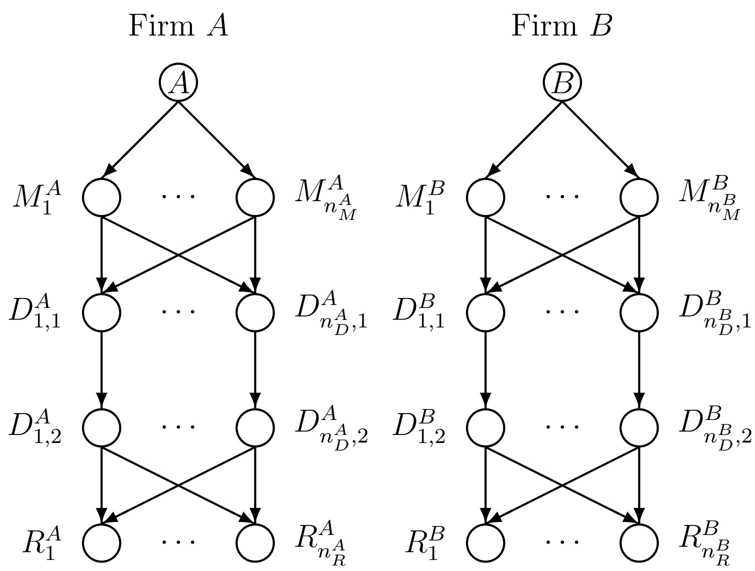

Figure 1: Supply Chains of Firms A and B Prior to the Merger

2. The Pre- and Post-Merger Supply Chain Network Models

This Section develops the pre- and post-merger supply chain network models with environmental concerns using a system-optimization approach. Section 2.1 describes the underlying network of the pre-merger related to each individual firm and their respective activities. Section 2.2 develops the post-merger model. Each firm is assumed to act as a multicriteria decision-maker so as to not only minimize costs, but also to minimize the emissions generated (see also Nagurney, Dong, and Mokhtarian (2002) and references within).

2.1 The Pre-Merger Supply Chain Network Model with Environmental Concerns

We first formulate the pre-merger multicriteria decision-making optimization problem faced by Firm A and Firm B as follows and refer to this model as Case 0. Following Nagurney (2009), we assume that each firm is represented as a network of its economic activities, as depicted in Figure 1. We assume that each firm produces a homogenous product. Each firm i; $i = A, B$, has n_M^i manufacturing facilities/plants; n_D^i distribution centers, and serves n_R^i retail outlets. Let $G_i = [N_i, L_i]$ for $i = A, B$ denote the graph consisting of nodes and directed links representing the economic activities associated with each firm i. Also let $G^0 = [N^0, L^0] \equiv \cup_{i=A,B}[N_i, L_i]$. The links from the top-tiered nodes i; $i = A, B$ in each network in Figure 1 are connected to the manufacturing nodes of the respective firm i, which are denoted, respectively, by: $M_1^i, \ldots, M_{n_M^i}^i$, and these links represent the manufacturing links. These models generalize the framework proposed in Nagurney (2009) to capture the environmental impacts associated with mergers (and acquisitions).

The links from the manufacturing nodes, in turn, are connected to the distribution center nodes of each firm i; $i = A, B$, which are denoted by $D^i_{1,1}, \ldots, D^i_{n_D{}^i,1}$. These links correspond to the shipment links between the manufacturing plants and the distribution centers where the product is stored. The links joining nodes $D^i_{1,1}, \ldots, D^i_{n^i_D,1}$ with nodes $D^i_{1,2}, \ldots, D^i_{n^i_D,2}$ for $i = A, B$ correspond to the storage links. Finally, there are shipment links joining the nodes $D^i_{1,2}, \ldots, D^i_{n^i_D,2}$ for $i = A, B$ with the retail outlet nodes: $R^i_1, \ldots, R^i_{n^i_R}$ for each firm $i = A, B$. Each firm i has its own individual retail outlets where it sells the product, as depicted in Figure 1.

Assume that there is a total cost associated with each link (cf. Figure 1) of the network corresponding to each firm i; $i = A, B$. We denote the links by a, b, etc., and the total cost on a link a by $\hat{c}_a$. The demands for the product are assumed as given and are associated with each firm and retailer pair. Let $d_{R^i_k}$ denote the demand for the product at retailer R^i_k associated with firm i; $i = A, B$; $k = 1, \ldots, n^i_R$. A path is defined as a sequence of links joining an origin node $i = A, B$ with a destination node R^i_k. Let x_p denote the nonnegative flow of the product on path p. A path consists of a sequence of economic activities comprising manufacturing, storage, and distribution. The following conservation of flow equations must hold for each firm i:

$$\sum_{p \in P^0_{R^i_k}} x_p = d_{R^i_k}, \quad i = A, B; k = 1, \ldots, n^i_R, \tag{1}$$

where $P^0_{R^i_k}$ denotes the set of paths connecting (origin) node i with (destination) retail node R^i_k.

Let f_a denote the flow of the product on link a. We must also have the following conservation of flow equations satisfied:

$$f_a = \sum_{p \in P^0} x_p \delta_{ap}, \quad \forall p \in P^0, \tag{2}$$

where $\delta_{ap} = 1$ if link a is contained in path p and $\delta_{ap} = 0$, otherwise. Here P^0 denotes the set of *all* paths in Figure 1, that is, $P^0 = \cup_{i=A,B;k=1,\ldots,n^i_R} P^0_{R^i_k}$. Clearly, since we are first considering the two firms prior to any merger the paths associated with a given firm have no links in common with paths of the other firm. This changes (see also Nagurney (2009)) when the mergers occur, in which case the number of paths and the sets of paths also change, as do the number of links and the sets of links, as described in Section 2.2.

