A Game-theory based Model for Analyzing E-marketplace Competition

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Abstract: The current e-marketplace provides many tools and benefits that bring sellers and buyers together, and promote trading within cyberspace. And due to certain unique features of e-commerce, the competition also takes on characteristics different from those found in traditional commerce. This paper analyses both the competition between sellers, and the stable state in e-marketplace through a proposed model that applies evolutionary game theory. The purpose is to better understand these relations and the current state within e-marketplace, as well as provide a tool for sellers to increase their profits. Here, the sellers are divided into four categories based on their scale (Large, Small) and sales strategy (Aggressive, Conservative). By developing Asymmetrical Competition Game Model in E-Marketplace (ACGME) in Nash Equilibrium, we analyze the composition of different sellers and how this proportion is affected by asymmetry among sellers. Finally, we conduct a simulation experiment to verify the effectiveness of our proposed model.

1 INTRODUCTION

e-Commerce is rapidly developing thanks to the advance in information technology and widespread use of Internet. The sales of the largest e-marketplace Alibaba reached $240 billion in 2013, and eBay also ran up to $83.33 billion during the same period. B2C e-commerce giant Amazon.com, understanding the potential of this industry, also started its e-marketplace service in 2000. E-marketplaces play an important role in the e-commerce, as it helps overcome geographical limitations, connect with new customers through search engine visibility and reduce costs. And most importantly, e-marketplace provided access to e-commerce for ordinary people and small shops. This feature tremendously accelerated the development of online shopping. As result, e-commerce has attracted increasing attention in the field of computing science and information technology. The relationships between three players in e-commerce: sellers, customers and e-marketplaces, have been a research hotpot.

The nature and structure of competition in e-marketplace is considerably different from the traditional marketplace. Traditionally, sellers usually competed in a single industry and competition is limited geographically. Nowadays, e-marketplace offers opportunities for all individuals who are interested in the ability to break these boundaries. More and more individual sellers entered the digital space, greatly increasing the competition. As such, it is necessary to analyze this new form of competition in e-marketplace in order to help the sellers' decision making process. For this purpose, we conduct this work to analyze the competition between sellers by applying evolutionary game theory. The sellers are divided into four categories based on their scale (Large, Small) and sales strategy (Aggressive, Conservative). By applying game theory and analysing asymmetry between sellers, we can model the competition in the e-marketplace using table 1. And using the Nash equilibrium of the proposed game model, we can obtain the composition for each type of seller and study the stable state of e-marketplace.

Table 1: Four competition models in the e-marketplace.

Large *vs.* Large	Large *vs.* Small
Small *vs.* Large	Small *vs.* Small

The rest of this paper is structured as follows. The next section references and discusses literature

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related to the focus of our study. Section 3 describes the asymmetry between different sellers and strategies they can adopt against competition. The stable state of e-marketplace is introduced in section 4, and an analysis of the result is presented in section 5. In section 6 we conduct a simulation to verify the effectiveness and performance of this model. Finally, section 7 concludes this paper with a summary, and explains the potential applications of this study.

2 LITERATURE

Evolutionary game theory (Maynard Smith, 1982) applied game theory to evolving populations of life forms in biology. Despite its original use, evolutionary game theory has become of increasing interest to other fields, and many researchers examined the applications of evolutionary game theory in economics. An extended analysis of 'Prisoners' Dilemma' by Daniel et al., (2005) identified four conditions of the game and observed that each condition has different evolutionary and informational requirement for cooperation. Witt (2008) studied the differences between major approaches in evolutionary economics, and analysed details of "evolutionary" aspects within the economy. Hodgson and Huang (2012) inquired both the differences and similarities between evolutionary game theory and evolutionary economics, and proposed potential for mutual emulation in these two fields. In recent years, the evolutionary game theory observed significant development, and is now applied to assist decision-making processes. Altman et al., (2008), Niyato and Hossain (2009) used evolutionary game approach in their wireless network selection study. Barari et al., (2012) proposed a decision framework that employed evolutionary game approach in the analysis of green supply chain contracts. Lee et al., (2010) proposed an evolutionary game theory based mechanism for adaptive and stable application in cloud computing.

