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A Regret Model for Managing Supply Chain Network Economic with Time-based Competition

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1. INTRODUCTION

Our study builds upon earlier supply chain network equilibrium works and makes two contributions. First, most existing supply chain network equilibrium models for time-sensitive products focus on the coordination of pricing and processing time in a supply chain network. Combining pricing and processing time seems contradictory. Our supply chain network economic model differs from these models. We take the viewpoint of human effects by introducing regret theory[1] and prospect theory[2] to describe the customer's purchase behavior for time sensitive products to show they can be reconciled. Second, most of the regret models in the field of choice theory, provide insights on customers choice in an alternative or uncompetitive environment. In this paper, the regret formulation is fairly general. The supply chain network economic model integrated with a regret theory captures customers choice behavior in a competitive supply chain network. It can be used in many situations, including customers are regret neutral. Furthermore, our article discusses the equilibrium relationship among customer behavioral preference, selling prices, and equilibrium flows. Moreover, we further modify the modified projection method to improve the computational speed of solving the variational inequality by introducing augmented Lagrange function. Two conclusions of our proposed model are worth paying attention:

(1) Our analyses and numerical examples suggest that the regret aversion parameter δ and regret weight r have a significant impact on the equilibrium flow and price. Specially, our results indicate that there exists a threshold δ_h and γ_h, if $\delta < \delta_h$ or $\gamma < \gamma_h$, variants' prices and firms' profits would reduce great, as the regret aversion parameter δ and regret weight r increase.

(2) The customers' price and time sensitivity coefficient have a significant impact on the equilibrium flows, prices and profits. The same strategy will lead to a distinct result on the demand markets with a different price or time sensitivity.

2. THE MODEL

Definition 1 (*Variant*). We view the same product with different attributes as variants. Each product has at least one variant in a supply chain network.

Definition 2 (*Time-pertinent chain*). A time-pertinent chain (T-chain) inducing an end variant of a product (or service) is a chain of coordinated processing time of business activities on each link.

Links in a supply chain network are divided into two types first provided by Zhang[3]: operation links and interface links. An operation link represents a business function and an interface link denotes a coordination function within a supply chain network. The operational cost on operation link a under the same time

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requirement depends on the flow on link a, $c_{a_w} = c_{a_w}(x_{a_w})$. The operational costs on interface links are given by c_b. Therefore, the cost on T-chain s_i will be given by:

$$c_{s_i} = c_{s_i}(x_{s_i}) = \sum_{a\in A} c_{a_w} \cdot \delta_{a_w s} + \sum_{b\in B_s} c_b \cdot \delta_{bs}. \tag{1}$$

Regret theory generally is based on two functions only[4]: an extended utility function and a function capturing the impact of regret[5]. We derive our extended utility from the Random Regret Minimization-approach provided by Chorus, Arentze, and Timmermans[5], in which we integrated customer regret attribute using a formulation derived from regret theory[1] and prospect theory[2]. The extended utility is followed:

$$U(p_i, t_i) = v(p_i, t_i) + f\Big(v(p_i, t_i) - v(p^{\wedge}, t^{\wedge})\Big). \tag{2}$$

where $U(p_i, t_i)$ is the extended utility function of choosing variant i, comparing with other variants' attributes, and $v(p_i, t_i)$ is the conventional von Neumann-Morgenstern utility function, $v(p_i, t_i) = C - \alpha p_i - \beta t_i$ and $v(p^{\wedge}, t^{\wedge})$ is the reference point of customers in their purchasing decisions. Let C, α, and β denote customer valuation, price sensitivity, and time sensitivity. Therefore, the probability of choosing variant (i) out of the total variants is

$$Pr_i(p_i, t_i) = \frac{e^{U(p_i,t_i)}}{\sum_{i=1}^{I} e^{U(p_i,t_i)}}, i = 1, \cdots, I. \tag{3}$$

We consider a continuum of customers of total mass N_k in demand market k, which is statistically identical and independent. We define U_s as the profit of all T-chains s, and assume each T-chain is a profit-maximizer.

$$U_s = \sum_{i=1}^{I} p_i \times N_k \cdot Pr_i(p_i, t_i) - \sum_{i=1}^{I} c_{s_i} \cdot x_{s_i}, \forall i, k, s. \tag{4}$$

Definition 3. Supply chain network economic equilibrium conditions with customer regret aversion.

A path flow and selling price$(X^*, P^*) \in \Omega$ constitutes a supply chain network economic spatial equilibrium with customer regret aversion if and only if the following equality holds true:

$$N_k \cdot Pr_i(p_i^*, t_i) \begin{cases} = \sum_{s\in S_i} x_{s_i}^*, \ if\ p_i > 0, \\ < \sum_{s\in S_i} x_{s_i}^*, \ if\ p_i = 0, \end{cases} \forall i, k, s \tag{5}$$

Theorem 1: Variational inequality formulation with customer regret aversion.

According to variational inequality theory and the flow conservation, functions (4) and (5) for all T-chains can be expressed as the following variational inequality:

$$\sum_{k=1}^{K}\sum_{a=1}^{A}\sum_{w=1}^{W}\left[\frac{\partial c_{a_w}(x_{a_w}^*)}{\partial x_{a_w}^*(x)} - p_i - \lambda_i\right] \times \left[x_{a_{wi}} - x_{a_{wi}}^*\right] + \sum_{k=1}^{K}\sum_{b=1}^{B}\left[\frac{\partial c_{b_i}(x_{b_i}^*)}{\partial x_{b_i}^*(x)} - p_i - \lambda_i\right] \times \left[x_{b_i} - x_{b_i}^*\right] + \sum_{k=1}^{K}\sum_{i=1}^{I}\Big[-N_k \cdot$$

Pripi∗,ti−Nk∂Pripi∗,ti∂pipi∗−λi+σ(Nk·Pripi∗,ti−∑Ww=1xaw·δaws)×pi−pi∗+∑Kk=1∑Ii=1Nk·Pripi, ti−∑Ww=1xaw·δaws×λi−λi∗≥0, (6)

where the term λ_i is the Lagrange multiplier associated with the constraints for demand markets k and the term σ is the penalty parameter in the augmented Lagrangian function.

3. CONCLUSIONS

In this paper, our basic assumption is that the customers are regret aversion and plan purchases by maximizing their extended utility function, and the supply chains seek profits maximization. A discrete choice model (MNL model) integrated with regret theory is designed to illustrate the customers decisions-making, which extends the inter supply chain competition to multiple dimensions. A regret theory based variational inequality is provided to express the equilibrium conditions in a supply chain network. Furthermore, some numerical examples are used to validate the results.

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