The path flows must be nonnegative, that is,

$$x_p \geq 0, \quad \forall p \in P^0. \tag{3}$$

We group the path flows into the vector x.

The total cost on a link, be it a manufacturing/production link, a shipment/distribution link, or a storage link is assumed to be a function of the flow of the product on the link; see, for example, Nagurney (2009) and the references therein. Hence, we have that

$$\hat{c}_a = \hat{c}_a(f_a), \quad \forall a \in L^0. \tag{4}$$

We assume that the total cost on each link is convex, is continuously differentiable, and has a bounded second order partial derivative. Assumptions of convexity and continuous differentiability are common in the economics literature regarding production cost functions (see, e.g., Gabay and Moulin (1980), Friedman (1982), Tirole (1988) and the references therein). Further more due to increasing congestion such assumptions are also reasonable regarding the transportation/shipment links (see Dafermos and Sparrow (1989)). A special case of the total cost function (4) that satisfies the above assumptions is a linear, separable function, such that $\hat{c}_a = h_a f_a$ for h_a nonnegative (see also Nagurney (2008)).

We also assume that there are nonnegative capacities on the links with the capacity on link a denoted by u_a, $\forall a \in L^0$. This is very reasonable since the manufacturing plants, the shipment links, as well as the distribution centers, which serve also as the storage facilities can be expected to have capacities, in practice.

We assume, as given, emission functions for each economic link $a \in L^0$ and denoted by e_a, where

$$e_a = e_a(f_a), \quad \forall a \in L^0, \tag{5}$$

where e_a denotes the total amount of emissions generated by link a in processing an amount f_a of the product. We assume that the emission functions have the same properties as the total cost functions (4) above. We now discuss the units for measurement of the emissions. We propose the use of the carbon equivalent for emissions, which is commonly used in environmental modeling and research (Nagurney (2006), Wu et al. (2006)), as well as in practice as employed by the Kyoto Protocol (Reilly et al. (1999)), to aid in the direct comparison of environmental impacts of differing pollutants. Emissions are typically expressed in a common metric, specifically, in million metric tons of carbon equivalent (MMTCE) (USEPA (2005)).

It is reasonable to assume that the amount of emissions generated is a function of the flow on the associated economic link (see, for example, Dhanda, Nagurney, and Ramanujam (1999) and Nagurney, Qiang, and Nagurney (2008) and the references therein).

Since the firms, pre-merger, have no links in common (cf. Figure 1), their individual cost minimization problems can be formulated jointly as follows:

$$\text{Minimize} \quad \sum_{a \in L^0} \hat{c}_a(f_a) \tag{6}$$

subject to: constraints (1) – (3) and

$$f_a \leq u_a, \quad \forall a \in L^0. \tag{7}$$

In addition, since we are considering multicriteria decision-making with environmental concerns, the minimization of emissions generated can, in turn, be expressed as follows:

$$\text{Minimize} \quad \sum_{a \in L^0} e_a(f_a) \tag{8}$$

subject to: constraints (1) – (3) and (7).

We can now construct a weighted total cost function, which we refer to as the generalized total cost (cf. Fishburn (1970), Chankong and Haimes (1983), Yu (1985), Keeney and Raiffa (1992), Nagurney and Dong (2002)), associated with the two criteria faced by each firm. The term α_{ia} is assumed to be the price that firm i would be willing to pay for each unit of emission on link a. This term, hence, represents the environmental concern of firm i associated with link a. A higher α_{ia} denotes a greater concern for the environment. Specifically, for notational convenience and simplicity, we define nonnegative weights associated with the firms $i = A, B$ and links $a \in L_i$, as follows: $\alpha_{ia} \equiv 0$ if link $a \notin L_i$ and $\alpha_{ia} = \alpha_i$, otherwise, where α_i is decided upon by the decision-making authority of firm i. Consequently, the multicriteria decision-making problem, pre-merger, can be expressed as:

$$\text{Minimize} \quad \sum_{a \in L^0} \sum_{i=A,B} \hat{c}_a(f_a) + \alpha_{ia} e_a(f_a) \tag{9}$$

subject to: constraints (1) – (3) and (7).

Note that the optimization problem above is equivalent to each firm solving its multicriteria decision-making problem independently. Observe that this problem is, as is well-known in the transportation literature (cf. Beckmann, McGuire, and Winsten (1956), Dafermos and Sparrow (1969)), a *system-optimization* problem but in *capacitated* form and with multicriteria decision-making; see also Patriksson (1994), Nagurney (2000, 2006b), and the references therein. Under the above imposed assumptions, the optimization problem is a convex optimization problem. If we further assume that the feasible set underlying the problem represented by the constraints (1) – (3) and (7) is non-empty, then it follows from the standard theory of nonlinear programming (cf. Bazaraa, Sherali, and Shetty (1993)) that an optimal solution exists.

