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Timing and eco(nomic) efficiency of climate-friendly investments in supply chains

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ABSTRACT

Emission trading schemes such as the European Union Emissions Trading System (EUETS) attempt to reconcile economic efficiency with ecological efficiency by creating financial incentives for companies to invest in climate-friendly innovations. Using real options methodology, we demonstrate that under uncertainty, economic and ecological efficiency continue to be mutually exclusive. This problem is even worse if a climate-friendly project depends on investing in of a whole supply chain. We model a sequential bargaining game in a supply chain where the parties negotiate over implementation of a carbon dioxide (CO_2) saving investment project. We show that the outcome of their bargaining is not economically efficient and even less ecologically efficient. Furthermore, we show that a supply chain becomes less economically efficient and less ecologically efficient with every additional chain link. Finally, we make recommendations for how managers or politicians can improve the situation and thereby increase economic as well as ecological efficiency and thus also the eco-efficiency of supply chains.

1. Introduction

The emission of greenhouse gases (GHG), for example, CO_2, NO_x, or CH_4, has been identified as a key driver of global warming. As global warming is expected to have fatal consequences at economic, ecologic, and social levels, it is necessary to reduce GHG emissions so as to prevent or at least reduce global warming. To date, several companies and states have set themselves the goal of reducing their own CO_2 emissions. For example, Wal-Mart recently announced its goal to eliminate 20 million metric tons of GHG emissions from its global supply chain by 2015 and the U.S. retailer Tesco plans to have its carbon–neutral supply chain in place by 2050 (Caro et al., 2011). Moreover, some firms explicitly attempt to offset not only their own emissions but also the emissions from all other firms involved in the supply chain.[1] The concept of eco-efficiency as an operational measure allows reporting a supply chain's economic performance per unit of environmental impact and thus makes it possible to compare companies and entire supply chains (Schaltegger, 1998). For example, the British low-cost-carrier EasyJet has successfully increased its eco-efficiency from 8.9 passenger-kilometers per emitted kilogram of CO_2 in 2001 to 11.8 passenger-kilometers per emitted kilogram of CO_2 in 2010.[2] Nevertheless, its Irish competitior Ryanair still shows a higher eco-efficiency of approximately 13.8 passenger kilometers per emitted kilogram of CO_2.[3] However, such proactive environmental awareness is rare and predominately driven by the threat of being punished by either customers or the government. Most companies need direct financial incentives to invest in climate-friendly projects. To this end, governments use different environmental policies, for example, cap-and-trade systems like the European Union Emission Trading System (EUETS) or environmental taxes to induce firms to mitigate emissions and thus improve their eco-efficiency.

The above examples make it abundantly clear that greening the supply chain is only possible through the joint efforts by multiple parties, rather than by single companies. Presently, however, there is a lack of in-depth research on two highly pertinent issues. First, when do firms optimally invest in emission mitigating strategies given uncertainty in emission allowance prices? And, second, how is timing affected by the structure of the supply chain?

The remainder of the paper is organized as follows. Section 2 provides a brief overview of related literature in the field of supply chain management and game theory with particular focus on real options. Section 3 presents an n-echelon supply chain model under the assumption that the costs saved by investing in a CO_2 saving

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[1] For example, the Brazilian company Natura Cosméticos has a zero-emission strategy and offsets not only its own emissions, but also any remaining emissions of all supply chain participants (Caro et al., 2011).

[2] http://2011annualreport.easyjet.com/corporate-responsibility/environment.aspx.

[3] http://www.ryanair.com/doc/about/ryanair_brighter_planet_2011.pdf.

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project are proportional to a random spot price for emission allowances and that investment timing is the result of a sequential bargaining game. Section 4 summarizes the numerical results of the comparative-static analysis; Section 5 discusses possible coordination policies that can further improve the economic and ecological efficiency of the supply chain. Section 6 concludes.

2. Literature review

2.1. Green supply chain management

As illustrated by the reviews of Seuring and Müller (2008), Schaltegger and Csutora (2012), and Dekker et al. (2012), the management of green supply chains is becoming a ''hot'' topic. It is now taken for granted that the management of green supply chains goes beyond classic supply chain management. Issues such as product life extension, product end of life, and recovery processes at product end of life, to name just a few, are critical to the success of greening a supply chain.[4] As noted by Benjaafar et al. (2010, p. 3), however, ''there is a need for model-based research that extends quantitative models.'' To date, attempts to guide the decision-making processes of managers focus on single firm decisions that are affected by different environmental policies, specifically, for example, the optimal decision when emissions may be subject to an environmental tax or an emission cap, and the literature discusses how these factors influence operational decisions (see, e.g., Letmathe and Balakrishnan, 2005; Elhedhli and Merrick, 2012; Song and Leng, 2012; Chaabane et al., 2012; Ruiz-Femenia et al., 2012). By definition, however, a supply chain is a network of different agents—suppliers, distributors, retailers, and the like—that participate in the sale, delivery, and production of a specific good or service. As such, the profitability of a supply chain depends heavily on the individual actions of each agent, thus making game theory well suited to studying this topic (Nagarajan and Sošić, 2008).

