RESEARCH STATEMENT

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My general research interests include revenue management, game-theoretic applications, stochastic inventory control, machine learning applications, and transportation engineering. Specifically, my current focuses are on explaining the phenomenon of opaque selling from the perspective of inventory management, as well as discovering optimal operational plans and managerial insights for firms practicing opaque selling. I am also interested in integrating machine learning with a variety of real-world business problems.

Background

In recent years, an interesting phenomenon in retailing is the rise of opaque or probabilistic goods. Besides offering a set of substitutable goods, a seller might also use price discounts to lure buyers into accepting a product whose true type is only revealed at the point of delivery.

The selling of opaque goods (opaque products, O-goods) by a modern online platform usually assumes the following form. The seller first creates an opaque product with some hidden characteristics and peddles it at a certain price discount to buyers, e.g., the color. Then, those buyers more indifferent to the hidden characteristics or more sensitive to the price differences would choose the opaque product over others. When it comes to order fulfillment or rationing, the seller would have the flexibility of choosing from among the bigger pool of available products that match the opaque product's less demanding specifications.

This interesting sales strategy has attracted the attention of many academic researchers. Notably, Elmachtoub, Wei, Zhou [1] and Elmachtoub, Yao, and Zhou [2] made substantial progress in understanding its quick rise and wide adoption. Yet, I believe more can still be done.

Understanding Opaque Selling from an Inventory-management Perspective

I study opaque selling in the backdrop of recurrent inventory replenishments. While upholding ex-ante symmetry and a two-product setup, the stylized model gives center stage to the theme of "inventory-level balancedness". The seller's preference for the latter can help explain both (i) the seemingly obvious balance-inducing rationing strategy wherein an opaque-good request is always satisfied by the regular product with a higher inventory level and (ii) the seller's welcome of more opaque selling.

Earlier works have covered (i) and partially (ii) while assuming the seller's practice of a can-order replenishment policy. The latter lets both products' inventories be brought up to pre-determined levels whenever either one is about to be depleted. Nevertheless, the resulting total prohibition of lost sales could be counter-productive due to the holdings of higher-than-necessary inventory levels. This is especially true given that opaque selling appears to be most useful when one but not both products has just run out of stock. In contrast, a different $(s_2, (S_1, S_1))$ policy could tolerate lost sales at opportune times in the spirit of the traditional (s, S) policy. It would not push the two regular products' inventory levels back to S_1 until the combined inventory level is about to drop to s_2.

Besides (i), the policy is instrumental in the complete coverage of (ii) in a holistic fashion: now the seller's total profit rate is shown to benefit from more opaque selling. Under the earlier can-order regime, only piecemeal cost rates such as those pertaining to setup costs or holding costs could be separately presented as beneficiaries of opaque selling. Also, in a comparative study, I can quantify (iii) the $(s_2, (S_1, S_1))$ policy's relative cost-effectiveness against the can-order policy.

All of the above is done by letting background parameters account for buyers' behaviors. More realistically, each buyer's individual product-type choice is linked to not only her own preferences but also the perceived quality of service the seller can provide. It is the aggregation of all individual choices that helps shape buyers' macroscopic behavioral patterns. The latter then induces the seller to realize the common perception of buyers. I also study such a strategic model and establish (iv) the existence of relevant equilibria. Numerical analyses based on this model enable the accruement of many valuable insights such as those pertaining to the s_2 and S_1 levels and the pricing of the opaque good.

The study has been wrapped up and submitted to *Management Science*. It is also available on *SSRN* [4]. I was awarded the Rutgers Graduate School Dean's Dissertation Fellowship due to it and will present it at the *INFORMS Annual Meeting 2022*.

Simultaneous Control of Rationing, Replenishment, and Potentially Even Pricing in the Presence of Opaque Selling

The already completed work can be thought of as explaining *why* opaque selling has become so popular. My current work shifts attention to *how* best to help a firm practicing opaque selling. Rather than set up a given replenishment policy in the background, it attempts to offer the best real-time decisions for both replenishment and rationing.

The current model allows a discount factor $\alpha > 0$ per time unit in a continuous-time discrete-item setting where the overall buyer arrival follows a Poisson process. Upon arrival, a buyer has certain probabilities to guide her requests for the various regular and opaque products. The concerned firm decides in real time on replenishment: whether to order or produce and which product to order or produce, as well as, rationing: which product to use to satisfy a just-arrived opaque-good request. While past studies of production systems such as Ha [3] could be of potential help, the model is particularly complex in (i) lost sales rather than backlogging is the main focus, and (ii) there is the additional layer of rationing to consider on top of replenishment.

As expected, themes like contraction mapping, submodularity, diagonal dominance, concavity, and mild monotonicity would all loom large in this study. Fitting the rationing aspect is a potentially new property of balance-inducing monotonicity. It spells out the value function's increasing trend when state variables move toward near-diagonal more balanced compositions. Key to the current joint rationing-replenishment control is some simultaneous preservation of all kinds of value-function properties. So far, I am glad to have verified such preservation. An immediate consequence is that even when the replenishment decision is jointly made, rationing should still follow the balance-inducing principle.

The so-far-given probabilities that drive buyers' behaviors are certainly influenced by the seller's regular- and opaque-good prices. Joint dynamic pricing-replenishment-rationing will also be in my sight. If theoretical derivations prove to be fruitless, I will at least try systematic computational studies to generate operational insights.

The aforementioned two projects would constitute the bulk of my Ph.D. dissertation being completed under the guidance of Professor Jian Yang. At this moment, I plan to hold my defense in April 2023.

Business Analysis and Machine Learning Applications

Besides theoretical modeling, I am also interested in business intelligence and machine learning applications for real-world problems. Unlike theoretical models, which could provide strictly explainable frameworks and general guidelines, practical analyses could form solutions at the finest level for those traditionally unsolvable business problems by applying advanced machine learning techniques. In this section, I will briefly introduce some studies in which I cooperate with other scholars.

A Big Data-Empowered Reinforcement Learning Approach to Resilience

Inspired by big data and IS resilience literature, we propose three design principles to build analytics resilience. To demonstrate its effectiveness and applicability, we propose a Drift-aware Contextual Thompson Sampling Model (DA-CBTS). Collaborating with a financial services firm, the proposed model exhibits promising performance and tremendous economic benefits through field experiments and offline evaluation on a major US-based airline. This work is under review at *Information Systems Research*.

Diminishing Returns to Social Capitalist Firms and Their Employee Advocates

We theorize that firms that push their employees to act as their advocates on social media will be rewarded but will see diminishing returns in information diffusion and audience attention. We test and

find support for our hypotheses on a unique data set of two Chinese interior design companies. Both company and employee "push" efforts and message recipients' "pull" do increase message diffusion, but there are diminishing returns for employees posting messages regarding reader count and attention.

The Analysis of Dockless Bikesharing Systems with a Parsimonious Model

We propose a parsimonious model which lets the dockless bike-sharing (DLB) service compete with other transportation modes. The market equilibrium can be reached by solving a nonlinear equation system. Hence, a problem maximizing (i) profit, (ii) ridership, and (iii) social welfare can be formulated. Through a numerical study, we find that the level of service is subject to rapidly diminishing returns to the fleet size. This work is under review at *Transportation Science*.

Future Work

In the meantime, I will continue to deepen my understanding of inventory and even joint inventory-revenue management involving opaque selling.

In the near future, I look forward to contributing to the following two topics:

1. *Mystery Box Selling*
   As a variant of opaque selling, selling through the mystery box is another rising trend in the online market. Unlike ordinary opaque selling, the seller of the mystery box may not be able to determine which actual product to deliver to fulfill the request, e.g., all the boxes may have the same appearance. Under this scenario, the problem becomes a pure pricing one. But if products are differentiable, e.g., one product is rarer and hence more valuable, the seller's pricing strategy would have to be in tandem with the replenishment and rationing decisions. Other challenges would arise when buyers are strategic or hold non-neutral risk attitudes.
2. *Nonatomic Game and its Application*
   In a nonatomic game, there is a large number of "bit" players whose individual decisions are negligible when in separation while environment-forming when in aggregation. One convenient way of modeling strategic buyers in opaque selling is treating them as bit players in a nonatomic game. I believe the application of nonatomic games should not stop just here. The nonatomic game setup can apply to many of my works in dealing with (a) the one seller and many buyers in opaque selling, (b) the company and its employee "advocates" in the social-capital research, and (c) a dockless bike-sharing operator and its user base. Taking advantage of the simplification inherent in nonatomic games, I hope to reach theoretical insights that would otherwise be elusive from regular game-theoretic models.

References

[1] Elmachtoub, A.N., Y. Wei, and Y. Zhou. 2020. Retailing with Opaque Products. Working Paper, Columbia University.

[2] Elmachtoub, A.N., D.D. Yao, and Y. Zhou. 2020. The Value of Flexibility from Opaque Selling. Working Paper, Columbia University.

[3] Ha, A.Y. 1997. Optimal Dynamic Scheduling for a Make-to-stock Production System. *Operations Research*, **45**, pp. 42-53.

[4] Qu, Y., and J. Yang. 2022. Understanding Opaque Selling from an Inventory-control Perspective. Working Paper, Rutgers University. SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4190400.