Computational modeling and multi-agent-based simulation framework for product branding

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Abstract—Aiming to deal with the complexity and dynamics of the product branding problem and investigate its evolution process, this paper proposes a framework for evolutionary product branding and emergence on the basis of computational modeling, and software agents' behaviors and interactions. In this framework, relevant conceptual, mathematical and computational models are formulated and explained. Two categories of agents with four kinds of basic behaviors and three types of interactions are defined and specified to support the emergence of product brands. Agents' behaviors and interactions are described in detail. In addition, a multi-agent-based evolution simulation paradigm for the product brand life cycle is presented by the authors. Our evolution model provides a foundation for analyzing the emergence and evolution of product brands and supporting decision-making for product branding management in the digital age.

Keywords—Product branding; computational modeling; evolution modeling for product brands; multi-agent system; simulation

I. INTRODUCTION

Product branding is a hot research topic in the field of marketing. The related literature can be classified into qualitative research [1] and quantitative research [2, 3]. The qualitative research focuses on the concept definitions, theoretical analysis, trend prediction, influence factors, and decision-making issues for product branding. The quantitative research tends to use associated methods to study the mechanisms of product brand formation, development, maturity, and decline and provide valuable information for branding decisions. The product brand has its life cycle, generally including four periods of formation, development, maturity, and decline. The product branding should be treated as a dynamic process evolving over time. Effective quantitative methods need to be employed to cope with the dynamics. According to the literature, the product branding process is also complex [4]. Its complexity is emerged by micro-level entities’ behaviors and interactions. A product branding system is composed of multiple heterogeneous entities that have their individual attitudes and behaviors, and pursue their own maximum benefits during their interactions. The system’s macro-level phenomena are emerged by these entities’ behaviors and interactions. Much of the current literature emphasizes the mathematical models in the quantitative research of product branding. It has a deficiency in dealing with the complexity, dynamics, emergence, and evolution of product branding. Simulation is also a quantitative tool and has been increasingly used in economic and social research. It not only has the advantages of the traditional mathematical and logical models, but also has a more important capability for complex system modeling and analysis. As such, the simulation technique can be utilized to explore the occurrences and evolution of product branding system. Since the product brand is emerged by micro-level entities’ behaviors and interactions, multi-agent software system is an ideal choice. Intelligent software agent can be smart and active, and can make decisions autonomously based on self-perception of its environments and interactions with other agents. A multi-agent system consisting of multiple agents, combined with complex adaptive system theory (CAS) [9], can be developed to represent a product branding community. This is a complex system research methodology that is powerful in modeling and analyzing micro-level agent interactions and macro-level emergence. It has incomparable strengths in tackling unstructured complex problems that are difficult to be solved by pure mathematical models.

This paper combines multi-agent-based system, simulation technique, with CAS to establish a new hybrid evolution framework for product branding. A conceptual model of product brand emergence on the basis of agents’ behaviors and interactions is given in Section II. Systematic and computational modeling work is reported in Section III. Conclusions and further work are provided in Section IV.

II. CONCEPTUAL MODELING OF PRODUCT BRAND EMERGENCE ON THE BASIS OF AGENTS’ BEHAVIORS AND INTERACTIONS

Product branding can be treated as a complex emergence phenomenon. This paper considers the product brand as the emergence of behaviors and interactions of firms, customers and wider community. We propose a conceptual model of product brand emergence, as shown in Figure 1. This model makes use of autonomous decision-making capabilities of agents and interactive features of multi-agent systems to represent the behaviors and interaction of entities in the product branding community for the purposes of analyzing emergence and evolution. This paper simplifies the product branding community as a system consisting of two types of important entities of firms and customers. The behaviors of
firm agents are defined as product innovation behavior, marketing behavior, and coordination behaviors with other firm agents. These behaviors directly affect the formation and development of firms’ product brands. Customer agents make their purchase decisions based on their maximum interests. Their decisions are significantly influenced by product quality, price, advertisement, and word of mouth in social media and other contexts. The conceptual model specifies three types of interactions: Interactions amongst firm agents, interactions amongst customer agents, and interactions between firm agents and customer agents. The product branding can be considered as the outcome or occurrences of these agents’ behaviors and interactions. Other factors affecting the product brand evolution are treated as external variables embedded in the conceptual model. In this way, the conceptual model is actually a dynamic evolution system.

![Diagram of firm agents' behaviors and interactions]

Figure 1. Product brand emergence based upon agents’ behaviors and interactions

### III. SYSTEM AND COMPUTATIONAL MODELING

In this section, a systematic and computational modeling framework for simulating and analyzing the behaviors and interactions of different kinds of agents as well as their influences on the product branding evolution is proposed and discussed.

