Internet Research

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Received 8 July 2016
Revised 11 March 2017
Accepted 16 April 2017

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Abstract
Purpose – Massively multiplayer online role-playing games (MMORPGs) create quasi-real social systems in which players can interact with one another, and quasi-real economic systems where players can consume and trade in-game items with virtual currency. The in-game currency price, an important indicator of a virtual economy, is highly contingent on players' behavioral interaction in MMORPGs. The purpose of this paper is to adopt a network perspective to examine how topological characteristics of social networks in an MMORPG, namely, network externalities, density, and closure, would exert impacts on the in-game currency price.
Design/methodology/approach – Players' behavioral data were collected from a popular MMORPG in China on a weekly basis for 52 weeks. With a time series analytical approach, the empirical model for the price function of in-game currency was estimated with vector autoregression.
Findings – The results show that the number of core avatars and network density are positively associated with in-game currency price, while network closure has a negative effect on in-game currency price. However, in-game currency price is found to have no significant relationship with the trade volume of the currency.
Originality/value – This study fills in an important research gap by investigating factors influencing the in-game currency price of MMORPGs from a network perspective, which contributes to the existing literature of network effects and advances our understanding about how players' interaction will influence the dynamics of a virtual economy. The findings could offer useful insights for online game companies to better understand their players' social interaction and consumption behavior.
Keywords Network externalities, Online games, Network density, Network closure, Price function
Paper type Research paper

Introduction
Massively multiplayer online role-playing games (MMORPGs) have become an important component of electronic business. The total generated revenue of MMORPGs around the world was about $19 billion in 2011 and is expected to reach $35 billion by 2017 (Statista, 2016). As the profitability of MMORPGs is deeply rooted in voluminous players' sustainable investment and participation in MMORPGs, it is of great significance to understand how players would attach value in playing MMORPGs and what kind of factors would influence their value attachment in MMORPGs.

An MMORPG is a virtual world with its self-contained social and economic system. The production and consumption behaviors occurring in a virtual economy resemble real-world economic behaviors (Castronova, 2001, 2008; Castronova *et al.*, 2009; Koster *et al.*, 1999; Lehdonvirta, 2005). In this sense, the real-world economic concepts, theories, and metrics could be

Internet Research
Vol. 27 No. 4, 2017
pp. 924-941
© Emerald Publishing Limited
1066-2243
DOI 10.1108/IntR-07-2016-0201

applied to examine a virtual economy. Particularly, in-game currencies in MMORPGs have similar functions as real-world currencies in offline economic systems, and their demand is determined by what we can exchange with it. In-game currencies are usually used for purchasing in-game items, which can benefit players in their participation in various in-game activities. Therefore, it is important to understand the price that players are willing to pay for in-game currencies, which represents the value they attach to playing the MMORPG.

Furthermore, players in MMORPGs are not independent from one another. Instead, each player can influence or be influenced by other players via multiple channels in MMORPGs. MMORPGs offer various social encounters for millions of players to meet, interact, and play together in a synthetic environment through text and voice chats (Cole and Griffiths, 2007; Ducheneaut *et al.*, 2007). An MMORPG holds communication networks which foster real-world-like social interactions among players. It is crucial to understand how such interactions via in-game networks could affect the value of the virtual world to players. Prior research has examined the effects of individuals' interaction on their consumption and financial behaviors in real-life contexts (e.g. Duflo and Saez, 2002; Hong *et al.*, 2004; Webster and Morrison, 2004). However, few studies have investigated the dynamics of a virtual economy from a network perspective.

To fill in this research gap, this study examines how in-game social networks between players of MMORPGs will influence the value of in-game currencies to players. First, as the host of social networks, an MMORPG with a greater number of active participants can provide a more vibrant gaming world and richer opportunities for social interactions, and thus should be more attractive to players. It follows that players in MMORPGs should be under the influence of direct network externalities (Economides, 1996; Katz and Srapiro, 1985). Second, topological characteristics of social networks in MMORPGs, such as network density and closure, may affect the value that individuals obtain from playing MMORPGs. Network density is important in building trust and support and in generating satisfaction and enjoyment among members of a social network (Coleman, 1990; Flap and Völker, 2001; Knoke, 2009). Social network closure affects the formation of strong or weak social ties among network members, and it affects members' opportunities for information and resource exchange (Burt, 1992; Gargiulo and Benassi, 2000).

Taken together, this study aims to test the effects of network externalities, density, and closure on the price of in-game currencies, which reflects the value of playing an MMORPG to players. With longitudinal behavioral data collected from a popular MMORPG in China, the study adopts time series analysis to estimate the price function of the in-game currency in the game and reveal the network effects on the currency price in a gaming world. This study contributes to the existing literature of network effects in MMORPGs and sheds light on the value people attach to social interactions and communication in a virtual economy.

Literature review

The theory of network externalities

Social networks share a fundamental economic property: the value of connecting to a network depends on the number of other people already connected to it. Other things being equal, being connected to a larger network is more beneficial than being connected to a smaller one (Shapiro and Varian, 1999). That is, network externalities exist when the value or utility of using a product or service to a consumer increases with the total number of users of that product or service (Farrell and Saloner, 1985; Katz and Srapiro, 1985; Economides, 1996; Shy, 2001).

Network externalities are also considered the demand-side economies of scale, which suggests that there be a positive relationship between consumption quantity and value. As the number of users grows, the product becomes more valuable and the expected product demand increases (Shapiro and Varian, 1999). Economides (1996) pointed out that the demand curve shape for a network product depends on two counterbalancing force: the law of demand and network externalities. The law of demand explains the reversed price-quantity relationship, thus making the demand curve slope downward. Network externalities result in a positive influence of the expected user base on consumers' willingness to pay, which shifts the demand curve upward. This theoretical prediction may be generalized to virtual economic systems in MMORPGs.

A significant body of research provides empirical evidence on the effect of network externalities on various network products or services. Some studies have traced the relationship of network products' value or price with its installed user base but without specifying the demand or price function explicitly (Gandal *et al.*, 2000; Goolsbee and Klenow, 2002). Other empirical studies estimated demand functions for network products but only focused on indirect network externalities. These studies revealed the connections between the demand of one product and its complementary product supply (Clements and Ohashi, 2005; Dranove and Gandal, 2003; Nair *et al.*, 2004). Nonetheless, few studies have explicitly examined the demand or price functions for products under direct network externalities, especially in the context of MMORPGs.

Castronova (2003) argued that MMORPGs host social networks and exhibit network externalities, and that each existing game player benefits from the addition of new players. In a study of World of Warcraft, Levine (2007) found that players tend to prefer large-scale titles when choosing an MMORPG to play. Meagher and Teo (2005) accounted for network externalities when modeling the monopolistic two-part pricing tariff in MMORPGs. Xu and Fu (2010) found that pay-to-play MMORPGs with more enlisted players tend to charge a higher subscription fee, suggesting the presence of network externalities. Wei and Lu (2014) revealed the positive effects of network externalities on individuals' continuous intention to play mobile social games. The aforementioned studies focused on the effect of network externalities on online game subscription or play but did not explicitly examine the direct network effect on in-game economic systems.

Topological characteristics of social networks in MMORPGs

When playing MMORPGs, players develop their own social connections by participating in real-world-like social exchanges with others (Shen *et al.*, 2014). The social capital theory denotes that topological characteristics underlying social networks will influence network values and individuals' actions within the community (Coleman, 1988). Thus, we argue that network structures developed in MMORPGs will influence players' network value and their behaviors.

Previous economic literature has suggested that structural characteristics of social networks will exert impacts on individuals' consumption behaviors in the real world (Webster and Morrison, 2004; Arabie and Wind, 1994). Such characteristics of social networks could also influence real-world financial behaviors, such as stock market participation (Hong *et al.*, 2004), retirement savings decisions (Duflo and Saez, 2002), and bank deposit decisions (Kelly and Gráda, 2000). Nonetheless, the economic and financial influences of topological characteristics in MMORPGs have not been fully examined. To fill in this gap, this study reviewed and examined the role played by two fundamental topological characteristics (i.e. density and closure) in determining the value of an MMORPG to players, which would in turn affect players' in-game consumption behavior.

Network density refers to the incidence of a direct relationship among all possible pairs in a network, which represents the degree of interconnectedness among members within a social network (Friedkin, 1982). Network density is demonstrated to have a significant influence on network value. Individuals tend to know one another and have intense social interactions in high-density networks (Haythornthwaite and Wellman, 1998). Network density could influence members' mutual trust and support within a network (Coleman, 1990). Previous research has found that high-density networks will build trust (Knoke, 2009), increase resource accessibility (Cadima *et al.*, 2012), and cultivate mutual collaboration (Ingold, 2017). Moreover, empirical evidence suggests that individuals from a high-density network have greater satisfaction (Flap and Völker, 2001), enjoyment (Piselli, 2007), and well-being (Chua and Wellman, 2015) than those from a low-density network. Therefore, a high-density network brings more network values to members in the network.

Network closure, another topological characteristic that has long received scholarly attention, represents members' tendency to cluster together within a network (Burt, 1992; Opsahl and Panzarasa, 2009). In social settings, network closure refers to the condition in which a person introduces two new contacts to each other (Opsahl, 2013). It occurs when a person befriends their friends' other friends. Being part of such a triangle could promote the formation of strong social ties (Simmel, 1950). According to Burt's (1992, 2005) studies on structure hole, as individuals with strong ties are cohesive with social control, they are more likely to move in the same social circles. Consequently, their information and knowledge tend to overlap with one another. Conversely, individuals with bridge connections to other groups could reach high information volume as they reach more people indirectly (Burt, 1992). Gargiulo and Benassi (2000) claimed that the benefits of social capital are derived from information diversity and brokerage opportunities created by the lack of connection among separate clusters in a social network. A recent study of social networks in MMORPGs indicated that network closure can shield the players from various views and resources (Shen *et al.*, 2014). Therefore, members embedded in a closed structure are less likely to obtain novel information and extract value than those in an open structure.

Some studies have been conducted to examine the characteristics of social network structure in MMORPGs, which focused on the effects of network structures on players' satisfaction and intention to play MMORPGs (Hsiao and Chiou, 2012; Jia *et al.*, 2015). Nevertheless, few studies have investigated the relationship between topological characteristics and in-game economic behaviors. In this study, we examine the roles of network density and closure in the change of in-game currency price changes in MMORPGs, which offers new perspective to understand a virtual economic system.

Real-money trading (RMT) and in-game currency

Virtual economies in MMORPGs interact with real-life economies (Knowles and Castronova, 2016). RMT refers to the exchange of in-game assets, such as currencies, items, and avatars, with real-world money, which could generate an enormous amount of economic value in real terms (Lehdonvirta, 2005; Ondrejka, 2004; Huhh, 2008). RMT can be observed in most MMORPGs as a common type of economic behavior for players and a normal part of game play (Castronova, 2006). In particular, RMT is an integral part of free-to-play MMORPGs. In the free-to-play business model, accessing the virtual game world is free, and players may then purchase additional virtual goods and services from game companies, using real-world or virtual currencies (Knowles and Castronova, 2016). Prior research has found positive effects of RMT in attracting players and generating benefits for game companies (Huhh, 2008), as well as negative consequences of RMT on game experiences, such as encouraging misuse of resources in a game and interfering with in-game communication systems (Castronova, 2006). Personal characteristics that can influence players' intentions toward RMT in MMORPGs have also been identified, such as players' social status, performance expectancy, perceived enjoyment, and uncertainty about sellers' behaviors (Constantiou *et al.*, 2012; Guo and Barnes, 2007).

Especially, previous studies have examined the factors influencing the value of in-game assets in RMT. Castronova (2004) used hedonic pricing model to identify and analyze the effects of various avatar attributes on the price of avatars, including avatars' experience level, gender, race, and class. Wang *et al.* (2013) examined the monetary value of avatars' productivity and found that it was positively associated with the number of active users, which could be explained by the law of demand. However, their study did not control the effect of network externalities on the value of avatars. Moreover, Wang *et al.* (2013) found that there is a negative connection between avatars' value and players' time spent on social networking, which is moderated by the in-game social hierarchy structure (i.e. the relative number of lower-level avatars to the higher-level avatars). However, their study did not examine the effects of other topological characteristics of social networks other than the social hierarchy.

Taken together, empirical research on the factors influencing the price of in-game currency in RMT is still lacking. To the best of our knowledge, the effects of network externalities and topological characteristics of social networks (e.g. network density and closure) on the price of in-game currencies have not been examined in MMORPGs.

Research hypotheses

According to the theory of network externalities (Farrell and Saloner, 1985; Katz and Srapiro, 1985; Economides, 1996; Shy, 2001), the value of playing an MMORPG increases with the total number of players involved in the game. In particular, free-to-play MMORPGs do not require a monthly subscription fee and allow players to use real-world money to purchase in-game currencies or items, which are crucial for players' involvement in various in-game activities. In this sense, in-game currency price in a free MMORPG represents the value of playing the game, which should be subject to direct network externalities. A larger number of players in a game network lead to a higher value or utility players can gain from participating in the game, and this higher value can result in higher willingness to pay for in-game currency. In market equilibrium, in-game currency price represents players' willingness to pay and thus captures the value or utility of playing an MMORPG. Therefore, this study postulates the following hypothesis:

H1. Other factors being fixed, in-game currency price is positively associated with the number of active players in an MMORPG.

As reviewed above, topological characteristics of social networks will affect the network value. From a network density perspective, a high-density network is positively associated with network value (Coleman, 1988; Putnam, 1995). Following this logic, the density of social networks developed in MMORPGs can affect the network value to players. Specifically, players who develop high-density networks in MMORPGs are likely to have more communication with one another, thus fostering mutual trust and instrumental benefits. Therefore, players tend to develop positive attitude and satisfaction with their experience in a game, and thus the value of playing MMORPGs to them increases. Moreover, empirical research on social interactions in MMORPGs has demonstrated that in-game social interactions are an important element in promoting players' enjoyment (Cole and Griffiths, 2007; Jia *et al.*, 2015; Lin *et al.*, 2015) and continuance intention to play (Chang *et al.*, 2014). Another study on MMORPGs reported a positive relationship between players' in-game social interactions and their intention to purchase virtual products (Jin *et al.*, 2017). Therefore, we infer that players are willing to pay more in MMORPGs when they develop a high-density network in the game. Thus, the second research hypothesis is as follows:

H2. Other factors being fixed, in-game currency price is positively associated with the density of players' interaction network in an MMORPG.

From a network closure perspective, individuals from a closed network are in a disadvantageous position to extract values (Burt, 1992; Gargiulo and Benassi, 2000). Network closure occurs when a person links to already connected individuals (Opsahl and Panzarasa, 2009). As connected individuals tend to share similar views and resources, network closure insulates one from different opinions (Shen *et al.*, 2014). In MMORPGs, players who develop a closed network structure tend to communicate with close contacts within the existing network. Thus, they have less access to novel information and tend to form great social control with each other. Nevertheless, players in an open network have more bridge connections to others players, thus giving them advantageous access to information and resources important in playing MMORPGs. Moreover, the theory of structural hole argues that the benefits of social capital decrease as the network places more constraints on relationships within it (Burt, 1992). Empirical studies have found that network closure hinders individuals' performance and organizational coordination (Gargiulo and Benassi, 2000; Shen *et al.*, 2014). An open network with structural holes tends to increase individuals' satisfaction with their jobs (Flap and Völker, 2001). Thus, we expect that being embedded in a closed interaction network in MMORPGs can have side effects on players' satisfaction with game play, which ultimately reduces their willingness to pay. Therefore, we propose the following hypothesis:

H3. Other factors being fixed, in-game currency price is negatively associated with the closure extent of players' interaction network in an MMORPG.

