Chen, X., Wang, X., & Chan, H. K. (2017). Manufacturer and retailer coordination for environmental and economic competitiveness: A power perspective. *Transportation Research Part E: Logistics and Transportation Review*, *97*, 268–281. https://doi.org/10.1016/j.tre.2016.11.007

Manufacturer and retailer coordination for environmental and economic competitiveness: a power perspective

Xu Chen[1], Xiaojun Wang[2*], Hing Kai Chan[3]

1. School of Management and Economics, University of Electronic Science and Technology of China, Chengdu, 611731, China, E-mail: xchenxchen@263.net

2. Department of Management, University of Bristol, Bristol, BS8 1TZ, U.K. E-mail: xiaojun.wang@bristol.ac.uk

3. Nottingham University Business School China, University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo, 315100, China. E-mail: hingkai.chan@nottingham.edu.cn

*Corresponding author

Abstract:

This study examines the role of power relationship and coordination in sustainable supply chain management. We investigate a two-echelon supply chain that consists of a manufacturer and a retailer whose customer demand is carbon emission sensitive. Using the game-theoretic approach, we compare the equilibrium solutions under three supply chain power structures to analyse the effect of power relationship on supply chain decisions and sustainability performance. A two-part tariff contract is designed to coordinate the supply chain. The findings provide important managerial insights that can help firms develop a better understanding of power relationship and coordination in achieving sustainability goals.

Keywords: Sustainable supply chain; power structure; supply chain coordination; game theory

1 Introduction

In the era of climate change, firms are exerted increasing pressure to reduce carbon emissions while maintain their economic competitiveness. However, the notion of "boundaryless responsibility" (Amaeshi *et al*. 2008) means that firms need to consider how they can achieve economic, environmental, and social objectives of the sustainability throughout their entire supply chain. It is important for them to look beyond their organizational boundaries and develop a more holistic solution for a sustainable supply chain. Sustainable supply chain management would require efforts from all segments of the supply chain. However, there are often conflicting interests between individual supply chain members such as tension between a manufacturer and a retailer considered in this study. In the UK and France, we have witnessed some high profile protests against major supermarket chains by the dairy farmers because of cheap prices of milk. Despite Apple's promise, published in annual Supplier Responsibility Report to improve working conditions and preserve the environment, some of the technology giant's suppliers are on the news headlines being accused over worker exploitation. Moreover, the UK government requires firms to measure and to report their annual greenhouse gas emissions of their own operations, and furthermore, it is also anticipated that companies will be required to report carbon footprint of upstream supply chain activities that are beyond a reporting firm's direct control.

Sustainable supply chain management requires a coordinated effort from all parties to achieve the sustainability objectives. Such an effort may be hampered by the trade-offs between different sustainability objectives and tensions between supply chain members. Furthermore, the power relationship between supply chain partners makes the coordination of a sustainable supply chain even more complicated. Referring to resource-dependence perspective, power depends on the criticality of the commercial and operational resources and the availability of alternatives for souring the same resource (Cox et al., 2002; Touboulic et al. 2014). Touboulic et al. (2014) shows the influences of power on how supply chain members manage their relationships and its effect of organizational response to the sustainability implementation. It is critical that power structures that exist in the supply chains are properly understood by managers in order to manage supply chains strategically and operationally (Cox

1999). Very little effort has been made in the existing literature to explore the issue of coordinating the sustainable supply chain with the consideration of power relationship. This study is going to fill this gap in the literature by addressing the following research questions:

(1) Should the supply chain members work on sustainability initiatives independently or coordinate their sustainability effort?
(2) If yes, how should members coordinate with each other to achieve economic and environmental competitiveness?
(3) What is the impact of supply chain power relationship on the coordination decisions and sustainability performances?

In order to answer these questions, a two-echelon supply chain is considered. It consists of a manufacturer and a retailer who purchases products from the manufacturer and sell them to end consumers. To take economic and environmental performances into consideration, the consumer demand faced by the retailer is assumed to be carbon emissions sensitive, as well as price sensitive. Based on game models, the manufacturer's optimal wholesale price and unit carbon emissions, and the retailer's optimal retail price are derived under three different supply chain power structures, that is, the equilibria of the manufacturer Stackelberg, vertical Nash and retailer Stackelberg, respectively. Through a comparison of the derived results from three power structures, we analyse the effect of the supply chain power relationship on operations decisions, coordination contracts, and sustainability performances. The main contributions of our work are as follows:

First, the notions of supply chain coordination (Simpson and Power 2005; Vachon and Klassen 2008; Swami and Shah 2013) and supply chain power relationship (Simpson *et al.* 2007; Pagell *et al.* 2010; Touboulic *et al.* 2014) have been recognised to play important roles in sustainable supply chain management by the existing literature. Achieving the economic and environmental sustainability requires a coordinated effort from the involved supply chain members (Swami and Shah 2013), and such an effort may be hampered by the power relationship in supply chains (Touboulic et al. 2014). Nevertheless, few studies have been brought the two important issues together to systematically examine their impact on accomplishing the economic and environmental competitiveness. To the best of our knowledge, this paper is the first attempt to explore this research avenue. The research findings derived from such an investigation will help firms seek optimal solutions based on their supply chain environments to improve the sustainability performances.

Second, more and more firms view the carbon emission reduction as a competitive strategy to win customer demand because of the increasing customer environmental consciousness (Liu et al. 2012; Kanchanapibul et al. 2014; Zhang 2015). We consider a demand function that is both price and carbon emissions sensitive and use the carbon emission attribute as a decision variable rather than a constraint, which complements to the existing low carbon supply chain literature that often uses the carbon emissions attribute as a constraint or considers the demand of single manufacturer (Nouira et al. 2014; Du et al. 2015).

Third, this research also makes important practical and policy contributions. Through the systematic analysis of optimal wholesale prices, retail prices, unit carbon emissions, and tariff contracts under different supply chain power structures, our findings provide valuable managerial implications, which will be beneficial for firms to make important strategic and operational decisions in order to achieve economic and environmental competitiveness. Furthermore, from the policy makers' perspective, our research findings provide interesting insights on how different supply chain power relationships affect firms' decision and, as a result, the economic and environmental performances of the entire supply chain. It is valuable for policy makers to create a more sustainable supply chain environment that can promote low carbon economy.

The remaining of this article is organised as follows. After a brief review of research background in Section 2, we present model assumptions and descriptions in Section 3. In Section 4, the manufacturer's optimal wholesale price and unit carbon emissions, and the retailer's optimal retail price are obtained in the manufacturer Stackelberg (MS) model, the vertical Nash (VN) model, and the retailer Stackelberg (RS) model respectively. In Section 5, we focus on how to achieve channel coordination through a two-part tariff contract for the sustainable supply chain. In Section 6, we examine the effect of power relationship on the coordination decisions and sustainability performances of the supply chain. A case study is presented in Section 7, in which numerical examples are provided to give more management insights. Finally, we discuss the managerial implications of our study and possible future work in Section 8.

2 Research Background

The literature reviewed in this article primarily relates to three research streams: (i) sustainable supply chain management, (ii) coordination in sustainable supply chain management, and (iii) the role of power in sustainable supply chain management.

2.1 Sustainable supply chain management: an overview

Sustainable development is defined as 'a development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). The concept of sustainability requires that a mix of social, economic and environmental factors should be incorporated into decisions on business development and resource allocation (Dyllick and Hockerts 2002; Gauthier 2005; Chiou et al. 2011; Yang et al. 2013; Wan et al. 2015; Li and Li 2016). Applying this concept to the sustainable supply chain management domain, Seuring & Müller (2008) defined it as management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account. Carter and Rogers (2008) used a conceptual theory building approach to incorporate relevant literature with complementary theories to introduce a theoretical framework of sustainable supply chain management. Similar to Seuring & Müller (2008), the core of their conceptualization is Elkington's (1998) triple bottom line: the intersection of environmental, social, and economic performance. Furthermore, the focus of supply chain sustainability has emerged from local optimisation of environmental factors to consideration of whole life cycle of a supply chain including the production, consumption, customer service and post-disposal disposition of products (Linton et *al.* 2007). Despite many efforts have been made over the past decade to develop models and frameworks to assess supply chain sustainability, the techniques of sustainability performance measurement has not yet fully matured and very few have an integrative focus on measuring environmental, economic and social dimensions (Labuschagne *et al.* 2005; Bai and Sarkis 2010; Erol *et al.* 2011; Zhu et al. 2011; Boukherroub *et al.* 2015; Chen and Wang 2016; Wang et al. 2016). A recent comprehensive review of the literature investigating corporate sustainability development in China showed that the integration of the three dimensions of sustainability and decision-making methodology is still rare (Bai *et al.* 2015). Furthermore, sustainability is a dynamic rather than a static concept and perceptions of sustainability have changed significantly over the last decade associated with changing awareness, knowledge, technology, market preferences and government policy (Vasileiou and Morris 2006).

2.2 Coordinating sustainable supply chains

Channel coordination is an important issue in supply chain management. According to Jeuland and Shugan (1983), channel coordination is defined as the setting of all manufacturer and retailer related decisions at the levels that would maximize the total channel profits. Effective management of sustainable supply chain requires coordination among various channel members. Relevant studies on the coordination problem have been well reported in the literature (Ingene and Parry 1995; Weng 1995; Xu et al. 2001; Raju and Zhang 2005; Cai 2010; Choi et al. 2013; Chen *et al.* 2014; Luo and Chen 2016), here we mainly focus on the literature concerning coordination in the context of sustainable supply chain management.