The classic game models focus on symmetric competition between players. However, the players are usually different from each other in real scenarios, which is the case for our research on e-marketplaces. The sellers are heterogeneous, varying in size, location and service level etc. There are less literature that focus on asymmetric competition but the following studies provide insight towards our work. Fishman (2008) extended the analytical framework of evolutionary game theory to games that have two distinct types of players, where the type-specific payoff functions are nonlinear. That is, asymmetric games where the payoffs for interactions are influenced by strategies from both types of players. Liu et al., (2012) proposed a game model considering the asymmetric interaction and the selection pressure of resources. Combining evolutionary game theory with dynamic stability theory, they concluded that evolutionary results depend on the asymmetric relation between players, and on the cost-to-benefit ratio of conflict.

There are also studies on evolutionary game theory focusing on the economic market. Although their content does not directly relate to our research, it still provides context and ground for this study. Ba et al., (2000) investigated the risk of frauds in e-marketplace and identified different equilibrium in the market using an evolutionary game theory approach. Then the authors explored the best method to effectuate transactions within the market, and justified the necessity of trusted third parties for e-marketplaces. Zheng et al., (2014) provided us insight into the charging mechanism in e-marketplaces, as they studied this topic by adopting the Leontief's model and drew interesting conclusions that less sellers generate more profit for e-marketplace service providers. After studying previous literature, we base our research on the hawk-dove game and study the asymmetric between sellers in e-marketplace. By employing evolutionary game theory we study the competition between vendors in the e-marketplace environment and analyse the optimal profit of the e-marketplace service providers.

3 SETUP OF ASYMMETRIC COMPETITION GAME MODEL IN E-MARKETPLACE (ACGME)

The Hawk-Dove Game is a classic example of evolutionary game theory applied in animal behaviour. In this model, we have two animals (not necessarily birds) that are capable of choosing from two strategies when in conflict with each other. An animal can choose the "hawk" strategy and escalate conflict to a fight or the animal can choose the "dove" strategy and peacefully back down. Hawk type animals will always choose to fight, so if two hawks meet, there will always be a fight. Winners receive the benefit, while losers be charged with the cost of the fight. Dove type animals always choose to flee, and will never be involved in a fight. There is no cost to be a dove, there is only the possibility of receiving no payoff.

This research analyzes the competition between sellers in e-marketplace based on the hawk-dove game. First, the asymmetric relation between sellers is introduced and modelled. Then, the strategies of sellers are described. Lastly, the proposed evolutionary game model is formally introduced.

3.1 Asymmetrical Parameter between Sellers: *h*

Asymmetry between sellers is a natural occurrence within the e-marketplace competition. Although various criteria can be employed to evaluate this asymmetry, we choose probability of purchase as the initial criteria. For the traditional market, two models have been proposed for analyzing consumer purchase probability. "Marketing Effort Model" believes that the probability of purchase depends on the sellers' marketing effort, as well as quality of product, price and customer relationship etc. However, the e-marketplace has distinctive characteristics. For example, because the business between sellers and customers is not held in person, many prefer to pay more just to minimize risks. For example, in the Brazilian e-marketplace "MercadoLivre", the exact same product, a book sold by two separate vendors from Sao Paulo, there are 100 consumers who chose the higher priced seller (R$ 109.80) while only nine chose the seller with the lower price, R$ 69.90. The only apparent difference we found in this case is that the higher priced vendor has a better reputation.

A different model, "Attraction model" is considered more suitable for studying online consumers' purchase probability. "Attraction model" indicated that the probability is directly related to the attraction of a product from consumers' perspective. This model defined an "attraction" value to measure asymmetry between sellers. Given a finite set of sellers, $S = \{s_1, \ldots, s_n\}$, for each seller $s_i \in S$, an "attraction" value is calculated. We assume that competition can be defined by the vector of attraction:

$$\mathbf{a} = (\mathrm{a}(s_1), \mathrm{a}(s_2), \ldots, \mathrm{a}(s_n)) = (\mathrm{a}_1, \mathrm{a}_2, \ldots, \mathrm{a}_n) \quad (1)$$

That is, the consumer purchase probability h is fully defined by **a**. The attraction may be a function of the seller's investment in marketing, the price of the product, and the reputation of the seller, among other factors. If a purchase probability is assigned to each seller based only on the attraction vector, the consumer purchase probability for each seller can be calculated using the following equation:

$$h_{s_i} = \frac{\mathrm{a}(s_i)}{\sum_{j=1}^{n} \mathrm{a}(s_j)}, \quad \text{for } i = 1, 2, \ldots, n \quad (2)$$

In this paper, the competition is analysed at a macroscopic level. All sellers of an e-marketplace are divided into two categories, Large and Small. Using this assumption, h represents the purchase probability of large sellers, while $(1 - h)$ represents the small sellers.