Furthermore, this study accounts for the relation between price and quantity of in-game currency. According to the law of demand and supply, a downward-sloping demand curve and an upward-sloping supply curve should be obtained given the assumption of perfect information and competition (Varian *et al.*, 1996). That is, a higher-priced product or service leads to a larger volume of the product or service provided by suppliers and available in the market. This larger volume then results in a lower level of willingness to pay by consumers. In a free market, the price will reach its equilibrium level under the forces of demand and supply. For a network product in the real world, the demand curve shape is dependent on both the law of demand and network externalities. When controlling for the positive network effect of the user base size on consumers' willingness to pay, the relationship between price and quantity should be negative as predicted by the law of demand. However, limited research has applied the law of demand and supply to examine the relation between equilibrium price and trade volume of in-game currencies in a virtual economy in MMORPGs. Following the price-quantity relationship in real-world economy, we postulate the following hypothesis:

H4. Other factors being fixed, in-game currency price is negatively associated with the trade volume of the currency in an earlier time period.

Research design

To test the research hypotheses proposed in the study, the study employed behavioral data collected from a specific server of a popular MMORPG in China for a 52-week time period. We developed an empirical model to account for the price of in-game currency. The model was estimated with vector autoregression (VAR), an econometric model that has been widely used in empirical studies in analyzing time series data (Qin and Peng, 2016; Ripberger, 2011).

MMORPG under study

China is one of the largest and fastest growing online gaming market in the world, having over 368 million online gamers (Bischoff, 2014) and obtaining around $5 billion in the first quarter of 2015 (China Internet Watch, 2015). The research context of this study is a popular MMORPG in China released in 2010, which is a real-time fantasy MMORPG based on a classic ancient Chinese mythology. In this MMORPG, the in-game currency (i.e. silver) is used in the trade of in-game items, such as magic weapons, armors, and gems from other players or the game company. Players can obtain and accumulate silver through a variety of in-game activities, such as completing tasks, killing monsters, producing and selling in-game items. Furthermore, players can exchange silver with real-world money, as RMT is a legitimate and common part of this game. Players can exchange real-world money with virtual hard currency (i.e. ingot) at a fixed rate in the game company's online system and then exchange the hard currency with in-game currency (i.e. silver) or items inside the game world. The trade of ingots and silver occurs among players themselves and the rate is usually floating, depending on the demand and supply of silver in a specific time window. In this sense, the MMORPG provides an ideal testbed to test the research hypotheses proposed in the study.

Additionally, the MMORPG under study provides a variety of in-game activities in the game world, which require multiple players with different sets of skills to collaborate or compete. The MMORPG offers profuse opportunities for players with interact with one another. It allows players to communicate with their peer players via text and voice during the game. Players can send text messages via chat windows or in-game mailboxes, or send voice messages via built-in or external voice software. Both textual and verbal communication behavior among players are recorded in the servers of the MMORPG.

Data and measurement

The MMORPG was operated in dozens of servers and has attracted millions of players in China. The game company provided us with a complete data record from one of the servers. With preliminary data cleaning, the data set included the attributes and behavior of about 60,000 players in 52 weeks from July 2013 to June 2014.

For each week, we tracked and collected data on the price and sale quantity of its in-game currency (i.e. silver), the number of active players, and the availability of promotional activities. The game company also provided us with the timestamp and players' IDs of the communication behavior over time, which allows us to construct a communication network among players at a specific time window (i.e. week in our study). In the network, the nodes are players and the links between nodes are the communication between two players. If a player communicates with another player in a specific week, there will be a link between them. The communication networks were then employed to extract time-variant topological characteristics (i.e. density, and closure) described in the measurement section. The construction of communication networks over time and the estimation of network characteristics were all implemented with NetworkX package in Python (https://networkx.github.io/).

Silver price. In the MMORPG under study, the in-game currency price (i.e. silver) refers to how much 1,000 silver is worth in Chinese yuan. As mentioned earlier, players can exchange silver with virtual hard currency (i.e. ingots) at a floating rate with other players in the game and then ingots can be exchanged with Chinese yuan at a fixed rate in the game company's online system. Accordingly, we collected daily exchange rate between silver and ingots in the game. Then we calculated the daily exchange rate between silver and Chinese yuan (i.e. silver price) based on the fixed rate between ingots and Chinese yuan. The average silver price for each week T is calculated and denoted as $Price_T$.

Silver quantity. The amount of in-game silver sales in a server in each week T, which is measured in millions, is collected and used as a measure for in-game currency quantity. It is denoted as $Quantity_T$.

Number of active players. In the study, the number of actively players is measured by the number of core avatars in the MMORPG under study. As the interaction, collaboration, and trade among MMORPG players occur via avatars in the virtual environment, the existence and the amount of core avatars in an MMORPG could substantially influence other players' gaming experience and their willingness to invest in the MMORPGs. Therefore, we argue that the number of core avatars in a specific time window, instead of the number of all online players in a specific time window, is a valid measurement of network externalities in the study. Core avatars refer to the avatars who are sophisticated in the MMORPG, which is operationalized as a composite score of four behavioral attributes, namely, players' in-game grade, mastery degree, practice degree, and VIP level. As these four attributes demonstrate high internal consistency (Cronbach's $\alpha = 0.67$), principal component analysis with varimax rotation is employed to reduce the four attributes to a composite measure of avatars' sophistication in the MMORPG. The greater composite score an avatar has, the more sophisticated the avatar is. Based on avatars' sophistication scores, the top 10 percent avatars in each week are classified as core avatars, and the remaining 90 percent are classified as general avatars. Then, we calculate the number of core avatars in each week, which is denoted as $Number\_Core_T$.