Among the earlier studies, Walton *et al.* (1998) investigated how to integrate suppliers into the environmental management processes based on case studies of five companies in the furniture industry and their results show that it is beneficial for integrating suppliers into environmental management practices. Their view is also supported by Rao (2002) in the questionnaire survey of ISO 14001 certified companies in five South-East Asian countries. In their case study of a sustainable cotton supply chain at a German company, Goldbach *et al.* (2003) indicated that the major difficulty of making a conventional supply chain sustainable is how to coordinate the activities of a complicated network that involved different players. Simpson and Power (2005) also pointed that efforts to improve or influence supplier's environmental management practices are critical to the buyer and it can be costly endeavour if it is not managed correctly. Vachon and Klassen (2006) examined the impact of upstream and downstream integration on extending green practices across the supply chain. Their finding shows that greater supply chain integration can benefit environment management in operations. Vachon and Klassen (2008) extended their earlier work by examining the role of supply chain collaboration in environmental management and manufacturing performance. They found that the benefits of collaborative green practices with suppliers were broadest whereas collaboration with customers yielded mixed outcomes. In their survey of Australia automotive supply chain, Simpson *et al.* (2007) found that suppliers were more responsive to their customers' environmental performance requirements where increasing levels of relationship-specific investment occurred. Pagell and Wu (2009) stated that cooperation with suppliers has become an essential component of developing sustainable supply chains. More recently, Choi et al. (2013) explored the significance of channel leadership in closed loop supply chains (CLSC) by examining the influence of different channel leadership models on the optimal decisions and performance. In their research, practical and novel channel coordination schemes are developed for the CLSCs under various supply chain configurations. Swami and Shah (2013) studied the problem of coordination of a manufacturer and a retailer in a green supply chain. Some critical questions such as extent of effort in greening of operations by manufacturer or retailer, level of cooperation between the two parties, and how to coordinate their operations, are addressed in their research. Panda (2014) investigated the coordination of a manufacturer–retailer chain and the research found that corporate social responsible retailer's perfect welfare maximizing motive resolves channel conflict and revenue sharing contract coordinates the channel. In both studies, the effect of the power dynamics between the manufacturer and the retailer on above questions was not considered.

2.3 Effect of supply chain power relationship on sustainability

One important stream of literature looks into the role of power, and imbalanced power in particular, in influencing sustainable supply chain practices. These studies mainly focus on the power relationships between manufacturers and their suppliers or between manufacturers and their customers, and the influences on sustainability practices. For instance, Pedersen and Andersen (2006) identified bargaining power as an important mechanism safeguarding codes of conduct. In their analysis of the US food industry, Pullman *et al.* (2009) provided the view that power imbalance is highly relevant to segments of the food supply chain and, as a result, affects the sharing of sustainability practice costs and resulting performance. More recently, Touboulic *et al.* (2014) studied how the influences of power affect organizational responses to the implementation of sustainability initiatives and their findings show that power particularly affects the sharing of sustainability-related risks and value between supply chain partners.

Another relevant stream of literature examines the impact of supply chain power dynamics on operational decisions and performances in general using game theoretical approach (Chen *et al.* 2016). For example, Ertek and Griffin (2002) examined the effect of power structure on price, profits and sensitivity of the market price through analysing the case where the buyer has dominant bargaining power and the situation where the supplier has dominant bargaining power in a two-stage supply chain. Using the game theoretical approach, Cai *et al.* (2009) analysed the effect of price discounts and price schemes on the dual-channel supply chain competition under different power structures. Similarly, Zhang *et al.* (2012), from the game theoretical perspective, examined the effect of products' substitutability and channel position on pricing decision under different power structures in two dual-exclusive channels. Their research findings indicated that the vertical Nash game is the equilibrium for the supply chain members and the balanced power structure always performs best for the whole supply chain. Using manufacturer and retailer Stackelberg games and Nash game, Shi *et al.* (2013) examined the impacts of different power structures on supply chains with random and price-dependent demand. Their study showed that power structure makes an impact on supply chain efficiency and the impact depends on both expected demand and demand shock. Gao et al. (2015) analysed the effect of various channel power structures on the optimal decisions and performance in a CLSC. Applying the game theoretic models, the research also explored the best channel power structure from the perspective of the supply chain and consumers. Chen and Wang (2015) systematically investigated the impact of different power structures on the decisions of pricing and channel selection between free and bundled channels in a mobile phone supply chain setting.

Although game theoretical approaches have been widely adopted to examine the effect of the supply chain power structure on firms' operations decisions and their performances, as far as our understanding, few studies have systematically analysed the impact of power relationship on the coordination of sustainable supply chains and the sustainability performance. Our paper complements the exiting literature by specifically providing analytical models to study power relationship and channel coordination in a sustainable supply chain environment. It will help develop a better understanding of the role of the supply chain power relationship in achieving sustainability goals.

3 Model descriptions and assumption

We consider a two-echelon supply chain that is composed of a manufacturer and a retailer. The retailer purchases products from the manufacturer and sells them to the end customers. The demand faced by the retailer is price and carbon emissions sensitive, and the decision variable of the retailer is retail price. The decision variables faced by the manufacturer are wholesale price and unit carbon emissions after green technology investment. Throughout this paper, we use the notations presented in Table 1.

Table 1: Notations

Notation	Descriptions
c	Manufacturer's unit production cost.
w	Manufacturer's unit wholesale price.
e_0	Manufacturer's initial unit carbon emissions.
e	Manufacturer's unit carbon emissions after green technology investment, $e \leq e_0$.
T	Manufacturer's green technology investment.
t	Manufacturer's green technology investment cost coefficient.
p	Retailer's unit retail price.
q	Demand faced by the retailer.
$\pi_m\ (w, e)$	Manufacturer's profit.
$\pi_r(p)$	Retailer's profit

In addition, following assumptions are employed in this study:

(1) $T = t(e_0 - e)^2$. This assumption means that the manufacturer's green technology investment is convexity on e, which attributes to diminishing returns from expenditures. The setting is popular in the literature (Yalabik and Fairchild 2011; Swami and Shah 2013; Choudhary *et al.* 2015).

(2) $q = \alpha - \beta p - \gamma e$. The assumption indicates that the demand faced by the retailer is price and emissions sensitive (Echeverría et al. 2014; Kanchanapibul et al. 2014). α is the maximal market demand (end consumer demand). β and γ are the price sensitivity and the carbon emissions sensitivity. This linear demand function has been used extensively in the literature relating to pricing and supply chain research as an acceptable approximation of demand (Choudhary *et al.* 2015; Hovelaque and Bironneau 2015; Luo *et al.* 2016). We adopt this linear demand function because it is more analytically tractable and helps derive closed-form insights.

(3) $p > w > c > 0$. This condition states that there is a positive profit margin for the manufacturer to sell products to the retailer, and there is a positive profit margin for retailer to sell products to the end consumers. To avoid the trial result, we assume that $2\beta t - \gamma^2 > 0$.

Base on the above assumptions, the manufacturer's profit is

$$\pi_m\,(w, e) = wq - cq - T$$

The first term is the revenue from product wholesale, the second term indicates the production cost, and the third term refers to the green technology investment. That is

$$\pi_m(w, e) = (w - c)(\alpha - \beta p - \gamma e) - t(e_0 - e)^2 \quad (1)$$

We assume that the retailer's unit marginal profit is m, then $m = p - w$. So

$$\pi_m(w, e) = (w - c)[\alpha - \beta(w + m) - \gamma e] - t(e_0 - e)^2 \quad (2)$$

Similarly, the retailer's profit is

$$\pi_r(p) = pq - wq$$

The first term is the revenue from product retail sales, and the second term represents the purchase cost. That is,

$$\pi_r(p) = (p - w)(\alpha - \beta p - \gamma e) \quad (3)$$

4 Different power structure models

In this section, we discuss the models with three different supply chain power structures, which are the manufacturer Stackelberg (MS) model, the vertical Nash (VN) model, and the retailer Stackelberg (RS) model respectively.

I. The Manufacturer Stackelberg (MS) model

In the case of a MS power structure, the manufacturer and the retailer make their decisions in sequence. The order of events is as follows. First, the retailer determines the retail price in response to the given manufacturer's wholesale price and unit carbon emissions. Then, the manufacturer takes the retailer's response function into account for the optimal wholesale price and unit carbon emissions in order to maximize profit. Finally, when the customer demand is realized, the manufacturer and the retailer gain their revenues.

Ⅱ. The Vertical Nash (VN) model

In the case of a VN power structure, the manufacturer and the retailer make their decisions simultaneously. The order of events is as follows. The manufacturer determines the response function of wholesale price and unit carbon emissions to maximize profit given the retailer's retail price, and the retailer determines the response function of retailer price to maximize profit given the manufacturer's wholesale price and unit carbon emissions. Finally, when the customer demand is realized, the manufacturer and the retailer gain their revenues.

Ⅲ. The Retailer Stackelberg (RS) model

In the case of a RS power structure, the retailer and the manufacturer make their decisions in the following order. First, the manufacturer determines the wholesale price and unit carbon emissions in response to the given retailer's retail price. Then, the retailer takes the manufacturer's response function into account for the optimal retail price to maximize profit. Finally, when the customer demand is realized, the manufacturer and the retailer gain their revenues.