We should note that, the role of large and small sellers is not unchangeable. They can be changed under specific conditions. For example, a large seller that loses the majority of its market share to a small competitor would result in an exchange in roles. Other external factors can also alter roles within a market, as sellers can obtain investments or business partnerships.

3.2 Strategies for Sellers

With basis on the hawk-dove game, we model the sellers in e-marketplace into two categories based on their business strategies {**Aggressive**, **Conservative**}, and all sellers can choose their strategy. A description of each strategy is listed below:

Aggressive: The sellers prefer to invest and stimulate sales, but risk losing money due to diminished returns as result of their investment.

The sellers who choose the aggressive strategy can choose to invest money on marketing, customer relationship, search engine optimization, etc. Although this strategy may increase sales volume, it can cost the sellers if the benefits do not correspond to the amount of investment.

Conservative: The sellers choose to not invest and receive no benefits as result of their lack of action.

The conservative sellers expect a normal profit. This strategy won't cost the seller, because they are not spending more on the business. But when in competition with aggressive sellers, they will always lose and receive no payoff.

Considering only these two strategies, we can expect three different competitive scenarios in the e-marketplace.

1) **Aggressive** *vs.* **Aggressive:** Both aggressive sellers choose to invest to increase sales volume. But in this scenario, one will win and the other will lose and see no return on the investment.
2) **Aggressive** *vs.* **Conservative:** In this case, the aggressive seller wins, as the investment increases its attractiveness to consumers.

Combined with a lack of competition from the conservative seller, the aggressive seller observes increased sales as result of added investment.

3) **Conservative** *vs.* **Conservative:** When two conservative sellers compete, the profit is divided equally among them.

4 ACGME AND STABLE STATE OF E-MARKETPLACE

A game can be described using three values {players, set of strategies for every player, payoff of every player}. In this paper, these values are {{large sellers, small sellers}, {aggressive, conservative}, {π_L, π_S}}, where π_L, π_S represent the profits for large and small sellers, respectively. Additionally, we define the cost of competing as ϕ.

In addition, we define a few competition rules here:

1) The consumers choose to buy a product from an advertised seller based on available information.
2) When different sellers advertise the same product, the probability of purchase is the same for all advertised sellers.
3) If no sellers advertise the product, the probability of purchase depends on *h*.

With the competition rules and all the parameters defined, we now introduce the payoff matrices for all the competition scenarios.

4.1 Large vs. Large and Small vs. Small

In this scenario, the competition between sellers is actually symmetrical. The payoff matrix is listed in table 2.

Because competition between sellers with the same strategy follows the same format, the scale of the sellers does not affect the result.

Table 2: Payoff matrix for symmetrical competition.

		Large sellers (Small)	
		Aggressive	Conservative
Large sellers (Small)	Aggressive	$\frac{V-\phi}{2},\frac{V-\phi}{2}$	V , 0
	Conservative	0 , V	$\frac{V}{2}$, $\frac{V}{2}$

When two sellers are both aggressive, the profit will be distributed evenly among players, that is $\frac{V-\phi}{2}$, $\frac{V-\phi}{2}$. The cost of competing is subtracted from the profit, and we obtain the result shown in the upper left cell. In the case an aggressive seller competes with a conservative one, following the rules in Section 3, the aggressive seller will receive all the profit. This is the result show in the upper right and lower-left cells. When two conservative sellers meet, because they don't involve themselves in a competition, the profit is divided among them, and no cost is taken from the profit either.

4.2 Large vs. Small

In this subsection, the competition between large and small players is analysed in more detail. When two different types of sellers compete, an asymmetrical relation occurs.

Table 3: Payoff matrix for asymmetrical competition.

		Samll sellers	
		Aggressive	Conservative
Large Sellers	Aggressive	$h(V-\phi),(1-h)(V-\phi)$	V , 0
	Conservative	0 , V	$hV,(1-h)V$

Here, we take into consideration the asymmetrical parameter defined as purchase probability h in the previous section. When a large and a small aggressive seller compete, the profit is be divided between sellers based on their asymmetric proportion, in addition to removing the competition cost, which means that the large player would receive hV, and the small $(1-h)V$. The results remain the same for when an aggressive seller competes with a conservative one. The lower-right cell represents the profit division between a large conservative seller and a small conservative seller. Again, we account for the asymmetrical parameter but there is no competition cost in this case. The payoff matrix is depicted in table 3.

4.3 An Overall Perspective

In order to simplify this analysis and our representation, we combined scale and strategy for sellers as one single category. The sellers in this case are equal, but the number of strategies for each seller has been expanded to four, which are {Large Aggressive, Large Conservative, Small Aggressive, Small Conservative}. This way, an asymmetric competition has been transformed into a symmetric one.

Table 4: An overall perspective of payoff matrix in ACGME.

		Player II			
		LA	LC	SA	SC
Player I	LA	*(V-ϕ)/2, (V-ϕ)/2*	*V,0*	*h(V-ϕ), (1-h)(V-ϕ)*	*V,0*
	LC	*0,V*	*V/2, V/2*	*0,V*	*hV, (1-h)V*
	SA	*(1-h)(V-ϕ), h(V-ϕ)*	*V,0*	*(V-ϕ)/2, (V-ϕ)/2*	*V,0*
	SC	*0,V*	*(1-h)V, hV*	*0,V*	*V/2,V/2*

***Note: L = large seller, S= small seller; A = aggressive seller and C = conservative seller. So SA means the small seller with aggressive strategy.**

Table 4 illustrate the payoff matrix of two competing players from an overall perspective. This matrix lists all competition scenarios in the e-marketplace for our proposed categories. Rows represent the first seller and columns represent the second. All elements in matrix are two-tuples where the first value is player I's payoff, and the second value is player II's payoff.

Once we defined all possible types of competition in the marketplace for our proposed categories, we proceed to calculate the equilibrium of this game in the following section.

4.4 Mixed Evolutionary Stable Strategy

As show in the previous section, we have now obtained the payoff function for all types of sellers. Next, we study the Evolutionary Stable Strategy (ESS) for our proposed game model. An ESS is an equilibrium refinement of the Nash equilibrium. It is a Nash equilibrium that is evolutionarily stable, once it is reached in a population; natural selection prevents alternative strategies from appearing in the system. Thus, the evolutionary stable state of our proposed game provides insight into the stable state and competition dynamics within the e-marketplace in the real world.

Defining $\{x_{LA}, x_{LC}, x_{SA}, x_{SC}\}$ as the proportions of every type vendor in e-marketplace, we can derive the profit for all type of sellers based on the payoff matrix.

$$\begin{aligned}
V_{LA} &= x_{LA} \times \frac{V-\phi}{2} + x_{LC} \times V + x_{SA} \times h(V-\phi) + x_{SC} \times V \\
V_{LC} &= x_{LA} \times 0 + x_{LC} \times \frac{hV}{2} + x_{SA} \times 0 + x_{SC} \times \frac{(1-h)V}{2} \\
V_{SA} &= x_{LA} \times (1-h)(V-\phi) + x_{LC} \times V + x_{SA} \times \frac{V-\phi}{2} + x_{SC} V \\
V_{SC} &= x_{LA} \times 0 + x_{LC} \times \frac{(1-h)V}{2} + x_{SA} \times 0 + x_{SC} \times \frac{hV}{2}
\end{aligned} \tag{3}$$

According to evolutionary game theory, the sellers in e-marketplace reach stable state when profits for every type of vendor are equal. As result, we obtain the following equations:

$$\begin{aligned}
V_{LA} &= V_{LC} \\
V_{SA} &= V_{SC} \\
V_{SA} &= V_{WA} \\
x_{LA} + x_{LC} &+ x_{SA} + x_{SC} = 1
\end{aligned} \tag{4}$$

Solving the above equations (4), we obtain the proportion of all four types of sellers in an e-marketplace at its stable state.

$$x_{LA} = x_{SA} = \frac{\frac{3}{2}V - hV}{\phi + 2V + 2h\phi - 4hV} \tag{5}$$

$$x_{LC} = x_{SC} = \frac{(\phi - V)(h + \frac{1}{2})}{\phi + 2V + 2h\phi - 4hV} \tag{6}$$

(5) and (6) represent the proportion for different types of sellers in an e-marketplace when it achieves the stable state.

Note that, there is an important condition when we study the evolutionary game: the cost of competition must be greater than the profit (V $<\phi$). If this condition is not fulfilled, then the game only has a pure strategy Nash equilibrium, the "aggressive" strategy. In this situation, all players will act as "aggressive" sellers because this strategy definitively yields more profit than the "conservative" strategy. When V $<\phi$, "aggressive" sellers are presented with the risk of loss, then part of sellers choose the "conservative" strategy, while others risk for the opportunity to win.

5 ANALYSIS OF STABLE STATE IN E-MARKETPLACE

From the results obtained in section 4, we could find that the stable state of e-marketplace is dependent on values V, ϕ, and asymmetrical parameter h. In this section we analyse the correlations between equilibrium and such parameters.

5.1 ESS with Cost ϕ and Profit V

Since both ϕ and V are characteristic to the e-marketplace and are similar, we define $k = \phi/V$ and study the correlation between k and final stable state.

Based on equations (5) and (6), we obtain:

$$x_{SA} + x_{WA} = \frac{1 - 2h + hk + \frac{1}{2}k}{k + 2 + 2hk - 4h} \quad (7)$$

Setting *h* as a series of constants, we generate figure 1. From the figure, we observe that the growth of aggressive sellers is inversely proportional to *k*. This means that when the cost is similar in value to the profit, then most sellers choose the aggressive strategy as they expect to receive profit at little risk. But when the cost is far more than profit, then few people takes the risk of a loss.

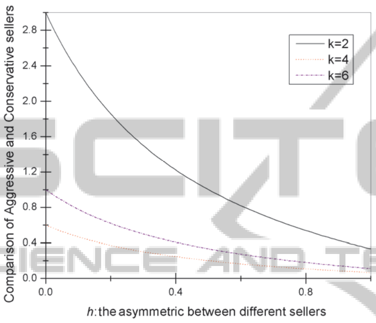

Figure 1: The correlation between aggressive strategists / conservative strategists and k = C/V.

Also from figure 1, we observe that the growth of aggressive sellers is proportional to asymmetrical parameter *h*. When the difference between types of vendors is small, the probability of wining is also not significantly different, and then most people shift towards competition.

5.2 ESS with Asymmetrical Parameter

The asymmetrical parameter is another important factor that can affect the final stable state of e-marketplace. In this paragraph, we set *k* as a constant in order to study the relationship between stable state and asymmetrical parameter *h*.

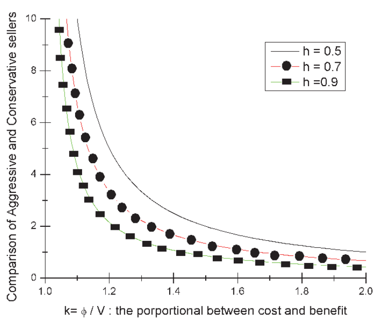

Figure 2: The correlation between aggressive sellers / conservative sellers and asymmetrical parameter *h*.

With equation (3), we find the proportion of aggressive sellers increases by decreasing the asymmetrical parameter *h*, which is shown in figure 2. This means that small sellers of e-marketplace perceive a big gap between them and the large sellers, which results in their adoption of the aggressive strategy.

6 A SIMULATION CASE STUDY

This section analyses the effectiveness of the proposed model through a simulation study. In the field of e-commerce, it is difficult to obtain real data from an e-marketplace because it is proprietary. Thus, we create a simulation experiment to test our model.

In our model, the stable state of e-marketplace is dependent on $k = \phi/V$ (defined in section 5), and the asymmetrical parameter *h*. So we set different values to these two factors and verify the final result.

For asymmetric parameter, we set *h* as three different levels:

a. High asymmetry: $h = 0.95$.
b. Medium asymmetry: $h = 0.75$.
c. Low asymmetry: $h = 0.55$.

This classification allows us to observe a complete picture of the competition in different asymmetrical scenarios. When $h = 0.95$, the asymmetry between sellers is high, which means large sellers dominate the marketplace. Then when *h* is closer to 0.5, the sellers are more comparable in number, which in turn means the marketplace has a highly competitive mechanism.

Additionally, we categorized the e-marketplace into two classes.

i. High profit. $V/\phi = 5/6$.
ii. High risk. $V/\phi = 1/2$.

In a high profit marketplace, an aggressive seller can compete at a reasonable cost. But in a high risk market, the competition cost is much higher than the profit, which presents a big risk for sellers that chose the "aggressive" strategy.