Let $\mathcal{K}^0$ denote the set where $\mathcal{K}^0 \equiv \{f | \exists x \geq 0, \text{ and} \, (1) - (3) \, \text{and} \, (7) \, \text{hold}\}$, where f is the vector of link flows. Also, associate the Lagrange multiplier β_a with constraint (7) for link a and denote the associated optimal Lagrange multiplier by β_a^*. This term may also be interpreted as the price or value of an additional unit of capacity on link a. We now provide the variational inequality formulation of the problem.

Theorem 1

The vector of link flows $f^{*0} \in \mathcal{K}^0$ is an optimal solution to the pre-merger problem if and only if it satisfies the following variational inequality problem with the vector of nonnegative Lagrange multipliers β^{*0}:

$$\sum_{a \in L^0} \sum_{i=A,B} [\frac{\partial \hat{c}_a(f_a^*)}{\partial f_a} + \alpha_{ia} \frac{\partial e_a(f_a^*)}{\partial f_a} + \beta_a^*] \times [f_a - f_a^*] + \sum_{a \in L^0} [u_a - f_a^*] \times [\beta_a - \beta_a^*] \geq 0,$$

$$\forall f \in \mathcal{K}^0, \forall \beta_a \geq 0, \forall a \in L^0. \qquad (10)$$

Proof: See Bertsekas and Tsitsiklis (1989) and Nagurney (1999).

2.2 The Post-Merger Supply Chain Network Model with Environmental Concerns

We now formulate the post-merger case, referred to as Case 1, in which the manufacturing facilities produce the product and then ship it to any distribution center and the retailers can obtain the product from any distribution center. Since the product is assumed to be homogeneous, after the merger the retail outlets are indifferent at which manufacturing plant the product was produced. Figure 2 depicts the post-merger supply chain network topology. Note that there is now a supersource node 0 which represents the merger of the firms with additional links joining node 0 to nodes A and B, respectively.

The post-merger optimization problem is concerned with total cost minimization as well as the minimization of emissions. Specifically, we retain the nodes and links associated with network G^0 depicted in Figure 1 but now we add the additional links connecting the manufacturing plants of each firm and the distribution centers and the links connecting the distribution centers and the retailers of the other firm. We refer to the network underlying this merger as $G^1 = [N^1, L^1]$. We associate total cost functions as in (4) and emission functions as in (5) with the new links. We assume, for simplicity, that the corresponding functions on the links emanating from the supersource node are equal to zero.

A path p now (cf. Figure 2) originates at the node 0 and is destined for one of the bottom retail nodes. Let x_p now in the post-merger network configuration given in Figure 2 denote

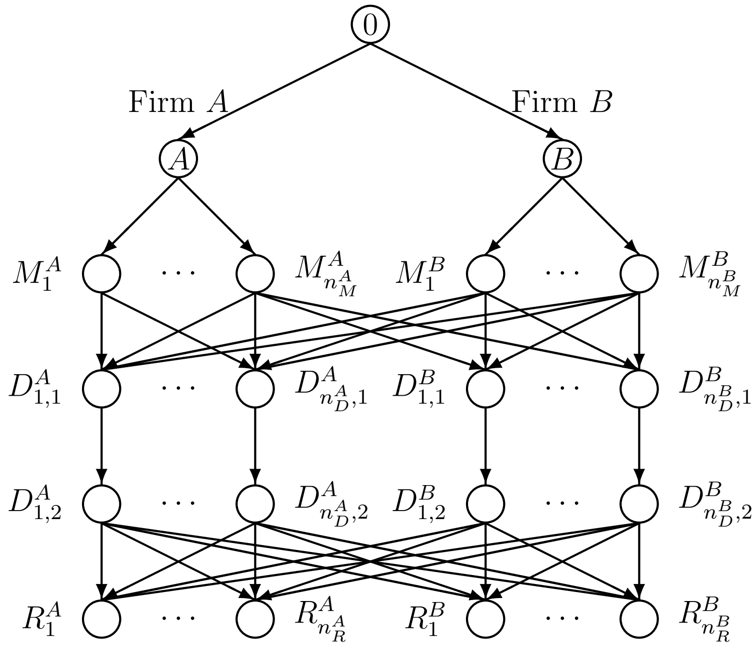

Figure 2: Supply Chain Network after Firms A and B Merge

the flow of the product on path p joining (origin) node 0 with a (destination) retailer node. Then the following conservation of flow equations must hold:

$$\sum_{p \in P^1_{R^i_k}} x_p = d_{R^i_k}, \quad i = A, B; k = 1, \ldots, n^i_R, \tag{11}$$

where $P^1_{R^i_k}$ denotes the set of paths connecting node 0 with retail node R^i_k in Figure 2. Due to the merger, the retail outlets can obtain the product from any manufacturing plant and any distributor. The set of paths $P^1 \equiv \cup_{i=A,B;k=1,\ldots,n^i_R} P^1_{R^i_k}$.

In addition, as before, we let f_a denote the flow of the product on link a. Hence, we must also have the following conservation of flow equations satisfied:

$$f_a = \sum_{p \in P^1} x_p \delta_{ap}, \quad \forall p \in P^1. \tag{12}$$

Of course, we also have that the path flows must be nonnegative, that is,

$$x_p \geq 0, \quad \forall p \in P^1. \tag{13}$$

We assume, again, that the links representing the manufacturing activities, the shipment, and the storage activities possess nonnegative capacities, denoted as u_a, $\forall a \in L^1$. This can be expressed as

$$f_a \leq u_a, \quad \forall a \in L^1. \tag{14}$$

We assume that, post-merger, the weight associated with the environmental emission cost minimization criterion is denoted by α and this weight is nonnegative. This is reasonable since, unlike in the pre-merger case, the firms are now merged into a single decision-making economic entity and there is now a single weight associated with the emissions generated.

Hence, the following multicriteria decision-making optimization problem must now be solved:

$$\text{Minimize} \quad \sum_{a\in L^1} [\hat{c}_a(f_a) + \alpha e_a(f_a)] \tag{15}$$

subject to constraints: (11) – (14). Note that L^1 represents all links in the post-merger network belonging to Firm A and to Firm B.

There are distinct options for the weight α and we explore several in Section 4, in concrete numerical examples. Specifically, in the case that the merger/acquisition is an environmentally hostile one, then we may set $\alpha = 0$; in the case that it is environmentally conscious, then α may be set to 1; and so on, with α being a function of the firms' pre-merger weights also a possibility.

The solution to the post-merger multicriteria decision-making optimization problem (15) subject to constraints (11) through (14) can also be obtained as a solution to a variational inequality problem akin to (10) where now $a \in L^1$, α is substituted for α_i, and the vectors: f, x, and β have identical definitions as before, but are re-dimensioned/expanded accordingly. Finally, instead of the feasible set $\mathcal{K}^0$ we now have $\mathcal{K}^1 \equiv \{f|\exists x \geq 0, \text{ and } (11)-(14) \text{ hold}\}$. We denote the solution to the variational inequality problem governing Case 1 by f^{*1}, β^{*1}. We now, for completeness, provide the variational inequality formulation of the Case 1 problem. The proof is immediate.

Theorem 2

The vector of link flows $f^{*1} \in \mathcal{K}^1$ is an optimal solution to the post-merger problem if and only if it satisfies the following variational inequality problem with the vector of nonnegative Lagrange multipliers β^{*1}:

$$\sum_{a\in L^1} [\frac{\partial \hat{c}_a(f_a^*)}{\partial f_a} + \alpha \frac{\partial e_a(f_a^*)}{\partial f_a} + \beta_a^*] \times [f_a - f_a^*] + \sum_{a\in L^1} [u_a - f_a^*] \times [\beta_a - \beta_a^*] \geq 0,$$

$$\forall f \in \mathcal{K}^1, \forall \beta_a \geq 0, \forall a \in L^1. \tag{16}$$

Finally, we define the total generalized cost TGC^0 associated with Case 0 as the value of the objective function in (9) evaluated at its optimal solution f^{*0} and the total generalized cost TGC^1 associated with Case 1 as the value of the objective function in (15) evaluated at its optimal solution f^{*1}. These flow vectors we obtain from the solutions of variational ienqualities (10) and (16), respectively. In the next Section, we discuss how we utilize these two total generalized costs to determine the strategic advantage or synergy associated with a merger/acquisition. In addition, we define TE^0 as the total emissions generated under solution f^{*0}; TE^1 as the total emissions generated under solution f^{*1}, and TC^0 and TC^1 the corresponding total costs. Due to the similarity of variational inequalities (10) and (16) the same computational procedure can be utilized to compute the solutions. Indeed, we utilize the variational inequality formulations of the respective pre- and post-merger supply chain network problems since we can then exploit the simplicity of the underlying feasible sets $\mathcal{K}^0$ and $\mathcal{K}^1$ which have a network structure identical to that underlying system-optimized transportation network problems. In particular, in Section 4, we apply the modified projection method of Korpelevich (1977) embedded with the equilibration algorithm of Dafermos and Sparrow (1969) (see also Nagurney (1993)) to solve all the numerical examples.

3. Quantifying Synergy Associated with Multicriteria Decision-Making Firms with Environmental Concerns in Mergers/Acquisitions

The synergy associated with the total generalized costs which captures both the total costs and the weighted total emissions is denoted by $\mathcal{S}^{TGC}$ and is defined as follows:

$$\mathcal{S}^{TGC} \equiv [\frac{TGC^0 - TGC^1}{TGC^0}] \times 100\%. \tag{17}$$

We can also measure the synergy by analyzing the total costs pre and post the merger (cf. Eccles, Lanes, and Wilson (1999) and Nagurney (2009)), as well as the changes in emissions. For example, the synergy based on total costs and proposed by Nagurney (2009), but not in a multicriteria decision-making context, which we denote here by $\mathcal{S}^{TC}$, can be calculated as the percentage difference between the total cost pre *vs* the total cost post merger:

$$\mathcal{S}^{TC} \equiv [\frac{TC^0 - TC^1}{TC^0}] \times 100\%. \tag{18}$$

The environmental impacts related to the relationship between pre and post merger emission levels can also be calculated using a similar measure as that of the total cost. Towards that end we also define the total emissions synergy, denoted by $\mathcal{S}^{TE}$ as:

$$\mathcal{S}^{TE} \equiv [\frac{TE^0 - TE^1}{TE^0}] \times 100\%. \tag{19}$$

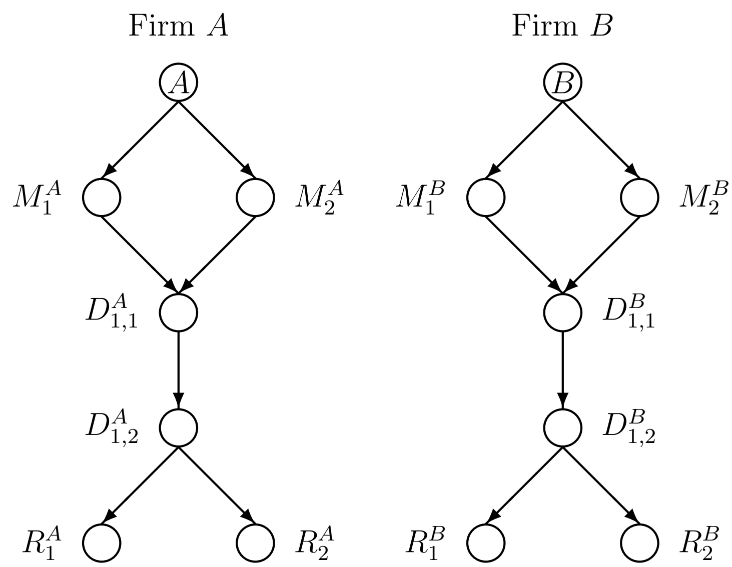

Figure 3: Pre-Merger Supply Chain Network Topology for the Numerical Examples

4. Numerical Examples

In this Section, we present numerical examples in which we utilize the synergy measures defined in Section 3. We consider Firm A and Firm B, as depicted in Figure 3 for the pre-merger case. Each firm owns and operates two manufacturing plants, M_1^i and M_2^i, one distribution center, and provides the product to meet demand at two retail markets R_1^i and R_2^i for $i = A, B$. Figure 4 depicts the post-merger supply chain network. The total cost functions were: $\hat{c}_a(f_a) = f_a^2 + 2f_a$ for all links a pre-merger and post-merger in all the numerical examples below, except for the links post-merger that join the node 0 with nodes A and B. By convention, these merger links had associated total costs equal to 0. The definition of the links and the associated emission functions for all the examples are given in Table 1. The modified projection method embedded with the equilibration algorithm was implemented in Matlab, and the computer system used was an IBM system at the University of Massachusetts Amherst. The solutions to the numerical examples are given in Table 2 for the pre-merger case and in Table 3 for the post-merger case. The synergy calculations are presented in Table 4.

Table 1: Definition of the Links and the Associated Emission Functions for the Numerical Examples

Link a	From Node	To Node	Ex. 1,4: $e_a(f_a)$	Ex. 2,3: $e_a(f_a)$
1	A	M_1^A	$10f_1$	$5f_1$
2	A	M_2^A	$10f_2$	$5f_2$
3	M_1^A	$D_{1,1}^A$	$10f_3$	$5f_3$
4	M_2^A	$D_{1,1}^A$	$10f_4$	$5f_4$
5	$D_{1,1}^A$	$D_{1,2}^A$	$10f_5$	$5f_5$
6	$D_{1,2}^A$	R_1^A	$10f_6$	$5f_6$
7	$D_{1,2}^A$	R_2^A	$10f_7$	$5f_7$
8	B	M_1^B	$10f_8$	$10f_8$
9	B	M_2^B	$10f_9$	$10f_9$
10	M_1^B	$D_{1,1}^B$	$10f_{10}$	$10f_{10}$
11	M_2^B	$D_{1,1}^B$	$10f_{11}$	$10f_{11}$
12	$D_{1,1}^B$	$D_{1,2}^B$	$10f_{12}$	$10f_{12}$
13	$D_{1,2}^B$	R_1^B	$10f_{13}$	$10f_{13}$
14	$D_{1,2}^B$	R_2^B	$10f_{14}$	$10f_{14}$
15	M_1^A	$D_{1,1}^B$	$10f_{15}$	$5f_{15}$
16	M_2^A	$D_{1,1}^B$	$10f_{16}$	$5f_{16}$
17	M_1^B	$D_{1,1}^A$	$10f_{17}$	$10f_{17}$
18	M_2^B	$D_{1,1}^A$	$10f_{18}$	$10f_{18}$
19	$D_{1,2}^A$	R_1^B	$10f_{19}$	$5f_{19}$
20	$D_{1,2}^A$	R_2^B	$10f_{20}$	$5f_{20}$
21	$D_{1,2}^B$	R_1^A	$10f_{21}$	$10f_{21}$
22	$D_{1,2}^B$	R_2^A	$10f_{22}$	$10f_{22}$