Regarding the manufacturer's optimal wholesale price (w^i) and unit carbon emissions (e^i), and the retailer's optimal retail price (p^i) in different power structures ($i = m, n, r$), the following lemma is obtained:

Lemma 1 ***The manufacturer's optimal wholesale price ($\mathbf{w}^i$) and unit carbon emissions (e^i), and the retailer's optimal retail price ($\mathbf{p}^i$) in three different power structures are summarized in Table 2.***

This lemma means that the manufacturer's optimal wholesale price and unit carbon emissions, and the retailer's optimal retail price are in existent and unique in the MS, VN and

RS power structures.

Table 2: Optimal decisions

Model	w^i	e^i	p^i
MS model $(i = m)$	$c + \frac{4t(\alpha - \beta c - \gamma e_0)}{8\beta t - \gamma^2}$	$\frac{8\beta t e_0 - \gamma(\alpha - \beta c)}{8\beta t - \gamma^2}$	$c + \frac{6t(\alpha - \beta c - \gamma e_0)}{8\beta t - \gamma^2}$
VN model $(i = n)$	$c + \frac{2t(\alpha - \beta c - \gamma e_0)}{6\beta t - \gamma^2}$	$\frac{6\beta t e_0 - \gamma(\alpha - \beta c)}{6\beta t - \gamma^2}$	$c + \frac{4t(\alpha - \beta c - \gamma e_0)}{6\beta t - \gamma^2}$
RS model $(i = r)$	$c + \frac{t(\alpha - \beta c - \gamma e_0)}{4\beta t - \gamma^2}$	$\frac{8\beta t e_0 - \gamma(\alpha - \beta c + \gamma e_0)}{2(4\beta t - \gamma^2)}$	$c + \frac{(6\beta t - \gamma^2)(\alpha - \beta c - \gamma e_0)}{2\beta(4\beta t - \gamma^2)}$

Regarding the effect of the manufacturer's green technology investment cost coefficient (t) on the optimal decisions for both the manufacturer and the retailer, the following corollary can be obtained:

Corollary 1 ***Both p^i and w^i are decreasing functions of t, and e^i is an increasing function of t, $i = m, n, r$.***

This corollary means that in each supply chain power structure, when the manufacturer's green technology investment cost coefficient (t) is high, that is, the manufacturer's green technology investment efficiency is low, then the manufacturer will invest less on green technology. As a result, the manufacturer's optimal unit carbon emissions after green technology investment (e^i) are high, which lead to less customer demand. In order to attract more customers, the retailer has to reduce the unit retail price (p^i). At the same time, since manufacturer's green technology investment is less, the manufacturer will set a low optimal wholesale price (w^i), $i = m, n, r$.

5 Supply chain coordination

In this section, an integrated supply chain is discussed as a benchmark. The firm's profit, denoted as $\pi^I(p, e)$, is

$$\pi^I(p, e) = (p - c)(\alpha - \beta p - \gamma e) - t(e_0 - e)^2 \quad (4)$$

The first term is the firm's revenue from product sales, and the second term represents the green investment. As to the firm's optimal retail price (p^I) and optimal unit carbon emissions (e^I) in an integrated supply chain, the following lemma is obtained.

Lemma 2 ***In an integrated supply chain,*** $\boldsymbol{p^I = c + \frac{2t(\alpha-\beta c-\gamma e_0)}{4\beta t-\gamma^2}}$, $\boldsymbol{e^I = \frac{4\beta t e_0-\gamma(\alpha-\beta c)}{4\beta t-\gamma^2}}$.

This lemma means that in an integrated supply chain, there are unique optimal retail price and optimal unit carbon emissions.

Now we discuss the supply chain coordination. Beside the wholesale price w, we assume that the retailer makes a lump-sum payment F to the manufacturer, and we call this mixed contract as *two-part tariff contract*. Under the two-part tariff contract, the manufacturer's profit, denoted as $\pi_{mm}(w,e)$, is

$$\pi_{mm}(w,e) = (w-c)(\alpha-\beta p-\gamma e) - t(e_0-e)^2 + F \quad (5)$$

Under the two-part tariff contract, the retailer's profit, denoted as $\pi_{rm}(w,e)$, is

$$\pi_{rm}(p) = (p-w)(\alpha-\beta p-\gamma e) - F \quad (6)$$

Regarding the supply chain coordination with the two-part tariff contract, the following proposition is obtained.

Proposition 1 ***The supply chain can be coordinated with a two-part tariff contract with the condition satisfies*** $\boldsymbol{w = c}$ ***and*** $\boldsymbol{F^m = \frac{32\beta^2 t^3(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(8\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}}$ ***in a MS power structure,*** $\boldsymbol{F^n = \frac{2\beta^2 t^3(36\beta t-7\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}}$ ***in a VN power structure,*** $\boldsymbol{F^r = \frac{t(4\beta t+3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)^2}}$ ***in a RS power structure.***

This proposition indicates that a two-part tariff contract can coordinate the supply chain and achieve the Pareto improvement, that is, both the manufacturer and the retailer can gain more profit than that without the two-part tariff contract. Under this contract, the manufacturer undertakes the green technology investment and gains no profit from the product sales, but gains revenue from the lump-sum payment paid by the retailer. The amount of the lump-sum payment paid by the retailer is affected by the supply chain power structure. At the same time, the retailer obtains profit from the product sales and makes a lump-sum payment to the manufacturer to compensate the manufacturer's green technology investment.

6 Discussions

In this section, we discuss the impact of power relationship on the supply chain's decisions, carbon emissions, profits and the retailer’s lump-sum payment.

Regarding the effect of power structure on the manufacturer’s optimal wholesale price and unit carbon emissions, and the retailer’s optimal retail price, the following proposition is obtained:

Proposition 2 $(a) w^m > w^n > w^r$; *(b)* $e^m > e^r > e^n$; *(c)* $p^m > p^r > p^n$.

This proposition indicates that the manufacturer’s optimal wholesale price in a MS power structure is higher than that in a VN power structure. Its optimal wholesale price is the lowest in a RS power structure. That is, the more supply chain power that the manufacturer has, the higher wholesale price will be set. This means that a dominant manufacturer is more likely to exercise its supply chain power to gain economic benefit rather than to invest on green technologies to improve its efficiencies in production and carbon emissions reduction. However, in order to achieve the sustainability objectives, fundamentally, we need firms to improve their energy efficiency and decrease their unit carbon emissions through green technology investment. Therefore, the short term economic gains from exercising supply chain power may not be sustainable over the long term as their competitors can improve their operation efficiencies and enhance their competitive capabilities, and as result, change the power relationship of the supply chain.

In addition, both the manufacturer’s optimal unit carbon emissions and the retailer’s optimal retail price is the lowest in a VN power structure and is the highest in a MS power structure. That is, the VN power structure will benefit both the environment and the customer, and in contrast, the MS power structure will hurt both the environment and the customer. This can be explained by the fact that a balanced supply chain power relationship provides a more competitive and fair supply chain environment. An enhanced but fairer competition will drive the supply chain parties to be more innovative and carbon efficient in making products and delivering customer services. This will certainly require the manufacturer and the retailer to invest more on technologies to improve their operational and carbon emission reduction capabilities. Such efforts will lead to improved economic and environmental performances of the individual members and the supply chain as a whole, and therefore make the supply chain more sustainable.

Regarding the effect of the supply chain power structure on the maximum profits of the manufacturer, the retailer, and the whole supply chain, the following proposition is obtained:

Proposition 3 $(a)\pi_m(w^m, e^m) > \pi_m(w^n, e^n) > \pi_m(w^r, e^r)$; $(b)\ \pi_r(p^r) > \pi_r(p^n) > \pi_r(p^m)$; $(c)\ \pi^n > \pi^r > \pi^m$.

From this proposition, we know that the manufacturer will gain more profit in a MS power structure and will generate less profit in a RS power structure. In contrast, the retailer will gain more profit in a RS power structure and generate less profit in a MS power structure. That means, the more supply chain power, the more profit that the manufacturer or the retailer will gain. This finding is in line with the findings of the existing literature (Zhang et al. 2012; Touboulic et al. 2014; Chen et al. 2016) that with an imbalanced power relationship, a dominant supply chain member is always in the premier position when negotiating prices, and is able to set a more favourable wholesale price or retail price for its own benefit. For the whole supply chain, a more balanced power relationship between the manufacturer and the retailer will lead to higher profit. Recalling the proposition 2, we found that the VN power structure will benefit the environment, the end consumers and the whole supply chain.

Regarding the effect of power structure on the retailer's lump-sum payment (F), the following proposition is obtained.

Proposition 4 $F^m > F^n > F^r$.

From this proposition, we know that the supply chain power relationship plays an important role in the retailer's lump-sum payment. If it is a MS power structure, a higher lump-sum payment will be paid to the manufacturer. In contrast, if it is a RS power structure, a lower lump-sum payment will be paid to the manufacturer. Again, similar to the explanation made earlier, more supply chain power will give the manufacturer or the retailer an advantage when negotiating the lump-sum payment with their supply chain count parties.

7 Case study

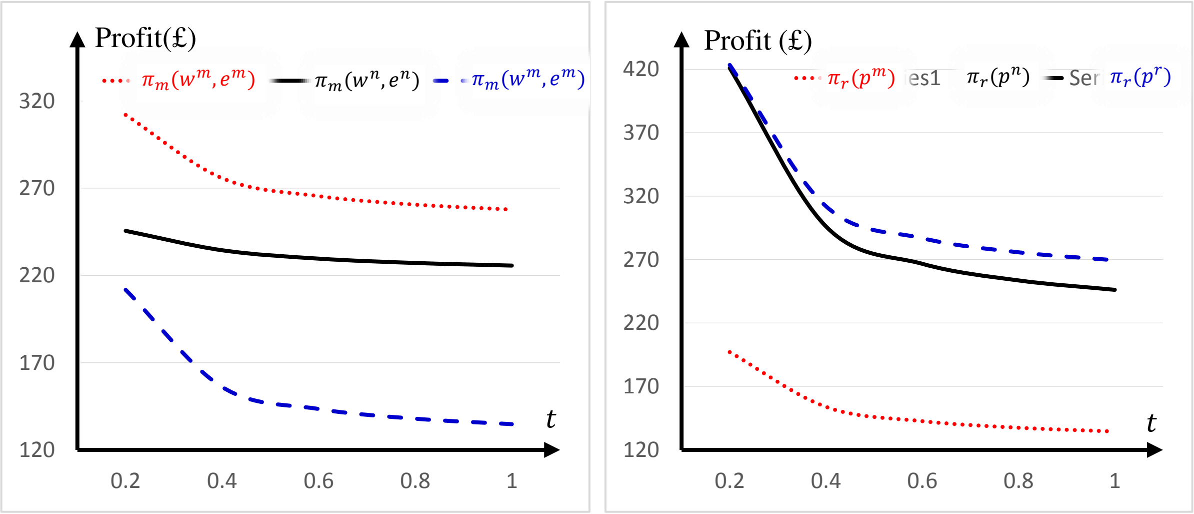
A case study of the food supply chain is presented here to illustrate how our analytical modelling results can be applied to the supply chains in the real world. Food provision is an essential part of our society. Whereas the production and distribution of food products become more efficient in many aspects, managing the sustainability of the food supply chain remains to be urgent than ever as the industry consumes a large amount of natural resources and faces ever increasing demand (Li et al. 2014). In addition, food supply chains are often key contributors of greenhouse gas emissions. For instance, in the UK, the food industry contributes about 40% of the national total emissions (Government Office for Science, 2011). Therefore, it is critical for food supply chains to improve the sustainability in order to regain and retain consumer trust and meet the future demand.

Furthermore, all three supply chain power relationships discussed in this research are common in the food supply chain. For instance, in many developed countries, consumers purchase their food products from grocery supermarkets. In fact, supermarkets are often the dominant force or supply chain leader (the retailer Stackelberg game). They are often described as the chain captain, who has the power to impose through strategic and operational decisions and drive the sustainability agenda. In the grocery food supply chain, there are also powerful and resourceful multinational food manufacturers e.g. Nestle and Danone. Therefore, there is often a balanced supply chain power relationship (the vertical Nash game) between the big food manufacturers and supermarkets. In addition, there is a different supply chain power relationship (the manufacturer Stackelberg game) when the powerful food manufacturers sell their products through smaller scale independent food retailers, which is also common in both developed and developing countries. In the United Kingdom, the grocery supply chain has received much attention from the general public and policy makers on its sustainability performance due to some recent high profile events such as the Horse Meat Scandal and the price dispute between diary producers and supermarket chains. While the imbalanced supply chain power relationship may contribute these incidents, the price dispute between TESCO (the UK largest supermarket) and Unilever (the largest food manufacturer) has again attracted wide media coverage.

In the following section, numerical analysis is provided to examine the impact of various factors on firms' operations decisions and economic and environmental performances. More specifically, we discuss the effect of manufacturer's green technology investment cost coefficient (t) and carbon emissions sensitivity (γ) on maximum profits of both the manufacturer and the retailer. There are hundreds types of food products involved in the daily transition in the grocery food supply chain. For the demonstration purpose, we only choose one product item in the illustrative example, in which, we specify that the food manufacturer's unit production cost (c) for this item as £1, the manufacturer's initial unit carbon emissions (e_0) as 20, the maximal market demand (α) as 100, and the price sensitivity (β) as 3.

7.1 Effects of manufacturer's green technology investment cost coefficient (t)

First, a numerical example is presented to illustrate the effects of manufacturer's green technology investment cost coefficient (t) on the maximum profits of both the manufacturer and the retailer. We assume that the carbon emissions sensitivity (γ) is 1. However, we will also analyse the effect of carbon emissions sensitivity with a different set of value for γ in the next section. The corresponding results are shown in Figure 1.



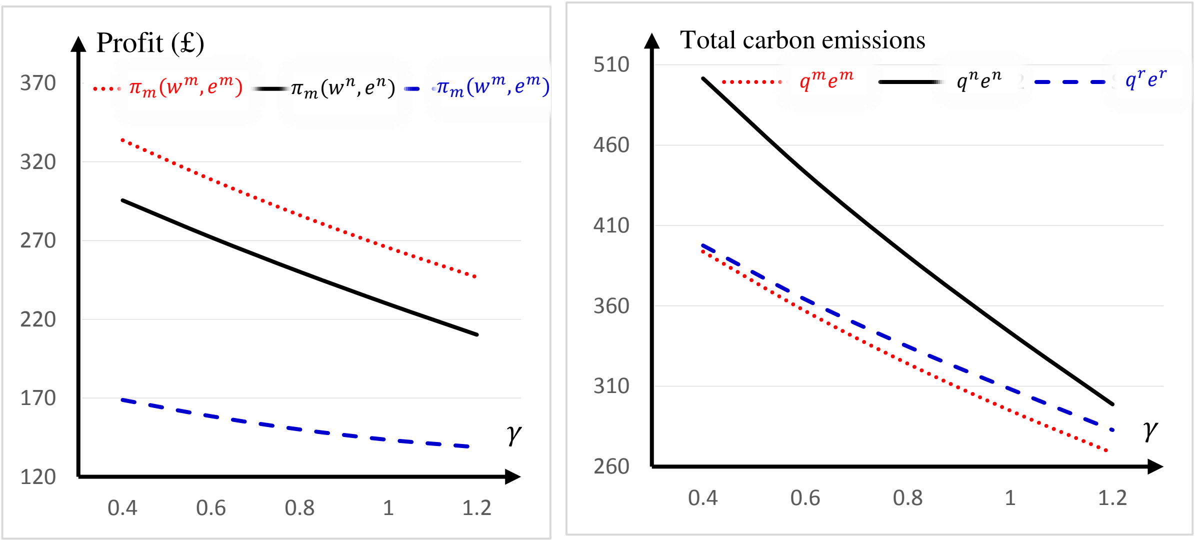
(a) (b)

Figure 1: Effects of t on firms' economic performance

From Figure 1, we observe that manufacturer's green technology investment cost coefficient (t) does affect the maximum profits of both the manufacturer and the retailer in each power structure. As the manufacturer's green technology investment cost coefficient (t) increases, the manufacturer has to invest more to achieve the carbon emissions reduction. Then the manufacturer's maximum profit decreases in each power structure. At the same time, in order to reduce the burden of green technology investment cost, the manufacturer wants to share the green technology investment cost with the retailer by adjusting the wholesale price, then the retailer's maximum profit will also decrease. So, when the manufacturer's green technology investment cost coefficient (t) increases, both the manufacturer's maximum profit (Figure 1a) and the retailer's maximum profit (Figure 1b) decrease in all three power structures. The above analysis indicates that in order to achieve the financial benefit (e.g. making more profit), supply chain members should try to gain more market power through increasing the economic scale of their businesses, and alternatively improve the efficiency of green technology investment through developing their technological and operational capabilities.

7.2 Effects of carbon emissions sensitivity (γ)

Now, we examine the effect of carbon emissions sensitivity (γ) on the manufacturer's maximum profits and total carbon emissions ($q^i e^i, i = m, n, r$). We specify that the manufacturer's green technology investment cost coefficient (t) as 0.1. The corresponding results are shown in Figure 2.



(a) (b)

Figure 2: Effects of γ on the manufacturer's economic and environmental performance

From Figure 2(a), we observe that carbon emissions sensitivity (γ) does affect the maximum profits and total carbon emissions of the manufacturer in each power structure. As the carbon emissions sensitivity (γ) increases, the manufacturer has to invest more to reduce his carbon emissions. Then the manufacturer's maximum profit decreases in each power structure. From Figure 2(b), we observe that carbon emissions sensitivity (γ) does affect the manufacturer's total carbon emissions in each power structure. As the carbon emissions sensitivity (γ) increases, that is, the customers demand is more sensitive on the carbon emissions sensitivity (γ), it will force firms to reduce carbon emissions in order to win customer orders. However, it requires more investment on green technology. Therefore, it is clear from Figure 2 that more sensitive customer demand toward carbon emission will, on the one hand, improve firms' environmental performance, and on the other hand, decrease their economic performance because of the additional cost involved in carbon emissions reduction. Firms have to deal with the dilemma between the economic and environmental objectives of the sustainability. As the evolving public attitude towards the environmental protection, in order to improve their long term competitive capabilities, it will be beneficial for firms to sacrifice the short term economic performance and reduce their carbon emissions through green technology investment. In this connection, the Government may be able to introduce relevant policy to subsidise or to help the industry, especially small and medium sized companies, to overcome this short term pain.

