Carbon pricing versus emissions trading: A supply chain planning perspective

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ABSTRACT

Carbon pricing (taxes) and carbon emissions trading are two globally practiced carbon regulatory policy schemes. This paper presents an analytical supply chain planning model that can be used to examine the supply chain performance at the tactical/operational planning level under these two policy schemes. Model implementation and analyses are completed using actual data from a company operating in Australia, where these environmental regulatory policies are practiced. Numerical results provide important managerial and practical implications and policy insights. In particular, the results show that there are inflection points where both carbon pricing and trading schemes could influence costs or emissions reductions. An erratic nonlinear emissions reduction trend is observed in a carbon pricing scheme as the carbon price increases steadily; whereas emissions reduction in a carbon trading scheme follows a relatively linear trend with a nonlinear cost increase. Overall, a carbon trading mechanism, although imperfect, appears to result in better supply chain performance in terms of emissions generation, cost, and service level; even though a carbon tax may be more worthwhile from an uncertainty perspective as emissions trading costs depend on numerous uncertain market conditions.

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1. Introduction

Environmentally sustainable supply chain (SC) planning, also termed green SC planning, aims to develop unified design, planning and optimization models in which economic goals such as profit maximization and cost minimization are integrated with environmental goals such as carbon and greenhouse gas emissions minimization (Sundarakani et al., 2010; Varsei et al., 2014). The adoption of green SC planning efforts is greatly influenced by two widely-practiced regulatory efforts including carbon pricing (taxing) and carbon trading schemes (Schaltegger and Csutora, 2012).

SC planning and optimization on its own is a relatively intricate process with numerous variables and constraints to be taken into consideration and the incorporation of environmental dimensions adds to its complexity (Fahimnia et al., 2014a). Organizations facing these complex decision environments can find utility in tools for planning and managing their SCs. The development of SC modeling tools that have effectively integrated and evaluated environmental issues, alongside economic and business concerns, have only started to receive significant interest (Benjaafar et al., 2013; Brandenburg et al., 2014; Seuring, 2013; Tang and Zhou, 2012). Many of these modeling efforts focus on strategic planning levels of analysis such as the design of SC networks, while challenges at the tactical and operational planning levels are less explored (Seuring, 2013). In fact, the developments in some areas such as reverse logistics have dominated the early and recent green SC modeling literature (Srivastava, 2007).

Motivated by actual regulatory climate change pressures that are evolving in Australia, we develop and apply an analytical planning model to explore how organizations can manage their SCs under two carbon regulatory schemes. Not only are practical implications associated with the modeling effort presented, but research implications including further model development and investigations of additional outcomes are thoroughly discussed in this paper. The primary objective of this work focuses on the development and analysis of SC planning under emergent regulatory regimes. The proposed SC planning model contributes to the green SC modeling literature through helping organizations, policymakers, and even NGO's evaluate the tactical and operational implications from broad-based regulatory policy decisions.

The remainder of the paper is organized as follows. We begin in Section 2 with some background on environmental regulatory policies and organizational responses to these policies. Green SC management modeling efforts specifically those with a clear focus

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on managing carbon emissions are also reviewed in this section. This background sets the stage for further identifying the need for research we are presenting in this paper. The mathematical optimization model is then presented in Section 3. We utilize practical data from an actual SC for model implementation and analyses in Section 4. Discussions are presented on evaluation of the numerical results and potential implications for organizations and policymakers. The paper concludes by providing a summary of findings, limitations of the study, and directions for future research in Section 5.

2. Carbon regulatory schemes and green SC models

Australia has been under domestic and international pressures to transition into a low-carbon economy. To help meet the goals of a low-carbon economy, Australian regulators have decided to implement a two-stage set of regulatory environmental policy mechanisms. At the first stage, organizations need to respond to a carbon taxation (pricing) scheme initiated in July 2012 (Fahimnia et al., 2013a; Jotzo, 2012). A tonne of carbon pollution is priced at $23 in 2012 rising by 5% per year. At the second stage, after three years of fixed-price period, the scheme is expected to convert into a full emissions trading scheme in 2015. That is, a fixed carbon tax will change to a floating price which means that open trading will set the market carbon price. The trading scheme caps the amount of permits issued and is guided by the overall national commitment (Jotzo and Betz, 2009).

The *carbon pricing scheme* aims to control emissions by taxing the generated carbon. Each greenhouse gas emitter is charged a tax proportional to the size of the emissions generated. A carbon charge is meant to encourage companies to reduce their emissions using various practices and technologies whose managerial and implementation cost is less than the charge. The primary challenge with this mechanism is how to price carbon so that maximum emissions reduction can be achieved while ensuring that the economy is not significantly hurt. Some initial investigations of the cost implications and carbon reduction potentials of the carbon pricing scheme in Australia have been preliminarily posited in logistics and SC settings (Fahimnia et al., 2013a; Fahimnia et al., 2014a) and reverse operations (Fahimnia et al., 2013b). The findings of these studies have shown that the proposed carbon tax of $23 per tonne of emissions is unlikely to add considerably to the overall SC costs and has a minor impact on changing the industry behavior for running greener logistics and SCs.

In a *carbon trading scheme* (also known as a cap-and-trade mechanism), a limited number of tradable emissions allowances, the cap, is created for distribution among the players in an economy. Companies generating more emissions than the allocated allowances receive significant fines or purchase emissions allowances off the market from those generating fewer than the allowed emissions. The scheme creates both pressures (significant fines for over-polluting) and incentives (financial reward for selling surplus allowances) to encourage appropriate environmental initiatives. The goal is to either have companies purchase market-priced credits/allowances or invest in practices and technology to reduce or eliminate greenhouse gas emissions (Sarkis et al., 2010).

The two primary challenges with a carbon trading mechanism include (1) how to identify a method by which to allocate the initial allowances to each company, and (2) how should the fine be evaluated for companies going over allocated allowances, if they do not wish to purchase allowances. Some emissions allocation methods have been proposed and investigated (Böhringer and Lange, 2005; Burtraw et al., 2001; Cramton and Kerr, 2002). In the most widely used allocation method, emissions allowances are grandfathered (allocated) according to the available historical emission data (Böhringer and Lange, 2005). In a *grandfathering emissions allocation method*, an annual emissions reduction goal is set, relying on historical data, to determine what allowances are allocated to the players in a way to achieve the agreed upon goal.

The published green SC models can be classified into three categories. The first category includes modeling efforts with no specific focus on the regulatory schemes, but only trying to minimize the SC environmental impacts including carbon emissions. For example, Diabat and Simchi-Levi (2009) formulated carbon emissions in production, storage and distribution and studied the impact of different emission caps on the SC's economic performance. Mallidis et al. (2012) have considered carbon and particulate matters emissions in a network design problem. Emissions are incorporated for different transportation modes as well as the dedicated or shared use of warehouses. A robust multi-objective model is also presented by Validi et al. (2014) for design of a capacitated network for the distribution of dairy products in Ireland. Harris et al. (2014) present an evolutionary multi-objective optimization approach for solving a large location–allocation problem with capacitated facilities. Emissions generated in depots and through transportation operations are incorporated in the environmental objective function.

The focus of papers in the second category is on SC modeling in a carbon pricing environment. For example, Fahimnia et al. (2014b) and Fahimnia et al. (2014a) present tactical/operational logistics and SC optimization models to examine the potential cost and emissions reduction impacts of the Australian carbon tax on selected case companies. Fahimnia et al. (2013b) investigate a closed-loop SC operating in a carbon pricing environment.

The third category comprises a larger number of published articles with specific focus on SC modeling and performance analysis in a carbon trading environment. Emission factors including the carbon trading price and carbon cap are important players in these models. For example, Ramudhin et al. (2010) present an integrated bi-objective model for the simultaneous minimization of logistics costs and greenhouse gas emissions. Carbon dioxide equivalent (tCO_2e) emissions generated in transportation and manufacturing processes is used as the environmental metric. Chaabane et al. (2012) adds reverse SC operations to this model and presents a life cycle assessment (LCA) analysis to examine the impact of carbon trading price on the SC configuration decisions. More recent modeling efforts in this context have tried to assess the impact of carbon price and carbon cap variations on SC decisions (Abdallah et al., 2012; Bojarski et al., 2009; Diabat et al., 2013). There are also studies focusing on modeling uncertainty in carbon related parameters. For example, emissions costs are expressed stochastically in Chaabane et al. (2012), Giarola et al. (2012) and Pishvaee et al. (2012).

To the best of our knowledge, a study that focuses on comparing the economic and carbon emissions performance of the SC under 'carbon pricing' and 'carbon trading' schemes is non-existent, especially a study with a clear focus on organizational SC planning dimensions. This paper aims to address this research gap by investigating the impacts of these carbon regulatory schemes on an actual SC operating in Australia, where these environmental regulatory policies are being practiced. In addition to contribution to the existing academic literature, the findings of this study can be of significant value for industry practitioners (from an investment perspective) and policymakers (a policy definition and setting perspective).

3. Mathematical model

In the SC under investigation, a set of *I* product types (indexed by *i*) are produced on *J* machine centers (indexed by *j*) in *M* manufacturing plants (indexed by *m*). Production costs and carbon emissions rates