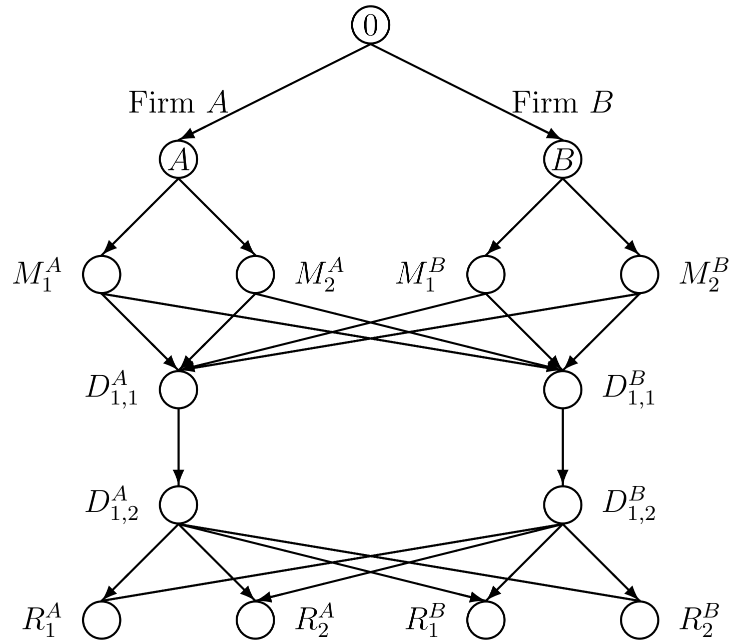

Figure 4: Post-Merger Supply Chain Network Topology for the Numerical Examples

Table 2: Pre-Merger Solutions to the Numerical Examples

Link a	From Node	To Node	Ex. 1 - 4: f_a^*
1	A	M_1^A	5.00
2	A	M_2^A	5.00
3	M_1^A	$D_{1,1}^A$	5.00
4	M_2^A	$D_{1,1}^A$	5.00
5	$D_{1,1}^A$	$D_{1,2}^A$	10.00
6	$D_{1,2}^A$	R_1^A	5.00
7	$D_{1,2}^A$	R_2^A	5.00
8	B	M_1^B	5.00
9	B	M_2^B	5.00
10	M_1^B	$D_{1,1}^B$	5.00
11	M_2^B	$D_{1,1}^B$	5.00
12	$D_{1,1}^B$	$D_{1,2}^B$	10.00
13	$D_{1,2}^B$	R_1^B	5.00
14	$D_{1,2}^B$	R_2^B	5.00

Example 1

The demands at the retailers for Firm A and Firm B were set to 5 and the capacity on each link was set to 15 both *pre* and *post* merger. The weights: $\alpha_{ia} = \alpha_i$ were set to 1 for both firms $i = A, B$ and for all links $a \in L^0$. Thus, we assumed that each firm is equally concerned with cost minimization and with emission minimization. The pre-merger solution f^{*0} for both firms had all components equal to 5 for all links except for the storage links, which had flows of 10. The associated β^{*0} had all components equal to 0, since the flow on any particular link did not meet capacity. The total cost was 660.00, the total emissions generated was 800.00 and the total generalized cost was 1460.00.

Post-merger, for each firm, the cost and emission functions were again set to $\hat{c}_a(f_a) = f_a^2 + 2f_a$ and $e_a(f_a) = 10f_a$, respectively, including those links formed post-merger. The demand at each retail market was kept at 5 and the capacity of each link, including those formed post-merger, was set to 15. The weight α, post-merger, was set to 1. The solution is as follows; see also Table 3. For both firms, the manufacturing link flows were 5; 2.5 was the shipment between each manufacturer and distribution center, 10 was the flow representing storage at each distribution center, and 2.5 was the flow from each distribution/storage center to each demand market. The vector of optimal multipliers, β^{*1}, post-merger, had all its components equal to 0. The total cost was 560.00, the total emissions generated were 800.00, and the total generalized cost was 1360.00. There were total cost synergistic gains, specifically, at $S^{TC} = 15.15\%$, yet no environmental gains, since $S^{TE} = 0.00\%$. Additionally, the total generalized cost synergy was: $S^{TGC} = 6.85\%$.

Example 2

Example 2 was constructed from Example 1 but with the following modifications. Pre-merger, the emission functions of Firm A were reduced from $e_a(f_a) = 10f_a$ to $e_a(f_a) = 5f_a$, $\forall a \in L^0$. Hence, Firm A now is assumed to produce fewer emissions as a function of flow on each link than Firm B. Additionally, pre-merger, the environmental concern of Firm B was reduced to zero, that is, $\alpha_{Ba} = 0$, for all links a associated with Firm B, pre-merger. Hence, not only does Firm A emit less as a function of the flow on each link, but Firm A also has a greater environmental concern than Firm B. Pre-merger, the optimal solution f^{*0} was identical to that obtained, pre-merger, for Example 1. The total cost was 660.00, the total emissions generated were 600.00, and the total generalized cost was 860.00. The components of β^{*0} were the same as in Example 1.

Post-merger, the emission functions of Firm A were as above and $e_a(f_a) = 5f_a$, on all links formed post-merger, and emanating from the original Firm A; the analogous links for Firm B had emission functions $e_a(f_a) = 10f_a$. We assumed an amicable merger. In particular, post-merger, we assumed that $\alpha = 0.5$. The optimal flow from node A to each manufacturer was 5.83, the optimal shipment from each original A's manufacturer to original A's distribution center was 3.12, while the distribution to B's distribution center was 2.71. Storage for Firm A possessed a flow of 10.83 and A shipped from its own distribution/storage center to its own as well as the retail markets of Firm B in the amount of 2.71. For Firm B, the optimal flow from node B to its manufacturing facilities was 4.17, with a shipment to its own distribution center of 1.87, and 2.29 to A's distribution center. The flow at B's original distribution/storage center was 9.17. Finally, the flow shipped from the original B to each retail outlet from its distribution/storage center was 2.29. The total cost was now 566.22, the total emissions generated were equal to 574.98, and the total generalized cost was now 853.71.

Thus, the synergies were: $S^{TC} = 14.21\%$ for the total cost; $S^{TE} = 4.23\%$ for the total emissions, and $S^{TGC} = 0.82\%$ for the total generalized cost. We can see that, as compared to Example 1, that even though cost synergies decreased by 0.94%, the total emission synergies increased by 4.23%, and the total generalized cost synergy decreased by 6.12%. In the event of an amicable merger between firms that have different environmental concerns and, thus, activities to reduce emissions, there was an increase in emission synergy. There was, nevertheless, a tradeoff between operational synergy gains with environmental benefits. As environmental benefits are increased, operational synergy decreased, even though, not quite as significantly as the environmental gains to society. However, it is interesting to note that the total generalized cost synergy decreased even more drastically than the environmental gains which signifies the influential effect environmental concerns had on the objective of the firm *pre* and *post* merger.

