Resources, Conservation and Recycling xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

# Designing coordination contract for biofuel supply chain in China

Fei Ye, Yina Li*, Qian Yang

*School of Business Administration, South China University of Technology, Guangzhou, 510640, China*

ARTICLE INFO

*Article history:*
Received 29 March 2016
Received in revised form
24 September 2016
Accepted 27 November 2016
Available online xxx

*Keywords:*
Biofuel supply chain
Random yield
Coordination contract
Sustainable production

ABSTRACT

To ensure the sustainable supply of agricultural feedstock for biofuel production and improve the performance of biofuel supply chain, coordination along the biofuel supply chain in a random yield environment is studied. Three types of coordination contract are examined, namely, an over-production risk-sharing contract (OPC), an under-production risk-sharing contract (UPC), and a mixed contract (MC) with an asymmetric Nash bargaining model. Though an OPC and a UPC can correct the farmers' over-production and under-production behavior, the expected increase in profit may not be realized by the biofuel producer or the farmers. The MC is feasible because it achieves an efficient supply chain, where supply chain optimization as well as the interests of all individual actors are respected simultaneously. The proposed contracts are tested with data from the cassava-based biofuel industry in China. The findings help practitioners and policy makers understand when and how to implement coordination contracts to achieve the sustainable supply of agricultural feedstock for biofuel production and supply chain Pareto improvement as well.



## 1. Introduction

With the China's rapid economic growth, the country has become the largest primary energy consumer in the world, relying heavily on coal and petroleum (see Fig. 1), and, also the largest emitter of greenhouse gases in the world (Dong et al., 2016). The interruptions in energy supply, environmental contamination, and growing dependence on energy imports (especially for crude oil, which imported accounts for about 60% of China's total need in 2015) combine to make energy security and environmental protection to be two major problems faced by China (Ren et al., 2015; Ren and Sovacool, 2015).

To have a sustainable future, China is seeking the adjustment on its energy structure by accelerating the use of renewable and environmentally friendly energy sources to substitute the traditional fossil fuels (Wen and Zhang, 2015; Dong et al., 2016). Biofuels are viewed as one of the most utilized sources of renewable energy and the promising alternatives to fossil fuels, especially in the transportation sector, due to their high potential to enhance energy security and mitigate environmental pollutions (Papapostolou et al., 2011; Ren et al., 2016). Moreover, as a leading agricultural nation, the development of the biofuel industry is conducive to promote the rural development in China.

In recent years, China has launched programs to promote the production and supply of biofuel. The biofuel output has been increased by about fivefold between 2005 and 2015 (see Fig. 2). However, this amount accounts for only 3.25% of the global total biofuel output in 2015 (see Fig. 3), and is still very small comparing to the apparent consumption of petroleum product. Thus, the limited production of biofuels in China cannot fill the gap between energy demand and supply (Chen et al., 2016).

Hence, for the sake of energy security and environmental protection, China's biofuel production should be increased remarkably. To increase biofuel production, the stable and abundant supply of feedstock is indispensable and the first priority (Chen et al., 2016). However, China is suffering an undersupply of agricultural feedstock for biofuel production. For example, cassava, one of the most important biofuel crops in China, relies heavily on imports: imported cassava accounts for more than 60% of China's total domestic need (Liu et al., 2013). Consequently, the design of sustainable biofuel supply chains to ensure the sustainable supply of agricultural feedstock, so as to enhance biofuel production is becoming more and more important nowadays.

With this circumstance, this study aims to investigate how to enhance the supply of agricultural feedstock from a supply chain management perspective using analytical approaches. We suppose a biofuel supply chain consisting of a biofuel producer

* Corresponding author.
*E-mail address:* bmliyina@scut.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.resconrec.2016.11.023
0921-3449/

and multiple small-scale farmers for the supply of agricultural feedstock and the production of biofuel. Since the biofuel producer and small-scale farmers belong to separate entities, they will have conflicting objectives and reach different decisions, leading to double-marginalization and inefficiency with less supply of agricultural feedstock in the whole supply chain. The present studies on supply chain coordination contracts provide us with good insights into designing benefit and risk-sharing coordinate contracts for biofuel supply chains to overcome the double-marginalization effect. Unfortunately, they cannot be applied to the biofuel supply chain directly, as that supply chain has unique characteristics (Sharma et al., 2013). For example, traditionally, in the agricultural industry, an independent buyer and an independent supplier will sign a purchasing contract before the growing season, specifying the purchasing quantity and wholesale price for the agricultural products. Then the supplier sells the actual yielded products to the buyer at harvest time. However, the yield of agricultural products, which is greatly affected by natural conditions, such as weather, pests and disease, is highly uncertain (Jones et al., 2001; Kazaz, 2004; Deo and Corbett, 2009; Ren et al., 2016). Consequently, the actual yielded products often differ greatly from that expected from the initial input, they might be over or under the quantity earlier specified in the contract. Hence, the supplier bears the risk of over-production, while the buyer bears the risk of under-production in yield uncertainty environment (Inderfurth and Clemens, 2014).

Therefore, in light of the characteristics of biofuel supply chain, designing fair, mutually beneficial, and risk-sharing coordination contracts to enhance the supply of agricultural feedstock and the performance of the whole biofuel supply chain is the objective of this study. Specially, we intend to answer the following research questions. Can the traditional supply chain coordination contracts still work for the biofuel supply chain? If not, what factors will affect the design of effective coordinate contracts for the biofuel supply chain? Whether and under what conditions various types of contracts are capable of achieving supply chain coordination and a win–win situation? How does the yield uncertainty of agricultural feedstock post impacts on the decision making behavior of biofuel supply chain actors and the coordination contracts?

The rest of this paper is organized as follows. Section 2 reviews the literature on the bioenergy supply chain and supply chain coordination in random yield environments. Section 3 defines the problem and presents the optimal decisions for a centralized and a decentralized biofuel supply chain. In Section 4, three types of coordination contracts, OPC, UPC, and MC, are proposed and the optimal coordination factors are obtained. Then in Section 5, we present an empirical application of the proposed coordination contracts with data from the cassava-based biofuel industry in China; the results and implications for both practitioners and policy makers are provided. Finally, the main conclusions are summarized in Section 6.

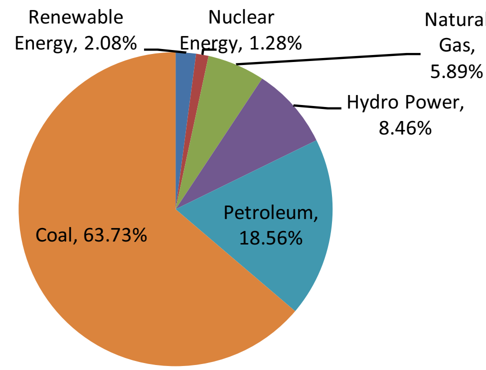


**Fig. 1.** China's primary energy consumption structure in 2015. Source: http://www.bp.com.

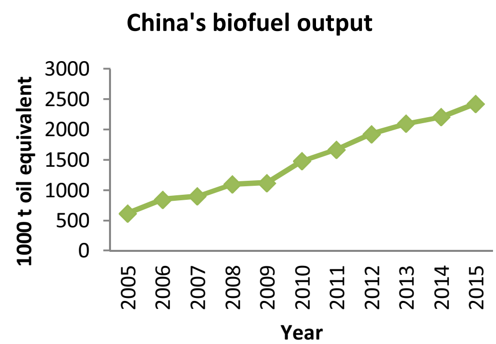


**Fig. 2.** China's biofuel output from 2005 to 2015. Source: http://www.bp.com.

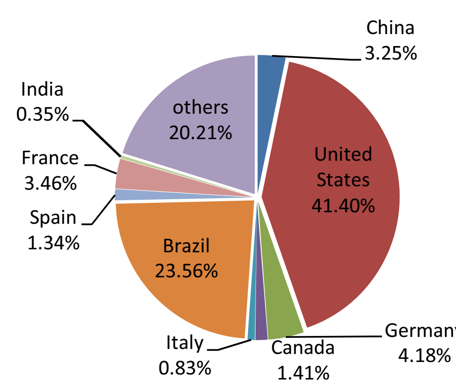


**Fig. 3.** The global distribution of biofuel output in 2015.

## 2. Literature review

There have been some studies of the bioenergy supply chain, but most of them have focused on its energy and greenhouse gas performance to see whether it is energy efficient (Dai et al., 2006; Liu et al., 2013; Holmgren et al., 2015; Jakrawatana et al., 2016). Only a few have focused on supply chain coordination among the actors. For example, Nasiri and Zaccour (2009) proposed a game-theoretic approach to model and analyze the process of utilizing biomass for power generation. Sharma et al. (2013) provided a comprehensive review of biomass supply chain design and modeling. Sun et al. (2013) developed a game-theoretic model to analyze the competitive agri-biomass supply chain. Wen and Zhang (2015) designed a 'straw acquisition' model for China's straw power plants, based on supply chain coordination. Ren et al. (2015) developed a mixed-integer non-linear programming model to design a biodiesel supply network to optimize the emergy sustainability index. However, these studies did not take the random yield environment into consideration.

The random yield problem has been well studied in the single-firm setting. Yano and Lee (1995) reviewed the studies on the ordering and producing problems in a random yield environment. Kazaz (2004) investigated olive oil production planning in a random yield and demand environment, where there were yield-dependent costs and prices. Kazaz and Webster (2011) further assumed the selling price is endogenous and affected by initial invested quantity to extend Kazaz's (2004) work. Ben-Zvi and Grosfeld-Nir (2007)