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Cloud computing and its impact on the Japanese macroeconomy–its oligopolistic market characteristics and social welfare☆

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ABSTRACT

The cloud computing market is rapidly expanding and changing the nature of ICT across all sectors; cloud computing transforms ICT from a tool dependent upon investment and physical ownership to one that can easily make use of outside resources. On the other hand, cloud computing services are being provided not only for simple data storage, but for many purposes through several different service models, such as SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). Due to, among other factors, the nature of its network externalities, the market seems to be gradually shifting to a market with oligopolistic characteristics in which the services are provided by a limited number of big-name firms. In this paper, the impact of the shift of the cloud computing market to a market with oligopolistic characteristics on utility-based social welfare is quantitatively estimated and analyzed utilizing DSGE (Dynamic Stochastic General Equilibrium) model-based simulation. The main objectives of the paper, rather than to ascertain the exact change of utility-based social welfare, are (1) to determine whether there is a (realistic) shifting path of macroeconomic variables in Japan's case, under the shift and (2) to illustrate the dynamic interaction of the macroeconomic variables. Utility-based social welfare is chosen, because for the purpose of evaluating policy measures it would be more suitable than GDP. Also, several kinds of policy measures for the sound development of the cloud computing market that the industry and government can take are discussed in a sense related to a market with oligopolistic characteristics.

1. Introduction

1.1. Cloud computing and its market in Japan

In September 2011, the U.S. Department of Commerce's (U.S. DOC) National Institute of Standards and Technology (NIST) released "The NIST Definition of Cloud Computing" and identified five important aspects of cloud computing, namely (1) on-demand self-service, (2) broad network access, (3) resource pooling, (4) rapid elasticity and (5) measured service.[1]

Given these characteristics, firms that choose to introduce cloud computing can operate on a platform provided by external cloud-service providers and accessed through digital networks. Because their operations were previously performed with their own hardware, software and data, all of which were self-owned, operated and maintained, an increase in efficiency is expected across all ICT-using sectors. As for cost, fixed costs, most of which have to be paid initially (initial cost), can be transformed to variable costs on a pay-as-you-go basis,

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[1] See "The NIST Definition of Cloud Computing" for details at https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf.

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and thus, financial efficiency is also expected to improve. In this respect, a firm that introduces cloud computing may save more, because if it procures its own system, it is likely that the specifications of that system would match the expected maximum workload in its product life of use rather than the specifications needed at the time of procurement. Moreover, because cloud computing lowers market entry costs, the number of market entrants is expected to increase. This would be especially true for Small and Medium-sized Enterprises (SMEs).[2 3]

Table 1 tabulates some of the published market forecasts related to cloud computing in Japan. The cloud computing market still occupies a small portion of the ICT market. However, it is expected to grow rapidly in the near future. According to the MM Research Institute, from 2016 through 2021, the domestic cloud market is expected to grow at the annual compounded rate of 20.6%, while ICT investment is expected to remain at the same level.

Cloud computing is classified broadly into the two categories of public and private cloud computing. Public cloud computing is provided as a service by an external service provider, with user firms paying on a pay-as-you-go basis, saving on initial costs. This is what the term "cloud computing" usually refers to. On the other hand, in private cloud computing, user firms build their own internal clouds, paying the initial costs. This improves productivity, among other things, through server virtualization, but its impact on macroeconomy may not dramatically exceed that of conventional ICT investment. Therefore, this paper focuses on public cloud computing.

1.2. Shifting to a market with oligopolistic characteristics

While cloud computing service may have a positive impact not only on the ICT market but also the whole economy as a General Purpose Technology (GPT)[4], its market seems to be gradually shifting to one with oligopolistic characteristics. This would be, among other reasons, because service is being provided not simply for data storage but also through service models known as SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service), and because of the nature of its network externalities.

Fig. 1 illustrates the recent development of the cloud infrastructure service (including IaaS, PaaS and hosted private cloud services) market.[5] Data is derived from press releases of Synergy Research Group. The market's quarterly revenue has been steadily growing and its rolling Year-to-Year growth rate is maintaining a high level of over 40%.

Table 2 tabulates worldwide market share of the cloud infrastructure service (including IaaS, PaaS and hosted private cloud services) market, with data again taken from a press release of Synergy Research Group. In this market, global big-name firms have secured large market shares; Amazon has the biggest market share, at 34%, followed by the Next 3 (Microsoft 11%, IBM 8% and Google 5%; total 24%). The combined market share of the BIG 4 (Amazon and the Next 3, namely Amazon, Microsoft, IBM and Google) exceeds half of the market (58%).

Also, the market share gain (last four quarters basis) of each of the BIG 4 is zero or greater (+1% for Amazon, +3% for Microsoft, 0% for IBM and +1% for Google), while those of the Next 10 and the Rest of Market are negative (−1% for the Next 10 and -5% for the Rest of Market). Together with the fact that this market is enjoying a steady annual growth rate of over 40%, as shown in Fig. 1, the annual growth rate of the BIG 4 should be much higher than that of the Next 10 and the Rest of Market combined, as the BIG 4 has been demonstrating a stronger presence.