Example 3

Example 3 was constructed from Example 2 but with the following changes. We now assumed that the merger was hostile, but with Firm B as the dominant firm, that is, the post environmental concern will be like that of Firm B. Hence, $\alpha = 0$. The pre-merger results are the same as in Example 2, and now we describe the post-merger results. The flows were symmetric for each original firm, with a flow of 5 from each manufacturer, a shipment of 2.50 to each distribution center with a flow of 10 in the storage center, and a product shipment of 2.50 to each retail outlet.

The total cost was 560.00, the total emissions generated were 600.00, and the total generalized cost was 560.00. Thus, the synergy results were 15.15% for the total cost, 0.00% for the total emissions, and 34.88% for the total generalized cost. It is of notable interest that the total cost synergy and the total emission synergy are identical to those obtained for Example 1. However, the total generalized cost synergy in this example was significantly higher. In Example 1, both firms showed concern for the environment *pre* and *post* merger, with $\alpha_{Aa} = \alpha_{Ba} = 1$, for all links a associated with Firm A and Firm B pre-merger; in this example, Firm B showed no concern for the environment pre-merger, and as the dominant firm, post-merger, $\alpha = 0$. So even though there was no benefit, environmentally, and no difference in total cost, there were significant gains in terms of the total generalized cost of the merged firm.

Example 4

Example 4 was constructed from Example 1 but with the following modifications. Pre-merger, we assumed that Firm A is environmentally conscious, that is $\alpha_{Aa} = 1$ for firm $i = A$ and for all links a associated with Firm A, while Firm B does not display any concern for the environment, that is, $\alpha_{Ba} = 0$ for all its links. Additionally, we now assumed that the merger was hostile with Firm A as the dominant firm, that is, Firm A imposes its environmental concern on Firm B. We assumed that, post-merger, $\alpha = 1$. The pre-merger optimal flows are the same as in Example 1. The total cost was 660.00, the total emissions generated were 800.00, and the total generalized cost was 1060.00.

The post-merger results were as follows. The optimal link flows were identical to those obtained for Example 3, post-merger. The total cost was 560.00, the total emissions generated were 800.00, and the total generalized cost was 1360.00. The synergy results were: 15.15% for the total cost; 0.00% for the total emissions, and -28.30% for the total generalized cost. When the dominant firm in the proposed merger was more concerned with the environmental impacts, the overall total generalized cost synergy was the lowest. This example illustrates the importance of not only demonstrating concern for the environment but also to take action in order to reduce the emission functions.

Table 3: Post-Merger Solutions to the Numerical Examples

Link a	From Node	To Node	Ex. 1: f_a^*	Ex. 2: f_a^*	Ex 3: f_a^*	Ex. 4: f_a^*
1	A	M_1^A	5.00	5.83	5.00	5.00
2	A	M_2^A	5.00	5.83	5.00	5.00
3	M_1^A	$D_{1,1}^A$	2.50	3.12	2.50	2.50
4	M_2^A	$D_{1,1}^A$	2.50	3.12	2.50	2.50
5	$D_{1,1}^A$	$D_{1,2}^A$	10.00	10.83	10.00	10.00
6	$D_{1,2}^A$	R_1^A	2.50	2.71	2.50	2.50
7	$D_{1,2}^A$	R_2^A	2.50	2.71	2.50	2.50
8	B	M_1^B	5.00	4.17	5.00	5.00
9	B	M_2^B	5.00	4.17	5.00	5.00
10	M_1^B	$D_{1,1}^B$	2.50	1.87	2.50	2.50
11	M_2^B	$D_{1,1}^B$	2.50	1.87	2.50	2.50
12	$D_{1,1}^B$	$D_{1,2}^B$	10.00	9.17	10.00	10.00
13	$D_{1,2}^B$	R_1^B	2.50	2.29	2.50	2.50
14	$D_{1,2}^B$	R_2^B	2.50	2.29	2.50	2.50
15	M_1^A	$D_{1,1}^B$	2.50	2.71	2.50	2.50
16	M_2^A	$D_{1,1}^B$	2.50	2.71	2.50	2.50
17	M_1^B	$D_{1,1}^A$	2.50	2.29	2.50	2.50
18	M_2^B	$D_{1,1}^A$	2.50	2.29	2.50	2.50
19	$D_{1,2}^A$	R_1^B	2.50	2.71	2.50	2.50
20	$D_{1,2}^A$	R_2^B	2.50	2.71	2.50	2.50
21	$D_{1,2}^B$	R_1^A	2.50	2.29	2.50	2.50
22	$D_{1,2}^B$	R_2^A	2.50	2.29	2.50	2.50

Table 4: Synergy Values for the Numerical Examples

Example	1	2	3	4
TC^0	660.00	660.00	660.00	660.00
TC^1	560.00	566.22	560.00	560.00
S^{TC}	15.15%	14.21%	15.15%	15.15%
TE^0	800.00	600.00	600.00	800.00
TE^1	800.00	574.98	600.00	800.00
S^{TE}	0.00%	4.23%	0.00%	0.00%
TGC^0	1460.00	860.00	860.00	1060.00
TGC^1	1360.00	853.71	560.00	1360.00
S^{TGC}	6.85%	0.73%	34.88%	−28.30%

4.1 Additional Examples

In addition, in order to explore the impacts of improved technologies associated with distribution/transportation we constructed the following variants of the above numerical examples. We assumed that the pre-merger data were as in Examples 1 through 4 as were the post-merger data except that we assumed that the emission functions associated with the new "merger" links were all identically equal to 0. The post-merger link flow solutions are given in Table 5 and the synergy computations in Table 6 for these additional four examples.