In addition to using these values in our simulation experiments, to calculate the proportion of different sellers in a stable state e-marketplace, we introduce a new element. To be more precise, 90% confidence interval is used to capture the interval for the real expected value and the simulation-generated value. Using the formula proposed in Law and Kelton (1991) and Choi et al., (2004), the 90% confidence interval is calculated using equation (8):

$$90\% - CI = ER \pm 1.645\sqrt{VR} \quad (8)$$

where ER and VR denote the expected result and the variance of result respectively. CIEP is defined to represent the bounds of the deviation of the real expected result from the simulation in the 90% confidence interval.

Table 5: The proportion of aggressive sellers in a high profit e-marketplace according to different asymmetric levels.

	h	ER	CIEP	SD
High	0.95	65.48%	1.65%	12.21%
Medium	0.75	75%	1.59%	12.23%
Low	0.55	81.90%	1.60%	12.23%

Table 5 shows the stable state of a high profit e-marketplace at different asymmetric levels. We find that the proportion of aggressive sellers decreases with a higher asymmetric level. The reason is that when the asymmetric level is high, the small sellers choose the conservative strategy to avoid risk of competition, and thus the expected result in a high asymmetric e-marketplace (h = 0.95) is 65.48%. Alternatively, market competition becomes larger as the opportunity to win the competition is greater, so the expected result is 81.90% when h = 0.55.

Table 6: The proportion of aggressive sellers in a high risk e-marketplace according to different asymmetric level.

	h	ER	CIEP	SD
High	0.95	27.50%	±1.44%	9.76%
Medium	0.75	37.50%	±1.42%	9.76%
Low	0.55	47.50%	±1.49%	9.77%

Table 6 illustrates the high-risk scenario for an e-marketplace. Under these conditions, most sellers tend to choose the conservative strategy. Where the asymmetric level between sellers is high, the aggressive sellers compose only 27.50% of the marketplace sellers. Even when the conditions are more competitive (h = 0.55), this value only reaches 47.50%, compared to 81.90% in the high profit simulation.

With the results from tables 5 and 6, we obtain the following observations:

1) The proportion of aggressive sellers decrease as the asymmetry between sellers increase. From the perspective of a seller, the opportunity to win in a competition is greater when the difference between sellers is smaller. Thus, sellers tend to choose the aggressive strategy under these conditions as they expect a positive outcome.
2) The decrease in aggressive sellers is significant when the marketplace is high-risk. Although the k value is only changed from 5/6 to 1/2, the proportion of aggressive sellers decreases by almost 50%. This demonstrates that sellers are very sensitive to this factor.
   This observation is important to e-marketplace administrators as it provides insight when deciding the fees / cost mechanism. When the service fee is high (high risk scenario), the number of aggressive sellers decreases. Thus, it is important to study the optimal cost structure in an e-marketplace to maximize profit for market hosts.
3) According to tables 5 and 6, the e-marketplace is more stable when it is in a high-risk scenario. But this is majorly due to the adoption of a conservative strategy for all sellers.

7 CONCLUSION

Following the rise of e-commerce, the emergence of e-marketplaces such as Alibaba, eBay and MercadoLivre creates new platforms for individuals to conduct business and effect transactions. Given the rapid growth of this market, it becomes important to study the relationships between all participants in an e-marketplace, in order to maximize profitability and efficiency, and understand potential advances. This work studied the e-marketplace as a population, and applied the evolutionary game theory to analyse the stable state of a marketplace.

Learning from the classic "Hawk-Dove" game model, we divided sellers into two categories, {Aggressive, Conservative}. Additionally, the sellers were classified by their scale, {Large, Small}. Based on this setup, we proposed an Asymmetrical Competition Game Model in E-marketplace (ACGME) to study competition in the e-marketplace.

The contributions of this study include:

1) Applied the evolutionary game theory to the research of e-commerce, studied the competition between different types of sellers, and demonstrated the effectiveness of applying evolutionary game theory in the area of e-commerce.
2) Classified the sellers based on their scale {Large, Small}, which is a more realistic approach to mimic a real world e-marketplace
3) Conducted simulation experiments to examine the performance and effectiveness of our

proposed model and obtained satisfactory results.

Although some assumptions were included in our research, they were within reasonable range and would not significantly impact the effectiveness our model. There are also some limitations to this research; we will continue this study to improve ACGME. As we move our focus to studying e-marketplace charging mechanisms, we use this research as basis and groundwork.

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