Table 3 tabulates the recent development of the cloud infrastructure service (including IaaS, PaaS and hosted private cloud services) market[6] share of the BIG 4, based on the press releases of Synergy Research Group. It should be noted that the trend of the BIG 4's market share has been one of growth, and it would be fair to expect that the BIG 4 will hold a larger market share and exert a larger influence on the market in the future.[7]

A similar trend can be observed in Japan's cloud computing service market.

Table 4 tabulates the most used public cloud computing service providers in Japan, based on MM Research Institute press releases. All of these results are based on its web survey conducted of businesspeople who are responsible for managing and/or operating information systems or who are in a position to make decisions and/or to choose information systems.[8 9]

[2] According to The Economist (August 27, 2016), nearly two-thirds of Amazon's AWS's (Amazon Web Services) more than one million customers are startups, although it increasingly also serves big firms, such as General Electric and Netflix.

[3] In referring to the cloud computing use rate statistics appearing in the Ministry of Internal Affairs and Communications' (MIC) 2016 Communications Usage Trend Survey, the MIC analysis noted an upward trend in cloud computing use in firms with less than 1 billion JPY (equivalent to 9.41 million USD as of the end of March 2018) capital:

Firms with less than 100 million JPY capital: 33.6% (2014), 36.9% (2015), 40.4% (2016).

Firms with capital between 100 million and 1 billion JPY: 43.7% (2014), 53.3% (2015), 59.5% (2016).

Firms with more than 1 billion JPY capital: 62.6% (2014), 76.7% (2015), 72.4% (2016).

[4] See Bresnahan and Trajtenberg (1995) and Helpman (1998).

[5] Data of and before 2016 Q1 are for cloud infrastructure services (IaaS, PaaS, private & hybrid combined) market.

[6] Data of and before 2016 Q1 are for cloud infrastructure services (IaaS, PaaS, private & hybrid combined) market.

[7] The Herfindahl-Hirschman Index (HHI) of 2017 2Q calculated based on the market shares of Amazon (34%), Microsoft (11%), IBM (8%) and Google (5%) is 1,346 (Firms with smaller shares are ignored, because such firms increase the HHI for sure, but not significantly). Also, the HHI of 2016 2Q calculated based on the market shares of Amazon (33%), Microsoft (8%), IBM (8%) and Google (4%) is 1,233 (Each market share of the BIG 4 was calculated based on the data in Table 2). The HHI increased from 2016 2Q to 2017 2Q.

[8] There is a drop in Amazon's use rate from 41.4% (Aug 2015) to 34.1% (Oct/Nov 2016) and, during a telephone interview with MM Research Institute, an analyst indicated that this would be due to an increase in the number of firms that use multiple cloud service providers.

[9] Since multiple answers were allowed in this survey, the HHI calculation is not feasible.

Table 1
Some examples of published market forecasts on cloud computing in Japan*1 (Unit: Billion JPY).

	2016	2017	2018	2019	2020	2021
Domestic IT Market (IDC, Nov 2017*)		16,578				
Domestic ICT Market (IDC, Aug 2016*)	25,496				25,163	
Domestic Cloud Market (MM Research Institute, Dec 2017*3)	1,400		2,129		3,206	3,571
Domestic Public Cloud Service Market (IDC, Sep 2017*)	384	489				1,099
(MM Research Institute, Dec 2017**)	388					1,056
Domestic Private Cloud Market (MM Research Institute, Dec 2017**)	1,012					2,516

Note 1: Tabulated based on press releases, which do not necessarily clearly define market, terms of use, or premises and assumptions used.
Note 2: * indicates calendar year.
Note 3: ** indicates fiscal year. Japan's fiscal year starts in April and ends in March.
Note 4: 1 USD is equivalent to 106.24 USD as of the end of March 2018.

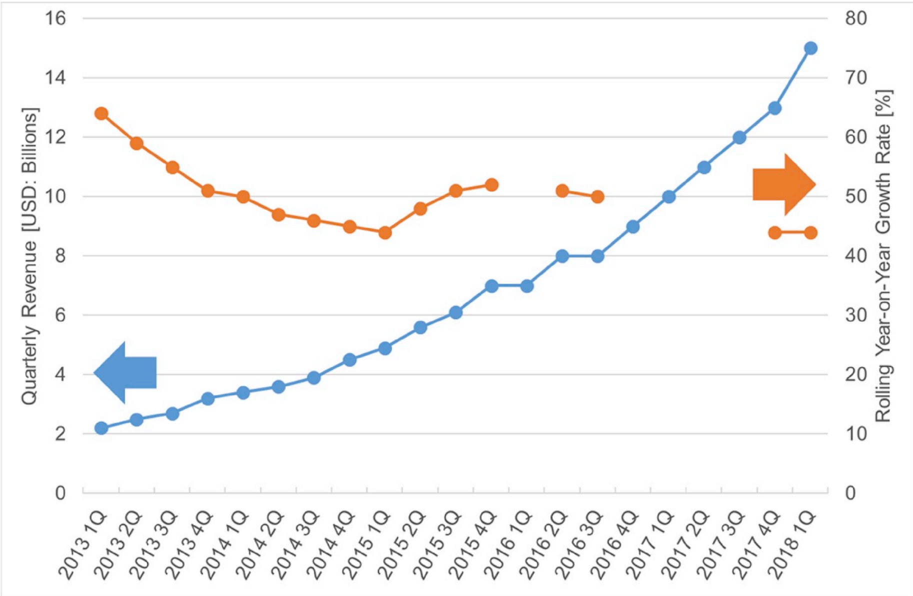

Fig. 1. Recent development of cloud infrastructure service (including IaaS, PaaS and hosted private cloud services) market. Source: Synergy Research Group's press releases. Note: Some data is taken by the author from a chart within the press release.

Table 2
Market shares of cloud infrastructure service (including IaaS, PaaS and hosted private cloud services) market (2017 Q2).

	Market Share	Market Share Gain (Last Four Quarters)
Whole Market	100%	±0%
The BIG 4	58%	N/A
Amazon	34%	+1%
The Next 3	24%	N/A
Microsoft	11%	+3%
IBM	8%	±0%
Google	5%	+1%
The Next 10	19%	-1%
The Rest of Market	22%	-5%

Source: Synergy Research Group’s press release
Note 1: The Next 10 includes Alibaba, Fujitsu, NTT, Oracle, Rackspace and Salesforce.
Note 2: Some data is taken by the author from a chart within the press release.

Table 3
Recent development of cloud infrastructure service (including IaaS, PaaS and hosted private cloud services): market share of the BIG 4 (Amazon, Microsoft, IBM and Google) on a yearly basis.

	2013 2Q	2014 2Q	2015 2Q	2016 2Q	2017 2Q
The BIG 4(Amazon, Microsoft, IBM and Google)	41%	46%	54%	53%	58%

Source: Synergy Research Group's press releases dated July 24, 2015 and July 27, 2017.
Note: 2016 2Q data is calculated by the author based on the data from the press release dated July 27, 2017.

Table 4
The most used public cloud computing service providers in Japan.
Source: MM Research Institute's press releases.

(Unit: %)

IaaS/PaaS (N = 251) as of Aug 2015		IaaS/PaaS (N = 223) as of Oct/Nov 2016		PaaS (N = 210) as of Dec 2017		IaaS (N = 262) as of Dec 2017	
Amazon	41.4	Amazon	34.1	Amazon	41.4	Amazon	35.5
Microsoft	18.7	Microsoft	20.2	Microsoft	29.0	Microsoft	24.8
Google	12.7	Google	10.8	Google	17.1	FUJITSU	12.6
NTT Com.	10.8	FUJITSU	10.3	FUJITSU	12.9	Nifty	9.5
FUJITSU	9.2	Sakura Internet	9.0	Salesforce	12.9	IBM	9.2
		Nifty	8.1	NTT Com.	10.0	NTT Com.	7.6
						Google	7.3

Note: Multiple answers were allowed.

1.3. Literature review

In order to estimate and analyze the impact of the shift of the cloud computing market to a market with oligopolistic characteristics on utility-based social welfare, DSGE (Dynamic Stochastic General Equilibrium) model-based simulation is conducted. DSGE is a sophisticated simulation tool employed to describe how macroeconomic variables collectively evolve as a result of shock (perturbation) applied to their initial state and converge to their steady state over time, by modeling the theory of microeconomics. It has been used primarily in the development of monetary and fiscal policies by academic researchers and policy makers, such as governments and international organizations.

A variety of research papers that employ the DSGE-model have been published so far, and it would be possible to classify these research papers into three major categories; (1) research on DSGE-modeling itself and DSGE-model parameter estimation method; (2) research on verification of goodness of fit of the DSGE-model to the actual economy and evaluation of the effectiveness of economic policies; and (3) research on application of DSGE-model to a particular sector. Since our analysis on the impact of cloud computing on the Japanese macroeconomy would fall into this third category, the following literature review is focused on this category.

With respect to the third category, many research papers have focused on the behavior of a particular industry sector or household sector and its relationship with a whole economy. For instance, Hou, Mountain, and Wu (2016) examined the macroeconomic effects of oil price shocks and the oil shock transmission mechanism in an oil-exporting country, Canada. Sanchez (2011) investigated the relationship between monetary policy and oil prices in the post-1990 period in Europe. Based on the importance of houses as one of the key durable goods for the household sector, Iacoviello and Neri (2010) studied sources and consequences of fluctuations in the US housing market and found that spillovers from the housing market to the broader economy are nonnegligible. Mayer and Gareis (2013) also analyzed the housing issue in Ireland, while Ng (2015) investigated the issue in the case of the Chinese economy. Further, Holden (2010) examined the change of patent policy and its impact on productivity.

In his pioneering research, Etro (2009) quantitatively estimated the impact of the diffusion of cloud computing based on DSGE simulations and demonstrated that it has made a positive contribution to GDP, employment and business creation in 27 European countries. Etro (2009) applied DSGE to the ICT field, using the theory of the endogenous market structure. His model can be summarized as follows: (1) cloud computing reduces the ICT initial fixed costs of entry and production of all firms in all sectors, turning part of those fixed costs into variable costs; (2) the lowered barriers to entry result in an increase to the number of market entrants; (3) competition in each market is enhanced and tends to reduce markups; and (4) as a GPT, cloud computing does not directly augment TFP (Total Factor Productivity); however, there occurs gradual ICT capital accumulation over time. In addition to Etro (2009), to the best of our knowledge, there exist three more research papers in which DSGE was applied to cloud computing: Takagi and Tanaka (2014), Tamegawa, Ukai, and Chida (2014) and Tamegawa, Ukai, and Chida (2015).

To the best of our knowledge, there do not exist any research papers that discussed the relationship between the shift of the cloud computing market to a market with oligopolistic characteristics and utility-based social welfare in the cloud computing market, utilizing the DSGE model-based simulation. Thus, this research paper would be the first to cover the cloud computing market, utility-based social welfare and DSGE model-based simulation simultaneously. If we do not limit our search to research papers that cover all of three of these areas simultaneously, there exist some. For example, Mendicino and Pescatori (2004) attempted a welfare-based monetary policy evaluation in a model with heterogeneous agents and households' credit constraints for household indebtedness and housing prices, utilizing DSGE model-based simulation. Thus, Mendicino and Pescatori (2004) covered utility-based social welfare and DSGE, but not cloud computing. Feng, Li, and Li (2014) conducted game theoretic study on optimal pricing behaviors of cloud service providers in monopolistic, duopolistic and oligopolistic markets of IaaS cloud service. Thus, Feng et al. (2014) covered cloud computing and monopolistic, duopolistic and oligopolistic markets, but not DSGE.

1.4. The Scope and purpose of the research

In this paper, we would like to quantitatively estimate the relationship between the shift of the cloud computing market to a market with oligopolistic characteristics and the utility-based social welfare of Japan, and provide data that can be used for policy formulation in the promotion, development and rule-making of the cloud computing market. We believe that the purpose of a policy measures would be to enhance social welfare and that utility-based social welfare would be one of the most suitable indicators for policy measure evaluation. This is the reason why we choose to estimate utility-based social welfare, rather than GDP, in this paper.

We assume that a market with oligopolistic characteristics can be represented by a market with constraint, a market in which the market entry cost is set at a higher value due to exogenous reasons. One example of exogenous reasons would be the introduction of a regulation concerning location of computing facilities (to require firms to locate computing facilities domestically as a condition for conducting business in that country). Another example would be the introduction of a regulation concerning source code (to require firms to disclose source code of software to authorities as a condition for conducting business in that country). Upon the introduction of these regulations, the market may be constrained and less competitive, and thus the market entry cost may become higher and the market may shift to one with oligopolistic characteristics.

Also, in this paper we consider the cloud computing market one with oligopolistic characteristics. This is (1) because the market share of the BIG 4 (Amazon, Microsoft, IBM and Google) is growing overall (see Table 3); (2) because the HHI is increasing (see footnote 6); (3) because in many cases cloud computing service is provided as SaaS, PaaS or IaaS, rather than simple data storage service, and thus the market possesses characteristics such as network externalities; and (4) because there exist research papers, such as Feng et al. (2014) and other subsequent papers, in which discussions are made based on the premise that IaaS cloud service is an oligopolistic market.

In addition, in this paper, we do not take the position that a market with oligopolistic characteristics or excess profit is inappropriate in and of itself, as far as there is no abuse of dominant/superior position. This is because a free and competitive market may become one with oligopolistic characteristics. Also, profit accumulated in a market with oligopolistic characteristics may be used for investment and/or R&D as part of the firms' long-term vision.

According to the Economic and Social Research Institute, Cabinet Office, Japan's FY2017 real GDP (from April 2017 through March 2018) was 533 trillion JPY,[10] and the size of Japan's 2017 domestic public cloud service market was 489 billion JPY[11] (see Table 1). It would be possible to argue that cloud computing has not been studied much in DSGE literature in the past, simply because the cloud computing sector is not as big in terms of % of GDP as the oil (Hou et al. (2016) and Sanchez (2011)) or housing sectors (Iacoviello and Neri (2010)). However, for the purpose of illustrating the dynamic interaction of the macroeconomic variables of the cloud computing sector, it would be useful to employ DSGE regardless of its size in terms of % of GDP.

The main objectives of the paper, rather than to ascertain the exact change of utility-based social welfare, are (1) to determine whether there is a (realistic) shifting path of macroeconomic variables in Japan's case, under certain conditions where the shift of the cloud computing market to a market with oligopolistic characteristics exists and (2) to illustrate the dynamic interaction of the macroeconomic variables.

The organization of this paper is as follows. In Section 2, the utility-based social welfare estimation scheme is presented based on the model of a system comprised of a single sector of cloud computing service and a simulation is conducted with the simulation parameters calibrated to the Japanese ICT market. Also, the simulation results are applied to the whole Japanese economy and the impact of the shift of cloud computing market to a market with oligopolistic characteristics on the macroeconomy in Japan is estimated, based on the relationship between the system and the whole Japanese economy. In Section 3, some free trade agreements are presented and discussed as an example of inter-government policy measures that would work against the shift of cloud computing market to a market with oligopolistic characteristics. Also, some common concerns of service users and potential service users for NOT using cloud computing service are identified and some remarks are made concerning possible counter policy measures that the industry and government can take. Section 4 contains a final summary and analysis. Further analytical details on the model are provided in the Appendix. Appendix A describes the model and the Japanese ICT market-calibrated simulation parameters used in Section 2. Appendix B explains the relationship between the system and whole Japanese economy.

2. The Model and its simulation results

2.1. Simulation premises

Utility-based social welfare of a system comprised of a single sector of cloud computing is considered based on the expected

[10] Equivalent to 5.02 trillion USD (Exchange rate as of the end of March 2018 is used: 1 USD = 106.24 JPY).

[11] Equivalent to 4.60 trillion USD (Exchange rate as of the end of March 2018 is used: 1 USD = 106.24 JPY).

lifetime utility function of the representative household described in Appendix A as $U_t(C_t, L_t) = E_0\left[\sum_{t=0}^{\infty}\beta^t\left\{\ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right\}\right]$, where $E_t[\cdot]$ denotes the mathematical expectation operator at discrete time period[12] t, β $(0 < \beta < 1)$ represents the subjective discount factor, C_t and L_t represent the consumption and hours of work of the representative household at time period t, χ (> 0) represents the weight of the disutility of labor and φ (≥ 0) represents the Frisch elasticity of labor supply to wages. Since representative household possesses firms in the system, this utility function can be considered to represent the utility-based social welfare of the system.

As mentioned in "1.4 The Scope and Purpose of the Research," we assume that a market with oligopolistic characteristics can be represented by a constrained market in which the market entry cost is set at a higher value due to exogenous reasons, such as the introduction of a domestic regulation.

In our setting, at time period 0, the system is at Cournot equilibrium ("initial Cournot equilibrium" or "baseline"). At time period 1, the system undergoes a sudden shock that makes the market entry cost increase and maintain that value. The system evolves according to the set of 15 simultaneous equations in Appendix A, and after a certain period of time has lapsed, it reaches the new steady-state ("constrained Cournot equilibrium").[13]

Accordingly, in order to estimate the decrease of utility-based social welfare due to a shift from the initial Cournot equilibrium to the constrained Cournot equilibrium, we define the change of utility-based social welfare ΔU to be the difference between (a) the utility-based social welfare of the system in which the initial Cournot equilibrium undergoes a sudden shock that makes the market entry cost increase and maintain that value, shifting to the constrained Cournot equilibrium and (b) the utility-based social welfare of the system in which the constrained Cournot equilibrium does not undergo any shock and the constrained Cournot equilibrium remains the same throughout the time-scale. Under this estimating scheme, we have:

$$\Delta U = -\left[\sum_{t=0}^{\infty}\beta^t\left\{\ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right\}\right] - \left[\sum_{t=0}^{\infty}\beta^t\left\{\ln(C_*) - \chi\frac{L_*^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right\}\right] = -\left[\sum_{t=0}^{\infty}\beta^t\left\{\left(\ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right) - \left(\ln(C_*) - \chi\frac{L_*^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right)\right\}\right]$$
$$\equiv -\left[\sum_{t=0}^{\infty}\beta^t\{uu_{shock} - uu_{stable\ (constrained)}\}\right] \tag{1}$$

where C_* and L_* represent consumption and hours of work at the time of t_* in which enough amount of time has elapsed so that the system reaches to the constrained Cournot equilibrium, respectively, $uu_{shock} = \ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}$ and $uu_{stable\ (constrained)} = \ln(C_*) - \chi\frac{L_*^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}} = constant$.

In solving, by hand, the set of 15 simultaneous equations in Appendix A at the constrained Cournot equilibrium, we have the following equation that describes the relationship between the market entry cost at the constrained Cournot equilibrium v_* and the number of existing firms at the constrained Cournot equilibrium n_*:

$$v_*^{1+\varphi} = \frac{\left\{A\cdot\frac{n_*-1}{n_*}\cdot\alpha^{\alpha}\cdot\left(\frac{1-\alpha}{r_*}\right)^{1-\alpha}\right\}^{\frac{1+\varphi}{\alpha}}}{\left\{\chi\cdot\frac{1-\beta(1-\delta)}{\beta(1-\delta)}\cdot n_*^2\left(1-\delta^k\frac{1-\alpha}{r_*}\cdot\frac{n_*-1}{n_*}\right)\right\}^{\varphi}\cdot n_*\cdot\left\{\alpha\cdot\frac{1-\beta(1-\delta)}{\beta(1-\delta)}\cdot(n_*-1) + \frac{\delta}{1-\delta}\right\}} \tag{2}$$

where A represents TFP (Total Factor Productivity), α represents labor share, r_* represents the interest rate at the constrained Cournot equilibrium, δ^k represents physical depreciation rate and δ represents market exit rate of firms.

Fig. 2 illustrates the graph of equation (2). Both the market entry cost at the constrained Cournot equilibrium v_* and the number of existing firms at the constrained Cournot equilibrium n_* are normalized by the market entry cost at the initial Cournot equilibrium v_0 and the number of existing firms at the initial Cournot equilibrium n_0, respectively ($v_* > v_0$ and $n_* < n_0$). By setting the market entry cost at the constrained Cournot equilibrium v_*, we know the number of existing firms at the constrained Cournot equilibrium n_*. The smaller n_* becomes, the higher v_* becomes, which matches our assumption that a market with oligopolistic characteristics can be represented by a constrained market, a market in which the market entry cost is set at a higher value due to exogenous reasons.

Since empirical data that describes the relationship between the advancement of the degree of oligopolistic characteristics and the increase of market entry cost does not seem to be available, we assumed that $\frac{n_*}{n_0} = 0.95$ and thus $\frac{v_*}{v_0} = 1.096$. The increase of the market entry cost of 9.6%[14] can have a considerably strong impact on the system, as Etro (2009) set the decrease of the market entry cost of 5% when he estimated the impact of the advancement of the cloud computing on the GDP. Thus, the size of the shock applied to market entry cost e_t, which appears in equation (A15) in Appendix A, is set to 0.096. In the simulation this shock is applied for the period of one quarter.

[12] The unit of time used is a quarter.

[13] In the simulation, in order to judge whether a variable reaches its steady-state, a 0.1% range of the steady-state value of the variable is used.

[14] (1.096–1.000)/1.000 = 0.096.

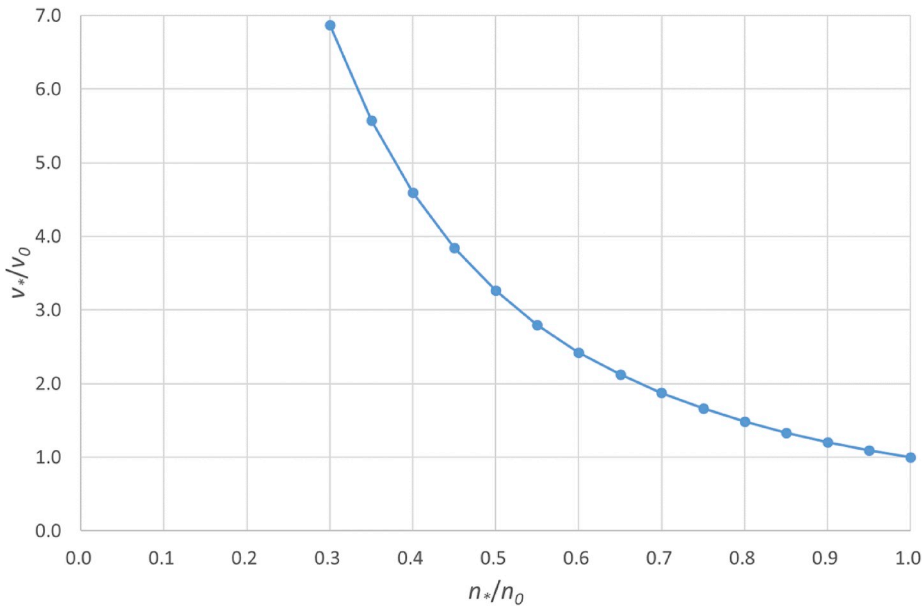

Fig. 2. Relationship between the market entry cost at the constrained Cournot equilibrium v_* and the number of existing firms at the constrained Cournot equilibrium n_*. Note: Both v_* and n_* are normalized by the market entry cost at the initial Cournot equilibrium v_0 and the number of existing firms at the initial Cournot equilibrium n_0, respectively.