The synergies computed for this variant of Examples 1 through 4 suggest an inverse relationship between total cost synergy and emission synergy. It is also interesting to compare the results for the variants of Example 1 and Example 4 in Table 6. Despite the fact that they both have identical total cost and total emission synergies, their respective total generalized cost synergies are, nevertheless, distinct. This can be attributed to the difference in concern for the environment pre- and post-merger.

Table 5: Post-Merger Solutions to the Variant Numerical Examples

Link a	From Node	To Node	Ex. 1,4: f_a^*	Ex. 2: f_a^*	Ex. 3: f_a^*
1	A	M_1^A	5.00	5.62	5.00
2	A	M_2^A	5.00	5.62	5.00
3	M_1^A	$D_{1,1}^A$	0.00	2.08	2.50
4	M_2^A	$D_{1,1}^A$	0.00	2.08	2.50
5	$D_{1,1}^A$	$D_{1,2}^A$	10.00	10.83	9.99
6	$D_{1,2}^A$	R_1^A	0.00	1.77	2.50
7	$D_{1,2}^A$	R_2^A	0.00	1.77	2.50
8	B	M_1^B	5.00	4.37	5.00
9	B	M_2^B	5.00	4.37	5.00
10	M_1^B	$D_{1,1}^B$	0.00	1.04	2.50
11	M_2^B	$D_{1,1}^B$	0.00	1.04	2.50
12	$D_{1,1}^B$	$D_{1,2}^B$	10.00	9.17	9.99
13	$D_{1,2}^B$	R_1^B	0.00	1.35	2.50
14	$D_{1,2}^B$	R_2^B	0.00	1.35	2.50
15	M_1^A	$D_{1,1}^B$	5.00	3.54	2.50
16	M_2^A	$D_{1,1}^B$	5.00	3.54	2.50
17	M_1^B	$D_{1,1}^A$	5.00	3.33	2.50
18	M_2^B	$D_{1,1}^A$	5.00	3.33	2.50
19	$D_{1,2}^A$	R_1^B	5.00	3.65	2.50
20	$D_{1,2}^A$	R_2^B	5.00	3.65	2.50
21	$D_{1,2}^B$	R_1^A	5.00	3.23	2.50
22	$D_{1,2}^B$	R_2^A	5.00	3.23	2.50

Table 6: Synergy Values for the Variant Numerical Examples

Example	1	2	3	4
TC^0	660.00	660.00	660.00	660.00
TC^1	660.00	578.46	560.00	660.00
S^{TC}	0.00%	12.35%	15.15%	0.00%
TE^0	800.00	600.00	600.00	800.00
TE^1	400.00	376.03	450.00	400.00
S^{TE}	50.00%	37.33%	25.00%	50.00%
TGC^0	1460.00	860.00	860.00	1060.00
TGC^1	1060.00	766.47	560.00	1060.00
S^{TGC}	27.40%	10.88%	34.88%	0.00%

5. Summary and Concluding Remarks

In this paper, we presented a multicriteria decision-making framework to evaluate the environmental impacts associated with mergers and acquisitions. The framework is based on a supply chain network perspective, in a system-optimization context, that captures the economic activities of a firm such as manufacturing/production, storage, as well as distribution. We presented the pre-merger and the post-merger network models, derived their variational inequality formulations, and then defined a total generalized cost synergy measure as well as a total cost synergy measure and a total emissions synergy measure. The firms, pre-merger, assigned a weight representing their individual environmental concerns; post-merger, the weight was uniform.

We presented several numerical examples, which, although stylized, demonstrated the generality of the approach and how the new framework can be used to assess apriori synergy associated with mergers and acquisitions and with an environmental focus. Specifically, we concluded that the operating economies (resulting from greater economies of scale that improve productivity or cut costs) may have an inverse impact on the environmental effects to society depending on the level of concern that each firm has for the environment and their joint actions taken to reduce emissions.

To the best of our knowledge, this is the first paper to quantify the relationships associated with mergers and acquisitions and possible synergies associated with environmental emissions. With this paper, we can begin to further explore numerous questions associated with mergers and acquisitions, environmental synergies, as well as industrial organization. For example, we note that this paper has focused on horizontal mergers, as was also the case in Nagurney (2009). Additional research is needed to evaluate the possible synergy associated with vertical integrations and the impacts on the environment. We expect that related issues will be especially relevant to the electric power industry and the associated supply chains. Of course, application of the models and measures in this paper to real-world practical settings is also of importance. We plan to pursue empirical applications in the future.

Finally, we emphasize that environmental emissions may have a very strong *spatial* component (see also, e.g., Dhanda, Nagurney, and Ramanujam (1999) and the references therein). Therefore, extensions of the models in this paper to an explicit spatial dimension would also be worthwhile.

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