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The Impacts of Carbon Quotas on Supply Chain Management

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Abstract— **Global warming has compelled us to reduce carbon dioxide emissions. To prevent climate change, in the coming future a carbon budget will be set for each country, and in turn the country will sell carbon quotas to companies. Companies can also buy or sell their quotas with each other. In other words, companies have to pay for the carbon dioxide emissions. In effect, it will deeply influence the whole supply chain of a company including sourcing, producing and distributing processes. Nowadays, with globalization, many multi-national companies deploy their manufacturing base in Asia where the production cost is low, and then transport products to major consuming markets viz U.S. and Western Europe either by sea or by air. Therefore this mode requires global oceangoing ships or long-haul flights, which consume fuel and generate carbon dioxide emissions. However, with the carbon quota or extra cost for consuming energy that will be further reflected in the corresponding price, the current mode will be significantly changed to adapt for the new constraint. Except the delivery cost adjusted by carbon quota, carbon charge will also affect the producing and storing processes, for both of them need energy consumption as well as greenhouse gas emissions. In short, the supply chain of a company is forced to be redesigned to conform to the carbon reduction obligation. This research aims to investigate the impacts of carbon quotas on supply chain management. Analytic models will be constructed to describe the trade-offs in supply chain when carbon quota is further considered. Numerical experiments will be conducted to examine the optimal solution to minimize the expected total cost.**

Keywords-Carbon quota, Supply chain management, Global Warming

I. INTRODUCTION

The purpose of this research is to study the impacts of global carbon emission reduction scheme on supply chain management and global business logistics. For the additional charge of greenhouse gas emissions, companies have no alternatives but to innovate new ways to reengineer the whole supply chain to reduce costs and, meanwhile, to lessen charge for pollution. Although there is no consentaneous charge of carbon dioxide, a gross price is US$40 for each ton of carbon dioxide. In the future, it will be inevitable to pay for the CO2 emissions by companies as well as consumers. In fact, in Europe such charge has been set for some specific industrial products. In U.S., similar scheme is also under consideration and preparation, and will be put into effect soon. In COPENHAGEN Climate Conference 2009, China has committed again to the United Nations Framework Convention on Climate Change and Kyoto Protocol implemented. In effect, companies in each country have to consider the change of supply chain to adapt the new carbon dioxide emission constraint. Instead of just balancing cost, service and quality, companies should also establish a green supply chain to reduce the carbon footprint. Although now it may be just ethical issue for some companies, it will evolve into a financial problem for most companies in the near future. In this work, we will mainly concern about the impact of carbon quotas on supply chain management. More specifically, the impacts of additional charge of carbon dioxide emission on the inventory control policy will be studied in detail, and the restructuring issue of supply chains for the assigned carbon quota will also be investigated. In the past, especially with globalization, long-haul delivery and Just-In-Time have been become common in global business. However, carbon quotas can force companies to redesign the policies they have employed since the previous best policy may become non-optimal if the charge for pollution is further considered in the cost function. This research also addresses this problem by formulating adjusted analytical models when carbon quota is taken as an additional constraint.

The outcomes of this research can help academicians as well as practitioners better understand the impacts of carbon charge on business. Analytical models will be formulated to describe the situation faced by companies when running global business. Carbon dioxide emission is not just an ethic issue, but will turn into an issue in terms of cost in the near future. Indeed, in Europe, some related schemes have been put into effect, which firms in the certain industry have to conform to. Carbon management is another critical concern that must be analyzed to reengineer the whole supply chain to reduce pollution.

II. LITERATURE REVIEW

The purpose of this research is to examine the impacts of carbon quotas on supply chain management. To our knowledge, previous research that directly concerns about this issue is rare, while literature on supply chain management and carbon control is prolific. There are also recent research articles on carbon management, where many of them are on carbon finance and carbon control policies. In the following part, the issues on supply chain management without considering the carbon problem, and relevant research on carbon management are reviewed. On the basis

of previous research, we further study the impacts of carbon emission constraint on supply chain management.

