Evolution of Specialization with Reachable Transaction Scope Based on a Simple and Symmetric Firm Resource Allocation Model

Xiao Sun, Yueting Chai*, Yi Liu, Jianping Shen, and Yadong Huang

Abstract: In the last decade, as an emerging transaction measure driven by computer and internet technology, e-commerce experienced explosive growth in many areas. It has greatly broken down the limitations of space and time to economic activities, thus changing the rules of business fundamentally. Significant work has been done to understand the laws of e-commerce from multiple dimensions, but the question of how e-commerce shapes firms' specialization and market structure from the perspective of spatial factors remains obscure. In this paper, we propose a simple and symmetric firm resource allocation model with a specialized-economy production function and market size constraint, to investigate how individual firms adjust resource allocation with reachable transaction scope expanded. It is shown that with the expansion of reachable transaction scope, individual firms discretely take back one unit resource from a low-investment direction and, instead, channel it to a "specialized direction". Meanwhile, at the macro level, an optimal division network evolves from a static self-sufficient stage to a diverse semi-specialized stage, and finally to a highly integrated completely specialized stage. Ergo, a Complex Adaptive System (CAS) based simulation framework is constructed. Designed simulation experiments are carried out and confirm to the analysis result of our proposed model.

Key words: e-commerce; evolution; reachable transaction scope; resource allocation; complex adaptive system

1 Introduction

Breaking down the limitations of space and time to economic activities, e-commerce has changed business logic fundamentally and brought boundless possibilities for both merchants and consumers. Due to underdeveloped and high-cost traditional offline commercial channels, Chinese consumers seem to have exhibited a strong desire to shop online. According to the National Bureau of Statistics, China's total

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e-commerce transaction volume reached 2.6 trillion dollars in 2014, with an annual growth rate of 59.4%. Another example is the day of November 11, which marks an online shopping festival created by Alibaba, and named Double-Eleven. On Double-Eleven day 2015, Chinese online shoppers were responsible for 14 billion dollars in transactions on just one e-commerce website, tmall.com. As a comparison, on Black Friday 2015, the total sales of offline physical stores in USA amounted to 10.4 billion dollars, according to ShopperTrak's statistical report. After more than 10 years of rapid development, nowadays no one would doubt e-commerce is playing a more and more important role in modern society and people's daily lives, especially in China.

In a context of ongoing vigorous development, however, for a prolonged period, e-commerce practitioners have been uncertain on one question, that is, what kind of business model or commercial

form is efficient now and promising in the future? In the last decade, e-commerce companies conducted various inquiries into this question. Take China's largest proprietary B2C company, JD, as an example, who started business as an online digital products seller in 2003 and experienced exponential growth since 2007, when they expanded their product line to large family appliances. Besides being an online store, as its core competency, JD also operates a substantial logistics business. Also, in 2010 JD reconfigured its role to be partly an e-commerce platform service provider, and opened information and distribution resources to small businesses. Meanwhile, Alibaba treads a different path. Since inception, Alibaba has positioned itself as a platform to serve small businesses. Instead of selling products, Alibaba runs an information platform and online payment tool through independent companies. As the lead investor, it has organized major express companies to optimize China's logistics infrastructure. Alibaba emphasized that it would never buy any vehicle or hire delivery personnel, but keep focused on building their core platform. Alibaba and JD basically represent two kinds of e-commerce business models. Between and beyond them there are diverse business models and numerous service configurations existing in the e-commerce market. Are they efficient at firm and market level? What is the development direction of e-commerce practitioners and the e-commerce market? Addressing these related issues has certain practical background and significance.

2 Related Work

Corresponding to the rapid growth of information technology, e-commerce is attracting significant academic attention in diverse areas. In the early stage, since eBay started business with an online auction, auction mechanisms[1,2] were a popular topic at that time. As a continuation and extension of this line of research, trading mechanism analysis and system design, such as SME e-commerce trading[3], culture sensitive design[4], social commerce design[5], and so on, attract much academic attention to this day. Meanwhile, as an interdisciplinary field, trust[6], reputation[7], privacy security[8], recommendation systems[9], data processing technology[10], and many other issues are pertinent to investigating the e-commerce domain.

Among these issues, we focus our attention on

firm-level resource allocation strategy according to external market conditions. Some related work has been done on this topic, in terms of model construction, empirical studies, computer simulations, or some combination of these three. For example, using a resource-based view of the firm and archival data on UK companies, Nath et al.[11] found firms would be better sustained if they focused on a narrow portfolio of products/services across diverse geographical markets. From the perspective of computer simulation, Coen and Maritan[12] modeled the process of firms competing for opportunities to invest capacities and resource allocation dynamics. In terms of model construction and analysis, Anders et al.[13] proposed a trust- and cooperation-based algorithm for a multi-agent system to determine specific total resource demand. After summarizing current studies on the firm resource allocation problem, they mainly focus on how resource allocation strategies can help to optimize individual or system level performance, but lack the evolutionary angle to explore how optimal individual resource allocation and optimal system structure change with external conditions. Indeed, current studies overlook underlying evolutionary dynamics, which has a dominant effect on determining optimal resource allocation. In our model, the evolutionary path will be emphasized and evolutionary dynamics will be explicitly expressed.

On the construction of individual-based models, new classical economy and its inframarginal analysis method, pioneered by Yang[14], provides much inspiration. Infrarmaginal analysis is a set of optimization methods to solve for optimal individual decisions and optimal network of division of labor. In new classical economy, individuals are conceived as a particular type of prosumer. The individual sells self-produced products to others, and buys needed products from others at the same time. The products individuals purchase are discounted according to a transaction efficiency parameter, which is a number between 0 and 1. Yang[14] drew the conclusion that with increasing transaction efficiency, individuals' optimal decisions jump among several corner point solutions and with it, the macro-level network of division of labor evolves. Inframarginal analysis has been exploited in many areas of economic research and boasts many achievements[15–17]. However, as a highly abstracted economic model, inframarginal analysis cannot be applied to e-commerce market

contexts directly. Two main reasons account for this. First, the consumer-producer assumption is not applicable in the e-commerce market, because e-commerce firms face end consumers and purchase nothing from them. For example, an online shopper can buy a product via amazon.com after paying some amount of money, but as a company, Amazon does not need to buy anything from such individual purchasers. The consumer-producer assumption is thus not empirically viable here. Second, the crucial evolutionary dynamic in inframarginal analysis, the transaction efficiency parameter, is too abstract to understand and measure effectively, and thus difficult to justify. Thus, inframarginal analysis poses certain problems in the context of e-commerce.

Complex Adaptive Systems (CAS)[18] is another mechanism by which to investigate micro-level individual decision-making behaviors and the evolution of macro system phenomena. From the perspective of CAS, numerous micro-level individuals' adaption behaviors lead to the complexity of the macro system. Following this idea, various systems have been investigated and identified to be a CAS, such as markets[19], supply chain networks[20, 21], eco-industrial parks[22], technological inventions[23], new products development[24], and so on. Also, combined with multi-agent based simulation technology, CAS concepts and methodologies have been exploited to address a large range of problems, including herd behavior[25], the risk-return relationship[26], in resource allocation systems, supply network evolution[27], natural resource management[28], rangeland system evolution[29], e-commerce transaction networks[30], and so on. CAS related concepts, theory, methodology, and techniques offer us a series of tools to investigate the dynamic, nonlinear, and discrete characteristics during the evolutionary process. However, in order to draw conclusions from CAS through simulations, a large number of parameters need to be tested repeatedly. Further, the conclusions generated from simulation experiments are typically fragmented, global optimal solutions are not typical.

Our contribution in this paper is to combine the approaches of model construction and computer simulation, in order to explore the evolutionary path of optimal firm resource allocation and optimal market structure based on external evolutionary dynamics, which is explicitly formulated in terms of reachable transaction scope. An individual firm based model is developed and utilized to derive global optimal solutions, and a series of CAS-based simulation experiments are carried out which validate analytical results.

We find that with the expansion of reachable transaction scope from local to full coverage, the individual firm discretely takes back one unit input from a low-investment direction and, instead, channels it to a "specialized direction". Accordingly, optimal market structure changes from a self-sufficient stage to a semi-specialized stage, and finally to a completely specialized stage. Of note, we propose and prove a series of definitions and propositions to characterize division network evolution. We find that in a fully evolved e-commerce market, firms are highly integrated and tightly coupled.

The remainder of this paper is organized as follows. In Section 3, model forms are proposed first, constraints are explained, and solutions are given. Then based on model analysis results, the evolution characteristics of division network are investigated and a series of propositions are given. Next, to validate our model, in Section 4, a CAS-based simulation framework is constructed, experiments are designed, and results are discussed. Finally in Section 5, we draw conclusions and several future research directions are suggested.