8 Conclusion and future research

Sustainability agenda has become increasingly important in ensuring sound business practices in everyday life. In this paper, a two-echelon sustainable supply chain is considered consisting of a manufacturer and a retailer. Based on game models, we derive the manufacturer's optimal wholesale price and unit carbon emissions, and the retailer's optimal retail price under three supply chain power structures. In addition, we design a two-part tariff contract that takes into account the relevant parameters of prices and green technology investment. Our analysis show that such a contract can coordinate the sustainable supply chain under different power structures and achieve the Pareto improvement. Finally, we discuss the effect of power relationship on the supply chain's decisions, coordination contracts, and sustainability performances. The main findings are as following:

Economically, the more power a retailer or a manufacturer has over its supply chain partner, the more economic benefit can be gained for the powerful supply chain member. The increased profit is mainly contributed by a higher retail price or wholesale price they can charge to their customers or a higher lump-sum payment received from its supply chain partner. From the whole supply chain point of view, a more balanced power between the manufacturer and the retailer, i.e., the VN model in this study, will generate the best economic performance. Interestingly, there is a dilemma between maximizing individual firms' profits and the whole supply chain's profits. Nevertheless, it is important to recognise that the business competition have already evolved from the competition of individual companies to the competition of supply chains. In order to achieve an economically sustainable supply chain, even for solely profit pursuers, it is essential to improve the economic performance of the whole supply chain to ensure a long term success.

Environmentally, the VN model also produces the best performance as it generates the lowest optimal unit carbon emissions. In contrast, the MS model produces the worst environmental performance as it generates the highest optimal unit carbon emissions. This can be explained by the fact that in the Manufacturer or Retailer Stackelberg models, the manufacturer or the retailer often exploits her power over her dependent supply chain members to gain economic benefit rather than improve their own operations efficiency or environmental capabilities to gain market competitiveness. In contrast, there is more supply chain competition in the VN model, which drives the manufacturer and the retailer to invest on technologies to improve their operations and environmental capabilities in order to gain market competitiveness.

Socially, a balanced supply chain relationship performs best as compared to the Stackelberg models. This is mainly reflected in two aspects. First, from the general public perspective, while generating the lowest optimal unit carbon emissions, the VN model also achieves the lowest optimal retail price. It means that if there is a balanced supply chain power, the environmentally friendly products are more affordable to the end consumers and therefore can be accessed and consumed by a wider population. Second, from the whole supply chain point of view, a balanced power also generates more profits as compared to the power imbalanced supply chains. Supply chain partners can therefore share the increased profits between them through a two-part tariff contract and gain mutual benefits. Consequently, they can either pay bonuses or dividends to existing staff to improve the welfare of existing staff or re-invest gained profit to recruit new staff.

Our findings provide many interesting managerial and policy implications. First, we derived the optimal wholesale price, retail price, unit carbon emissions and lump-sum payment under three different supply chain power structures, which will be beneficial to manufacturers and retailers in different supply chain environments to make optimal operational decisions to improve their profits. Second, we discuss the implications of the supply chain power relationship to the sustainability performances from the perspectives of economics, environment and society, which enables manufacturers and retailers to make strategic decisions toward sustainable supply chain management. For instance, in order to achieve the sustainability goals, dominant members may not exploit their power over dependent supply chain count parties but rather treat them like strategic partners. A similar view is shared by the work of Pagell *et al.* (2010). It is valuable for business leaders and policy makers to create an effective supply chain environment that can promote sustainable development across different industrial sectors.

Indeed, we see this paper as an early attempt to understand key decisions of coordinating sustainable supply chains under different power structures and their impact on the sustainability performances. Similar to other previous work published in the literature, the present model also has its own limitations, which imply fruitful directions for future research. For example, a linear additive deterministic demand function is adopted in the paper. Although this simple form of demand function has the advantages of being analytically more tractable and is widely applied in similar studies (Yalabik and Fairchild 2011; Choudhary et al. 2015, He et al. 2015, Hovelaque and Bironneau 2015; Luo et al. 2016), using deterministic models does not consider the cost associated with demand uncertainty. One future extension is to investigate the research problem using other forms of demand function including stochastic models to explore how different demand functions might influence the result. Furthermore, although social implications of a sustainable supply chain are discussed from the view of consumer affordability of low carbon emissions product and the mutual benefits of supply chain parties, we have to acknowledge that the social aspect of the sustainability is not specifically quantified as compared to the economic and environmental aspects. It will be an interesting future research extension to incorporate the key indicator that specifically measures the social performance in the analytical model. Finally, our model assumed the two-echelon supply chain consisting of a retailer and a manufacturer. In the real world, supply chains are often much more complicated than this simple form of supply chain structure. Despite the value and contribution discussed above, the research would generate more interesting insights and provide better decisions support if other supply chain parties such as consumers and logistics service providers can be incorporated in the modelling. It would also be interesting to consider multi-retailers and/or multi-manufacturers and analyse the effect of vertical and horizontal power relationships on supply chain decisions and sustainability performances.

Acknowledgments

The first author is partially supported by National Natural Science Foundation of China (No. 71272128, 71432003), and Specialized Research Fund for the Doctoral Program of Higher Education (No. 20130185110006).

Reference

1. Amaeshi, K.M., Osuji, O.K., Nnodim P., 2008. Corporate social responsibility in supply chains of global brands: A boundaryless responsibility? Clarifications, exceptions and implications. *Journal of Business Ethics*. 81(1), 223-234.
2. Bai, C., Sarkis, J., 2010. Integrating sustainability into supplier selection with grey system and rough set methodologies. *International Journal of Production Economics.* 124(1), 252-264.
3. Bai, C., Sarkis, J., Dou, Y., 2015. Corporate sustainability development in China: review and analysis. *Industrial Management & Data Systems*. 115(1), 5-40.
4. Boukherroub, T., Ruiz, A., Guinet, A., Fondrevelle, J., 2015. An integrated approach for sustainable supply chain planning. *Computers & Operations Research.* 54, 180-194.
5. Cai, G., Zhang, Z., Zhang, M., 2009. Game theoretical perspectives on dual-channel supply chain competition with price discounts and pricing schemes. *International Journal of Production Economics*. 117(1), 80-96
6. Cai, G., 2010. Channel selection and coordination in dual-channel supply chains. *Journal of Retailing*. 86(1), 22-36.

7. Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management.* 38(5), 360-387.
8. Chen, X., Hao, G., Li, L., 2014. Channel coordination with a loss-averse retailer and option contracts. *International Journal of Production Economics*. 150, 52-57.
9. Chen, X., Wang, X., 2015. Free or bundled: channel selection decisions under different power structures. *Omega.* 53, 11-20.
10. Chen, X., Wang, X., 2016. Effects of carbon emission reduction policies on transportation mode selections with stochastic demand. *Transportation Research Part E: Logistics and Transportation Review*, 90, 196-205.
11. Chen, X., Wang, X., Jiang, X., 2016. The impact of power structure on retail service supply chain with an O2O mixed channel. *Journal of the Operational Research Society.* 67(2), 294-301.
12. Chiou, T.Y., Chan, H.K., Lettice, F., Chung, S.H., 2011. The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan. *Transportation Research Part E: Logistics and Transportation Review*, 47(6), 822-836.
13. Choi, T.M., Li, Y. and Xu, L., 2013. Channel leadership, performance and coordination in closed loop supply chains. *International Journal of Production Economics*, 146(1), 371-380.
14. Choudhary, A., Suman, R., Dixit, V., Tiwari, M. K., Fernandes, K. J., Chang, P. C. 2015. An optimization model for a monopolistic firm serving an environmentally conscious market: use of chemical reaction optimization algorithm. *International Journal of Production Economics,* 164, 409-420.
15. Cox, A. 1999. Power, value and supply chain management. *Supply Chain Management: An International Journal*, 4(4), 167-75.
16. Cox, A., Ireland, P., Lonsdlale, C., Watson, G., 2002. Supply chains, markets and power: Mapping buyer and supplier power regimes. London: Routledge.
17. Du, S., Ma, F., Fu, Z., Zhu, L., Zhang, J., 2015. Game-theoretic analysis for an emission-dependent supply chain in a ‘cap-and-trade’ system. *Annals of Operations Research*, 228(1), 135-149.
18. Dyllick, T., Hockerts, K., 2002. Beyond the business case for corporate sustainability. *Business Strategy and the Environment*. 11(2), 130-141.
19. Echeverría, R., Moreira, V. H., Sepúlveda, C., Wittwer, C. 2014. Willingness to pay for carbon footprint on foods. *British Food Journal*, 116(2), 186-196.
20. Elkington, J., 1998. Cannibals with Forks: The Triple Bottom Line of the 21st Century, New

Society, Stoney Creek, CT.