Inventory management is one of the most fundamental elements in management science or operations research. In this section, we employ Aviv's (2003) classification for inventory models: models related Bayesian updating mechanism, models with Markov-modulated, models with time-series demand. The role of the classification follows different approaches used to model inventory problems. The first approach (see, e.g. Scarf 1959) assumes that the distribution of demand is not known precisely, but with an unknown parameter. With the arrival of new demand information, the critical stock level function is obtained by using Bayesian updating mechanisms to learn about future demand from past history. Iglehart (1964) consider the dynamic inventory problem with the demand following exponential or range family distribution, as well as unknown parameter. Basing on the result when the demand density is known, they provide the inequalities for the optimal purchase policies for the case with unknown parameter of distribution. Azoury (1985) considers Bayesian formulations of two dynamic inventory models: the depletive model of consumable items and the non-depletive model of reparable items. Zhou (1998) discusses the statistical approaches for demand estimation by Bayesian updating with new information. It can come from new market orders, macro-level aggregated demand and expert beliefs. Sethi et al (2003) consider the periodic review inventory system with regular demand forecast update, as well as with two delivery modes: fast and slow delivery. Order quantities by the two modes are decided at the beginning of each period. They respectively develop the dynamic programming and obtain the characterization of the optimal policy, with and without fixed ordering costs, for the finite-horizon problem. Choi, Li and Yan (2003) analyze the trade-off between ordering earlier with a lower product cost but less accurate demand information, and ordering later with a higher product cost but lower uncertainty of demand. Updating demand forecast using a Bayesian approach with arrived new information, they develop a multi-stage dynamic optimization problem and derive the optimal ordering police. With the second approach, the demand process is modeled as a Markovian process. Song and Zipkin (1993) suggest that the main advantage of Markov-chain approach is its natural and flexible framework for creating an appropriate nonstationary environmental model. They study the inventory problem with varying demand rate, and model the demand as a continuous-time Markov chain with a discrete state space and provide the qualitative descriptions of optimal policies. Beyer and Sethi (1998) analyze the inventory problem with unbounded Markovian demands, ordering costs, and inventory/backlog (or surplus) costs that are lower semicontinuous. The situation for Finite-horizon and infinite-horizon, as well as stationary and nonstationary cases are considered in their models. Chen and Song (2001) consider the inventory system for a serial of companies in a supply chain with Markov-modulated demand. To minimize the log-run average costs in the system, they provide echelon base-stock policies with state-dependent order-up-to-levels, which are optimal for this system. Liu (2003) considers the problem for inventory management and production planning in the paper industry with Markovian demand and capacity limitation. Formulating two finite-state continuous-time Markov chains for the random demand and capacity processes respectively, he models the production planning as a stochastic optimal control problem with the objective of minimizing the discounted surplus and production costs. The third approach has been to model the demand as a time series, such as a weighted moving average, where there is correlation between consecutive demand realizations. Graves (1999) consider an adaptive base-stock policy for a single-item inventory system with a nonstationary demand. The demand follows an autoregressive integrated moving average process. Based on the analysis for single-stage problem, he then extends the two-stage model to multi-stage system. Liu (2001) shows that Exponential-weighted Moving Average forecasting model and Minimum Mean Square Error forecasting model are robust to AR(1) demand within a wide range in supply chain management. Dong and Lee (2003) study the multi-echelon inventory system with time-correlated demand process, and provide a lower-bound approximation to the optimal echelon inventory levels. They show that the structure of the optimal stocking policy for time-independent demand still holds for time-series demand process. Furthermore, the impact of leadtimes and correlation on the performance of the echelon inventory system are also studied under an autoregressive demand process

For the carbon problems, many researchers have concerned about the technology of pollution reduction, carbon finance and carbon control policies (Skjaerseth and Skodvin, 2003; Levy and Newell, 2000, 2005; Hofman, 2001; Kolk and Levy, 2001; Dunn, 2002; Kolk and Pinkse, 2004; Okereke, 2007; Ratnatunga, 2008; Gallo et al, 2009). However, no research directly addresses the impacts of carbon quotas on supply chain management with analytical models. Recently, a research report was released by Butner et al (2008), where the general concepts and basic analysis of carbon management in supply chain management are provided. In that report, the generic framework of these impacts is analyzed, however, no analytical models are considered to measure the influence accurately. This research aims to address this issue.

III. METHODOLOGY

In this research, analytical models, numerical experiments and simulations are employed to quantify the economic impacts of carbon quotas on supply chain management. More specifically, we examine whether the additional charge for carbon dioxide emission can change the operational policy in supply chain.

Firstly, the impacts of this additional cost for carbon quotas on inventory management are studied. Newsvendor problem, which is one of the fundamental models for stochastic inventory management and has been studied and applied in various business settings, is revisited by further considering the cost related to carbon quotas. Consider a typical single period newsvendor model with which an

optimal inventory level needs to be determined to minimize the expected cost usually including the ordering cost, the expected overstocking and shortage costs. It is traditionally assumed that the decision variable has no impact on the holding cost for consumed stock during this period. The average holding cost for this portion of inventory is approximately calculated as the product of unit holding cost and half of the expected demand. It is a good approximation when the unit holding cost is significantly lower than the unit backorder cost because the optimal solution of inventory level can make sure the probability of stocking out is low. However if this condition does not hold, the approximation may deviate much and cannot measure the expected holding cost for cycle inventory accurately. When we further consider the carbon charge, the unit holding cost will rise, especially for those products that require special conditions for storage. In such situation, it is necessary to reconstruct the newsvendor model to reflect the cost incurred more accurately. In this part of the research, we examine the impact of additional carbon charge on the newsvendor model. Numerical experiments show that the carbon charge and standard deviation of the demand distribution have the significant influence on the newsvendor model and the consumed inventory holding cost should be considered in the cost function of the newsvendor model.

Secondly, the impact of carbon quota on the transportation mode is studied. With carbon charge, load consolidation is more frequently employed to reduce the incurred carbon dioxide generation. Usually the frequency of shipments is positively related to the carbon quota consumption. More shipments generate more pollution by fuel consumption. Consolidation enables multiple shipments to be transported together, and in effect it will reduce the carbon dioxide emission. However, in particular industry, frequent shipments with small loads have been used to better satisfy customer demands. With the further carbon charge, the inventory control policy has to be reexamined to adapt to the new constraint. In this research, we will also analyze the impacts of carbon quota on the frequency of shipments and in turn the inventory control policy.

IV. FUTURE RESEARCH

In the coming future, we will use analytical models to examine the impacts of carbon quote on supply chain management. More specifically, numerical models will be developed to analyze the new balance with the consideration of carbon charge.

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