3   Model

Market evolution cannot occur without micro individuals. Numerous independent and autonomous individuals drive system level evolutionary behaviors[18]. In this paper, we follow this bottom-up idea. To explore the evolution of the market, a micro-level resource allocation model should first be established to characterize individual firms.

3.1   Conceptual description

In a market where all consumers need n types of service, the firm resource allocation strategy is modeled conceptually as Formula (1).

$$
\begin{aligned}
\text{Max} \quad & P(\boldsymbol{L}, \boldsymbol{S}) \\
\text{s.t. } & R(\boldsymbol{L}) = 0; \\
& p_i = f(l_i), \quad i = 1, 2, ..., n; \\
& C(p_i, s_i) \leqslant 0, \quad i = 1, 2, ..., n; \\
& M(N, s_i) \leqslant 0, \quad i = 1, 2, ..., n; \\
& s_i \in \mathbf{N}^+
\end{aligned}
\tag{1}
$$

In the above conceptual model, n represents the number of demanded services. $P(\boldsymbol{L}, \boldsymbol{S})$ is the profit function of the individual firm, where vector $\boldsymbol{L} = [l_1, l_2,$

$\ldots, l_n]$ represents its resource allocation scheme among n service directions, and vector $S = [s_1, s_2, \ldots, s_n]$ represents the number of consumers who purchased services from this firm, $s_i \in \mathbf{N}^+$. $R(L) = 0$ is the resource constraint of the individual firm. It implies the total amount of resources a firm could access cannot be exceeded, and is limited by an upper bound. $p_i = f(l_i)$ is the production function of the i-th service, where p_i represents the output amount of the i-th service. $C(p_i, s_i) \leqslant 0$ is the production capacity constraint of the individual firm; thus, the number of consumers who purchased the i-th service from a firm is limited by its output amount. $M(N_i, s_i) \leqslant 0$ is the market size constraint of the individual firm; thus, the number of consumers who purchased the i-th service from a firm is limited by the market size that a firm could achieve under current external condition. Parameter N is a positive integer, which represents the number of consumers within the current reachable transaction scope.

3.2 A simple and symmetric firm resource allocation model

3.2.1 Fundamental model form

The conceptual model (1) should be further specified for the purposes of application. In this paper, a model characterized as a simple and symmetric firm resource allocation model is proposed and expressed as Formula (2).

$$
\begin{aligned}
\text{Max} \quad & \sum_{i=1}^{n} s_i \times \text{price}(p_i) \\
\text{s.t.} \quad & \sum_{i=1}^{n} l_i = 1, \quad i = 1, 2, \ldots, n; \\
& p_i = l_i^b, \quad i = 1, 2, \ldots, n, \quad b > 1; \quad (2) \\
& s_i \leqslant \frac{p_i}{p_{i0}}, \quad i = 1, 2, \ldots, n; \\
& s_i \leqslant N, \quad i = 1, 2, \ldots, n; \\
& s_i \in \mathbf{N}^+
\end{aligned}
$$

"Simple" here means that in this model we do not consider other organizational behaviors of firms, only their resource allocation schemes. A more concrete resource constraint function $\sum_{i=1}^{n} l_i = 1$ indicates the total resources a firm could control is limited by 1, which means a firm cannot expand its production scale by recruiting new workers, but can only adjust resource allocation among different service directions. Moreover, we focus our attention on services rather than physical commodities, thus the inventory problem is not included in our model. Symmetric here means different types of service are actually identical in our model. That is to say, we do not differentiate services according to their features but use an identical production function $p_i = l_i^b$ to characterize their input-output relationships. Parameter b in the production function is set to be greater than 1, thus there are increasing returns to specialization. It implies the more resources a firm puts into one service direction, the more output it can gain per unit investment. This phenomenon is called specialized-economy, it exists when the production function is convex. Figure 1 demonstrates the shape of the production function used in our model. As it shows, both the first and second derivatives of this production function are positive. In addition, for any $x_3 - x_2 = x_2 - x_1$, we have the inequality $y_3 - y_2 > y_2 - y_1$.

Individual firms are rational and driven by a certain target. In our model, the firm's optimization objective is to maximize profits. The profit function is defined as $\sum_{i=1}^{n} s_i \times \text{price}(p_i)$, where s_i represents the number of consumers who have bought the i-th service from this firm, and $\text{price}(p_i)$ represents the price of the i-th service. Pricing strategy of service will be discussed in detail later. Production capacity constraint is characterized as $s_i \leqslant p_i / p_{i0}$, where p_{i0} is the amount of the i-th service that a consumer demands. This production capacity constraint demonstrates a truism: a firm cannot sell services in excess of output amount. Market size constraint is characterized as $s_i \leqslant N$, where N represents the number of consumers a firm could access. This capacity constraint illustrates another obvious point of logic: The number of consumers who have bought services from a firm cannot exceed its market size, under the assumption that both firms
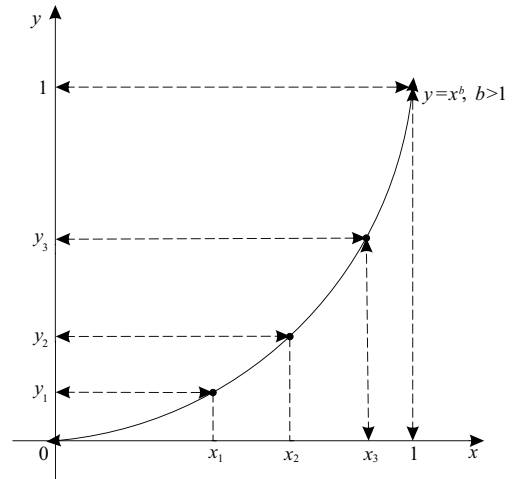

Fig. 1 Shape of production function with specialized-economy.

and consumers are geographically fixed. An intuitive demonstration of the market size constraint is shown in Fig. 2, where the upper layer represents firms, and the lower layer represents consumers. Both firms and consumers are distributed randomly with one-to-one correspondence and tied to the initial location. Any given firm can only sell services to consumers within the circumference of the circle, which is centered by that firm, with a radius equal to s. Specifically, this parameter, s, is named the reachable transaction scope in this paper.

We also assume that consumers demand all n types of service and transactions can be fulfilled only when all of a consumer's demands could be met. This assumption has certain practical background in empirical data. Take e-commerce transactions as an example. When shopping online, consumers generally go through three periods, they are browsing an e-commerce website, paying through an electronic payment system and then receiving the commodity from the logistics service provider. Through the whole e-commerce transaction process, the e-commerce firm's role is to offer the service of information flow, then the service of cash flow, and finally deferring to logistics firms whose role it is to offer the service of physical distribution. The absence of any one of these three services will lead to the failure of online shopping. We cannot imagine a consumer would pay for a product which could not be delivered to him, or a seller would send a product to a person who will not pay for it.

3.2.2 Pricing strategy

Under the above assumptions and settings, the firm's service pricing strategy will be discussed in detail.

At the beginning, when reachable transaction scope is 0, each firm can only offer services to the corresponding one consumer in their locality. At this time, for a consumer-firm pair, the amount of service supplied is
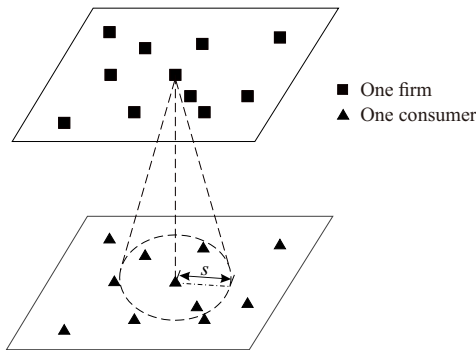

Fig. 2 Two-layer structure of firms and consumers.

just equal to the amount of service demanded. As mentioned above in Section 3.2.1, different services are seen as identical in our model, so at initialization, for any type of n services, a consumer's demand is n^{-b} and a firm's optimal resource allocation scheme is $l_1 = l_2 = \cdots = l_n = 1/n$.

To be sustained, firms need to earn money. If, initially, the money that a firm charges for one unit service is set as parameter c, then every firm earns a profit of nc and every consumer pays a cost of nc to avail of all n types of service. Specifically, the amount of nc is set to be the minimum profitability that a firm must obtain in order to maintain operations. With the expansion of reachable transaction scope, the number of consumers that a firm could access increases. Due to the effect of specialized-economy demonstrated in Fig. 1, the firm could adjust its resource allocation scheme to be more focused, thus serving more people to enhance its profitability. If the firm has no ambition to earn more money but just wants to maintain the least necessary profitability, we would invoke a temporary assumption such that for every type of service offered by this firm, its price will be set as follows.

$$\text{price}(p_i) = \frac{nc}{\sum_{i=1}^{n} \frac{p_i}{n^{-b}}} = \frac{n^{1-b}c}{\sum_{i=1}^{n} l_i^b} \tag{3}$$

Because of the symmetric property of our model, if reachable transaction scope is large enough, then there always exists a division network in which people can get all n types of service from firms with symmetric resource allocation. Take $n=3$ as an example, if the business model, $l_1 = a, l_2 = b, l_3 = c$, is competitive, then $l_1 = a, l_2 = c, l_3 = b$; $l_1 = b, l_2 = c, l_3 = a$; $l_1 = b, l_2 = a, l_3 = c$; $l_1 = c, l_2 = b, l_3 = a$; and $l_1 = c, l_2 = a, l_3 = b$, are the other five competitive business models. Therefore, consumers can get all n types of service at the same cost. More generally, the cost to acquire all services is expressed as Formula (4).

$$\text{Cost}(p_1, p_2, \ldots, p_n) = n \times \text{price}(p_i) = \frac{n^{2-b}c}{\sum_{i=1}^{n} l_i^b} \tag{4}$$

Compare the initial cost nc with $\text{Cost}(p_1, p_2, \ldots, p_n)$, the following relationship can be derived.

$$\text{initialCost} - \text{Cost}(p_1, p_2, ..., p_n) =$$
$$nc - \frac{n^{2-b}c}{\sum_{i=1}^{n} l_i^b} =$$
$$\frac{n^{2-b}c \left(n^{b-1} \sum_{i=1}^{n} l_i^b - 1 \right)}{\sum_{i=1}^{n} l_i^b} \geqslant$$
$$\frac{n^{2-b}c (n^{b-1} n^{1-b} - 1)}{\sum_{i=1}^{n} l_i^b} = 0 \tag{5}$$

That is to say, due to the effect of specialized-economy, although the firm's minimum necessary profitability level is unchanged, the consumer could buy the same amount of service with less money. It is surely unfair that all the benefits generated from the firm specialization are captured by consumers. Actually, the firm has an incentive for acquiring money in order to improve their survival status. However, because of the pressure from rivals, the firm cannot capture those benefits unilaterally. Here we define a parameter ζ to represent the proportion of the benefit captured by the firm, ζ belongs to the open interval of 0 and 1. Now the pricing strategy price(p_i) is updated as Formula (6).

$$\text{price}(p_i) = \frac{n^{1-b}c}{\sum_{i=1}^{n} l_i^b} + \frac{1}{n} \times \frac{\zeta n^{2-b}c\left(n^{b-1}\sum_{i=1}^{n} l_i^b - 1\right)}{\sum_{i=1}^{n} l_i^b} = \frac{n^{1-b}c\left(1 - \zeta + \zeta n^{b-1}\sum_{i=1}^{n} l_i^b\right)}{\sum_{i=1}^{n} l_i^b} \quad (6)$$

Finally, our proposed simple and symmetric firm resource allocation model could be transformed into a more specific form as follows.

$$\text{Max} \quad \sum_{i=1}^{n} s_i \times \frac{n^{1-b}c\left(1 - \zeta + \zeta n^{b-1}\sum_{j=1}^{n} l_j^b\right)}{\sum_{j=1}^{n} l_j^b}$$

$$\text{s.t.} \quad \sum_{i=1}^{n} l_i = 1, \quad i = 1, 2, ..., n;$$
$$p_i = l_i^b, \quad i = 1, 2, ..., n, \quad b > 1;$$
$$s_i \leqslant \frac{p_i}{p_{i0}}, \quad i = 1, 2, ..., n; \quad (7)$$
$$p_{i0} = n^{-b}, \quad i = 1, 2, ..., n;$$
$$s_i \leqslant N, \quad i = 1, 2, ..., n;$$
$$s_i \in \mathbf{N}^+;$$
$$\zeta \in (0, 1)$$

3.2.3 Model solution

Problem (7) is a discrete and non-convex optimization problem, which resists being solved analytically. Some further transformation and simplification is necessary to find the optimal solution. Considering price(p_i) and s_i are two non-negative values, s_i should be maximized in its feasible region if we want to maximize the objective function. After removing the negative integer constraint to s_i, a brief form of the original optimization problem is obtained as Formula (8).

$$\text{Max} \quad n^{1-b}c \times \left(\frac{1 - \zeta}{\sum_{i=1}^{n} l_i^b} + \zeta n^{b-1}\right) \times$$
$$\sum_{i=1}^{n} \min(n^b l_i^b, N)$$
$$\text{s.t.} \quad \sum_{i=1}^{n} l_i = 1; \quad (8)$$
$$b > 1;$$

$$\zeta \in (0, 1)$$

The optimal solution of problem (8) is subject to parameter N, which is the number of consumers that a firm could access for purposes of service provision. It is important to observe a certain fact to solve problem (8). As mentioned in Section 3.2.2, the smallest amount of services that a consumer needs in our model is n^{-b}, so for any resource allocation scheme, if there exists $l_i \in (0, 1/n)$, then it will not be optimal. Because the investment of l_i is insufficient to serve even one person, l_i is wasted. Based on this recognition, we can analyze this optimization problem from three perspectives.

First, let us consider an extreme case. If N is always bigger than n^b, namely when $\sum_i \min(n_b l_i^b, N) = n_b l_i^b$, the optimization problem could be simplified into Formula (9). Considering $\zeta n^b c$ is a positive constant and the constraint $b > 1$, the maximum value of the objective function could be achieved when there is a $l_i = 1$ and for any $j \neq i$, $l_j = 0$. That is to say, if the market size that a firm could access has exceeded a certain threshold, then the optimal business model is to focus on one service direction and direct all resource into it. This business model is named the completely specialized model, because accordant firms offer only one type of service.

$$\text{Max} \quad nc \times (1 - \zeta) + \zeta n^b c \times \sum_{i=1}^{n} l_i^b$$
$$\text{s.t.} \quad \sum_{i=1}^{n} l_i = 1$$
$$b > 1; \quad (9)$$
$$\zeta \in (0, 1)$$

Further, there is another extreme case at the other side of this story. When parameter N equals 1, which means the individual firm can only access one consumer in its locality, the optimization problem could be simplified into Formula (2). Considering $n^{1-b}c(1 - \zeta)$ is a positive value, the maximum value of the objective function could be achieved when $l_i = 1/n$. It means, if the market size is so small that a firm can only serve one local consumer, then the optimal business model is to allocate resources across all service directions equally. This business model is named the self-sufficient model herein, for a firm in this state offers all types of service by itself.

$$\text{Max} \quad \frac{n^{1-b}c(1 - \zeta)}{\sum_{i=1}^{n} l_i^b}$$
$$\text{s.t.} \quad \sum_{i=1}^{n} l_i = 1; \quad (10)$$
$$b > 1;$$
$$\zeta \in (0, 1)$$

Now, the cases between the two forgoing extreme situations are investigated. With increasing N, the firm has more and more space to adjust its resource allocation scheme to earn more money. As analyzed in the previous paragraph, l_i is either zero or not less than $1/n$, thus starting from the initial self-sufficient state, firm's resource allocation adjustment will not be continuous, but discretely reducing $1/n$ amount input from one service direction and reallocating it among others. The question how to allocate this $1/n$ amount of resource is related with the form of the production function. In our model, the production function $p_i = l_i^b$ is convex, an easy proof would show that more output could be gained if this $1/n$ amount of resource is wholly added to one chosen direction, which is named the specialized direction in this paper, rather than distributed more widely. Similarly, if the market size is expanded further and N is large enough to permit more adjustment, a $1/n$ amount of resource will be taken back from a low-investment direction and channeled into a specialized direction, which is chosen in the first reallocation step. By this logic, with the expansion of reachable transaction scope from completely localized to full coverage, the firm's optimal resource allocation scheme switches from an equal allocation to a wholly specialized allocation, gradually and systematically.

3.2.4 Background story

The evolution of China's commercial society from a traditional offline market to an e-commerce market is a practical demonstration of the analytical results of our proposed model. Different from developed countries such as America, China did not experience a steady and sufficient self-development process, but went through a pronounced and dramatic evolution from a traditional agricultural society to an industry dominated society in about 30 years, and now it's on the way to becoming a society characterized by modernization. Therefore, China offers us a good case study to take a look at the evolution of economic society via technology development. Basically, retail commerce consists of three service elements, they are information flow service, cash flow service, and logistics service. We are going to see how these three service elements combine and separate during China's commercial evolution process.

Now, returning to the early stage of reform and opening-up of China, when the country's commercial facilities were extremely inadequate and the impact of merchants and products was restricted to their local areas. At that time, the first Chinese merchants typically employed a primitive business model. They utilized their own housing to create storefronts, purchased selected commodities or even produced commodities themselves, and sold them to people via face-to-face transactions. Another interesting example which is characteristic of the Chinese context is the traveling salesman, who carries around certain portable goods and sells them by walking around the streets. This was an era when the three basic service elements are self-sufficient by virtue of being supplied by merchants themselves.

While as the economy developed and facilities were improved, Chinese merchants were able to access more consumers, and new business formats, such as the marketplace and emporium, started to emerge. In a marketplace or emporium, instead of owning shops themselves, sellers rent space to do business. In some emporiums, orders and cash are settled together centrally. So, as we can see, the service elements are initially apart.

Then at last, when it comes to the era of e-commerce in the 21st century, commercial affairs have changed fundamentally. Due to internet technology, physical restrictions on merchants have dissipated. On one hand, internet and information technology empowers individuals to make contact with others from any corner of the world. All supply and demand information can be gathered and displayed on a website. Merchants and consumers do not have to be in close proximity to match with each other. Further, merchants are relieved of requiring shelves and shops; with the help of online shops, there is no need to own or rent a shopfront to run a business. An extreme example is a digital commodity, which does not require any physical storage. In the market for online digital commodities, the phenomenon of long-tail economy resonates incisively and vividly.

In the e-commerce environment, a new but obvious change could be observed that the three service elements separate further, or even completely. What will happen if a consumer wants to buy something now? First, he will search for it on an e-commerce website, look through its description, and communicate with the seller if necessary. Then if satisfied with the product and price, the consumer will pay for it through online banking or third party payment tools. After payment, the product will be delivered to him by third party logistics firms. Considering the whole consuming process, product information is passed on

by e-commerce websites, the payment is accomplished with the help of online payment tools, the product is sent to the buyer by logistics firms. All three basic service elements are provided by independent and highly specialized firms. Technological advances are thought to play an important role in these changes, but what are the underlying evolutionary mechanisms and dynamics? We will explain this with the help of our proposed simple and symmetric firm resource allocation model.

3.2.5 A specific example

After setting the number of services n to be 3, specialized-economy degree parameter b to be 2, and surplus proportion parameter ζ to be 0.5, our model is embodied as the following form.

$$\text{Max} \quad \frac{c}{6} \times \left(\frac{1}{\sum_{i=1}^{3} l_i^b} + 3 \right) \times \sum_{i=1}^{3} \min(6l_i^2, N)$$

$$\text{s.t.} \quad \sum_{i=1}^{3} l_i = 1 \tag{11}$$

As we analyzed in Section 3.2.3, the optimal solution to problem (11) jumps between several discrete points based on the value of parameter N. Figure 3 demonstrates the transformation process of the optimal business model. The equilateral triangle in Fig. 3 represents the plane of $l_1 + l_2 + l_3 = 1, l_1 > 0, l_2 > 0, l_3 > 0$, and the three-dimensional location vector of every point represents the resource allocation scheme. At the beginning, when the reachable transaction scope is limited to localities, the optimal solution is the red center-point of the equilateral triangle, which represents the self-sufficient business model. Next, when the reachable transaction scope is expanded to exceed the first threshold, optimal resource allocation changes towards a more specialized scheme,
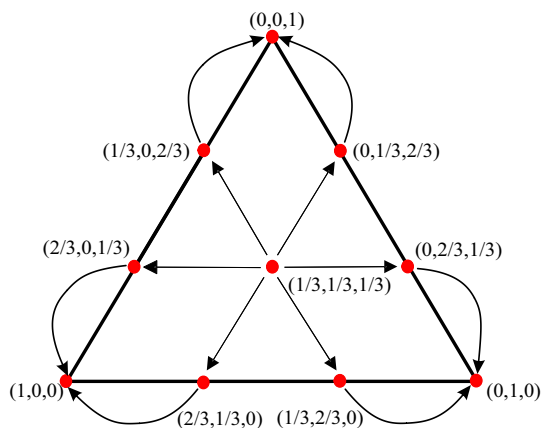

Fig. 3   Optimal business model evolution.

1/3 amount of resource is taken back from a randomly chosen service direction and channeled to one of the other directions. In this stage, there are six optimal business models, which lie on the three edges of the equilateral triangle. At last, when the reachable transaction scope is continually expanded until larger than the second threshold, the optimal business model changes to be completely specialized. The firm takes 1/3 amount of resource back from the direction with less investment and puts it into the specialized direction. In this stage, only three completely specialized business models are competitive in the market, which lie on the three vertexes of the equilateral triangle.

3.3   Characteristics of division network evolution

Besides the evolutionary behavior of individual firms, there is another type of evolution at the macro level, that is the evolution of the division network. Different from the situation in the manufacturing field, where real and large-volume transactions are taking place every day among different companies, firms in the retail market typically confront end-users directly. In the retail field, the buyer-seller relationship between two firms may not really exist, rather it is an implicit linkage. For example, in order to buy a product, a consumer may get information service from company A, payment service from company B, and logistic service from company C. So there are implicit linkages among companies A, B, and C. We could say company A buys payment and logistics services from companies B and C, or company B buys information and logistics services from companies A and C, or company C buys information and payment services from companies A and B. These three expressions tell us the same thing.

On this basis, the evolution of a division network in the retail market can be demonstrated. Let a red square denote one unit of information service input, a yellow square denote one unit of payment service input, and a blue square denote one unit of logistic service input, then the evolution of the retail market division network could be demonstrated as Fig. 4. Figure 4a presents a self-sufficient stage, when individual firm unilaterally offers three basic services to consumers. Figure 4b illustrates the structure of a semi-specialized division network, when individual firms randomly abandon one service direction to become more focused. In this stage, firms with different resource allocation schemes generally have implicit linkages with each other. At last, when the reachable transaction scope has exceeded the
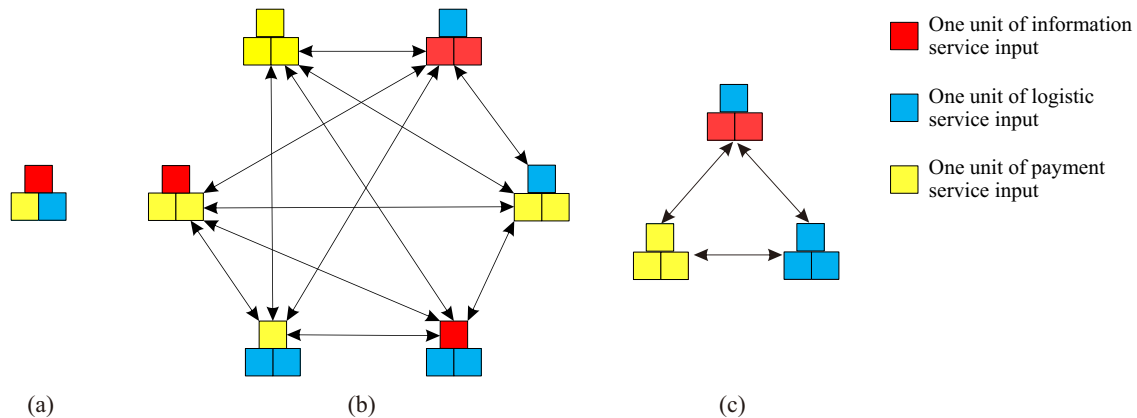
Fig. 4 Optimal division network evolution: (a) self-sufficient stage, (b) semi-specialized stage, and (c) completely specialized stage.

second threshold, the competitive business model turns out to be completely specialized, as Fig. 4c shows.

Although Fig. 4 reveals the evolutionary process of a relatively simple market, some interesting rules can be delineated from it, which may have more general significance beyond this application. First, as we see, there are three optimal division networks during the whole evolutionary process, which exactly equals the number of required service elements. Second, if we conceived the division network as a graph, it could be found that the number of vertexes changes from low to high, then back to low again. Third, as for the edges of the division graph, they are different in terms of the content flowing in them. For example, for a firm with a certain business model, it may get more than one type of service through a single edge, or it may get the same type of service through more than one edge. Also, with the evolution of the division network, a firm needs more and more services offered by other firms with different business models.

Some investigation is required to further understand division network characteristics. Our attention is focused on three features mentioned in the last paragraph: the number of evolutionary stages, the number of competitive business models and linkages among them, and the edge-properties in every division graph.

Next, in what follows, some propositions and definitions, with necessary proofs, are posited.

Proposition 1. In a market consisting of n types of service, there are n optimal division networks in the whole evolutionary process.

As we have analyzed in Section 3.2.4, the firm evolves from its current business model to the next competitive business model by taking $1/n$ amount of resource back from a low-investment direction and channeling it to a specialized direction. Once a firm selected a specialized service direction, it would be unjustifiably costly for this firm to switch to another specialized service direction, for resource depletion is unavoidable in the transition process. Therefore, the investment in the specialized service direction increases from $1/n$ to 1 during the whole evolutionary process, and in every step $1/n$ amount of investment is added. Clearly, such a process takes n steps and there are n optimal division networks in total.

Proposition 2. In the i-th $(1 \leqslant i \leqslant n)$ evolutionary stage, there are $C_n^1 C_{n-1}^{n-i}$ competitive business models in the current optimal division network.

In the i-th evolutionary stage, any competitive business model contains a specialized direction with i/n amount of resource investment and the other $(n - i)$ nonzero service directions obtain $1/n$ amount of resource investment. So to count all the possibilities, we first choose one specialized direction from n types of service, containing C_n^1 possible choices, then we choose $n - i$ nonzero alternative service directions from the remaining $n - 1$ services, which represents C_{n-1}^{n-i} possible choices. Combing these two types of choices together, there are $C_n^1 C_{n-1}^{n-i}$ competitive business models in the i-th optimal division network.

Definition 1. The set of services that flow in one edge is defined as this edge's elements set, and the size of one edge's elements set is defined as this edge's diversity.

Definition 2. For a certain division graph, the purity of this graph is defined as $(\sum_{i=1}^{i=n} x_i / i) / \sum_{i=1}^{i=n} x_i$, where x_i is the number of edges connecting to the same business model and with a diversity of j, n is the

maximum edge diversity in the current division graph.

The purity degree of a division graph is a number between 0 and 1. The closer a division graph's purity degree is to 1, the less types of service an edge contains. Figure 5a shows purity degree trends from the second evolutionary stage when the number of required service types equals 6, 10, and 15, respectively. It is shown that the purity degree of the optimal division network first decreases below 1 and then increases back to 1 again in the last evolutionary stage.

Proposition 3. For the i-th optimal division graph in the evolutionary process, if n is the maximum diversity that an edge could have in the current division graph, then for any $i < n$, we have the following formula, where x_j is the number of edges connecting to the same business model and with a diversity of j.

$$x_j = C_{n-i}^j C_{i-1}^j + C_{i-1}^1 C_{i-2}^{j-1} C_{n-i+1}^{n-i+1-j} + \\ C_{n-i}^1 C_{i-1}^j C_{n-i+1}^{n-i-j} \qquad (12)$$

First, one point needs to be emphasized, that in the i-th evolutionary stage of a market with n types

of service, every business model contains $n - i + 1$ services, and needs to get the remaining $n - i$ services from other business models.

The three components of Formula (12) are considered in three concrete cases.

The first case is two business models have the same specialized direction. In this case, if one business model is kept fixed, in order to obtain an edge with a diversity of j, the other business model needs to choose j services from all $n - i$ services contained by the fixed business model and replace them with j services selected from $i-1$ services needed by the fixed business model. So in this case, there are $C_{n-i}^j C_{i-1}^j$ possible combinations in all.

The second case is two business models have different specialized directions, and each business model does not contain the other one's specialized service. In other words, these two business models' specialized services are complementary. In this case if one business model is kept fixed, in order to obtain an edge with a diversity of j, the other business model
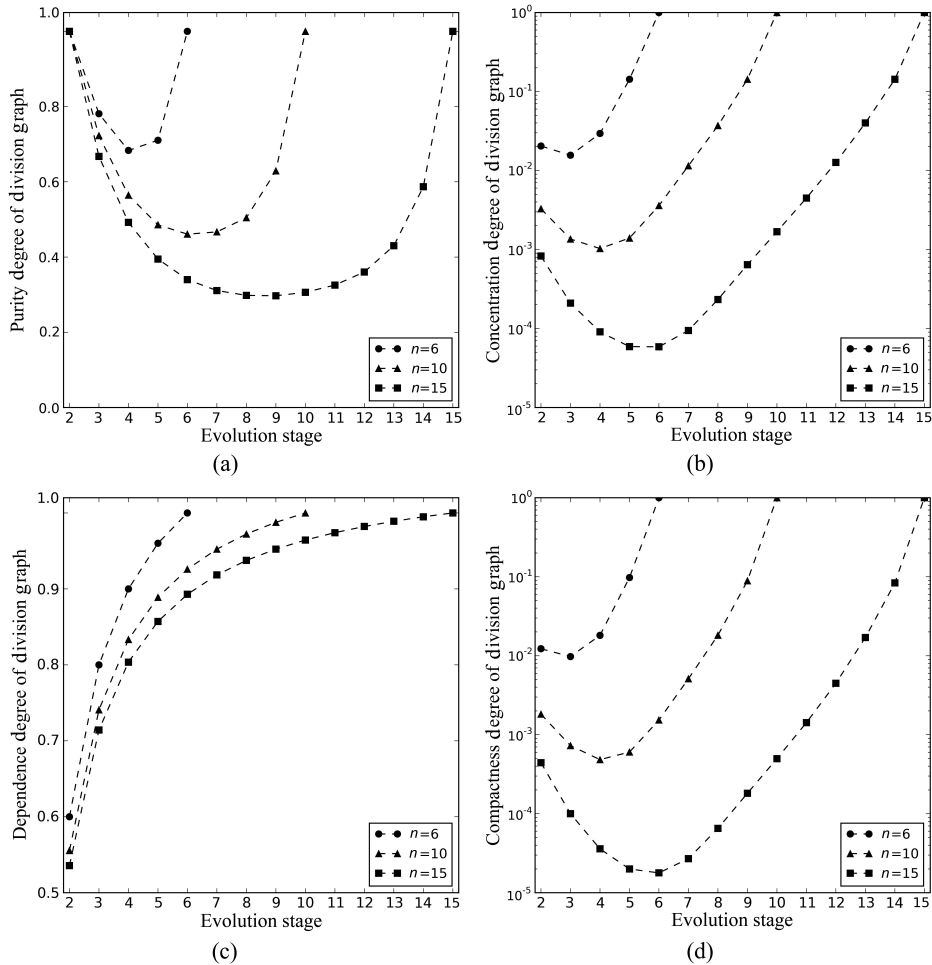

Fig. 5   Evolution of division network edges: (a) evolution of purity degree, (b) evolution of concentration degree, (c) evolution of dependence degree, and (d) evolution of compactness degree.

needs to first pick one service as specialized direction from $i-1$ services contained by the fixed business model, and then pick $j-1$ services as complementary directions from $i-2$ services needed by the fixed business model, and finally pick $n-i-1-j$ services as mutual directions from $n-i-1$ services. Therefore, in this case, there are $C_{i-1}^1 C_{i-2}^{j-1} C_{n-i+1}^{n-i+1-j}$ possible combinations in all.

The third case is when two business models have different specialized directions, and two specialized directions are their mutual services. In this case if one business model is kept fixed, in order to obtain an edge with a diversity of j, the other business model needs to pick one service as specialized direction from $n-i$ services contained by the fixed business model first, and then pick j services as complementary directions from $i-1$ services needed by the fixed business model, and at last pick $n-i-j$ services as mutual directions from $n-i+1$ services. Therefore, in this case, there are $C_{n-i}^1 C_{i-1}^j C_{n-i+1}^{n-i-j}$ possible combinations in all.

The number of edges connecting to the same business model and with a diversity of j in the i-th evolution stage is the sum of the results in the above three cases.

Definition 3. For a certain division graph, its dispersibility is defined as the number of edges connecting to the same business model and contain the same type of service.

Proposition 4. For the optimal division network in the i-th evolution stage, its dispersibility could be calculated through Formula (13), where x_j is the number of edges connecting to the same business model and with a diversity of j, n is the maximum diversity an edge could have in the current division graph.

$$\text{Dispersibility}(G_i) = \sum_{j=1}^n \frac{x_j}{C_{i-1}^j} \qquad (13)$$

Based on the definition, we could find x_j is a multiple of all combinations of j services selected from $i-1$ services set. If we assume the multiple as m, then in all the edges with a diversity of j, for a certain type of service, it could be found m times. Therefore, the dispersibility of a division graph is the sum of all multiples.

Definition 4. The reciprocal of a division graph's dispersibility is defined as its concentration degree.

The concentration degree of a division graph is a number between 0 and 1. The closer a division graph's concentration degree is to 1, for a certain type of service needed by a business model, the less providers it has. Figure 5b shows the concentration degree trend

from the second evolutionary stage when the number of required service types is 6, 10, and 15, respectively. It is shown that the concentration degree of the optimal division network first decreases from a nonzero value before increasing to 1 in the last evolution stage.

Definition 5. In the current division graph, the proportion of services that a business model needs to get from others is defined as this division graph's dependence degree.

The dependence degree of a division graph is a number between 0 and 1. Dependence degree 1 denotes that in the current division graph all business models are completely specialized, while dependence degree 0 denotes that the current competitive business model is self-sufficient. Figure 5c shows the dependence degree trend from the second evolutionary stage when the number of required service types equals 6, 10, and 15, respectively. It is shown that the dependence degree of the optimal division network monotonically increases from a nonzero value to 1.

Definition 6. The result which is obtained by multiplying a division graph's purity degree, concentration degree, and dependence degree together is defined as this division graph's compactness degree.

The compactness degree of a division graph is a number between 0 and 1. It is an indicator of the degree of integration of the current economic system. If a division graph has a compactness degree of 1, then conclusions could be drawn from three perspectives. First, in such a division network, each firm offers only one type of service and gets the other necessary services from outside partners. Second, each firm gets every needed service from only one firm. Third, no firm gets services from firms which operate according to multiple business models.

Figure 5d shows the compactness degree trend from the second evolutionary stage when the number of required service types equals 6, 10, and 15, respectively. It is shown that the compactness degree of the optimal division network first decreases from a nonzero value and then increases to 1 in the last evolutionary stage.

4   Simulation Experiment

In order to validate our simple and symmetric firm resource allocation model, a CAS simulation framework is constructed and simulation experiments are carried out. A complex adaptive system perspective is well suited for modeling the dynamic evolution

process of the e-commerce market and firm resource allocation behaviors therein. For just as CAS theory argues, there are numerous autonomous and intelligent individuals in the Chinese e-commerce market, various macroeconomic phenomena emerge from these individuals' interaction and adaption behaviors.

4.1   Simulation framework

From top to bottom, three kinds of agents are delineated and defined in our simulation experiment. They are environment agents, firm agents, and consumer agents.

The agents and action rules are listed and described in detail in Table 1.

Environment agent represents the external conditions which individual firms operate within and are constrained by. It functions under two cases, before the simulation starts and at the end of every simulation cycle. Before the simulation starts, the environment agent first generates the macroscopic market in which firms and consumers undertake various interactive activities. Specifically, a two-dimensional world will be generated with a specified

Table 1   Description of agents and rules.

Agent class	Rule	Rule description
Environment	Rule E1: Size of world and number of entities	This rule defines the size of the world which is a two-dimensional plane for entities (firms and consumers) to exist in, and generates a certain amount of entities which are distributed geographically at random.
	Rule E2: Entity evolution process	This rule specifies the processes of elimination, mutation, and learning in intergenerational cycles. That is, at the end of every cycle, a certain proportion of firms which exhibit the lowest fitness values will be eliminated, and some mutation firms will be born and introduced into the market whenever unmet demand exceeds a threshold, and the other firms will learn and adjust their business models according to the performance of their nearby neighbors.
	Rule E3: Type of needed services	This rule sets the number and type of services needed by consumers.
	Rule E4: Reachable transaction scope	This rule sets the maximum distance that one firm has access to for the purposes of service provision.
	Rule E5: Specialized-economy degree	This rule governs the degree of specialized-economy, that is, the productivity a firm can gain from specialization.
Firms	Rule F1: Resource allocation adjustment	This rule governs the firm's resource allocation adjustment process among all service directions. One firm can choose to increase or reduce the resource it puts into one direction according to prevailing business conditions.
	Rule F2: Production	This rule defines how much service a firm can provide based on its business model and specialization degree among all directions.
	Rule F3: Pricing strategy	This rule sets up the price of every service provided by a firm.
	Rule F4: Fitness updating	This rule defines the updating process of a firm's fitness value. The fitness value of a firm depends on the number of consumers who bought its services and the price per unit service.
	Rule F5: Learning	This rule defines the learning process of firm. A firm will learn from the firm with the highest fitness value in its reachable transaction scope. Specifically, it will copy the business model and resource allocation scheme of the targeted firm.
	Rule F6: Mutation	This rule defines firm mutation process. After the elimination of firms at the end of every cycle, if unmet demand exceeds a certain threshold, then new firms will be introduced as mutations, which means these firms will choose business models and generate resource allocation schemes randomly.
Consumers	Rule C1: Service provider selection	This rule describes the process by which consumers choose service providers. A consumer will search their horizon and choose the firm which obtained the highest fitness value in the last simulation cycle and at least has one unit of required service.
	Rule C2: Consuming	This rule defines how a consumer consumes a service. A consumer will consume one unit service from every selected service provider if all their demand could be met by the current market.

size, and equivalent firms and consumers will be randomly and geographically distributed. It should be noted that firms and consumers in our model exhibit stationary one-to-one locational correspondence. One consumer should not be understood in terms of their existing only one person in every location, but should be regarded as a collection of all demands. Basic market and product attributes will also be set in this step, including the number of required services, the form and parameters of the production function, and the length of reachable transaction scope. Finally, at the end of every simulation cycle, the environment agent will eliminate the firms with the lowest fitness values and introduce some mutation firms if necessary, imitating the process of natural selection.

Firm agent represents the decision making body in our proposed model. It has the autonomous right to change its business model and allocate its resource. In our CAS-based simulation, the global resource allocation is made by numerous dissipated individual firms instead of via central planning. Based on its business model, resource allocation and production function, each firm produces a certain amount of services at the beginning of every simulation cycle, priced reasonably based on pricing strategy, which was discussed in detail in Section 3.2.2. Then for every type of service, consumers will search the firms in their horizon and choose the lowest price option and obtaining at least one unit amount of services. The horizon of a consumer is equal to current reachable transaction scope. If all demand could be met, a consumer would purchase one unit service amount from selected service providers respectively. After all consumers have attempted to locate service providers and purchase services, whether successfully or not, each firm would calculate its profits gained in this simulation cycle in terms of fitness value. The firms whose average fitness value in the last three cycles rank below a specified threshold calculated based on the fitness of all extant firms, would be eliminated and announced as terminated. Whenever the number of consumers whose demand has not been satisfied exceeds a threshold, the environment agent will invoke some mutation firms and distribute them randomly across the locations of the previously terminated firms. A mutation firm is a newborn firm which randomly chooses a business model and randomly allocates its resources to service directions. After the elimination and mutation

procedure, extant firms learn from others one by one. Each extant firm will search all the other extant firms in current reachable transaction scope, compare their fitness values, and copy the most competitive firm's business model and resource allocation scheme. In order to avoid the formation of a herd[25], which would cause excess volatility, each firm can only be learned from once.

On the whole, the simulation process can be summarized by five steps. They are market generation, service production, service consumption, firm elimination and mutation, and learning procedure. In the market generation step, a market with a specified size is created and a series of environmental variables are determined. Then firms produce services based on their resource allocation, and consumers purchase services one by one. After completion of the consumption step, based on its profitability, a firm will be either eliminated or survive to the next cycle. At last, after each extant firm conducts learning procedures, this simulation cycle ends. By this way, the simulation experiment is carried on interactively and the market division network keeps evolving until reaching an equilibrium state.

There are two more details which should be emphasized in our simulation framework. In order to provide evolution an initial impetus, some firms are born as mutations before the simulation starts. Whether the genes of mutation firms will be passed on or culling occurs, is decided by simulation mechanism. Specifically, the elimination procedure will retain the competitive entities across all mutations, and the learning procedure will spread these competitive business models around the market. Also, in order to accelerate the process to reach equilibrium and balance firms' herd behaviors, some smart firms are generated. Different from the action rules of simple firms listed in Table 1, smart firms do not adjust their business models according to neighbors' fitness, but according to market shortage. At the end of every cycle, a smart firm investigates the firms and consumers in current reachable transaction scope, compares every service's supply and demand amount, and allocates his resource based on market shortage. That is, if the supply of some type of service could not meet all consumers' demands within current reachable transaction scope, then the smart firm will put more resources in that direction, aiming to balance supply and demand.

4.2 Experimental design

While this simulation experiment is primarily designed to validate our simple and symmetric firm resource allocation model in Section 3, we also try to gain more knowledge on the dynamic characteristics of the e-commerce market evolution process. The following three aspects attract our attention in particular. The first two correspond to the validation of our proposed model, and the third concerns e-commerce market dynamic evolutionary characteristics in terms of firm number, profitability, and cost related affairs.

(1) Evolution of the division network

In Section 3.2.6, we draw a conclusion that with the expansion of reachable transaction scope, firms will be increasingly specialized and several optimal division networks will emerge. Do experimental simulation results confirm this conclusion? Additionally, the analytical solution is focused on the final-state situation. However, there does not exist any visible or appreciable power above to satisfice this. So can the analytical equilibrium be reached in reality? If yes, what dynamic and discrete transition processes are associated with it? Such questions need to be answered through simulation experiments.

