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Oil-importing optimal decision considering country risk with extreme events: A multi-objective programming approach ☆

Jianping Li [a], Ling Tang [a,b], Xiaolei Sun [a,*], Dengsheng Wu [a]

[a] Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

From perspective of energy security, this study focuses on oil-importing optimal decision based on multi-objective programming approach. Different from other models, country risk is considered as the main objective to minimize risk exposure of importing disruption. What is more, this model connects emergency management with programming, and optimal decisions are solved under different scenarios of emergency, where one given kind of extreme events break out and impact exporting regions to different degrees. Specifically, two main steps are involved in the proposed methodology, including impact analysis of the extreme events and optimization programming under scenarios of emergency. The first step is to statistically analyze whether and to what extent the given extreme events impact country risk of oil-exporting sources. Secondly, a multi-objective programming model is formulated, and optimal decision is simulated under different scenarios with extreme events. For illustration, China's oil-importing optimization is performed to verify the practicability of the novel methodology. The experimental results suggest that wars in Middle East may significantly enhance country risk of Middle East; and China's oil-importing optimal plan should be changed correspondingly. This further indicates that the proposed methodology can be utilized as an effective tool to adjust oil-importing plan according to certain extreme events.

1. Introduction

From perspective of energy security, many countries, e.g. OECD, European countries, Japan, China, India and others are confronted with the dilemma between the lack of oil resources and the increase in demand for oil caused by economic development. Therefore, these countries have to import oil from other overseas countries with rich oil resources [1]. In this perspective, oil-importing optimal decision has become extremely important for these importing countries.

In extant studies, most oil-importing optimizations have paid much more attentions to supply chain and product transportation for a better business performance, in order to control importing costs [2–4]. These researches offered some optimal plans for energy enterprises' operation to minimize the importing costs. However, they rarely considered risk exposure of disruption in energy imports for governmental policy. Actually, energy security can be generally understood as insurance measures taken against the risks of disruptions in energy imports at reasonable prices [5–7]. Thus, an appropriate portfolio of oil imports should not only control importing costs at an appropriate level, but also minimize risk exposure of disruption in energy imports to ensure a sustainable and reliable supply of energy [8,9].

Actually, there have been numerous researches focusing on the risk exposure against a reliable energy supply, and a series of assessment models have been formulated to evaluate the risk exposure in diversifying oil-importing sources. For example, based on the Hirschman–Herfindahl index (HHI), Neff introduced the correlation between productions of different sources to assess diversifying state of energy supply in the Asia-Pacific region [10]. Lesbirel (2004) quantitatively measured both systematic and specific risks associated with Japanese energy imports using Sharpe's One-way Analysis of Variance [5]. Wu et al. [11] used improved portfolio approach to quantify the diversification index of China's crude oil imports. He et al. [12] proposed an OICR Index incorporated with country risk to evaluate oil-importing risk. These above studies gave assessment to existing importing planning; however, they have not answered the question what a portfolio of imports from various regions is appropriate and optimal.

Under this background, this paper tries to complement extant studies and formulate a novel optimal decision methodology to obtain optimal portfolio of oil imports with two objectives: i.e. minimizing importing costs and managing risk exposure against

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* Corresponding author. Tel.: +86 10 59358806.
E-mail address: xlsun@casipm.ac.cn (X. Sun).

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a reliable supply. In the international oil market, the cost and the risk are often conflicted with each other; that is, low importing cost is often accompanied with high risk exposure of imports disruption. For example, many oil exporters, such as Iraq, Sudan and Libya, are quite unstable regions, where conflicts or wars are vulnerable to emerge, though they have rich oil resources with relatively low price. Furthermore, the correlation coefficient between the average of China's importing costs from different regions (including Middle East, Eurasia, South & Central America, Asia Pacific, North America, North Africa, West Africa and East & Southern Africa) and the importing risks compiled by International Country Risk Guide (ICRG) is about −0.1021 in the year of 2009. Thus, Multi-Objective Evolutionary Algorithms (MOEA) can be introduced to solve Pareto-optimal oil-importing planning with the two conflicting objectives in the novel methodology.