2.2. Game theory

Over the last few years, research in operations management and, most recently, green supply chain management has been enlivened and enriched by the application of game theory. Two strands of literature have emerged. The first strand deals with the fact that the outcome in a supply chain is the result of a cooperative decision-making process. Here, the agents jointly maximize the supply chain's profit in a cooperative game-theoretical manner.[5] In contrast, the second strand of literature allows the agents in a supply chain to individually maximize their profits, leading to an application of non-cooperative game theory.[6]

In the context of sustainable management, however, only a few quantitative models apply game theory to discover optimal emission-mitigating strategies to guide operational decision making in supply chains. For example, Benjaafar et al. (2010) use a multiple-firm lot-sizing model to model a supply chain consisting of N firms where each firm is confronted with certain environmental policies. Decisions about ordering and production are made either independently or jointly. In a two-firm setting, the results show that under carbon constraints, that is, a strict emission cap imposed on each firm individually, the value of the supply chain is higher for joint decision making than for non-cooperative decision making. Thus, meeting the emission targets is less costly if firms in the supply chain collaborate, indicating that collaborative decision making outperforms individual decision making. However, in this same scenario of emission caps, there are circumstances when overall emissions increase if firms decide jointly. Changing the emission policy rules such that emission caps are imposed supply-chain-wide yields significant improvements, that is, the supply chain produces the least emissions at lower costs. Although the emission cap policy dominates, there are other alternatives for limiting emissions, of which the cap-and-trade policy yields the most significant cost reduction in a collaborative setting. This occurs when the cap is very high and as a consequence the supply chain can make additional profits from selling emission savings on the carbon exchange market. Notably, the results are based on the assumption that the market price for carbon is fixed. Consequently, market price uncertainty, which is the real-world situation, is completely ignored.

The impact of a cap-and-trade policy on a two-stage emission-dependent supply chain is also investigated by (Du et al., 2012).[7] In contrast to Benjaafar et al. (2010), market risk is explicitly considered and the authors use a sequential game to investigate the firms' individual decision making. A single manufacturer has to decide on its optimal production quantity given demand uncertainty and an assigned emission quota. If it emits too much, extra permits can be acquired from a permit supplier. As a result, first the seller must decide on an optimal price for its permits, after which the manufacturer decides whether to accept or reject the offer. The results show that the bargaining power of the permit supplier (manufacturer) increases (decreases) if the government imposes a stricter environmental protection policy. Consequently, the value of the supply chain decreases. Moreover, an increase in market risk, that is, higher demand uncertainty, also affects the bargaining power of both parties. The findings reveal that higher demand uncertainty increases the permit supplier's propensity to lower carbon permit prices in order to induce the manufacturer to raise production. In a related article, the authors expand the analysis to account for the perspective of authorities (Du et al., 2012). Here, the authors endogenize the choice of the emission cap size set by a policy decision maker. The results show that this also affects the bargaining power of the participants, that is, the optimal emission cap will either strengthen or weaken (weaken or strengthen) the bargaining power of the manufacturer (supplier) depending on whether the social optimum calls for a tighter or relaxed environmental policy.

Zhang and Liu (2013) consider a three-level green supply chain where a manufacturer is responsible for the launch of a green product. Raw materials are purchased from a suppler and the final product is sold to a retailer who brings the product to market. It is only implicitly assumed that the greener product reduces supply chain emissions. Different from the above-discussed papers, however, the derived non-cooperative and cooperative solutions are supplemented by different coordination mechanisms—revenue sharing, the Shapley value coordination method, and the Nash negotiation mechanism—in order to achieve cooperation among the members. The findings reveal that the Nash negotiation mechanism outperforms non-cooperative decision making and is the perfect coordinated situation compared to all other methods. Also noteworthy is that allowing for vertical integration, such that firms

[4] See, e.g., Linton et al. (2007) for a discussion.

[5] The literature sometimes refers to this cooperative approach as a centralized supply chain (Giannoccaro and Pontrandolfo, 2004). Specifically, the situation of joint profit maximization is identical to a situation where decision making is centralized by a global planner.

[6] Cachon and Netessine (2004) and Li and Whang (2002) provide an excellent overview of game-theoretical applications in the supply chain management literature. The flat panel industry, however, has shown that cooperation and competition are not the only way to manage supply chains; rather, a mixture of competition and cooperation is also rational. These co-opetition supply chains are the focus of work that bridges non-cooperative and cooperative game theory. See, e.g. Gurnani et al. (2007).

[7] A two-stage emission-dependent supply chain consists of a single emission-dependent manufacturer and a single permit supplier. See Du et al. (2012).