Density of communication networks. The study focuses on the effects of two topological characteristics on the fluctuation of in-game currency price: network density and network closure. Network density of players' communication network in the MMORPG represents the communication among players that is actually realized (Wasserman and Faust, 1994) and can reflect the extent of information exchange among players. The network density of the communication network in each week, denoted as $Density_T$, is defined as a ratio of the number of existing edges to the number of possible edges in a communication network at time T. Specifically, it is calculated as follows:

$$Density_T = \frac{2E_T}{N_T \times (N_T - 1)}$$

where E_T is the number of existing communication ties among all players at week T and N_T the number of all players at week T.

Closure of communication networks. Network closure of a communication network refers to the degree to which players' communication partners are also partners with each other in the communication network. It is measured by global clustering coefficient, which was originally proposed by Watts and Strogatz (1998), and has become a popular measure of network closure in social networks. The variable is denoted as $Closure_T$. Specifically, it is calculated as follows:

$$Closure_T = \frac{\sum \tau_{\Delta,T}}{\sum \tau_T}$$

where $\sum \tau_T$ is the total number of triplets in a communication network at week T and $\sum \tau_{\Delta,T}$ the subset of these closed triplets in the network at week T.

Promotion. An MMORPG may host special events, promotions, or discounts of in-game items for a certain period of time that may affect in-game currency price and players' willingness to participate in the game activities. Information on whether or not the game offers any promotions or discounts during week T is collected from the game's official website. The dummy variable $Promotion_T$ is coded as 1 if promotional activities are present in in-game items in week T; otherwise, it is coded as 0.

Holiday. This study also accounts for the possible effects of holidays on silver price and quantity. We collect information on whether a week T is a public or school holiday. The dummy variable $Holiday_T$ is coded as 1 if the Tth week is under summer vacation, winter vacation, or public holidays; otherwise, it is coded as 0.

Merging of servers. This study also control for the possible effects brought about by the merging of servers. In the MMORPG under study, players in one server can only interact, play and trade with other players in the same server. In this sense, each server could be considered as an independent virtual economy. However, a server may be merged with other servers by the game company, which could lead to the fluctuation of silver demand and supply in the merged server. Accordingly, a dummy variable $MergeServer_T$ was included in our model to control for the variation of silver price and quantity caused by the merging of servers. $MergeServer_T$ is coded as 1 if the server under study was merged with other servers in week T and 0 otherwise.

The descriptive statistics of the key variables are reported in Table I and the variations in the variables over the 52-week study are shown in Figure 1. The price of silver in the server decreased in the first few weeks and then stayed relatively steady over time. There was some fluctuation in the exchange volume of silver, which could be due to the launch of promotional activities, the merge of servers or holidays. Overall the number of core avatars reduced, but it increased when the server under study merged with other servers. There was an increasing trend in network density, suggesting an increase in the extent of information exchange among players over time. The network closure did not vary a lot during the period of study.

Empirical model for the price function of the in-game currency

Considering the law of demand and network effects, the price function (i.e. inverse demand function) of in-game currencies in the MMORPG is proposed as follows:

$$Price = f^{-1}(Quantity, Number\_Core, Density, Closure, Promotion, Holiday, MergeServer). \quad (1)$$

In the above model, the price and the quantity of the in-game currency are endogenous variables in the demand and supply system. The number of core avatars, network density, and network closure are considered exogenous variables in the model.

Table I. Descriptive statistics of the variables

Variables	*M*	SD	Min.	Max.
$Price_T$	0.013	0.003	0.009	0.020
$Quantity_T$	2,478.5	686.1	1,347.0	4,276.3
$Number\_Core_T$	635.2	197.8	394.9	1,188.0
$Density_T$	0.002	0.001	0.001	0.004
$Closure_T$	0.124	0.008	0.100	0.138
$Promotion_T$	na	na	0.000	1.000
$Holiday_T$	na	na	0.000	1.000
$MergeServer_T$	na	na	0.000	1.000