Risk exposure of oil-importing disruption is strongly influenced by a series of national-level risks in oil-exporting regions, such as political instability, terrorism, accidental events and a combination thereof. These factors may impact not only the stability of exporting regions, but also the energy security of importing countries. These risks mentioned above are, basically, components of country risk in exporting regions [13]. In the international energy market, country risk of exporting regions can be generally referred as potentiality of decrease in the expected energy supply, which oil importers or investors would be confronted [14,15]. Specifically, an exporter's country risk may hinder its oil importers from a reliable and stable oil supply through reducing its own total supply [12,16,17]. For example, due to the Iraq War, the total oil supply of Iraq was significantly cut off by about 35.38% from 2039.791 in 2002 to 1318.044 thousand barrels per day in 2003. Therefore, as a special risk at the national level, country risk can be introduced to reflect the risk exposure against a reliable and stable crude oil supply in the oil-importing programming.

Amongst various impacting factors, extreme events, such as terrorist attack, civil conflict and regional war, may play the most important role in country risk and further the international oil market [18–21]. Oil-importing plan should accordingly be adjusted when country risk of exporting sources is strikingly changed by such extreme events. Consequently, it is necessary to recognize impact of the given kind of extreme events on country risk, and then adjust the importing strategy timely. Therefore, this paper introduces an adjustment coefficient of country risk into the multi-objective programming model to express the impact of extreme events. Accordingly, the oil-importing optimization is simulated under different scenarios of emergency with different impact coefficients.

Generally speaking, this paper tries to formulate a novel methodology for oil-importing optimal decision with extreme events based on multi-objective programming. Distinct from other studies, major features of the proposed oil-importing programming can be summarized in two perspectives. First, country risk is considered as the main objective in order to minimize the risk exposure of oil-importing disruption. Secondly, this novel model connects emergency management with oil-importing programming, and the impact of given extreme events on the optimal solution is especially focused on.

The main motivation of this study is to formulate a novel oil-importing optimization model with two main objectives of importing costs and risk exposure, with the consideration of extreme events. Specifically, two main related questions are addressed in the proposed methodology. First, whether and to what extent does one given kind of extreme events impact country risk of oil-exporting sources? Secondly, how does the optimal diversification policy change due to such extreme events? The rest of the paper is organized as follows. The proposed oil-importing optimization methodology is formulated in Section 2. For illustration purpose, an experimental study is presented in Section 3 in order to verify the practicability of the proposed methodology. Some conclusions are finally given in Section 4.

2. Methodology

In this section, the oil-importing optimization methodology considering risk exposure with extreme events is formulated based on multi-objective programming. The methodology framework is first presented in Section 2.1. The following subsections then give the detailed description of the two main steps.

2.1. Framework

In perspectives of importing costs and risk exposure, the elementary diagram for oil-importing optimization model can be designed, as shown in Fig. 1.

The proposed oil-importing optimization is aimed to supply an appropriate portfolio of oil imports, and specifically to determine the decision variables, x_i, i.e. the share of exporting region i in the total imports of importer. The optimal solution (represented as gray dotted lines in Fig. 1) is solved from its initial solution (represented as gray full lines in Fig. 1) with two objectives: i.e. minimizing importing costs and minimizing risk exposure. However, when extreme events take place, country risk of the related exporting regions might be impacted. Thus, different optimal solutions (represented as red dotted lines in Fig. 1) can be generated under new importing conditions.

Accordingly, the proposed methodology can be decomposed into two main steps: i.e. impact analysis of extreme events and multi-objective programming with extreme events. Fig. 2 gives the overall framework of the proposed methodology.

Step 1: Impact analysis of extreme events.

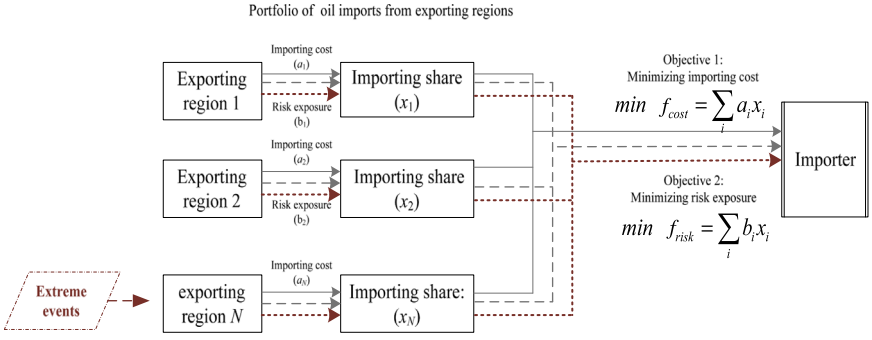

Fig. 1. Elementary diagram.