21. Erol, I., Sencer, S., Sari, R., 2011. A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain. *Ecological Economics*. 70, 1088-1100.
22. Ertek, G., Griffin, P.M., 2002. Supplier-and buyer-driven channels in a two-stage supply chain. *IIE Transactions*. 34(8), 691-700.
23. Gao, J., Han, H., Hou, L. and Wang, H., 2016. Pricing and effort decisions in a closed-loop supply chain under different channel power structures. *Journal of Cleaner Production*, 112, 2043-2057.
24. Gauthier, C., 2005. Measuring corporate social and environmental performance: the extended life-cycle assessment. *Journal of Business Ethics.* 59(1), 199-206.
25. Goldbach, M., Seuring, S., Back, S., 2003. Co-ordinating sustainable cotton chains for the mass market. *Greener Management International*. 43, 65-78.
26. Government Office for Science. 2011. Foresight Project on Global Food and Farming Futures. Synthesis Report C12: Meeting the challenges of low-emissions world. URN 11/632.
27. Hovelaque, V., Bironneau, L., 2015. The carbon-constrained EOQ model with carbon emission dependent demand. *International Journal of Production Economics*, 164, 285-291.
28. Ingene, C.A., Parry, M.E., 1995. Channel coordination when retailers compete. *Marketing Science.* 14(4), 360-377.
29. Jeuland, A.P., Shugan, S.M., 1983. Managing channel profits. *Marketing science.* 2(3), 239-272.
30. Kanchanapibul, M., Lacka, E., Wang, X., Chan, H.K., (2014). An empirical investigation of green purchase behaviour among the young generation. *Journal of Cleaner Production*, 66, 528-536.
31. Labuschagne, C., Brent, A.C., van Erck, R.P.G., 2005. Assessing the sustainability performance of industries. *Journal of Cleaner Production.* 13(4), 373-385.
32. Li, D., Wang, X., Chan, H.K. and Manzini, R., 2014. Sustainable food supply chain management. *International Journal of Production Economics,* 152, 1-8.
33. Li, X. and Li, Y., 2016. Chain-to-chain competition on product sustainability. *Journal of Cleaner Production*, 112, 2058-2065.
34. Linton, J.D., Klassen, R., Jayaraman, V., 2007. Sustainable supply chains: an introduction. *Journal of Operations Management.* 25, 1075-1082.
35. Liu, Z. L., Anderson, T. D., Cruz, J. M., 2012. Consumer environmental awareness and competition in two-stage supply chains. *European Journal of Operational Research*, 218(3), 602-613.

36. Luo, Z., Chen, X., Wang, X., 2016. The role of co-opetition in low carbon manufacturing. *European Journal of Operational Research.* 253(2), 392-403.
37. Luo, J., Chen, X., 2016. Coordination of random yield supply chains with improved revenue sharing contracts. *European Journal of Industrial Engineering*. 10(1), 81-102.
38. Nouira, I., Frein, Y., Hadj-Alouane, A.B., 2014. Optimization of manufacturing systems under environmental considerations for a greenness-dependent demand. *International Journal of Production Economics*, 150, 188-198.
39. Pagell, M., Wu, Z., Wasserman, M.E., 2010. Thinking differently about purchasing portfolios: An assessment of sustainable sourcing. *Journal of Supply Chain Management.* 46(1), 57-73.
40. Pagell, M., Wu, Z., 2009. Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. *Journal of supply chain management.* 45(2), 37-56.
41. Panda, S. 2014. Coordination of a socially responsible supply chain using revenue sharing contract. *Transportation Research Part E: Logistics and Transportation Review*, 67, 92-104.
42. Pedersen, E.R., Andersen, M., 2006. Safeguarding corporate social responsibility (CSR) in global supply chains: how codes of conduct are managed in buyer‐supplier relationships. *Journal of Public Affairs.* 6(3-4), 228-240.
43. Pullman, M.E., Maloni, M.J., Carter, C.R., 2009. Food for thought: Social versus environmental sustainability practices and performance outcomes. *Journal of Supply Chain Management.* 45(4), 38-54.
44. Raju, J., Zhang, Z.J., 2005. Channel coordination in the presence of a dominant retailer. *Marketing Science.* 24(2), 254-262.
45. Rao, P., 2002. Greening the supply chain: a new initiative in South East Asia. *International Journal of Operations & Production Management.* 22(6), 632-655.
46. Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production.* 16(15), 1699-1710.
47. Shi, R., Zhang, J., Ru, J., 2013. Impacts of power structure on supply chains with uncertain demand. *Production and Operations Management.* 22(5), 1232-1249.
48. Simpson, D.F., Power, D.J., 2005. Use the supply relationship to develop lean and green suppliers. *Supply chain management: An international Journal.* 10(1), 60-68.
49. Simpson, D., Power, D., Samson, D., 2007. Greening the automotive supply chain: a relationship

perspective. *International Journal of Operations & Production Management.* 27(1), 28-48.

50. Swami, S., Shah, J., 2013. Channel coordination in green supply chain management. *Journal of the Operational Research Society.* 64(3), 336-351.
51. Touboulic, A., Chicksand, D., Walker, H., 2014. Managing imbalanced supply chain relationships for sustainability: a power perspective. *Decision Sciences.* 45(4), 577-619.
52. Vachon, S., Klassen, R.D., 2006. Extending green practices across the supply chain: the impact of upstream and downstream integration. *International Journal of Operations & Production Management.* 26(7), 795-821.
53. Vachon, S., Klassen, R.D., 2008. Environmental management and manufacturing performance: The role of collaboration in the supply chain. *International Journal of Production Economics.* 111(2), 299-315.
54. Vasileiou, K., Morris, J., 2006. The sustainability of the supply chain for fresh potatoes in Britain. *Supply Chain Management: An International Journal.* 11(4), 317-327
55. Walton, S.V., Handfield, R.B., Melnyk, S.A., 1998. The green supply chain: integrating suppliers into environmental management processes. *International Journal of Purchasing and Materials Management.* 34(1), 2-11.
56. Wan, L., Luo, B., Li, T., Wang, S. and Liang, L., 2015. Effects of technological innovation on eco-efficiency of industrial enterprises in China. *Nankai Business Review International*, 6(3), 226-239.
57. Wang, C., Wang, C., Luo, B., Luo, B., Liu, Y., Liu, Y., Wei, Z. and Wei, Z., 2016. The impact of executives' perceptions of environmental threats and organizational slack on innovation strategies. *Nankai Business Review International*, 7(2), 216-230.
58. WCED (World Commission on Environment and Development), 1987. Our common future. Oxford: Oxford University Press
59. Weng ZK. 1995. Channel coordination and quantity discounts. *Management Science*, 41(9), 1509-1522.
60. Xu, K., Dong, Y., Evers, P. T. 2001. Towards better coordination of the supply chain. *Transportation Research Part E: Logistics and Transportation Review*, 37(1), 35-54.
61. Yalabik, B., Fairchild, R.J., 2011. Customer, regulatory, and competitive pressure as drivers of environmental innovation. *International Journal of Production Economics*. 131(2), 519-527.
62. Yang, C.S., Lu, C.S., Haider, J.J., Marlow, P.B., 2013. The effect of green supply chain

management on green performance and firm competitiveness in the context of container shipping in Taiwan. *Transportation Research Part E: Logistics and Transportation Review*, 55, 55-73.

63. Zhang, R., Liu, B., Wang, W., 2012. Pricing decisions in a dual channels system with different power structures. *Economic Modelling*. 29(2), 523-533.
64. Zhang, L., Wang, J., You, J., 2015. Consumer environmental awareness and channel coordination with two substitutable products. *European Journal of Operational Research*, 241(1), 63-73.
65. Zhu, Q., Geng, Y., Sarkis, J., Lai, K. H. 2011. Evaluating green supply chain management among Chinese manufacturers from the ecological modernization perspective. *Transportation Research Part E: Logistics and Transportation Review*, 47(6), 808-821.

Appendix

Proof of Lemma 1

I. The Manufacturer Stackelberg (MS) model

From (3), we get $\frac{d\pi_r(p)}{dp} = \alpha - 2\beta p + \beta w - \gamma e$ and $\frac{d^2\pi_r(p)}{dp^2} = -2\beta < 0$, that is, $\pi_r(p)$ is concave in p. Let $\frac{d\pi_r(p)}{dp} = 0$, we get $p = \frac{\alpha+\beta w-\gamma e}{2\beta}$. Replace $p = \frac{\alpha+\beta w-\gamma e}{2\beta}$ to (1), we get $\pi_m(w,e) = \frac{1}{2}(w-c)(\alpha-\beta w-\gamma e) - t(e_0-e)^2$. Let $\frac{\partial\pi_m(w,e)}{\partial w} = \frac{\partial\pi_m(w,e)}{\partial e} = 0$, we get $w^m = c + \frac{4t(\alpha-\beta c-\gamma e_0)}{8\beta t-\gamma^2}$ and $e^m = \frac{8\beta t e_0-\gamma(\alpha-\beta c)}{8\beta t-\gamma^2}$. Recall $p > w > c$ and $e \le e_0$, we get $q = \alpha - \beta p - \gamma e > \alpha - \beta c - \gamma e_0 > 0$. Since $\frac{\partial\pi_m(w,e)}{\partial w} = \frac{1}{2}(\alpha + \beta c - 2\beta w - \gamma e)$, $\frac{\partial\pi_m(w,e)}{\partial e} = 2t(e_0-e) - \frac{1}{2}\gamma(w-c)$, $\frac{\partial^2\pi_m(w,e)}{\partial w^2} = -\beta < 0$, $\frac{\partial^2\pi_m(w,e)}{\partial e^2} = -2t$ and $\frac{\partial^2\pi_m(w,e)}{\partial w\partial e} = \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} = -\frac{\gamma}{2}$, then $\begin{vmatrix} \frac{\partial^2\pi_m(w,e)}{\partial w^2} & \frac{\partial^2\pi_m(w,e)}{\partial w\partial e} \\ \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} & \frac{\partial^2\pi_m(w,e)}{\partial e^2} \end{vmatrix} = \frac{8\beta t-\gamma^2}{4} > 0$, that is, $\pi_m(w,e)$ is joint concave in w and e. Replace w^m and e^m to $p = \frac{\alpha+\beta w-\gamma e}{2\beta}$, we get $p^m = c + \frac{6t(\alpha-\beta c-\gamma e_0)}{8\beta t-\gamma^2}$.