Note: na, not applicable to the variable

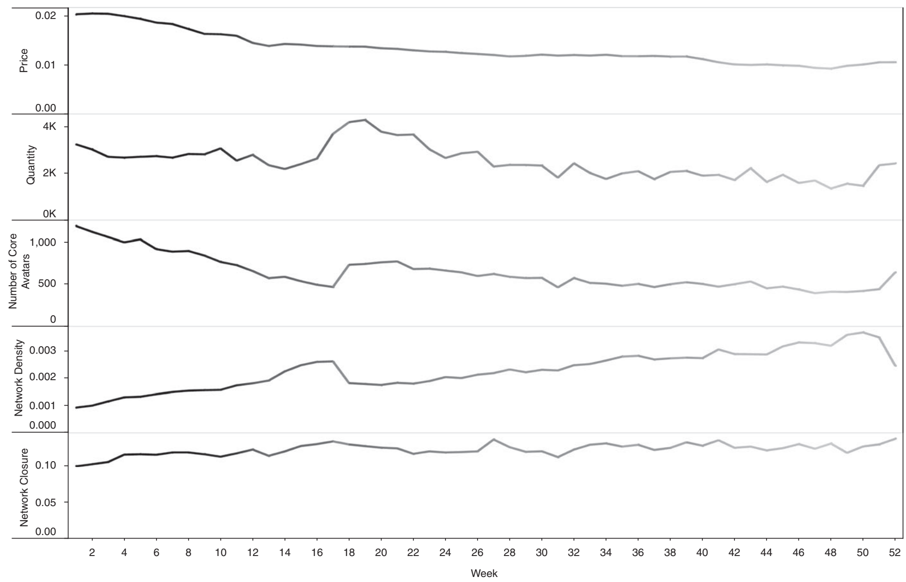

Figure 1. The variation of variables over the 52 weeks

An empirical model is constructed based on Equation (1) using the Cobb-Douglas function (Cobb and Douglas, 1928). One reason for using the Cobb-Douglas function is that the diagnosis of the data reveals large variations in the number of core avatars, as shown in Table I. The Cobb-Douglas function is used to reduce the effects of extreme variation on data and thus redress heteroscedasticity (Lee, 1988; Gujarati, 1992). Furthermore, the Cobb-Douglas function captures the effects of independent variables on the dependent variables in elastic terms (Cobb and Douglas, 1928; Douglas, 1976). For instance, the price function coefficients represent the percentage change of price in response to a 1 percent change in independent variables, such as exchange volume and number of core avatars.

Accordingly, the empirical model for in-game currency pricing is as follows:

$$Price_T = C \cdot Price_{(T-1)}^{\alpha 1} \cdot Quantity_{(T-1)}^{\alpha 2} \cdot Number\_Core_T^{\alpha 3} \cdot Density_T^{\alpha 4} \cdot Closure_T^{\alpha 5} \cdot \exp(\alpha 6 \cdot Promotion_T) \cdot \exp(\alpha 7 \cdot Holiday_T) \cdot \exp(\alpha 8 \cdot MergeServer_T). \quad (2)$$

Then, we take the logarithm of both sides in Equation (2) and obtain the following estimable expression:

$$\log Price_T = c + \alpha_1 \cdot \log Price_{(T-1)} + \alpha_2 \cdot \log Quantity_{(T-1)} + \alpha_3 \cdot \log Number\_Core_T + \alpha_4 \cdot \log Density_T + \alpha_5 \cdot \log Closure_T + \alpha_6 \cdot Promotion_T + \alpha_7 \cdot Holiday_T + \alpha_8 \cdot MergeServer_T \quad (3)$$

If the effect of direct network externalities is present, the coefficient α_3 in Equation (3) should be positive as predicted by *H1*. Similarly, the coefficient α_4 is predicted to be positive, consistent with the positive effect of network density on online gaming value as stated in *H2*. According to *H3*, which postulates the negative effect of network closure on the in-game currency price, the coefficient α_5 is expected to be negative. In addition, the coefficient α_2 corresponds to *H4* with regard to the negative relationship between price and quantity of the in-game currency.

Analytical design

VAR, a macroeconometric framework, is adopted in this study to estimate the model. It was developed by Sims (1980) and has been utilized in empirical research to estimate the joint significance of coefficients for a block of endogenous and exogenous variables (Hannan and Freeman, 1984). The VAR model can help us examine whether multiple time series data are correlated with each other when their own past values are controlled. In the current study, the price and quantity of silver in the MMORPG are the endogenous variables, and the rest are exogenous variables in the VAR model. The number of time lags for the VAR model in this study is one week, and it is determined by the likelihood ratio tests of models with different lags of endogenous variables[1].

The zero-order correlations of the variables are reported in Table II. Note that the variables log$Price_T$, log$Quantity_T$, log$Number_Core_T$, log$Density_T$ and log$Closure_T$ were significant correlated with one another, which may lead to multicollinearity. To address the collinearity issue, we further take first differences of all variables in the VAR model. The results of the first difference model are consistent with the original model, which implies that our estimation model is robust[2].

Findings

The VAR results are reported in Table III. The results show that in the price function, the number of core avatars (i.e. log$Number_Core_T$) has a positive and significant effect on in-game currency price ($\beta = 0.154$, $p = 0.005$). In other words, a larger number of active players in a server can lead to a higher value of game network to each player and thus a higher price of

Table II.
Zero-order Pearson correlation

	1	2	3	4	5	6	7
1. log*Price*$_T$	–						
2 log*Quantity*$_T$	0.623***	–					
3. log*Number_Core*$_T$	0.904***	0.700***	–				
4. log*Density*$_T$	−0.929***	−0.695***	−0.970***	–			
5. log*Closure*$_T$	−0.669***	−0.267	−0.646***	0.725***	–		
6. *Promotion*$_T$	−0.012	0.088	−0.154	0.100	0.203		
7. *Holiday*$_T$	0.373**	−0.058	0.304*	−0.296*	−0.210	−0.018	
8. *MergeServer*$_T$	−0.067	0.153	−0.206	0.202	0.222	0.141	−0.127

Notes: $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

Table III.
The results of vector autoregression estimation

Variables	log*Price*$_T$ β	SE	*p*-value	log*Quantity*$_T$ β	SE	*p*-value
log*Price*$_{(T-1)}$	0.932***	0.046	0.000	0.080	0.218	0.714
log*Quantity*$_{(T-1)}$	0.035	0.026	0.189	0.679***	0.125	0.000
log*Number_Core*$_T$	0.154**	0.055	0.005	0.760**	0.262	0.004
log*Density*$_T$	0.179*	0.085	0.035	0.441	0.403	0.274
log*Closure*$_T$	−0.322**	0.101	0.002	0.035	0.480	0.941
Promotion$_T$	0.009	0.008	0.257	0.076*	0.038	0.045
Holiday$_T$	0.013	0.007	0.082	−0.112**	0.035	0.001
MergeServer$_T$	0.045**	0.017	0.006	0.386***	0.078	0.000
Constant	−1.144**	0.364	0.002	0.749	1.724	0.664
R^2		0.990			0.861	
n		51			51	

Notes: $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

in-game currency in the server. Therefore, *H1* is supported. In real terms, doubling the number of core avatars in a server can lead to an 11.3 percent increase in silver price.

The coefficient of log*Density*$_T$ is found to be positively associated with log*Price*$_T$, and it is statistically significant at a moderate level ($\beta = 0.179$, $p = 0.035$). This result suggests another type of positive network effect: more players connecting and interacting with one another in the game network leads to a higher value of participation in the game world and a higher silver price. Therefore, *H2* is supported in this study. Based on the estimated coefficient of log*Density*$_T$, when the network density doubles in a server, the silver price will increase by about 13.2 percent.

The variable log*Closure*$_T$ is found to have a negative relation to log*Price*$_T$ and is statistically significant ($\beta = -0.322$, $p = 0.002$). This finding indicates that a closer social network in the server can lead to a lower value of the game to players and correspondingly a lower silver price. In this sense, *H3* is supported. The coefficient of log*Closure*$_T$ implies that silver price will decline by 20.0 percent when the clustering coefficient doubles.

The association between log*Quantity*$_{(T-1)}$ and log*Price*$_T$ in price function is not statistically distinguishable from 0 ($p = 0.189$). That is, *H4* was not supported in this study. Furthermore, the Granger causality test suggested that the lagged quantity of silver is not a significant predictor of silver price, $\chi^2 = 1.725$, $p = 0.189$.

In addition, whether or not game companies offer promotions or discounts does not have a significant effect on the silver price ($p = 0.257$). Similarly, whether there is a school or public holiday does not have a significant relationship with silver price ($p = 0.082$). *MergeServer*$_T$ is found to have a positive and significant impact on the silver price

($\beta = 0.045$, $p = 0.006$). It implies that merging a server with other servers would lead to an increase in the silver price by vitalizing the in-game economy and stimulating the demand of silver in the merged new server.

The VAR model also accounts for the variations in the quantity of silver caused by lagged quantity, silver price, and the exogenous variables. The results show that $\log Quantity_{(T-1)}$ is a significant predictors of $\log Quantity_T$ ($\beta = 0.679$, $p = 0.000$), indicating the amount of silver traded in the current period increases with the quantity of silver traded during an earlier period. The variable $\log Number\_Core_T$ is found to be positively connected to $\log Quantity_T$ ($\beta = 0.760$, $p = 0.004$), which is statistically significant. It means that an increase in the total number of core avatars will lead to an increase in the trade volume of silver. In addition, whether it is school or public holiday period has a negative and significant effect on the trade volume of silver ($\beta = -0.112$, $p = 0.001$). One possible reason is that a proportion of players may have other activities and thus do not play the MMORPG regularly during the holiday period, which leads to a decline in the supply and demand of silver. $MergeServer_T$ is positively associated with $\log Quantity_T$ ($\beta = 0.386$, $p < 0.001$), implying that merging servers could increase the trade volume of silver. However, the lagged silver price is not significant in predicting the quantity of silver as suggested by Granger causality test ($\chi^2 = 0.134$, $p = 0.714$).

Discussion

This study provides empirical evidence on the roles of network characteristics in the virtual economic systems of MMORPGs. One important finding is the positive effect of the number of core avatars on the in-game currency price, which implies direct network externalities. More active players indicate a larger social network hosted in the game and thus a higher value of game play in the virtual game world. In this case, players become more willing to pay for the in-game currency to purchase in-game items and to participate in various activities. In market equilibrium, this results in a higher in-game currency price, consistent with the theory of network externalities (Farrell and Saloner, 1985; Katz and Srapiro, 1985; Economides, 1996; Shy, 2001).

Moreover, this study examines the network effects on MMORPGs from a structural perspective. The findings reveal a positive effect of network density on the in-game currency price in a game, which means that the value of playing an MMORPG increases with the levels of connections and social interactions in the virtual world of the MMORPG. This finding is consistent with the social capital theory, which argues that social relationships bring positive outcomes to network members (Coleman, 1988). Additionally, the in-game currency price is found to be negatively associated with the clustering coefficient. That is, a more open social network in the game world leads to a higher value of the MMORPG to players. This finding is in accordance with the structural hole theory: weak ties developed in open networks increase the accessibility to information and resource, whereas a closed network decreases social capital benefits (Burt, 1992).

Nonetheless, this study finds little connection between the price and quantity of the in-game currency. One possible explanation is that information asymmetry is present in the virtual world. Put differently, players may not have enough information on the amount of the in-game currency available in a game world or the actual exchange volume of the currency in the game. In this case, they may not be able to adjust their willingness to pay, and the currency price may not reflect variations of quantity supplied, thus leading to market failure and an insignificant relationship between the price and quantity of the in-game currency. Additionally, there could be other factors influencing the demand of in-game currency, such as the players' income level and the price of other in-game assets. The relationship between the in-game currency price and its quantity may not be completely revealed without controlling the effects of these factors.

Taken together, this study confirms the effects of network size, density, and closure on the value of in-game currency in an MMORPG. Limit research of RMT has investigated the roles of such structural factors in determining the price of in-game currency. Social network analysis has been utilized to explain real-world consumption or financial behaviors, but has not been applied into the context of a virtual economy. The present study fills in this research gap by examining the effects of network externalities, density, and closure on in-game currency price of an MMORPG.

In addition, our study makes two important attempts in methodological sense to the best of our knowledge. First, large-scale longitudinal behavioral data from an MMORPG server were employed to measure theoretical variables involved in the study. The behavioral data are initiated by players themselves, which allows us to observe players' behavior in an unobtrusive and direct way, and in turn develop more valid measurement of theoretical concepts in the study. Moreover, the behavioral data are recorded with timestamp, which allows us to adopt a dynamic perspective to examine the subtle interplay between theoretical concepts. Such dynamic perspective can help strengthen the internal validity of our theoretical findings.

Second, we construct communication networks from which two fundamental and important network characteristics (i.e. density and closure) are extracted. MMORPGs are virtual societies in which players communicate, compete, and cooperate with one another. To examine social and economic phenomena in such a virtual world, it would be desirable to take into account the roles of network perspective or concepts. In earlier research of MMORPGs, such network perspectives were unusual mostly due to the unavailability of necessary data. Our study made an attempt to build a communication network based on players' interaction record in the game and extract two global characteristics of the communication network. Moreover, such global network characteristics are time-variant thanks to the dynamic behavioral data retrieved from the MMORPG server.

This study has practical implications. The findings of this study could offer useful information for online game companies, particularly the developers. This study confirmed effects of network externalities, density, and closure on the MMORPG's value to players. It implied that aside from improving the MMORPG's intrinsic quality (e.g. graphics and storylines), building a large player base is important for the game to thrive in the market. Additionally, external stimuli (e.g. new player-vs-player or player-vs-environment activities) could be designed and carried out in an MMORPG to foster social interactions and communication. Such stimuli can lead to an increase of the value of playing and enhance their willingness to invest in the game. It could bring more profit for the online game company by stimulating the vitality of the in-game economy and RMT.

For game players, this study helps them to understand the dynamics of an in-game economic system and provide guidelines to make consumption decisions, such as the exchange of in-game currencies, magical weapons, and items. The findings of this study suggested that in-game currency price is influenced by network size, density, and closure. In this sense, when observing any significant changes in the number of players in their server or the social network structure of the in-game community, the game player could anticipate the fluctuation in the price of in-game currency and thus make the decisions of RMT or in-game purchase accordingly.

The current study also has some limitations. First, due to data constraint, this study examined the silver price of one server of the MMORPG under study. As a result, it might not fully reveal the significance and shape of relationships under study. Future studies can extend the sample size by including data from other servers of this MMORPG, which could yield a large data set for empirical model estimation. Such data analysis could help reveal not only the time effect but also the influences of server characteristics on silver price, and thus reveal a more complete picture on the mechanism and dynamics driving the fluctuation of virtual currency price.

Second, for the measurement of core avatars, the choice of the threshold in the study is mostly data driven. To adopt a consistent threshold across 52 weeks and capture the right-skewed distributions of avatars' sophistication score in each week, we decide to choose 10 percent as the threshold. Although we do not have much theoretical support for it, such soft threshold has been adopted in other studies to identify opinion leaders and influential users (e.g. Sun *et al.*, 2014). Therefore, we think the threshold is a tenable practice in our study. Future research could further explore this issue and determine the critical value of the threshold as a new research domain.

Third, there could be other factors related to the demand and supply of in-game currency, which are not examined in the present study due to the lack of available data. Such factors include the income level of players, the price of other in-game items, and so forth. Additionally, microstructure variables (e.g. liquidity) may also impact the virtual economy. It would be promising for future research to collect richer data to control for the above-mentioned factors, which could improve the estimation of the relation between in-game currency price and its quantity.

Fourth, in addition to the in-game exchange of silver, players can purchase more advanced virtual item from or sell silver to other players outside the virtual world via an online trading center. Such trade outside the game world is not controlled in the study, as data on the transaction history in the trading center are not available. Nonetheless, as players can observe silver price listed on the in-game platform and outside trading center when making a trade decision, there should be little difference in silver price between the two markets. In this sense, the results of the current study would not be critically confounded.

Finally, this study examines the variations of the in-game currency price in one MMORPG. Thus, we need to be cautious when interpreting the results and generalizing the findings to other MMORPGs. It would be theoretically interesting for future research to examine and compare the network effects between Chinese MMORPGs and MMORPGs from other regions and to detect possible differences in the value people attach to communication networks across various cultures.

Conclusion

In conclusion, this study confirms the social network effects on the value of MMORPGs. The findings of this study suggest a positive effect of the number of active players on in-game currency price, which provides empirical evidence on the presence of network externalities in MMORPGs. Moreover, the findings reveal significant effects of social network density and closure on in-game currency price, which offers a new perspective to examine social network effects in MMORPGs. Taken together, this study contributes to the existing literature of network externalities and social network analysis, which further advance our understanding about how communication network and social interaction impact the dynamics of a virtual economic system.

Notes

1. R^2 and Durbin-Watson statistics are used to assess the model fitness. For the current model, R^2 is equal to 0.990 for log*Price* regression and to 0.861 for log*Quantity* regression. The Durbin-Watson statistics of the VAR model is 1.360.
2. The first difference of the variable X is expressed as $D\_\log X_T = \log X_T - \log X_{(T-1)}$. Detailed results of the first differnce model are omitted to conserve space.

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