#### A. Product Brand Modeling

The product brand has its life cycle with four periods: formation, development, maturity, and decline. The degrees of product branding at different periods vary and thus are not the same. In this paper, the degree of product branding is defined as a function of market share rate and coverage rate of a product brand.

\[
\text{Degree}_{\text{brand},k,t} = \alpha \frac{\sum_{i=1}^{n} \text{Sale}_{\text{brand},k,t}}{n} + (1 - \alpha) \frac{\sum_{i=1}^{n} \text{Customer}_{\text{brand},k,t}}{n}
\]

\[
\text{Degree}_{\text{brand},k,t} \text{ is the branding degree of product brand } k \text{ of firm } j \text{ at the evolution period } t; \text{ Sale}_{\text{brand},k,t} \text{ is the sale volume of product brand } k \text{ of firm } j \text{ at the evolution period } t; \text{ Customer}_{\text{brand},k,t} \text{ is the customer number of product brand } k \text{ of firm } j \text{ at the evolution period } t; \sum_{i=1}^{n} \text{Sale}_{\text{brand},k,t} \text{ and } \sum_{i=1}^{n} \text{Customer}_{\text{brand},k,t} \text{ are respectively the total sale and total customer number of product brand } k \text{ of a specific market at the evolution period } t; n \text{ denotes the total number of firms considered; } \alpha \text{ is a coefficient representing the relative importance of market share rate and coverage rate of the product brand.}

#### B. Agents’ behaviors modeling

The branding degree mainly depends on firms’ strategies, micro-level behaviors and the interactive relationships with other firms, competitors and their customers. According to complex system theory, firms’ behaviors and interactions emerge their product brands. In this section, the behaviors of firms and customers will be discussed.

1) Firm agents’ behaviors

In order to develop and build their product brands, firms need to innovate, do marketing, and coordinate with other related firms effectively. Therefore, this paper defines three types of basic behaviors which are product innovation behavior for sustainable development, marketing behavior for customer attraction, and coordination behaviors with other firms for cooperation.

**Product innovation behavior**: This behavior drives and contributes to the formation and development of a product brand. Product innovation is closely associated with current innovation knowledge, capital investment, and technology/labor inputs. Innovation is not always successful. In this paper, we assume that the probability of successful product innovation at each evolution period is \( P \). In essence, product innovation can be considered as knowledge creation and production. Thus, the model for knowledge production can be employed. On the basis of the knowledge production function given in [5], we define the growth of innovation knowledge of product brand \( k \) of firm \( j \) after one-time innovation activity at the evolution period \( t \) as follows:

\[
\Delta K_{j,k,t} = \delta_{j,k} K_{j,k,t}^{\varphi} T_{j,k,t} L_{j,k,t} K_{j,k,t}^{\varphi}
\]
Within this formula, $IK_{j,k,t}$ is the current innovation knowledge of product brand $k$ of firm $j$ at the evolution period $t$; $K$ and $L$ are dynamic variables, respectively representing capital investment and technology/labor inputs for product innovation. $\beta$ and $\lambda$ respectively stand for the efficiencies of capital investment and technology/labor inputs in knowledge production process. $\varphi$ describes the spillover efficiency and effect of knowledge production based on the innovation knowledge at the previous period. If $\varphi > 0$, it is called positive effect. If $\varphi < 0$, it is called drag effect. $\delta$ is a comprehensive factor except for such factors as capital, technology, labor, and previous innovation knowledge. Successful innovation will increase agents’ innovation knowledge which will in turn improve product quality and reduce product price. Hence, the product quality and price are affected by the amount of firm’s innovation knowledge. The quality is proportional to the amount of knowledge, while price is inversely proportional.

**Marketing behavior**: In order to sell their products, firms tend to use several ways to attract their customers. The product quality marketing, price marketing, and advertising campaigns are three main kinds of marketing behaviors. These behaviors can influence customers’ purchase decisions. The quality is affected by product innovation. The price can be fluctuating with a certain proportion to the basic price determined by product innovation, and accounting management. The advertisement is fully determined by its investment. Therefore, high quality, low price and big advertisement investment of a product brand may lead to more attraction to customers and may create more customer awareness.

**Coordination behavior with other firms**: Many firms tend to cooperate with their partners or collaborators for high performances, such as cost reduction, differentiation, quality, and image. The coordination behaviors with other firms include: quality coordination on the basis of product cooperation innovation; price coordination, advertisement coordination, and brand union coordination, on the basis of profit and benefit distribution mechanisms. The effect of coordination behaviors influences the purchase decisions of customers. Quality coordination behavior can be referred to the cooperative innovation model in the literature [6]. Price coordination, advertisement coordination, brand union coordination are determined by benefits distribution mechanisms.

2) **Customer agents’ behavior**

Customers are sensitive to product quality, price, advertisement, and word of mouth from other customers when they are making purchase decisions. Their purchase decisions are normally based on their maximum benefits and are affected by these factors. Following the literature [7], this paper defines the benefit function of customer $i$ to the product brand $k$ of firm $j$ at the evolution period $t$ as follows:

$$V_{i,j,k,t} = S_iQ_{j,k,t}Q_{j,k,t} + S_iP_{j,k,t}P_{j,k,t} + S_iA_{j,k,t}A_{j,k,t} + S_iM_{j,k,t}M_{j,k,t}$$

In the formula, $S_iQ_{j,k,t}$ is the sensitive degree of customer $i$ to the product quality of the product brand $k$ of firm $j$ at the evolution period $t$; $Q_{j,k,t}$ is the product quality of the product brand $k$ of firm $j$ at the evolution period $t$; $S_iP_{j,k,t}$ is the sensitive degree of customer $i$ to the product price of the product brand $k$ of firm $j$ at the evolution period $t$; $P_{j,k,t}$ is the product price of the product brand $k$ of firm $j$ at the evolution period $t$; $S_iA_{j,k,t}$ is the advertisement investment of the product brand $k$ of firm $j$ at the evolution period $t$; $A_{j,k,t}$ is the advertisement investment of the product brand $k$ of firm $j$ at the evolution period $t$; $S_iM_{j,k,t}$ is the sensitive degree of customer $i$ to the word of mouth of the product brand $k$ of firm $j$ at the evolution period $t$; $M_{j,k,t}$ is the word of mouth of the product brand $k$ of firm $j$ at the evolution period $t$. Assuming that the expect benefit of customer $i$ to the product brand $k$ is $V^E_{i,k}$. If $V_{i,j,k,t} \geq V^E_{i,k}$, the customer will purchase the product of the brand $k$ of the firm which can deliver the maximum benefit to the customer; if $V_{i,j,k,t} < V^E_{i,k}$, the customer will not buy the product of the brand $k$ of firm $j$.

C. **Agents’ interactions modeling**

1) **Interaction amongst firm agents**

Modeling the interactions among firm agents aims to coordinate each other. The ways for coordination include quality coordination, price coordination, advertisement coordination, and brand union coordination. Relevant coordination behaviors are conducted by firms only when their benefits obtained from the coordination are higher and better than their expected values. The effect and consequences of interactions between firm agents influences the purchase decisions of customers.

2) **Interactions between firm and customer agents**

The contents of interactions between firm agents and customer agents include product quality, price, advertisement, advertising campaign, and the word of mouth. High product quality will improve the customers’ preferences to a product brand. Low price will improve the customers’ choices for a product brand. Large advertisement investment and intense advertising campaign will enable customers know more about a product brand, help attract...
more potential customers, and build up customer loyalty. Good interactions between firm agents and customer agents may lead to the favorable purchase decisions by customers.

3) Interaction amongst customer agents

The content of interactions among customer agents includes buzz, mentions, the word of mouth for a product brand online and offline. Customers will be greatly affected by these, which can be either positive or negative. The positive side will increase customers’ trust, loyalty and confidence to a product brand. The negative mentions will lead to bad influence to customers’ purchase decisions. Both affect customers’ purchase behaviors. A model of word of mouth for interaction between customer agents can be found in literature [8].

D. System evolution solution

Micro-level agents’ behaviors and interactions emerge the macro-level phenomena, such as customers’ likes and loyalty, and image of a product brand. In the life cycle of a product brand, the evolution process can be simulated by the proposed conceptual and computational framework, combined with Holland’s CAS theory [9] and intelligent software agent implementation.

The interactions amongst relevant entities or agents are non-linear. Some buzz, mentions or words of mouth may exponentially cause significant emergence to arise from online or offline communities. Some occurrences may help improve a product name. Some may damage a brand negatively. The brand, the firm, competing brand, competitors, customers, communities interact with each other. Patterns may appear from these interactions. At the macro level, emergence such as big name, reputation, popularity and good customer loyalty may emerge [10].

Data can be collected from simulation experiments, and analysis can be performed to support product branding management.

IV. Conclusions and Further Work

This paper has been sought to provide a quantitative framework for modeling and simulating the evolution process of product branding. In this paper, a conceptual, mathematical and computational model for product branding has been proposed. A multi-agent-based simulation framework combined with CAS theory and algorithms have also been discussed.

Further research work is being done to create and validate a multi-agent-based simulation and CAS system for product branding analysis. The target system and associated methods will be tested and evaluated using real-world cases.

Dealing with the product branding problem requires a hybrid approach that integrates the benefits and powers of human experience, managerial judgment, mathematical and logical modeling, computer simulation, intelligent software agent technology, CAS algorithms, and expert systems [11, 12]. The specific strengths of diverse decision support and artificial intelligence methods and techniques will be utilized to match and fit the particular facets or properties of the problem, the thus will provide enhanced support and effective solution [11, 12]. Relevant research work of this project is being undertaken by the authors to implement this hybrid approach.

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