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Optimisation of an enterprise's production technology upgrade strategy under a carbon tax: pay the tax or an upgrade fee?

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Abstract

Carbon tax is one of the important policy levers used to reduce CO_2 emissions. When an enterprise is subject to a carbon tax, it has to balance the trade-off between the 'long-term tax fee' and the 'short-term upgrade fee'. In this research, we explore how to optimise an enterprise's production technology upgrade strategy based on existing low-carbon technologies, to minimise the total upgrade cost subject to an expected total cost per product. We propose an integer programming model to formulate the problem, and present a 'multi-agent system – genetic algorithm' (MAS-GA) method for its solution. The model is applied to a numerical example and the results indicate that the MAS-GA method is feasible.

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Keywords: Carbon Tax; Production Technology Upgrade; Strategy Optimisation; Multi-agent System; Genetic Algorithm

1. Introduction

To cope with global warming, the world reached a consensus for reducing CO_2 emissions through a series of negotiations. Some countries adopt a carbon tax policy to achieve target reductions, such as: Denmark, Finland [1], Canada [2], etc. When an enterprise is subjected to a carbon tax, it will see an increase in extra tax costs, which drives total cost increases. If it does not reduce its carbon emissions, it has to pay this extra cost for the long-term, which is not conducive to its development [3]. Therefore, the carbon tax will urge an enterprise to upgrade its production technology to reduce carbon emissions [4]. On the other hand, the enterprise has to invest a lot of extra capitals in the short-term when it chooses to upgrade. It has been an important problem for enterprises when considering how to balance the trade-off between the 'long-term tax fee' and the 'short-term upgrade fee'.

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Many scholars have studied enterprise investment strategies for low carbon technologies under the carbon tax policy. For example, Baker et al. [5] determine a firm's profit maximising R & D investment strategy under an uncertain carbon tax. Shittu et al. [6] address the optimal R & D investment response of a decision-maker, or an engineering manager, at company level with a portfolio of alternative technologies, to a rising carbon tax. Thoma et al. [7] research how carbon tax influences power plant investment decisions under uncertainty, and obtain that a carbon tax will change respective profitability rankings of different technologies.

These optimisations were based on research and development (R & D) which proved useful for the long-term development of an enterprise. However, the new technology may fail and the journey from theory to practice is often long. During the R & D period, enterprises have to use existing low-carbon technologies to solve cost problems caused by the carbon tax. Nevertheless, the literature concerning optimisation based on existing low-carbon technologies is sparse. To fill this research gap, we propose an integer programming model to optimise enterprise's technology upgrade strategies by using existing low-carbon technologies under a carbon tax policy in this research.

2. Methodology

2.1. Problem representation

A typical production activity consists of several production phases, such as procurement and processing of materials, parts production, assembly, and so on. Each phase contains a number of production processes, in which the detailed production is undertaken. Thus, the symbol $P_{i,j}$ is used to represent the *j*th production process of phase *i*. The production processes, whose *i* values are larger, are closed to the production of product; those with a smaller *i* value, are closed to the processing of materials.

This research is based on the following assumptions: (1) per product is chosen as the basic research object; (2) each production process can choose to upgrade or not, but can only upgrade to one technology; (3) the more advanced the technology, the greater the upgrading cost required, the lower its production cost (relatively), and the lower its carbon emissions during production (relatively speaking).

As the production cost and carbon emissions are gradually accumulated as production progresses, $CPC_{i,j}$ is used to represent the cumulative production cost when accumulating to phase *i* process *j*, and $CE_{i,j}$ represents the cumulative carbon emissions. Similarly, $CUC_{i,j}$ indicates the cumulative upgrade cost.

For production process $P_{i,j}$ in phase *i* process *j*, its $CPC_{i,j}$ not only depends on the selection of the technology used, but also on previous production processes' (production processes linked to $P_{i,j}$) cumulative production cost. Therefore, its $CPC_{i,j}$ can be calculated as follows:

$$CPC_{i,j} = \sum_{m} pc_{i,j,m} I_{i,j,m} + \sum_{k \in input_{i,j}} CPC_{i-1,k} \quad (1)$$

where $pc_{i,j,m}$ is the production cost per product when it uses the *m*th technology; $I_{i,j,m}$ is the indicator function ($I_{i,j,m} = 1$ means the *m*th technology is selected; otherwise, $I_{i,j,m} = 0$); $input_{i,j}$ is its collection of previous production processes. Similarly, its $CE_{i,j}$ and $CUC_{i,j}$ can be calculated as follows:

$$CE_{i,j} = \sum_{m} e_{i,j,m} I_{i,j,m} + \sum_{k \in input_{i,j}} CE_{i-1,k} \quad (2)$$

$$CUC_{i,j} = \sum_{m} uc_{i,j,m} I_{i,j,m} + \sum_{k \in input_{i,j}} CUC_{i-1,k} \quad (3)$$

where $e_{i,j,m}$ is the carbon emissions per product when it uses the *m*th technology; $uc_{i,j,m}$ is the upgrade cost when it upgrades to the *m*th technology.

After accumulation to the final production process $P_{n,1}$, its $CPC_{n,1}$ is the per product total production cost TPC. This is the same to the per product carbon emissions TE and the total upgrade cost TUC: