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Dynamics from open innovation to evolutionary change

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This paper proposes a dynamic model of interaction among open innovation, complex adaptive system, and evolutionary change logically.In addition, this paper applies the model to Smart phone industry to explain the value of this model, and validation it logically.
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Abstract

We created conceptual models that people may use to analyze and forecast the dynamic effects of open innovation, which we applied to the smartphone sector using a model-based analysis approach. In addition, we built an open innovation simulation model for the smartphone sector. The dynamic model of open innovation linked logic and concepts relating to open innovation, complex adaptive systems, and evolutionary change. The model can be used to analyze the dynamic effects of open innovation strategies and open innovation simulation for the selection of future strategies.

Keywords: Open innovation, Complex adaptive system, Evolutionary change, Smartphone

Research question: background

As the knowledge-based economy develops, the amount of knowledge in the world rapidly increases along with the velocity of circulation. Firms are increasingly utilizing not only their own technologies, but also external knowledge and other technologies. In addition, the open innovation phenomenon is rapidly spreading into many industries, nationwide, and worldwide, as firms provide their unused technologies to be utilized by others. User innovation, customer innovation, collective intelligence, crowdsourcing and open source innovations will be referred to as open innovation (OI) in that they are innovation based on the transfers across the boundaries of knowledge and technology. The life cycles of cutting-edge products are becoming shorter and shorter, and brand-new products of firms are routinely being imitated by others. This is called the commodity trap and is getting increasingly common. Consequently, as a process enabling the relentless innovation of technology, OI is receiving more and more attention (D'Aveni 2010). Given this situation, we wanted to answer the following questions.

What kind of dynamic effects can be drawn out from complex innovation systems and market evolution driven by OI strategies and open business models for firms?

What is the trend in the modern smartphone sector, with particular focus on the strict competition among Apple, Samsung, and Nokia?

Here, we will build up a model that can be used to analyze and forecast the dynamic effects of open innovation and apply it to the smartphone sector using a model-based analysis and an agent-based modeling (ABM) simulation. We will search for solutions to the following specific questions by building up a dynamic model of OI.

1) What kind of effects can OI at a firm level, give to and take from, complex adaptive systems, such as the national innovation system (NIS), regional innovation system (RIS), and sectoral innovation system (SIS) (Nelson and Winter 1982)?
2) How can firms escape falling into the commodity trap and suffering from a harmfully shortened product life cycle when engaged in the dynamic process of open innovation?
3) How do a dominant design and technological regime appear, change, and disappear in the dynamic process of open innovation?
4) What is the status of specific technologies, or other knowledge selected by firms, in the market during the dynamic process of open innovation?

With this study, we seek to set up a theory about the whole process by which open innovation (OI) is realized at firm level. Concretely speaking, it is a theory about all the processes by which new ideas or technologies are adopted by a firm, how they are used to create new products or processes, and how, in the end, they are incorporated into a dominant design. More industries are increasingly confronted by the peril of the commodity trap in which imitation or the pursuit of cutting-edge products is made within very short time frames. For this reason, a firm needs to dynamically analyze the impacts of its own OI strategy at the introductory stages of new knowledge, technologies, or ideas. In analyzing the open innovation of a firm, we cannot fully understand and analyze the whole open innovation process without analyzing the dynamic process of specific OI strategies. First of all, concrete OI strategies of firms, and analyses of the dynamic processes involved, are more important than ever. OI, at a firm level, is no longer an option but a must for the survival of not only corporate giants, the likes of IBM, 3M, or Intel, but also of small and medium enterprises (SMEs; Vrande et al. 2009;).

Literature review

The need for a new approach for firms to deal with the increasing OI phenomenon in the form of strategies, business models, user innovation, collective intelligence, and crowdsourcing, is on the rise. Firms need new ways to escape the commodity trap and to prevent injury from short product life cycles.

There is also a need for connections within OI, at a firm level, complex adaptive systems, such as RIS, SIS, and NIS, and an evolutionary change in markets. There needs to be a research framework aimed at solving this problem. Finally, we want to understand the total cycle of innovation in firms: from new ideas to new products and from a dominant design to the choice of the technological regime (Lee and Lim 2001). The following are theories intended to answer these questions (Heredero and Berzosa 2012). First, resource- and knowledge-based theories treat OI as a way to exploit resources and knowledge complementarities (Mowery et al. 1996; Das and Teng 2000; Nonaka 1994; Simon 1991). This resource-based perspective focuses on strategies for exploiting existing firm-specific assets (Teece et al. 1997). Well-known companies, such as IBM, Texas Instruments, Philips, and others appear to have followed a “resource-based strategy” wherein they accumulate valuable technology assets, often guarded by an aggressive intellectual property policy (Teece et al. 1997; Shuen 1994). However, this theory cannot explain the dynamic changes that originate from occurrences, such as the commodity trap and shortened product life cycles.

Second, according to the Transaction Cost Theory, open innovation will decrease transaction costs through vertical disintegration of firms. This theory was derived from the Coase Theorem and New Institutional Economics (Coase 1937; Williamson 1991; Kogut 1988; Jacobides and Winter 2005). Although this logic does not concentrate on the strategy of a firm, it coincides with the direction of this study where it focuses on establishing and analyzing a model of the dynamic process of open innovation. But what the Transaction Cost Theory can explain is not the dynamics but just the usefulness of OI in restricted areas, such as cost reduction (Jacobides and Winter 2005).

Third, the history-friendly model might be used to analyze and predict dynamic changes in economic phenomena through history divergent simulation by a history replication method (Malerba et al. 2001; Malerba et al. 1999a, b, 2001, 2008; Nelson and Winter 1982; Yoon and Lee 2009). However, the basic analysis target of the history-friendly model is not a firm but a sectorial innovation system. Consequently, it has limits for the simulation analysis of the dynamic process caused by OI at a firm (e.g., business model or strategy). After all, the analysis beyond history replication is left in a black box because this theory has adopted an approach based on simulation at the level of sectorial innovation system. Our study focuses on the analysis of the black box itself, the dynamic change that OI brings about to a firm.

Fourth, according to the Dynamic Capabilities Theory, collaborative innovation is established to develop the dynamic capabilities of a firm, and thus, enhances its competitive advantage. This theory was proposed and developed by several firm strategy research groups and Schumpeterian economists (Teece and Pisano 1994; Teece et al. 1997; Teece et al. 1997; Arthur 1994). The dynamic capabilities framework analyzes the sources and methods of wealth creation and capture by private enterprise firms operating in environments with rapid technological change (Teece et al. 1997). According to this theory, the competitive advantage of firms is seen resting on distinctive processes (e.g., ways of coordinating and combining) shaped by the specific asset positions of each firm (e.g., portfolio of hard to trade knowledge assets and complementary assets) and the evolutionary paths it adopted or inherited (Teece et al. 1997). But dynamic Capabilities Theory cannot directly explain the trigger of dynamic capabilities. There is no sufficient explanation to the starting point of the introduction of new ideas, knowledge, or technology, as a dynamic activity performed by a firm. To discuss dynamic capabilities at a corporate level, our study seeks to build up a model of the dynamic processes involved in OI to analyze those processes, starting from the decision of a firm to adopt an OI strategy, and then apply it to the current smartphone sector.

Fifth, evolutionary theories of business activity note that some firms struggle to meet the demands of their environments and reside at the margins of survival (Fortune and Mitchell 2012). In turn, selection processes remove struggling firms from the business landscape, if they fail to improve (Nelson and Winter 1982; Aldrich 1999). According to this theory, firms survive by overcoming the obstacles as they dissolve their obsolete skills or assets and by acquiring required new skills or assets (Fortune and Mitchell 2012). However, this theory does not well explain both radical innovation, which arises frequently and appears in unpredictable ways, and acquisition and dissolution aimed directly at knowledge and technology, in a knowledge-based age. In other words, what is required is a direct analysis of the concrete dynamic processes at a corporate level. Thus, our study seeks to find out how evolutionary technology management and strategy, i.e., open innovation technology management strategy at a corporate level, evolves in a complex adaptive system.

For all these reasons, we need to develop a theoretical concept model that can explain the processes from open innovation of new ideas or technology to the appearance of a dominant design and the evolution of NIS, RIS, or SIS. The growing literature on strategic alliances, the virtual corporation, buyer-supplier relations, and technology collaboration indicates the importance of external integration and sourcing (Teece et al. 1997). Namely, there is a growing necessity to analyze the dynamic process of open innovation, which is the subject of this study.

Model building: methods

There is a deep relationship between these three factors (open innovation, complex adaptive systems, and evolutionary change) and they are arranged in a conceptual order based on the name of the model, not in a temporal order. Conceptually, open innovation at a firm goes through a complex adaptive system and then leads to evolutionary change. However, in reality, a specific complex adaptive system can trigger OI through evolutionary properties at any given firm. The OCE conceptual model in Fig. 1 is based on the conceptual order that is needed to analyze the dynamic changes triggered by OI at an individual firm.

The basic agent of open innovation is the firm. The agent chooses action based on its own independent judgment. Its actions influence other agencies or environments, and also be influenced by agencies and environments. In that sense, social organizations, individuals, and governments can be agents of open innovation as well. Firms make various degrees of open innovation (incremental to radical, inbound or outbound) through diverse channels and corporate open innovation influences NIS, RIS, and SIS.

The complex adaptive system exhibits various levels of emergence from price or product differentiation to change in dominant design or even emergence of new

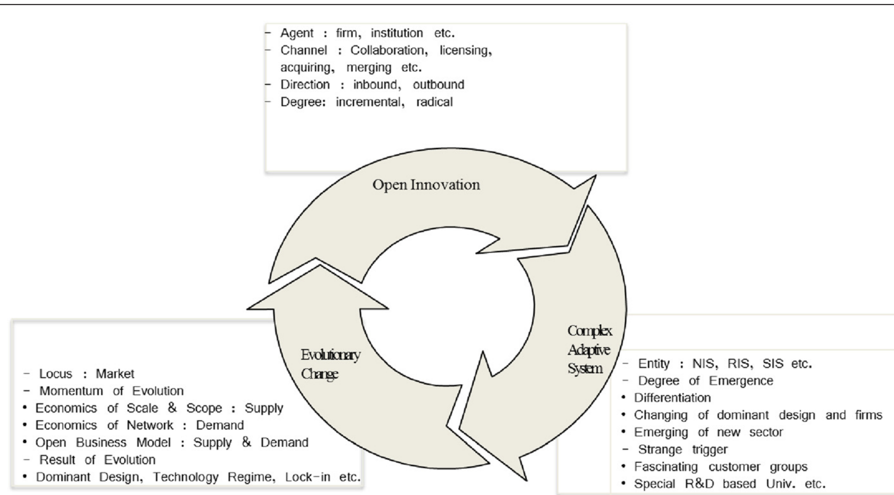

Fig. 1 OCE model concept

sectors. The complex adaptive system influences evolutionary change in corporate open innovation by way of strange trigger. This might include a certain degree of accordance of fascinating customer groups with the technology regime, technological capabilities of related SIS, RIS, or NIS, and the existence and level of rival firms or suppliers. Of course, unique historical heritage, location, ecosystem, or environment of the innovation system are unique features, which work as an strange trigger with certain effects on the diverse OI activities of a firm.

Corporate OI goes through evolutionary stages in the market, blooming into various types and levels of emergence, or being influenced by strange triggers, under complex adaptive systems. The basic locus of evolution is a market. Corporate OI shows up as dominant design thanks to various evolutionary factors (e.g., economies of scale and scope, economics of networks, or open business models). After all these, corporate OI creates a market lock-in, by initiating path dependence and forming a technology regime. The degree of corporate OI creates a variety of evolutionary effects according to the degree of complexity of the complex adaptive systems.

This OCE conceptual model can be analyzed by case studies. Furthermore, the OCE agent based model (ABM) can be built to simulate the situation (Carcia et al. 2007). It is based on the premise of building the model to analyze the courses of open innovation, the complex adaptive system, and evolutionary change, starting from strategy at a corporate level.

We will now assemble the OCE model in three stages. First, we will build up open innovation factors, processes, and their connections with complex adaptive systems. Second, we will build up diverse complex adaptive system factors and their relationships with open innovation and evolutionary change (Yoon, and Lee 2009;). Third, we will construct evolutionary change that results from a complex adaptive system and its interaction with open innovation (Malerba et al. 1999a, b, 2008).

Open innovation in the OCE model

All innovation based on the inflow and outflow of technologies, knowledge, and ideas crossing the boundary of firms, is considered "open innovation", which is the intended target of the OCE model.

On one hand, it is a fact that the concept of an agent of open innovation has undergone substantial change over time. Schumpeter thought of an entrepreneur, a person, as the agency of innovation in the initial stage of his research, and a large company as the agency in the latter stage (Schumpeter 1934, 1942). After a discussion of the strategy at a corporate or national level was activated by Porter (1980, 1990), approaches to open innovation strategy in institutes, such as firms, social organizations, or government agencies, have also been discussed, analyzed, and carried forward diversely in direct or indirect methods. In the discussion centered on the firm as the basic agent in OCE model analysis, open innovation inside the firm becomes the target of its strategy. On the other hand, open innovation outside a firm, which can result in a market or system failure, is the target of government policy.

The OCE model, as an open innovation channel, takes into consideration the factors on the technology-pushed side, as well as the factors on market-driven side (e.g., collaboration, acquisition and merging, licensing, customers, suppliers, competing firms, university and national research laboratories, etc.). In reality, an apparent disjunction between changes in technology and productivity can be observed, for instance during the so-called "productivity paradox" of the 1980s and 1990s (Tunzelmann and Wang 2007). The reason is that, first of all, in shaping production function, traditional theories or the Dynamic Capabilities Theory failed to take into consideration the source of new knowledge and technology. It is not only the capabilities of producers that should be taken into consideration as bases of productivity or dynamic change but also the capabilities of consumers (Tunzelmann and Wang 2007). One of the important considerations in the OCE model is the various channels through which knowledge and technology flow in. For example, open innovation considers merging and acquiring (M&A) as an open innovation channel to acquire tacit knowledge. The embeddedness of key capabilities and the knowledge that they embody, often motivate firms to acquire an entire entity to obtain these capabilities, as opposed to simply licensing specific goods or hiring employees (Capron et al. 1998). In fact, the higher the level of corporate scale a firm has, the more it seeks complete, open innovation, including tacit knowledge as well as codified knowledge through M&A.

From the corporate viewpoint, the degree of OI varies from incremental, representing the improvement of existing products, to radical innovation, representing the launching of completely new products on global markets as well as into domestic markets.

The difference in the degree of OI causes the appearance of the emergence at various levels of the complex adaptive system (CAS). Regarding the relation between the level of OI and corporate achievement, there is a reverse U-curve in the quantitative analysis of the relation between the OI and corporate achievements of a great number of firms (Laursen and Salter 2006). However, the relation between the degree of corporate OI activity and corporate achievement will vary according to the corporate environment (Drnevich and Kriauciunas 2011). Namely, it is useless to make a quantitative analysis of the relation between the degree of corporate OI and achievement. Rather, it is reasonable to make an analysis of the dynamic process of the corporate OI strategy, that is, the process for achieving the OI strategy of a specific firm, which is what OCE model analysis is intended for.

Quantitative analysis of the determinants of OI showed a variety of factors that determine the success of OI, such as attitude toward openness, entrepreneurship, internal system for openness, and capability for corporate absorption (Yun and Mohan, 2012a). Of course, the RIS, NIS, or SIS under which a firm functions (as factors external to the firm) were presented by way of a quantitative analysis of factors to determine the level of achievement of OI. According to an OCE model approach, related to the analysis of the processes of dynamic change resulting from a corporate OI strategy, corporate achievement is not determined by the specific factors of open innovation. Rather, the factors that determine corporate achievement during the dynamic processes of OI work differently, and in some cases, the same factors have quite different effects. Namely, only through an analysis of the dynamic effects of open innovation is it possible to find the concrete factors that influence the achievement of OI, at a corporate level, and to analyze this influence.

On one hand, the degree of corporate OI determines how well the firm catches up with the leading firm in the belonging sector. Catch-up strategies basically assumes three patterns, namely, path-following catching-up, stage-skipping catching-up, and path-creating catching-up, which have target sectors of other national innovations (Lee and Lim 2001). In a knowledge-based economy, when a technological life cycle is being shortened, technological catch-up types move from path-following catching-up based on a closed innovation strategy to stage-skipping catching-up, pursuing a medium degree of open innovation and a path-creating catching-up pattern with a high degree of open innovation. The higher the degree of corporate OI, the more rapidly and creatively a related firm can catch up. The model to determine a catch-up pattern includes, as internal determinants, factors representing OI, an example of which is an access to an external knowledge base or other available knowledge and resources.

Complex adaptive systems in the OCE Model

Currently, the topic of complexity is attracting a great deal of interest, but there remains a question of what can be said meaningfully about complexity (Simon 1995). There are several complexity theories like Chaos Theory in mathematics that deal with the complexity of nonlinear dynamic systems whose long-term behavior is unpredictable. Systems theory, which possesses many interacting components, deals with another form of complexity. There is also the Computational Complexity Theory that uses agent-based modeling. This theory is applied to physical and economic issues all together. Complex systems arise naturally in the economy because economic agents, whether they are banks, consumers, firms, or investors, continually adjust their moves, purchasing decisions, prices, and forecasts in response to the situations these moves, decisions, prices, or forecasts create in the market (Arthur 1999, 2009). The complexity in this study includes computational complexity as it uses a computer for analysis. The factors used to configure the system respond to and have an influence on the system itself. For this reason, it is called a complex adaptive system (Fleming and Sorenson 2001). Enterprises, which are representative agents and which make up complex systems, are not just collections of production factors, they are "repositories of competence" that create, coordinate, and deploy knowledge. In this case, it is the knowledge of the "specific connections that seem to work in a particular environment" (Potts 2001).

The degree of complexity of a complex adaptive system is shown concretely by the degree of competition between firms or institutions in that system (Choi et al. 2001; Surana et al. 2005). Complexity arises when the dependencies among the elements become important, and complex adaptive systems are composed of interacting, thoughtful agents such as firms, customers, or banks (Miller and Page 2009).

Complex adaptive systems usually operate for a global optimum, and exhibit many levels of aggregation and interaction (Holland and Miller 1991). Innovation systems are themselves complex adaptive systems composed of complex structures of complex populations (Kastelle et al. 2009). There are several kinds of complex adaptive systems in innovation systems, among them are the national innovation system (NIS), the regional innovation system (RIS), and the sectoral innovation system (SIS). The complexity of NIS as a complex adaptive system varies among countries. In the end, the results of corporate OI can determine the creativeness and complexity of the NIS. The differences in the creativeness and complexity among NISs are determined by corporate open innovation, while the degree or level of corporate OI is influenced by the institutions that form the NIS. As a complex adaptive system, the NIS is a reflection of the firms, major affiliated agencies, complementarities, self-organization, and proper emergence of the complex adaptive systems in it (Manzini 2009).

Meanwhile, the OI of firms can determine the creativeness and complexity of the belonging RIS. At the same time, the openness and creativeness of the belonging cluster or RIS, can determine the degree of OI of the firms (Cooke 2005). For example, in Taiwan, the foundation of the Hsinchu Cluster in which knowledge, technology and capital are free to flow through connections to Silicon Valley, is ascertained through the activation of diverse OI activities of the belonging firms (Saxenian and Hsu 2005).

Corporate OI can increase the creativeness and complexity of a specific sector, while the sectoral innovation system determines the OI of the related firms. Although corporate OI has an effect on the improvement of corporate differentiated competitiveness, it increases the complexity and creativeness of the SIS if it is combined with various positive feedback loops, such as economies of scale, network effects, and open innovation business models. If this occurs, the existing dominant design in the related SIS fades away, and fierce competition occurs to establish a new dominant design. Dominant firms of the belonging SIS change rapidly, new markets are set up, or the initial market size and the SIS scope rapidly expand. In the end, the sectoral specificities in the geography of a corporate location are determined by corporate OI, that is, how the firms in the SIS combine their knowledge, technology, and manufacture of products (Bottazzi et al. 2005).

Complex adaptive systems (NIS, RIS, or SIS) lead open innovation of firms in specific directions. The existence of a fascinating customer group in some sectors plays the role of an strange trigger, and this makes innovation systems accept the OI made in the sector more easily. Triggering effects may also occur in the case of innovation systems with R&D capabilities and technology capabilities focused in the related sector. Certain firms may influence universities by funding, while national university systems crucially affect the competitive advantage of firms in the global market (Francisco et al. 2007). The features and properties of an innovation system act as determinants of acceptance, regarding both the degree and direction of OI of individual firms.

Political intervention by governments is required to enhance the level of openness in complex adaptive systems, or to promote the activation of NIS, RIS, and SIS, through knowledge production, distribution, and consumption. To fix a system failure is to connect technology to markets continuously by making sufficient knowledge and technology available in the innovation system. Government intervention in system failures of complex adaptive systems is aimed at promoting the OI of individual firms. Consequently, the core responsibility of a government is to build an open NIS, open RIS, or open SIS, which in turn produce and distribute new knowledge and technology into the innovation system by enhancing the complexity of the complex adaptive system, that is, the openness of the innovation system.

Evolutionary change in the OCE Model

Evolutionary economics inherited from Schumpeter's legacy involves coevolution of national industries, technology, and institutions, such as universities, research laboratories, and patents (Nelson 1994). This study does not analyze evolutionary results at the level of the economy, but looks at evolutionary effects reached as a result of differentiation strategies by which OI is established at a specific firm. At the current rates of growth in knowledge, rates of its use and formation of positive feedback loops of new types (e.g., SNS), and the selection of OI strategies at a corporate level, produces rapid evolutionary results in markets. This phenomenon, the evolutionary results from OI at corporate levels in markets, is applicable not only to large, market-dominating companies, but also to SMEs. Before firms could carry forward OI strategies, they should check the evolutionary effects of related OI strategies, which are linked to corporate competitiveness and profits. The time frame from open innovation to evolutionary results is being shortened very sharply. How cutting-edge, new technological products face falling into the commodity trap in such short times is the proof of the current, shortened, technology life cycle.

An evolutionary model of technological change is proposed in which a technological breakthrough, or discontinuity, initiates an era of intense technical variation and selection, culminating in a single dominant design product (Anderson and Tushman 1990). Namely, the pinnacle of evolution in innovation is the very formation of a dominant design. A dominant design goes through a variety of incremental technical progressions according to the differentiation strategies of many firms, by way of open innovation. A dominant design is not fixed. It goes through an evolutionary process created by the OI based on the discontinuous technology of a firm, and then forms another dominant design.

Companies with the best products will not always win, as chance events may cause "lock-in" of inferior technologies (Arthur 1983). The process from dominant design formation to its lock-in is the evolutionary result of open innovation based on new knowledge and technology. Various dynamic evolutionary powers trigger the process from dominant design formation to its lock-in. Similar to biological evolution, the evolution of markets related to technological innovation is never locked-in forever. While switching costs may favor the incumbent during rapid technological change, switching costs can become quickly swamped by switching benefits (Teece et al. 1997). Increasing returns, network effects, economies of scope, and open business models are the forces that enable switching benefits to surpass switching costs.

In economics, positive feedback arises from increasing returns (Arthur 1994). In economies, a positive feedback loop is the driving force making a specific technology win a position of a dominant design on the market and then creating a lock-in. The market mechanisms that make up this positive feedback loop are economies of scale, economies of scope, economies of network, and open business models.

Economies of scale are a positive feedback loop on the supply-side that increases supply so long as profit increases in direct proportion to the increase in supply. In cases where increasing returns are caused by economies of scale, a lock-in for current technology occurs. If one among the competing technologies happens to be adopted by historical events, and increasing returns are created through economies of scale, this technology becomes a dominant design and gradually becomes locked-in (Arthur 1989).

Economies of scope are another positive feedback loop on the supply side. It is more efficient for a single supplier to supply a variety of products than for different suppliers to supply products singly in the same product field. This logic also justifies M&A in microeconomics. When various new types of open innovation occur in a traditional manufacturing industry, they undergo an evolutionary process to a dominant design and a lock-in through economies of scope. However, evolutionary phenomena, based on economies of scale or scope, lose their power the moment the positive feedback stops. If alternative technology appears suddenly through the OI of another firm, and is powered by the positive feedback loop, the existing dominant design can disappear suddenly (Anderson and Tushman 1990).

Economies of network form a positive feedback loop on the demand side. Demand increases geometrically as the bandwagon effect occurs in proportion to the increase in demand. For example, as the number of Microsoft (MS) office users grows, more people are likely to use it. In addition, the exchange and distribution of documents, which were produced by MS Office, becomes more convenient. Accordingly, the number of users of MS office increases more. A variety of social network systems (SNSs, such as Facebook, Twitter, and KakaoTalk) also have positive feedback loops based on economies of network. A creative open innovation based on a new idea evolves into a new dominant design if it is powered by a positive feedback loop thanks to the economies of network based on fortuitous initial users. This positive feedback loop on the demand side has a relatively solid and long-term sustainability. Sales of the QWERTY keyboard have been solidly sustained through keyboards that are more efficient, and it has been developed since it evolved into a dominant design based on the economies of network. Such long sustainability is possible if a new idea reaches the status of dominant design because of the economies of network and even a minimal, steady effect from economies of scale is present at some level.

An open business model has features similar to an evolutionary game. It refers to a phenomenon in which there is a positive feedback loop wherein consumers of products turn into producers of products, then, the said producers turn back into consumers, now concentrating more on related products. For example, the Apple App Store is an open business model where consumers of Apps may turn into producers of Apps then go on to consume more Apps (Chesbrough 2006). Namely, it is a positive feedback loop in which economies of network coincide with economies of scale on both the demand and supply sides. Apple’s iTunes, iBook, and Passbook also possess features of open business models. In the case of firms reaching a dominant design through evolution by use of an open business model, it has a very solid evolutionary quality even if this may not cause rapid growth like that based on economies of scale (based on supply). Its positive feedback loop is made relatively stable by economies of network (demand), and considerable self-supply occurs simultaneously as some consumers become producers as well. In the positive feedback loop of an open business model, consumers turn into suppliers and supply diverse products that are not comparable with those produced due to economies of scope.

The smart phone market case: results and discussion

We will apply this model to three agents in the smartphone sector (Samsung, Apple, and Nokia). In this OCE conceptual model of the smartphone sector, we will analyze the open innovation of the three agents, the appearance of the complex adaption system, and the evolutionary change in the sector.

Second, we will build up an OCE simulation model based on ABM, then, simulate the open innovation of the three major agents, the changing of smartphone sector at complex adaptive system, and the evolutionary change in the market. Based on these OCE models (conceptual and simulation), we expect to explain the reality of the smartphone sector in more detail, and then create appropriate strategies or policies for each major agent.

This OCE conceptual model is intended for the smartphone sector, and the agents Samsung, Apple, and Nokia. The target of analysis is limited to these three firms, and its scope to the smartphone sector. The interval of this analysis covers from the release date of the iPhone, from 11st June 2007 to 30th November 2012.

First, let us look into the open innovation of three firms. Samsung's OI strategy is in total contrast to that of Apple's. Most core components of the hardwares of the smartphone depend on self-production (i.e., processor, camera module, display, and communication module, are all produced by Samsung, with its own assembly line operation) and assembly in the cities of Suwon, Asan, Tangjeong, and Gumi in Korea. Furthermore, almost all smartphone hardware production personnel are full-time workers. By retaining a large number of smartphone hardware research personnel, Samsung gained second position after IBM for achievements in patent applications and registrations in the U.S. In this area, Samsung is fully focused on self-development (R&D, production, and assembly) of the four major components, based on closed innovation. This closed innovation strategy enabled very rapid development of new models of smartphone hardware. Samsung has used a strategy of diversification to various sizes and styles of hardware, and has created new markets based on five-inch smartphones and the smart pencil.

However, Samsung pursued quite a different strategy for its smartphone software. When Samsung, which enjoyed market dominance second only to Nokia in the feature phone field, entered the smartphone industry, it did not have a smartphone operating system (OS). Because of this, Samsung pursued the strategy of allowing global enterprises to provide diverse software for its smartphone, and of producing the smartphone hardware for itself. It licensed Microsoft Windows, which had overwhelmed the existing global computer OS market, and released the Omnia Phone around June 2009, soon after the release of Apple's iPhone. In the end, Samsung introduced Google android OS for its own smartphone and arrived at global success. Later, Samsung developed the Bada OS based on the Open Source Software of Linux. Bada OS was applied to the Samsung Smart TV, which then overwhelmed the global market, and to its smartphone targeted at the EU market. Samsung then launched a joint development of the new smartphone OS for a new global market with Nokia. As Nokia's smartphone OS strategy is currently changing, Samsung is gearing up to develop the new smartphone OS Tizen based on open source software with a Linux foundation, and with Intel as a major partner for the joint development. Now, again, Samsung is preparing to develop and release a smartphone utilizing the MS Windows 8. Samsung is pursuing typical OI strategies for the development of smartphone software (e.g., OS based on open source, licensing MS OS, and joint R&D with Nokia and Intel).

Next, let us look at the process by which Apple developed its smartphone. Its OS was developed by a typical closed innovation method. By performing R&D based on OS capabilities accumulated while developing the iPod, iTunes, and the Apple computer, Apple entered the smartphone OS field and continues to develop products there, now going forward to version iOS6.0. It is perfecting the concept of OS by developing a single OS for both SmartPad and smartphones. It is also showing competitiveness by continuously adding to diverse open business models based on its OS (e.g., News Board, iTunes, iBook, Passbook, and iTunes). Besides this, it is upgrading its ever-differentiating OS functions (including voice recognition functions, such as Siri), more frequently than any other smartphone-manufacturing company.

In contrast to its software strategies, Apple pursues open innovation strategies for outsourcing almost all of its hardware (display, processor, camera module, and communication module) and assembly. Apple outsources almost all its hardware needs to companies that have the best technology and patent holdings in the world (Samsung for its processor, LG for its display, and the camera module from a Japanese firm) and has its assembly done by firms in Taiwan and China. Apple retained major product concepts, core design patents, and system patents related to smartphone hardware. Apple, with its OI-type hardware expansion strategy, has supply cycles of at least 1 year, which is relatively long in this market. Consequently, Apple's smartphone hardware is not particularly diverse.

At the time the Apple iPhone appeared, Nokia reigned supreme in the global feature phone and smartphone markets. In fact, Nokia developed the world's first smartphone hardware called "Simon." It first appeared in the "Wireless World Conference", an international mobile phone exhibition in 1993. This smartphone was like an ordinary mobile phone, equipped with the first LCD display and an embedded PDA.

However, Nokia dominated the global feature phone market and became the leading developer of the smartphone; it failed to create a strategy to lead the smartphone market.

At the time, Nokia was also dominating the global market in the field of smartphone OS through the Symbian. The Symbian OS was released in 2001, long before smartphones became popular. Although it used to have a market share of about 80 % as the top smartphone OS, it has been losing popularity. Although it had decreased, it still had a market share of 41 % as of October 2010. Since Nokia was first, it had a big lead over its rivals. Because Nokia released Symbian as an open source OS in 2008, it has been managed by a foundation in which the major global mobile phone makers participate. Nowadays, some members have opted out making the OS in danger. In particular, it lost out to Apple and Google on user interface (UI) and outsider developer support, which has forced it to catch up. The Apple iPhone significantly advanced smartphone development with its LCD monitor OS that made multitouch possible, and then developed a facile development tool support system and developer system through its App Store. Compared to this, Symbian is clearly outdated. In order to improve its smartphone OS strategy (but still based on its own OS), Nokia started a new OS development project with Samsung, but later called it off. Later it switched to an MS OS-based smartphone strategy. Recently, it released its Lumia smartphones based on MS Windows 8. As Nokia changes not into a multiple OS strategy as Samsung did, but into an MS OS-based strategy, the global market share of the Symbian OS is decreasing rapidly.

In other words, Nokia is stuck with a closed innovation strategy for its own smartphone OS, and a similarly closed innovation strategy for its own smartphone OS. As a result, the sales of Nokia, which used to be the world's largest smartphone maker, are rapidly dwindling.

Second, let us move to the complex adaptive system of the smartphone sector. Samsung has deployed a smartphone OI strategy focused on software. A variety of phones are differentiated and released to meet the requirements and expectations of each region. The same OS is used for all the various sizes and types of smartphones. Using this approach, Samsung has succeeded in the development of new smartphones (e.g., one with a note-taking feature, one with a five-inch screen, and a Bada OS-based European-style smartphone), which have features different from those of other firms. In the smartphone sector, Samsung has supplanted Nokia, and has now become an effective global competitor of Apple.

Apple has done a great deal to create the global smartphone sector, through its OS-based OI strategy focused on hardware. It has created smartphone-dominant designs with leading features (i.e., telephone, internet, touch screen, and mobile music service) through iPhone. Furthermore, it created a new SmartPad sector with its iPad.

Nokia failed in open innovation on both the sides of hardware and software. Though it was the leading developer in the smartphone sector, it failed to develop a global dominant design in that sector and has since watched its initial market share rapidly decrease.

It is certain that the smartphone sector is itself a typical complex adaptive system. As the scale of the sector market has expanded, parts of the old sector have become entirely new sectors. This smartphone sector has such a high degree of complexity that its domination has changed rapidly from Nokia to Apple and Samsung. In terms of dominant designs, new ones have appeared and previous ones disappeared, before the new ones have even settled down.

We will now analyze the evolution of smartphone sector.

Apple formed its positive feedback loop based on an open business model. For example, some consumers of iPhones developed iPhone applications and uploaded them to the iPhone App Store, and because of this, the roles of the consumers of iPhones and of iPhone applications, were strengthened. Similar to the evolutionary game theory, the open business model allows consumers to turn into producers, and producers to turn back into strengthened consumers. The open business model does not show the phenomenon of exponential increase unlike the positive feedback loops provided by supply-side economies of scale and scope. However, it has a structure that is increased by the number of smartphone users, based on the foundation that the correlated ecosystem is expanded cumulatively and the intensity of usage by users becomes greater. In other words, although the positive feedback loop based on the open business model does not allow such rapid growth as do economies of scale, the intensity of usage by consumers is extreme. The number of users increases greatly and enables the formation of a new smartphone ecosystem that will not break up easily.

Samsung, by creating a positive feedback loop on the supply side through economies of scale and scope, has created evolutionary results: early differentiation attained became a dominant design, which then evolved into a lock-in. The economies of scope have made access to various types of smartphone hardware easy in relatively short cycles, based on very diverse OS. In addition, Samsung has succeeded in producing smartphone hardware that is competitive in quality and price through economies of scale attained by large-scale production based on closed innovation.

Nokia created its initial economies of scale before the supply side of the smartphone industry was well developed. As new concepts and differentiated smartphones appeared, those initial economies of scale disappeared rapidly. Recently, Nokia has attempted to make a comeback by releasing a new smartphone OS, MS Windows 8. By using an OS based on Windows 8 (Web-based, similar to MS Office), this move is expected to enable economies of network. In this case, what is expected is that the vast numbers of Windows consumers will become favored users of the new Nokia products. If Nokia succeeds in creating economies of network based on new consumers in the mobile sector using MS Windows 8, it will be able to form a positive feedback loop much stronger than what could have been created by supply-side economies of scale or scope.

OCE model simulation: results and discussion

The OCE ABM simulation predicts future business results created by the selection of different OI strategies by competing firms. This simulation model was developed based on the results from analyzing the current OCE conceptual model. In addition, the OCE ABM model was aimed at predicting the market share of each firm among competing

		Firm B	
		Technology Sharing	Without Technology Sharing
Firm A	Technology Sharing	$\pi_A + \alpha_{AB}P_B + \beta_{AB} - \gamma_{AB}P_A$ $\pi_B + \alpha_{BA}P_A + \beta_{BA} - \gamma_{BA}P_B$	$\pi_A - \gamma_{AB}P_A$ $\pi_B + \alpha_{BA}P_A + \beta_{BA}$
	Without Technology Sharing	$\pi_A + \alpha_{AB}P_B + \beta_{AB}$ $\pi_B - \gamma_{BA}P_B$	π_A π_B

π_A: Product value added on firm 'A' by its own technology

α_{AB}: Degree of convergence from the 'B' Firm technology to 'A' Firm technology

β_{AB}: Opportunity benefit of 'A' Firm by no R&D investment in 'B' firm technology

γ_{AB}: Degree of losing monopoly profit of 'A' by sharing its technology with of firm 'B'

P_A: Value of technology owned by firm 'A'

π_B: Product value added on firm 'B' by its own technology

α_{BA}: Degree of convergence from 'A' Firm technology to 'B' Firm technology

β_{BA}: Opportunity benefit of 'B' Firm by no R&D investment in 'A' firm technology

γ_{BA}: Degree of losing monopoly profit of 'B' by sharing its technology with of firm 'A'

P_B: Value of technology owned by firm 'B'

Premise: Firm A has one technology. Firm B has one technology. $P_A = P_B$

Fig. 2 Prisoner's dilemma game for OI agents in the future smartphone market, according to a variety of choices for open innovation and degrees of complexity.

The strategies to be chosen by agents in the iterated game (model) are indicated in Fig. 2, which shows the award values of the open innovation game.

Figure 2 shows a payoff matrix of dynamic open innovation games. For simplicity, let us assume there are only two competing firms, A and B. π_A(or π_B) is product value of firm A (or B) by its own technology. Without technology sharing, each firm gets $\pi_A(\pi_B)$ only (Christensen and Rosenbloom 1995). If a firm, let us it to be firm A, receives technological cooperation from the other firm, it can enjoy two more value that is added from that cooperation. First, it can develop its own technology to more advanced level using technology of the other firm (benefit of technology advance, T_A). This benefit depends on the value of the other firm's technology (P_B) and its degree of convergence to Firm A technology (α_{AB}) (Duysters and Hagedoorn 1998). With more value of technology and degree of convergence, Firm A can enjoy more benefit of technology advance ($T_A = \alpha_{AB}P_B$). Second, Firm A can enjoy opportunistic benefit of commercializing firm B technology without any investment on it (benefit of opportunistic usage, β_{AB}) (Teece 1986). On the other hand, technology cooperation requires cost of losing technology monopoly. The sharing cost is greater when the technology value (P_A) and the degree of losing monopoly profit (γ_{AB}) are greater (Porter 1985; Shan 1990).

With the foregoing explanations, we can get a payoff table, Fig. 2. All four of the payoff values satisfy the conditions of the prisoner's dilemma just if we have a minimum hypothesis that $\alpha_{AB^*PB+}\ \beta_{AB\geq}\gamma_{AB^*}\ P_A$ (Press and Dyson 2012; Axelrod and Dion 1988). Any firm which chooses open innovation has higher expectation benefits of open innovation than losing expectation benefit of monopoly of its own technology. The payoff values of the prisoner's dilemma were set based on the basic logic of open innovation strategies.

In this model, according to the degree of openness and the degree of complexity, OCE model was simulated based on payoff values in Fig. 2. Our OCE simulation model (NetLogo 4.0.3) is based on the "NetLogo Ethnocentrism model," which is a NetLogo version of the ethnocentrism model (Hammond and Axelord 2006; Wilensky 2006). We used 'openness' instead of 'mutation rate', which is a chance of each trait mutating. It means how much ratio of new knowledge, which is different from existing knowledge, appears at the sector. We use 'complexity' instead of 'death rate', the chances of dying or mortality, making room for future offspring and immigrants (see Appendix 1). Complexity means what ratio of firms among competitors disappears in the sector when they are defeated in open-closed innovation strategy competition. High competition means high complexity. OCE model for Smartphone market has 4 agencies according to their innovation types, open or closed, in Hardware (H/W) and Operating System (OS) like Fig. 3. These 4 agencies breed descendants according to the ABM programming logic in Appendix 2. Breeding logic at Appendix 2 is basically complex that the breeding possibility of any type of agency is not confirmed even though it follows prisoner's dilemma but fluid according to the level of open innovation and complexity.

Figure 4 shows OCE simulation results in smartphone market. In high open innovation situation, OC and CO agencies win over OO and CC. This has enough

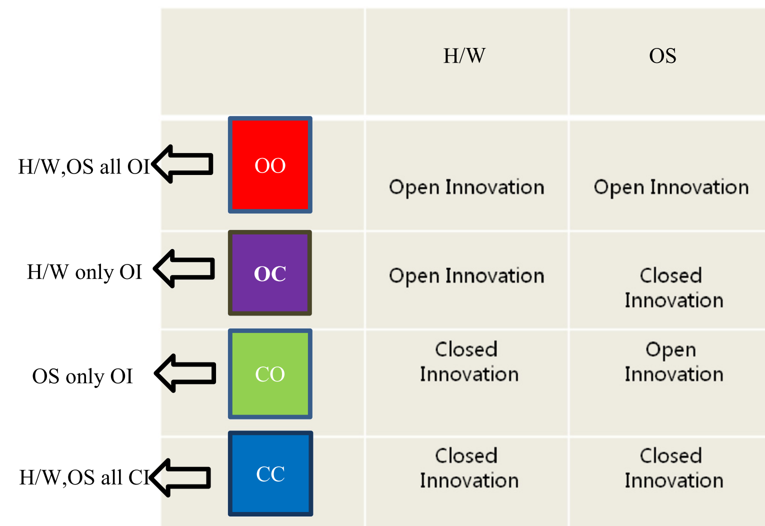

Fig. 3 4 Agencies in OCE model for Smartphone sector

meaning in that firms should use closed innovation and open innovation simultaneously when new technology appears in high speed. In high complexity, the fluctuation in percent in market between the competing firms was very severe (upper parts of Fig. 4.) High fluctuation between the firms in high complexity situation means that the firms compete each other more seriously because death rate of losing agencies increases.

The example of CO in high complexity and high OI can be recent Samsung. And the example of OC in high complexity and high OI can be recent Apple. Until 2013, whenever Samsung and Apple introduce new product in smartphone market, they try to use newest technology in both of H/W and S/W. So they are in high open innovation condition. In addition, whenever they introduce new

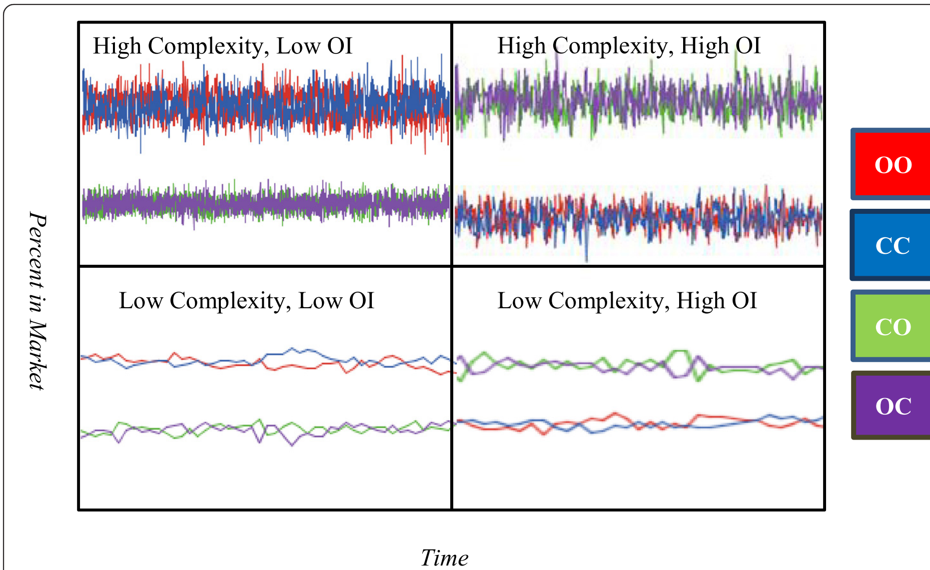

Fig. 4 OCE simulation results in Smartphone sector

products, market share fluctuates between these 2 firms. Samsung produce nearly all H/W parts of its smartphone by itself and adopts a lot of OSs from outside. So Samsung is a CO agency in high complexity and high open innovation condition. Oppositely, Apple produces its OS by itself and adopts almost part of its smartphone H/W from outside. So Apple is a OC agency in high complexity and high open innovation condition.

The example of CC in high complexity and high OI can be Nokia and Blackberry. Until recently, Nokia has its own OS made by MS and keep most of its H/W parts made by itself. Blackberry is similar in situation with Nokia because it also has its own OS and H/W manufacturing system. Nokia occupies only small part of market share in smartphone market under competition with Blackberry. And the example of OO in high complexity and high OI can be Amazon smart pad if we expand examples of our OCE model into related business. If Amazon moves to smartphone sector, it will be OO example in high complexity and high OI. Additionally two significant findings can be caught from OCE simulation results in smartphone market (Fig. 4). One is the changing of winning groups from (OC & CO) to (OO & CC) with the change in open innovation level. When the innovation level goes down in the market, dominant firms may change their open innovation strategy from one-open-and-open-closed to all-open or all-closed. Another finding is that although high complexity makes high fluctuation in market share, complexity itself is not the trigger of changing in dominant strategy and dominant firm. So the decrease in profit rate and increase in death rate as results of fierce competition in smartphone market should be thought as the change in complexity.

Attention should be paid to Fig. 5. The results of the simulations indicate that winner groups in the market begin to change when the level of open innovation has reached at a critical point. That is, in the case of the current smartphone

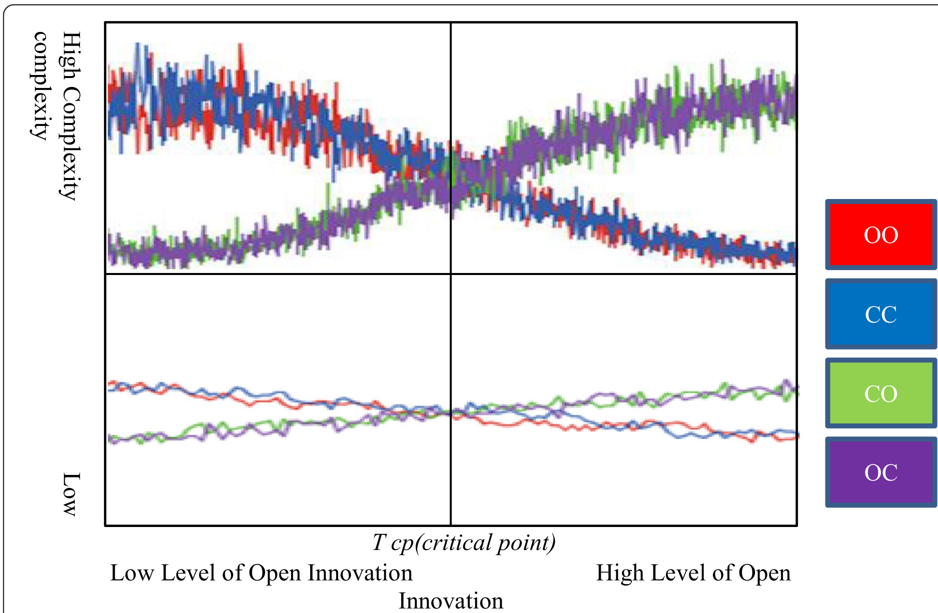

Fig. 5 Change of OCE simulation results according to the level of open innovation

sector with a high degree of open innovation, dominant firms peruse OC, or CO strategies. However, the results indicate that, if the degree of open innovation decreases as the market matures, firms that pursue OO, or CC strategies will dominate smartphone market. If the need for new knowledge decreases because the market and related technologies have matured, the innovation strategies of firms may be changed from OC, or CO strategies to CC or OO strategies. From this, we can guess that if smartphone market matures, diverse OO strategy firms like Amazon kindle which producing Smart pad with any OS and any H/W can appear. In addition, current OI or CI firms may move to CC strategies when smartphone market and related technologies matures.

Implications and conclusion

Open innovation grows with technology openness strategy of firms, complex adaptive systems, and market responses stimulated by technology innovations. The firms are main entities that make such evolution in the market as important autonomous agents in the whole innovation system. Open innovation can evolve and arrive at a dominant design, and often be locked-in according to a positive feedback loop. This might be provided by supply-side economies of scale and scope, demand-side economies of network, or by an open business model that affects both the supply and demand sides. But sometimes, open innovation may fail because of many surrounding conditions in market, technology and regulations.

We have tried to answer the question that 'in what conditions of market and technology, open innovation is going to be effective?', and 'which types of open innovation will be more?'. In this purpose, we developed repeated open innovation game situation and have set and run an ABM model for the situation. For the analysis and implications of the model, we selected smartphone market and major players in it, Apple, Nokia, and Samsung. With brief case study on smartphone market, we could find innovation strategies of the players and could apply their strategies into the model.

With the results of ABM model, we could find several important implications. First, in highly innovative situation that usually happens at the early stage of industry (high open innovation situation), one-open-and-one-closed open strategy, that keeps a firm's own core part (H/W or OS) to be closed and weak part to be openly searched, can be effective. As example, Samsung keeps closed their H/W part and openly searches OS from outside. Apple is doing oppositely, it searches and adopts its H/W from outside and keeps closed its OS. Second, in less innovative situation of matured market, all-open or all-closed strategy can be preferred. In matured market, technologies of all competing firms do not show significant difference and price competition is much more important. In such a situation, all-open strategy that aims to get more cost advantage and compatibility with other formats, or all-closed strategy that aims to keep closed its own core competence and brand equity, are going to be much more effective.

Technology firms that are going to make important decisions on technology openness can get meaningful implications from the results. A firm could change their open innovation strategy based on market condition. In early stage of high open innovation, it could adopt one-open-and-one-closed strategy. But, with matured market and low open innovation situation, it could change its strategy to all-closed or all-open strategy.

The model of open innovation suggested here still have much room for development and ABM model could be more precisely developed with more consideration. Through additional research, this model should be developed, validated, and fascinated. Several concrete cases should be added to validate this model enough. But, additional cases will be the goals of future research. But the findings of the model still give beneficial implications for the firms in high technology industries for their open innovation strategies, about which strategy going to adopt and when to change their technology openness.

Appendix 1

Table 1 Comparing between H&A model and OCE model

H&A model	OCE model
Mutation ratio	Level of open innovation
Death rate	Level of complexity (competition level)
Cost of cooperation	[Firm A = $\gamma_{AB}P_A$]
	[Firm B = $\gamma_{BA}P_B$]
	γ_{AB} : Degree of losing monopoly profit of firm A by sharing its technology with firm B
	γ_{BA}: Degree of losing monopoly profit of firm B by sharing its technology with firm A
	P_A : Value of technology owned by firm A
	P_B : Value of technology owned by firm B
Benefit of receiving	[Firm A = $\alpha_{AB}P_B + \beta_{AB}$]
	[Firm B = $\alpha_{BA}P_A + \beta_{BA}$]
	α_{AB} : Degree of technology convergence from firm B technology to firm A technology
	β_{AB} : Opportunistic benefit of firm A by not investing in and freely using firm B technology
	α_{BA} : Degree of convergence from firm A technology to firm B technology
	β_{BA} : Opportunistic benefit of firm A by not investing in and freely using firm B technology
Lattice Size	Lattice Size
= Size of Population	= Size of Market
Percent = Amount of Population	Percent = Amount of Market
Color	Color
Blue : humanitarian	Red : H/W, S/W all open-innovation (OI)
Green : ethnocentric	Blue : H/W, S/W all closed-innovation (CI)
Yellow : traitorous	Violet : H/W OI, S/W CI
Red : selfish	Green : H/W CI, S/W OI

Appendix 2

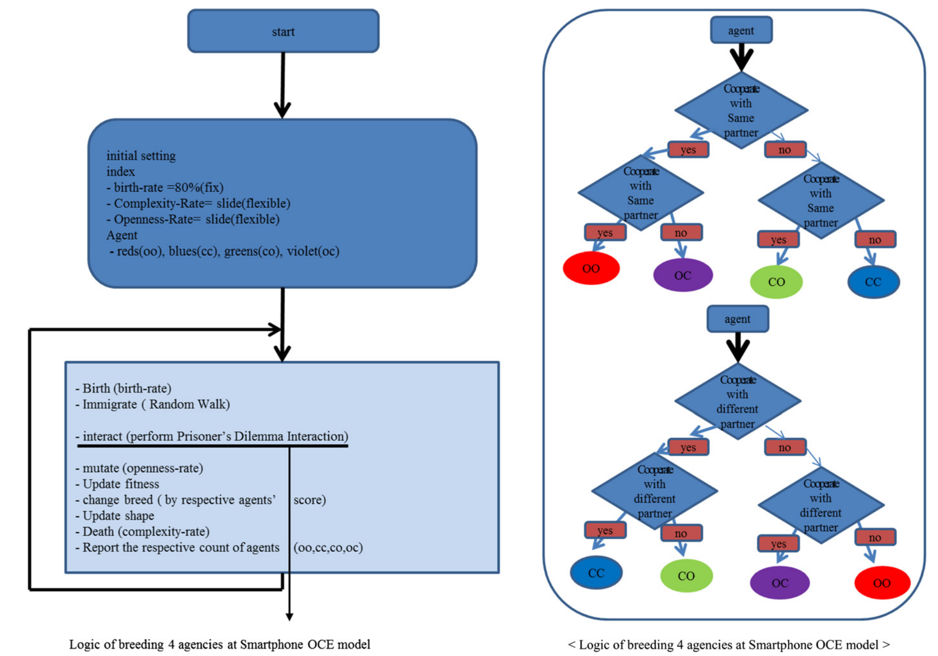

Fig. 6 ABM program Algorism and Logic of breeding 4 agencies at Smartphone OCE model < Logic of breeding 4 agencies at Smartphone OCE model >

Abbreviation
OCE: open innovation, complexity adaptive system, and evaluation change, This is defined by authors to explain the dynamic change of open innovation.

Competing interests
The authors declare that they have no competing interests.

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