Ⅱ. The Vertical Nash (VN) model

From (2), we get $\frac{\partial\pi_m(w,e)}{\partial w} = \alpha - \beta(w-c) - \beta(w+m) - \gamma e$, $\frac{\partial\pi_m(w,e)}{\partial e} = 2t(e_0-e) - \gamma(w-c)$. From $\frac{\partial\pi_m(w,e)}{\partial w} = \frac{\partial\pi_m(w,e)}{\partial e} = 0$, we get $w^n = c + \frac{2t(\alpha-\beta c-\gamma e_0)}{6\beta t-\gamma^2}$, $e^n =$

$\frac{6\beta te_0-\gamma(\alpha-\beta c)}{6\beta t-\gamma^2}$. Recall $p > w > c$ and $e \leq e_0$, we get $q = \alpha - \beta p - \gamma e > \alpha - \beta c - \gamma e_0 > 0$. Since $\frac{\partial^2\pi_m(w,e)}{\partial w^2} = -2\beta < 0$, $\frac{\partial^2\pi_m(w,e)}{\partial e^2} = -2t$ and $\frac{\partial^2\pi_m(w,e)}{\partial w\partial e} = \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} = -\gamma$, then $\begin{vmatrix} \frac{\partial^2\pi_m(w,e)}{\partial w^2} & \frac{\partial^2\pi_m(w,e)}{\partial w\partial e} \\ \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} & \frac{\partial^2\pi_m(w,e)}{\partial e^2} \end{vmatrix} = 4\beta t - \gamma^2 > 0$, that is, $\pi_m(w,e)$ is a joint concave in w and e. Similarly, from (3), we get $\frac{d\pi_r(p)}{dp} = \alpha - 2\beta p + \beta w - \gamma e$ and $\frac{d^2\pi_r(p)}{dp^2} = -2\beta < 0$, that is, $\pi_r(p)$ is concave in p. From $\frac{d\pi_r(p)}{dp} = 0$, we get $p^n = c + \frac{4t(\alpha-\beta c-\gamma e_0)}{6\beta t-\gamma^2}$.

Ⅲ. The Retailer Stackelberg (RS) model

From (2), we get $\frac{\partial\pi_m(w,e)}{\partial w} = \alpha - \beta(w-c) - \beta(w+m) - \gamma e$, $\frac{\partial\pi_m(w,e)}{\partial e} = 2t(e_0 - e) - \gamma(w-c)$, From $\frac{\partial\pi_m(w,e)}{\partial w} = \frac{\partial\pi_m(w,e)}{\partial e} = 0$, we get $w = c + \frac{2t(\alpha-\beta p-\gamma e_0)}{2\beta t-\gamma^2}$ and $e = \frac{2\beta te_0-(\alpha-\beta p)\gamma}{2\beta t-\gamma^2}$. Replace $w = c + \frac{2t(\alpha-\beta p-\gamma e_0)}{2\beta t-\gamma^2}$ and $e = \frac{2\beta te_0-(\alpha-\beta p)\gamma}{2\beta t-\gamma^2}$ to (3), we get $\pi_r(p) = \left[p - c - \frac{2t(\alpha-\beta p-\gamma e_0)}{2\beta t-\gamma^2}\right]\left[\alpha - \beta p - \gamma\frac{2\beta te_0-(\alpha-\beta p)\gamma}{2\beta t-\gamma^2}\right]$, then we get $\frac{d\pi_r(p)}{dp} = \frac{2\beta t[2\beta t(3\alpha+\beta c-4\beta p-3\gamma e_0)-\gamma^2(\alpha+\beta c-2\beta p-\gamma e_0)]}{(2\beta t-\gamma^2)^2}$ and $\frac{d^2\pi_r(p)}{dp^2} = \frac{-4\beta^2 t(4\beta t-\gamma^2)}{(2\beta t-\gamma^2)^2} < 0$, that is, $\pi_r(p)$ is concave in p. Let $\frac{d\pi_r(p)}{dp} = 0$, we get $p^r = c + \frac{(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)}{2\beta(4\beta t-\gamma^2)}$. Replace p^r to $w = c + \frac{2t(\alpha-\beta p-\gamma e_0)}{2\beta t-\gamma^2}$ and $e = \frac{2\beta te_0-(\alpha-\beta p)\gamma}{2\beta t-\gamma^2}$, we get $w^r = c + \frac{t(\alpha-\beta c-\gamma e_0)}{4\beta t-\gamma^2}$ and $e^r = \frac{8\beta te_0-\gamma(\alpha-\beta c+\gamma e_0)}{2(4\beta t-\gamma^2)}$. Recall $p > w > c$ and $e \leq e_0$, we get $q = \alpha - \beta p - \gamma e > \alpha - \beta c - \gamma e_0 > 0$. Since $\frac{\partial^2\pi_m(w,e)}{\partial w^2} = -2\beta < 0$, $\frac{\partial^2\pi_m(w,e)}{\partial e^2} = -2t$ and $\frac{\partial^2\pi_m(w,e)}{\partial w\partial e} = \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} = -\gamma$, then $\begin{vmatrix} \frac{\partial^2\pi_m(w,e)}{\partial w^2} & \frac{\partial^2\pi_m(w,e)}{\partial w\partial e} \\ \frac{\partial^2\pi_m(w,e)}{\partial e\partial w} & \frac{\partial^2\pi_m(w,e)}{\partial e^2} \end{vmatrix} = 4\beta t - \gamma^2 > 0$, that is, $\pi_m(w,e)$ is a joint concave in w and e. Hence, the manufacturer's optimal wholesale price and unit carbon emissions, and the retailer's optimal retail price are existent and unique in the MS, VN and RS power structures. This completes the proof.

Proof of Corollary 1

$\frac{dw^m}{dt} = -\frac{4r^2(\alpha-\beta c-\gamma e_0)}{(8\beta t-\gamma^2)^2} < 0$, $\frac{dw^n}{dt} = -\frac{2r^2(\alpha-\beta c-\gamma e_0)}{(6\beta t-\gamma^2)^2} < 0$ and $\frac{dw^r}{dt} = -\frac{r^2(\alpha-\beta c-\gamma e_0)}{(4\beta t-\gamma^2)^2} < 0$, that is, w^i is a decreasing function of t, $i = m, n, r$. $\frac{de^m}{dt} = \frac{8\beta\gamma(\alpha-\beta c-\gamma e_0)}{(8\beta t-\gamma^2)^2} > 0$, $\frac{de^n}{dt} = \frac{6\beta\gamma(\alpha-\beta c-\gamma e_0)}{(6\beta t-\gamma^2)^2} > 0$ and $\frac{de^r}{dt} = \frac{8\beta\gamma(\alpha-\beta c-\gamma e_0)}{(8\beta t-2\gamma^2)^2} > 0$, that is, e^i is an increasing function of t, $i = m, n, r$. $\frac{dp^m}{dt} = -\frac{6r^2(\alpha-\beta c-\gamma e_0)}{(8\beta t-\gamma^2)^2} < 0$, $\frac{dp^n}{dt} = -\frac{4r^2(\alpha-\beta c-\gamma e_0)}{(6\beta t-\gamma^2)^2} < 0$ and $\frac{dp^r}{dt} = -\frac{r^2(\alpha-\beta c-\gamma e_0)}{(4\beta t-\gamma^2)^2} < 0$, that is, p^i is a decreasing function of t, $i = m, n, r$. So, both p^i and w^i are decreasing functions of t, and e^i is an increasing function of t, $i = m, n, r$.

Proof of Lemma 2

From (4), we get $\frac{\partial \pi^I(p,e)}{\partial p} = \alpha - 2\beta p + \beta c - \gamma e$, $\frac{\partial \pi^I(p,e)}{\partial e} = 2(e_0 - e)t - (p - c)\gamma$. From $\frac{\partial \pi^I(p,e)}{\partial p} = \frac{\partial \pi^I(p,e)}{\partial e} = 0$, we get $p^I = c + \frac{2t(\alpha-\beta c-\gamma e_0)}{4\beta t-\gamma^2}$ and $e^I = \frac{4\beta t e_0-\gamma(\alpha-\beta c)}{4\beta t-\gamma^2}$. Recall $p > w > c$ and $e \leq e_0$, we get $q = \alpha - \beta p - \gamma e > \alpha - \beta c - \gamma e_0 > 0$. Since $\frac{\partial^2 \pi^I(p,e)}{\partial p^2} = -2\beta < 0$, $\frac{\partial^2 \pi^I(p,e)}{\partial e^2} = -2t$ and $\frac{\partial^2 \pi^I(p,e)}{\partial p \partial e} = \frac{\partial^2 \pi^I(p,e)}{\partial e \partial p} = -\gamma$, then $\begin{vmatrix} \frac{\partial^2 \pi^I(p,e)}{\partial p^2} & \frac{\partial^2 \pi^I(p,e)}{\partial p \partial e} \\ \frac{\partial^2 \pi^I(p,e)}{\partial e \partial p} & \frac{\partial^2 \pi^I(p,e)}{\partial e^2} \end{vmatrix} = 4\beta t - \gamma^2 > 0$, that is, $\pi^I(p,e)$ is joint concave in p and e. This completes the proof.

Proof of Proposition 1

From (6), we get $\frac{d\pi_{rm}(p)}{dp} = \alpha - 2\beta p + \beta w - \gamma e$ and $\frac{d^2\pi_{rm}(p)}{dp^2} = -2\beta < 0$, that is, $\pi_{rm}(p)$ is concave in p. Let $\frac{d\pi_{rm}(p)}{dp} = 0$, we get $\alpha - 2\beta p + \beta w - \gamma e = 0 = 0$. In order to coordinate the supply chain, replace $p = p^I$ and $e = e^I$ to aforementioned equation, we get $\beta(w - c) = 0$, then $w = c$.