(2) Edges linking different business models

In Section 3.2.6, we defined the purity degree, concentration degree, dependence degree, and compactness degree of a division network to characterize the edges linking different business models. As Fig. 5 delineates, with the evolution of the division network, the purity of the optimal division graph first decreases from one to a nonzero value and then rises towards 1 again; the concentration follows a similar rule, while the dependence of the optimal division graph increases monotonically from 0 to 1. As a result, the compactness degree of the optimal division network rises from 0 to 1. These propositional characteristics need to be validated by simulation experiments.

(3) Number and profitability of firms

In the current e-commerce market, we can observe two obvious phenomena. On one hand, offline stores feel more and more pressure from the online market and some types of offline stores, such as electronics hypermarkets and bookstores, have to reduce in size or even cease operations. On the other hand, online business participants are involved in fierce competition, price wars and advertising wars emerge

one after another. Most e-commerce firms maintain low profitability or even lose money. So the question is, at the micro level, how does the number of firms change with the expansion of reachable transaction scope? How does individual firm's profitability evolve? What will consumers and society gain from these changes?

Before the simulation experiment, some necessary variables and parameters should be initially assigned. Values of all parameters in the simulation are listed in Table 2. Specifically, in our simulation experiment, environment agent will generate a two-dimensional square world with a 5×5 area. Then 400 firms and 400 consumers are distributed randomly in the world, with one-to-one correspondence. Three types of services are needed in the market, each of which has a production function of $p_i = l_i^2$, where $l_i \in [0, 1]$. The mutation rate is set to be 5%, whenever unmet demand exceeds 5% of total demand, mutation firms will be invoked. Also, in the first simulation cycle, 10% mutation firms will be born to provide an initial evolutionary impetus, and 20% smart firms will be born to balance strength to avoid the herd phenomenon. Through the whole simulation experiment, reachable transaction scope increases from 0 to 1, with a step of 0.01. For a certain value of reachable transaction scope, the simulation will run for 500 iterations, and the average results of the last 10 iterations will be recorded as final results. To avoid possible deviations in a single experiment, the whole simulation experiment will be repeated 10 times, so there are 100×10 simulations in all, and each simulation contains 500 iterations.

4.3 Results and discussions

4.3.1 Division network evolution: Specialization degree and competitive business model

As seen in Fig. 6a, with the expansion of reachable transaction scope from 0 to 1, the number of consumers

Table 2   Values of parameters in simulation experiments.

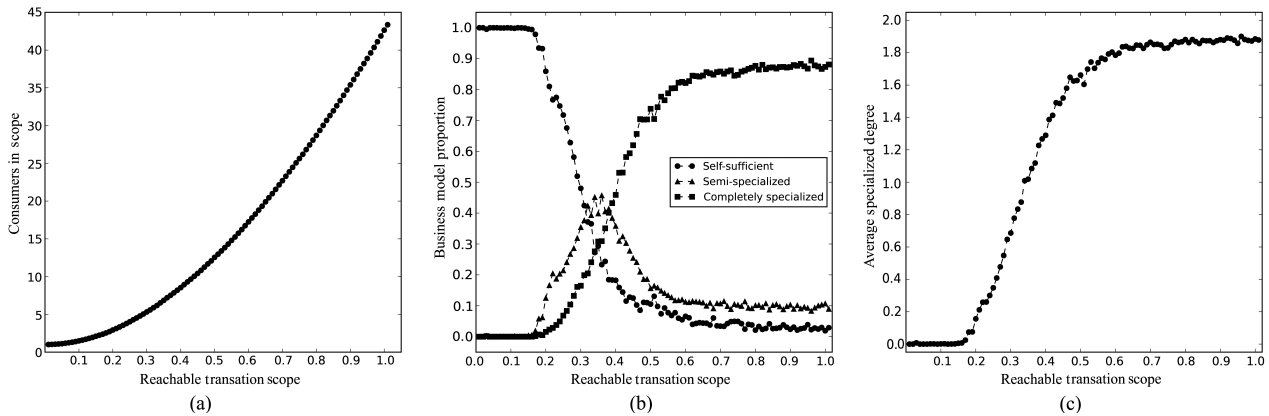| Parameter	Value
World size	5×5
Firm number	400
Consumer number	400
Needed service types	3
Specialized-economy degree	2
Mutation rate	5%
Mutation introducing threshold	5%
First mutation rate	10%
Smart firms rate	20%
Reachable transaction scope	[0, 1]

Fig. 6   Simulated firm-level evolution: (a) individual firms market size, (b) business models, and (c) average specialized degree.

that a firm could access increases exponentially. When the market size converges on the first threshold, in our simulation experiment it is when reachable transaction scope increases to circa 0.15 and the average market size reaches circa 2, self-sufficiency is no longer the only active business model. Semi-specialized and completely specialized business models begin to appear and grow. During the process, reachable transaction scope increases from 0.15 to 0.37 and the number of self-sufficient firms continues to decrease towards a minimum, while semi-specialized firms and completely specialized firms keep growing. It should be noted that although the number of semi-specialized firms is always bigger than the number of completely specialized firms in this period, it starts to fall towards the end of the period. When reachable transaction scope exceeds the second threshold, which is circa 0.37 in Fig. 6b, the completely specialized business model becomes the most competitive business model and keeps on growing until it accounts for nearly 90% of all firms. Meanwhile, the number of semi-specialized firms decreases until it only accounts for about 10%, and then remains stable. While self-sufficient firms are cleared out of the market swiftly, the remaining few self-sufficient firms can be explained as mutations introduced in every simulation iteration. In sum, as Fig. 6c demonstrates, with the expansion of reachable transaction scope, the average specialized degree of all extant firms rises from 0 to nearly 2, which means the competitive business model changes from self-sufficient to semi-specialized and, finally, to completely specialized. Simulation experiment results confirm the analytical results associated with our proposed model in Section 3.2.5.

4.3.2   Evolution of edges in division networks

Four defined indicators to characterize the evolution of

division network edges in Section 3.2.6 are calculated and demonstrated in Fig. 7: purity degree, concentration degree, dependence degree, and compactness degree. Diverging somewhat from their base definitions and derivations, in Fig. 7, the first three indicators are calculated directly from simulation experiment data whilst the compactness degree is a multiplicative function of them. Overall, the trends contain substantial realistic and dynamic information. When the reachable transaction scope is below 0.15 and all firms are self-sufficient, we set the purity degree and concentration degree to 1, and the dependence degree to 0.

As Fig. 7 demonstrates, the purity degree of the division network edges first decreases below 1 before rising to 1 again. Thus a number of firms used to offer more than one service to the same single firm. Because only three types of service exist in our simulation experiments, this downtrend in purity degree is short lived. Meanwhile, the concentration degree experiences a steep decline before gradually rising back towards 1. This sheds light on how the evolutionary process is manifested by quite a lot of business models existing in the market, and for a certain service type one firm has linkages with a range of other firms. It is a period when different types of firms are loosely joined together. As for the dependence degree, it is another expression of the specialized degree. So as we can see, with the expansion of reachable transaction scope, the dependence degree increases monotonically from 0 to 1. Finally the compactness degree is calculated and shown as Fig. 7d. It should be noted that the process of increasing compactness degree actually includes two stages, corresponding to the two evolutionary stages of the division network in Fig. 6b. When reachable transaction scope is expanded from 0.2 to 0.4, the compactness degree of the division network goes through its first increasing stage, rising from almost 0
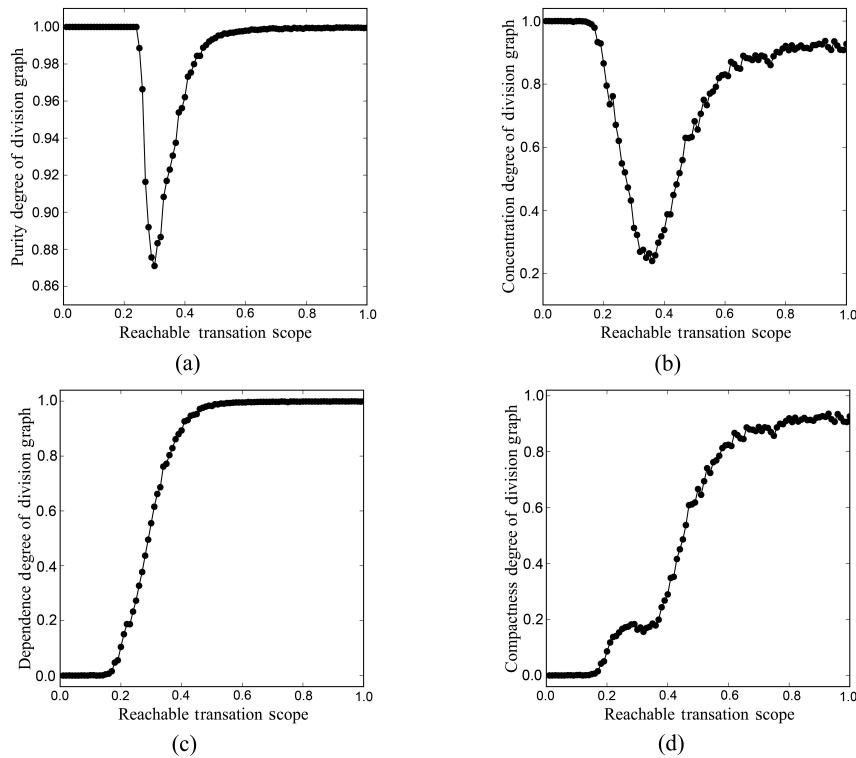
Fig. 7 **Simulated division network evolution: (a) purity degree, (b) concentration degree, (c) dependence degree, and (d) compactness degree.**

to about 0.2. After hovering around 0.4 for a while, it then monotonically increases to 1. This is the second evolutionary stage, in which the economic system achieves the greatest degree of integration degree and different types of firm are tightly coupled.

4.3.3 Firm evolution

At the micro level, Fig. 8 discloses the evolution of firms from two perspectives: number of extant firms and average profitability. Also, it illustrates what this firm-level evolution will bring to consumers and wider society.

First, with the expansion of reachable transaction scope, the number of firms increases marginally *n* the beginning before dropping sharply from nearly 400 all the way down to 130. Second, the profitability of individual firms decreases from 1.1 to below 0.7 in the first stage and then increases to above 1.2. The initial increase in firm numbers can be explained by the introduction of mutations. When reachable transaction scope is below the first threshold 0.2, self-sufficiency is the only competitive business model and any attempt to invoke new business models will lead to termination. So at that time, markets are stable and silent, no mutation firm can survive. When reachable transaction scope is 0.2, the market size has enlarged

enough for firms to try new business models. So mutation firms with competitive business models can survive and spread their genes, and the number of total firms increases slightly due to this. When reachable transaction scope is expanded further, more and more firms employ specialized business models. If total demand remains unchanged, and a more specialized business model can raise individual firm's output, the number of extant firms declines consistently. As for profitability, the decrease in the number of firms does not increase earnings of the remainder. This is because the expansion of reachable transaction scope has broken local exclusive markets and merges them gradually. In the early stage, individual firm's output exceeds total consumers' demand that it could access. In this situation, the individual firm faces great competitive pressures from others and could not sell all of its service units, thus average profitability keeps decreasing in this stage. When reachable transaction scope is expanded to be so large that individual firm could not meet total consumers' demand with the current reachable transaction scope, competitive pressures will ease gradually. Firms start to sell more and more services, and their average profitability rises. Finally, extant firms can gain more profit than at any other time in
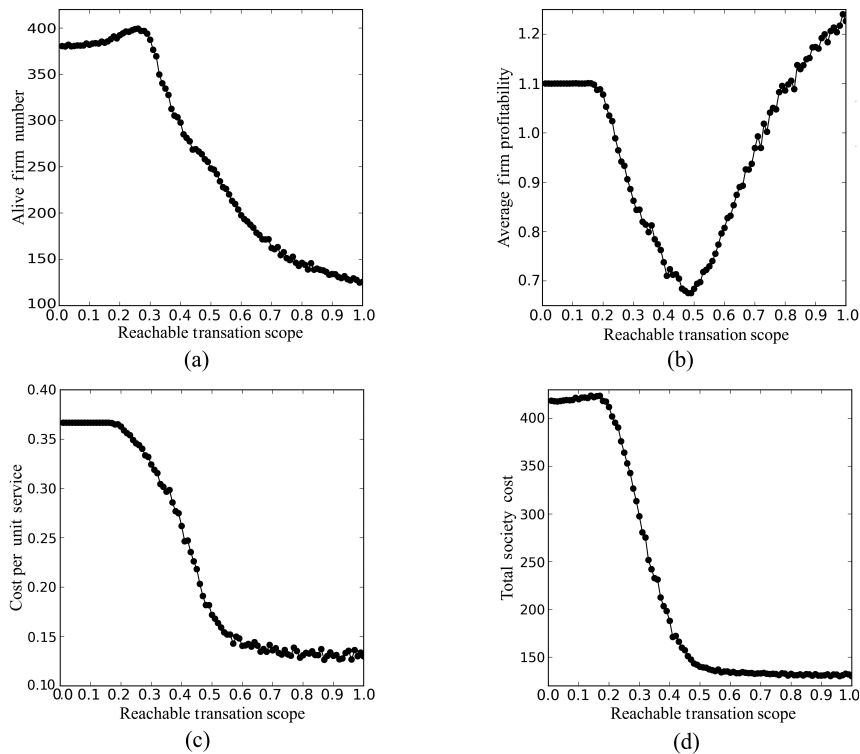
Fig. 8   Simulated society-level evolution: (a) change in average firm number, (b) change in average profitability, (c) change in cost per service unit, and (d) change in total social cost.

evolutionary history.

What changes will firm-level evolution bring to ordinary consumers and society as a whole? Figures 8c and 8d posit an answer to this question from the perspectives of average service cost and total social cost. As Formula (5) expresses, the average price of unit service decreases with the expansion of reachable transaction scope. This is because specialized business models enable individual firms to offer more service, so they are willing to reduce price in order to sell more. Figure 8c confirms this and Fig. 8d shows how total social cost obeys the same rule.

Therefore in summary, if we see e-commerce as a strength which has expanded reachable transaction scope to a considerably large value, then we can speculate that in a highly developed and fully evolved e-commerce market, firm's profitability and ordinary consumer's wealth level are both promoted. However, on the way to achieving this, numerous firms need to close down or change their business model.

5   Conclusion and Future Work

In this paper, we proposed a simple and symmetric firm resource allocation model to investigate how firms allocate resources among different directions based on

differences in reachable transaction scope, and how division networks form, function, and evolve with it. Specifically, we focus our attention on the evolution of the e-commerce market, in which individual firm's reachable transaction scope has been greatly expanded to cover the global market. Our interest is how this fundamental change drives firm and market level evolutionary behavior, and whether any observed or deduced trends can characterize this evolutionary process.

Through the analysis of our proposed model, two principal conclusions are drawn. First, at the firm level, with the expansion of reachable transaction scope, the firm discretely takes back one unit of investment from a low-investment direction and channels it into the specialized direction. The firm-level evolutionary path is characterized as a process in which firms constantly abandon some type of service to focus on an increasingly specialized direction, which is chosen at the initialization step of evolution. Second, at the market level, the optimal division network transfers discretely among several graphs. A series of definitions and propositions are given and proved to represent market level evolution. Compactness degree is a defined comprehensive indicator to characterize relationships among firms. With the expansion of

reachable transaction scope, the compactness degree of the division network rises from 0 to 1. Thus in a highly developed and fully evolved e-commerce market, individual firms exhibit great dependence on outside companies. Excepting the specialized direction case, individual firms get every other service from completely specialized firm which only offer one service. We found that in a fully evolved e-commerce market, firms are highly integrated and tightly coupled.

Furthermore, in order to validate our proposed model and related analytical results, we build a CAS-based simulation framework and carry out a series of simulation experiments. Environment agent, firm agent, and consumer agent, together with their action rules, are constructed respectively. By introducing the natural selection mechanisms of mutation, elimination, and adaptation, we attempt to determine how the macroeconomic system evolves with numerous micro-level individuals. The results of these simulation experiments accord with the propositions and conclusions derived from our proposed model, whilst offering substantial additional dynamic and detailed information. Besides validation, with the help of simulation experiments, we investigated how the number of extant firms, average profitability of individual firms, and cost per unit service change during the evolutionary process. We found that in a fully evolved e-commerce market, individual firms can gain more money than at any prior time in evolutionary history. Meanwhile, consumers can buy the same amount of service with less money. From this perspective, e-commerce is a win-win choice for both firms and consumers. However, it should be noted that some firms cannot adapt and survive the culling procedures in this evolution.

There are numerous opportunities for future research which could build on this study. First, our proposed model does not consider business expansion or different product/service features. Thus model development is a possible direction for future research in order to resonate better with actual empirical contexts. Second, the pricing strategy in our model is a rough and exogenous mechanism, but actual market price is an endogenous variable. So individual firm's pricing strategy needs to be further investigated and re-specified. Third, in our CAS-based simulation framework, evolution is driven by individual's mutation and learning behavior. In real markets, besides learning procedures, gaming behavior is increasingly ubiquitous. So from a simulation perspective, micro-

level individual interactions and gaming behaviors can be further explored and developed to reflect intelligent agent characteristics.

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