In a MS power structure, the manufacturer is the market leader and gain the extra profit from the supply chain coordination, that is, $\pi_{rm}(p^I) - \pi_r(p^m) = \frac{32\beta^2 t^3(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(8\beta t-\gamma^2)(4\beta t-\gamma^2)]^2} - F = 0$, then we get $F^m = \frac{32\beta^2 t^3(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(8\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$. For the manufacturer, $\pi_{mm}(p^I, e^I) - \pi_m(w^m, e^m) = F^m - \frac{16\beta^2 t^3(\alpha-\beta c-\gamma e_0)^2}{(8\beta t-\gamma^2)(4\beta t-\gamma^2)^2} > 0$. So, in a MS power structure, $w = c$ and $F^m = \frac{32\beta^2 t^3(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(8\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$ is a coordination and Pareto contract for the supply chain.

In a VN power structure, the retailer and the manufacturer have same supply chain power and they gain half the extra profit from the supply chain coordination, that is, $\pi_{rm}(p^I) - \pi_r(p^n) = \pi_{rm}(p^I, e^I) - \pi_r(w^n, e^n)$. Since $\pi_{rm}(p^I) - \pi_r(p^n) = \frac{16\beta^2 t^3(5\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2} - F$ and $\pi_{rm}(p^I, e^I) - \pi_r(w^n, e^n) = F - \frac{4\beta^2 t^3(16\beta t-3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$, then $F^n = \frac{2\beta^2 t^3(36\beta t-7\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$. So, in a VN power structure, $w = c$ and $F^n = \frac{2\beta^2 t^3(36\beta t-7\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$ is a coordination and Pareto contract for the supply chain.

In a RS power structure, the retailer is the market leader and gain the extra profit from the supply chain coordination, that is, $\pi_{mm}(p^I, e^I) - \pi_m(w^r, e^r) = F - \frac{t(4\beta t+3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)^2} = 0$, then we get $F^r = \frac{t(4\beta t+3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)^2}$. For the retailer, $\pi_{rm}(p^I) - \pi_r(p^r) = \frac{t(4\beta t+\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{2(4\beta t-\gamma^2)^2} - F^r > 0$. So, in a RS power structure, $w = c$ and $F^r = \frac{t(4\beta t+3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)^2}$ is a coordination and Pareto contract for the supply chain.

So, the supply chain can be coordinated with the two-part tariff contract, and the condition satisfies $w = c$ and $F^m = \frac{32\beta^2 t^3(6\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(8\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$ in a MS power structure, $F^n = \frac{2\beta^2 t^3(36\beta t-7\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{[(6\beta t-\gamma^2)(4\beta t-\gamma^2)]^2}$ in a VN power structure, $F^r = \frac{t(4\beta t+3\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)^2}$ in a RS power structure. This completes the proof.

Proof of Proposition 2

(a) From lemma 1, we get $w^m - w^n = \frac{2t(\alpha-\beta c-\gamma e_0)(4\beta t-\gamma^2)}{(8\beta t-\gamma^2)(6\beta t-\gamma^2)} > 0$, that is, $w^m > w^n$. Similarly, from lemma 1, we get $w^n - w^r = \frac{t(\alpha-\beta c-\gamma e_0)(2\beta t-\gamma^2)}{(6\beta t-\gamma^2)(4\beta t-\gamma^2)} > 0$, that is, $w^n > w^r$. So, $w^m > w^n > w^r$.

(b) From lemma 1, we get $e^m - e^r = \frac{\gamma^3(\alpha-\beta c-\gamma e_0)}{2(8\beta t-\gamma^2)(4\beta t-\gamma^2)} > 0$, that is, $e^m > e^r$. Similarly, from lemma 1, we get $e^n - e^r = -\frac{\gamma(\alpha-\beta c-\gamma e_0)(2\beta t-\gamma^2)}{2(6\beta t-\gamma^2)(4\beta t-\gamma^2)} < 0$, that is, $e^r > e^n$. So, $e^m > e^r > e^n$.

(c) From lemma 1, we get $p^m - p^r = \frac{\gamma^2(\alpha-\beta c-\gamma e_0)(2\beta t-\gamma^2)}{2\beta(8\beta t-\gamma^2)(4\beta t-\gamma^2)} > 0$, that is, $p^m > p^r$.

Similarly, from lemma 1, we get $p^n - p^r = -\frac{(\alpha-\beta c-\gamma e_0)(2\beta t-\gamma^2)^2}{2\beta(6\beta t-\gamma^2)(4\beta t-\gamma^2)} < 0$, that is, $p^r > p^n$. So, $p^m > p^r > p^n$. This completes the proof.

Proof of Proposition 3

(a) From lemma 1 and (1), we get the manufacturer's maximum profit in a MS power structure is $\pi_m(w^m, e^m) = \frac{t(\alpha-\beta c-\gamma e_0)^2}{8\beta t-\gamma^2}$, the manufacturer's maximum profit in a VN power structure is $\pi_m(w^n, e^n) = \frac{t(\alpha-\beta c-\gamma e_0)^2(4\beta t-\gamma^2)}{(6\beta t-\gamma^2)^2}$, and the manufacturer's maximum profit in a RS power structure is $\pi_m(w^r, e^r) = \frac{t(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)}$. Then $\pi_m(w^m, e^m) - \pi_m(w^n, e^n) = \frac{4\beta^2 t^3(\alpha-\beta c-\gamma e_0)^2}{(8\beta t-\gamma^2)(6\beta t-\gamma^2)^2} > 0$, then $\pi_m(w^m, e^m) - \pi_m(w^n, e^n) > 0$, that is, $\pi_m(w^m, e^m) > \pi_m(w^n, e^n)$. Similarly, $\pi_m(w^n, e^n) - \pi_m(w^r, e^r) = \frac{t(\alpha-\beta c-\gamma e_0)^2(14\beta t-3\gamma^2)(2\beta t-\gamma^2)}{4(4\beta t-\gamma^2)(6\beta t-\gamma^2)^2} > 0$, that is, $\pi_m(w^n, e^n) > \pi_m(w^r, e^r)$. So, $\pi_m(w^m, e^m) > \pi_m(w^n, e^n) > \pi_m(w^r, e^r)$.

(b) From lemma 1 and (3), we get the retailer's maximum profit in a MS power structure is $\pi_r(p^m) = \frac{4\beta t^2(\alpha-\beta c-\gamma e_0)^2}{(8\beta t-\gamma^2)^2}$, the retailer's maximum profit in a VN power structure is $\pi_r(p^n) = \frac{4\beta t^2(\alpha-\beta c-\gamma e_0)^2}{(6\beta t-\gamma^2)^2}$, and the retailer's maximum profit in a RS power structure is $\pi_r(p^r) = \frac{t(\alpha-\beta c-\gamma e_0)^2}{2(4\beta t-\gamma^2)}$. Then $\pi_r(p^m) - \pi_r(p^n) = -\frac{16\beta^2 t^3(\alpha-\beta c-\gamma e_0)^2(7\beta t-\gamma^2)}{[(8\beta t-\gamma^2)(6\beta t-\gamma^2)]^2} < 0$, that is, $\pi_r(p^n) > \pi_r(p^m)$. Similarly, $\pi_r(p^n) - \pi_r(p^r) = -\frac{t(\alpha-\beta c-\gamma e_0)^2(2\beta t-\gamma^2)^2}{2(4\beta t-\gamma^2)(6\beta t-\gamma^2)^2} < 0$, that is, $\pi_r(p^r) > \pi_r(p^n)$. So, $\pi_r^r(p^r) > \pi_r^n(p^n) > \pi_r^m(p^m)$.

(c) From lemma 1, (1) and (3), we get the supply chain's maximum profit in a MS power structure is $\pi^m = \frac{t(12\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{(8\beta t-\gamma^2)^2}$, the supply chain's maximum profit in a VN power structure is $\pi^n = \frac{t(8\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{(6\beta t-\gamma^2)^2}$, and the supply chain's maximum profit in a RS power structure is $\pi^r = \frac{3t(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)}$. Then $\pi^m - \pi^r = -\frac{t\gamma^2(16\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)(8\beta t-\gamma^2)^2} < 0$, that is, $\pi^r > \pi^m$. Similarly, we get $\pi^n - \pi^r = \frac{t(10\beta t-\gamma^2)(2\beta t-\gamma^2)(\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)(6\beta t-\gamma^2)^2} > 0$, that is, $\pi^n > \pi^r$. So, $\pi^n > \pi^r > \pi^m$. This completes the proof.

Proof of Proposition 4

From proposition 3, we get that $F^m - F^n = \frac{2\beta^2 t^3[104\beta t(2\beta t-\gamma^2)+80\beta^2 t^2+9\gamma^4](\alpha-\beta c-\gamma e_0)^2}{(4\beta t-\gamma^2)[(8\beta t-\gamma^2)(6\beta t-\gamma^2)]^2} > 0$, that is, $F^m > F^n$. Similarly, from proposition 3, we get that $F^n - F^r = \frac{t[(18\beta t-\gamma^2)(2\beta t-\gamma^2)+2\gamma^4](\alpha-\beta c-\gamma e_0)^2}{4(4\beta t-\gamma^2)(6\beta t-\gamma^2)^2} > 0$, that is, $F^n > F^r$. So, $F^m > F^n > F^r$. This completes the proof.