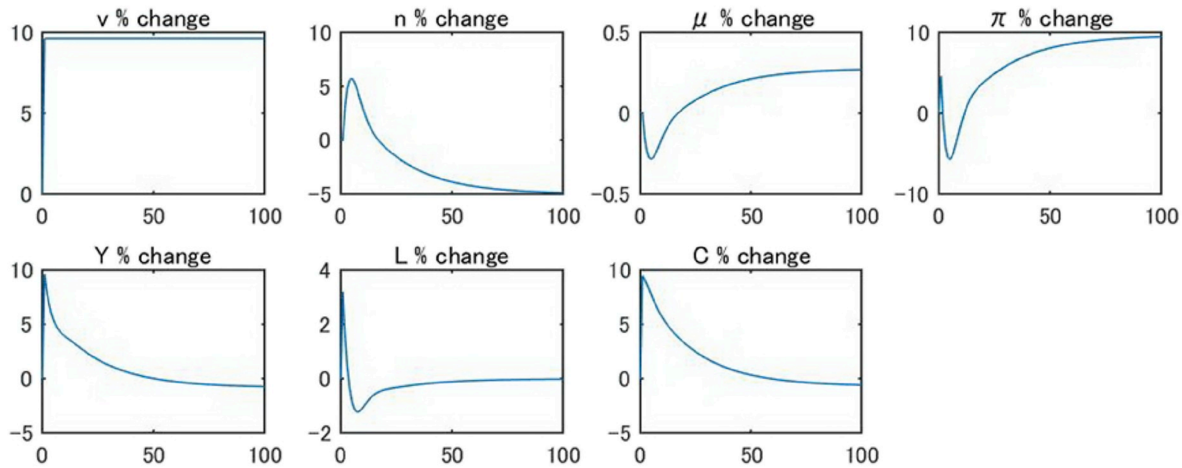

Fig. 3. Simulation result ($\frac{n_*}{n_0}$ = 0.95). Note: The horizontal axis represents time t and its unit is a quarter.

2.2. Simulation results

Fig. 3 is the result of the simulation where $\frac{n_*}{n_0}$ = 0.95. Also, the change of utility-based social welfare ΔU equals −0.373 in terms of the consumption at the initial Cournot equilibrium C_0. Therefore, the utility-based social welfare loss equals 37.3% in terms of C_0.

The market entry cost v increases sharply due to the applied shock and then maintains its steady-state value at the constrained Cournot equilibrium (v_*). As a result of the increase of v, the number of firms n increases at the early stage; however, it then gradually decreases and reaches its steady-state value, which is smaller than its initial value. As n decreases, the price markup μ increases, the profit of the representative firm π increases and the output Y decreases.

This simulation result could be understood with the following story and model equations described in Appendix A: An increase of the market entry cost v causes a decrease of the number of new entrants ne, which decreases the number of firms n (A5). As n decreases, the market becomes less competitive, increasing the degree of oligopolistic characteristics, and the price markup μ increases (A13), raising the profit of the representative firm π. Accordingly, the output contributed by existing firms YC, which is equal to the product of π and n^2 (A14), decreases and the output contributed by market entrants $ne*v$ increases. Consequently, the output Y, which is comprised of YC and $ne*v$ (A6), decreases, because the decrease of YC is larger than the increase of $ne*v$.

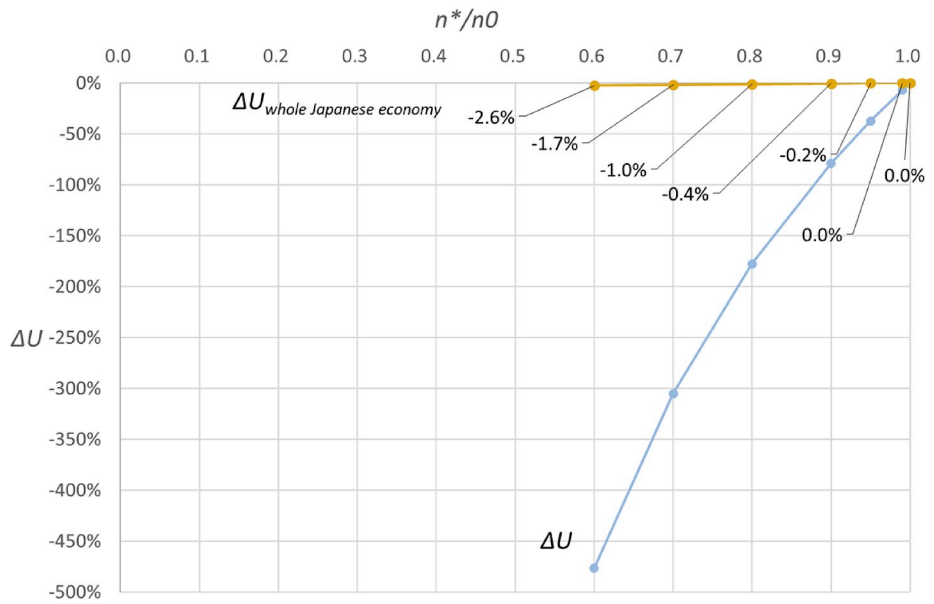

Fig. 4. The change of the utility-based social welfare ΔU and the change of the utility-based social welfare of the whole Japanese economy $\Delta U_{whole\ Japanese\ economy}$ for each simulation result of $\frac{n_*}{n_0}$ = 0.60, 0.70, 0.80, 0.90, 0.95, 0.99 and 1.00.

Based on Appendix B (the relationship between a system comprised of a single sector of cloud computing service and the whole Japanese economy), the impact on the whole Japanese economy can be estimated by multiplying the coefficient of 5.48×10^{-3} by the simulation result in a system comprised of a single sector of cloud computing. Thus, the change of the utility-based social welfare of the whole Japanese economy $\Delta U_{whole\ Japanese\ economy}$ equals -0.204% in terms of consumption.

Fig. 4 illustrates the values of the change of the utility-based social welfare ΔU and the change of the utility-based social welfare of the whole Japanese economy $\Delta U_{whole\ Japanese\ economy}$ for each simulation result of $\frac{n_*}{n_0}$ = 0.60, 0.70, 0.80, 0.90, 0.95, 0.99 and 1.00.[15] It is observed that as the number of existing firms at the constrained Cournot equilibrium n_* decreases, which means that the degree to which the oligopolistic characteristics of the market increase, the change of the utility-based social welfare ΔU and the change of utility-based social welfare of the whole Japanese economy $\Delta U_{whole\ Japanese\ economy}$ decrease (the utility-based social welfare loss increases).

3. Policy measures of industry and government for cloud computing market

3.1. Domestic regulation and free trade agreements in the field of electronic commerce

Globally, in the field of electronic commerce, there are some countries that are interested in such policy measures as the introduction of a regulation concerning location of computing facilities and the introduction of a regulation concerning source code. On the other hand, there are several countries that expect electronic commerce to contribute to economic growth, and some of them have begun signing trade treaties, such as the TPP 11 Agreement[16] and the Japan-EU Economic Partnership Agreement,[17] both of which include several policy measures to avoid unnecessary barriers to use and development of electronic commerce.

In particular, Chapter 14 of the TPP 11 Agreement deals with electronic commerce and includes several articles to avoid unnecessary barriers to use and development of electronic commerce,[18] [19] concerning topics including cross-border transfer of

[15] For each case, similar to the case of $\frac{n_*}{n_0}$ = 0.95, the market entry cost at the constrained Cournot equilibrium ν_* is set based on equation (2).

[16] On March 8, 2018, the Ministers and Senior Officials representing Australia, Brunei Darussalam, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore and Vietnam signed the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (TPP 11 Agreement) at Santiago, Chile.

[17] On July 17, 2018, Mr. Shinzo Abe, the Prime Minister of Japan, H.E. Mr. Donald Tusk, President of the European Council and H.E. Mr. Jean-Claude Juncker, President of the European Commission signed the Agreement in Tokyo, Japan, expecting that this Agreement will promote the liberalization and facilitation of trade and investment between Japan and the European Union and will further vitalize both economies by strengthening reciprocal economic ties in wide-ranging fields.

[18] Article 14.2 Scope and General Provisions: “1. The Parties recognise the economic growth and opportunities provided by electronic commerce and the importance of frameworks that promote consumer confidence in electronic commerce and of avoiding unnecessary barriers to its use and development.”

[19] These are newly crafted agreements, and they are not found in the sections of the WTO service negotiations relevant to arrangements in telecommunications.

information by electronic means,[20] location of computing facilities[21] and source code.[22]

In the case of the Japan-EU Economic Partnership Agreement, electronic commerce is stipulated in Section F. Electronic commerce is expected to contribute to economic growth and increase trade opportunities in many sectors,[23] and there are several articles to facilitate electronic commerce, concerning topics including source code policy.[24] Also, there is an article stating that both parties will reassess the need for inclusion of provisions on the free flow of data within three years.[25]

If we apply the simulation result from Section 2 to this setting, the following description of the situation would be possible. If a country introduces domestic regulations, such as regulations requiring firms to locate computing facilities domestically or to disclose source code of software to authorities, the market entry cost of the country would increase, causing a decrease in the number of market participants and a decrease in the utility-based social welfare. On the other hand, if the country is a member-state of a free trade agreement under which these domestic regulations are not allowed, sudden market entry cost increase would not occur, and accordingly, a decrease in the number of market participants and the utility-based social welfare would not occur, either.

3.2. Some basic principles for formulating policy measures for cloud computing market

In this sub-section, referring to two survey results, we would like to focus on three common concerns of service users and/or potential service users for NOT using cloud computing service: (1) data security; (2) personal data protection; and (3) cloud portability (cloud inter-operability). We also would like to make some remarks concerning possible counter policy measures that the industry and government can take.

Table 5 tabulates the survey results on the reasons for NOT using cloud computing service. This data was taken from 2014 Communications Usage Trend Survey conducted by the MIC. Answers were from those who answered "Not used and no plans to use in the future" (n = 513), allowing multiple answers.

Table 6 tabulates the web-survey results to the question "For each situation, to what degree do you think a shift from private to public cloud computing will occur?" This web-survey was conducted by the MIC in March 2014. The purpose of the web-survey was to understand the usage trend of cloud computing and other new ICT services by Japanese firms, and it targeted businesspeople who have a position at their firms that involves screening and/or making final decisions on ICT investments, which include internal ICT systems, network infrastructure, servers and information securities, representing 34 industry segments. The number of total respondents was 1,527, with 762 respondents representing firms that have introduced cloud computing and 765 respondents representing firms that have not. For each situation about 40–50% of the respondents agreed that there will occur a shift from private to public cloud computing ("Big shift" and "Some shift"). It is true that this question is asking the likeliness of a shift from private cloud to public cloud, however it may be fair to consider that the result would indicate a similar likelihood of a shift from non-cloud users to cloud users, because of the similar natures of private cloud service and conventional ICT.

Based on these two survey results, besides firm-specific internal concerns, it would be fair to conclude that there exist three common concerns of (1) data security; (2) personal data protection; and (3) cloud portability (cloud inter-operability) among service users and/or potential service users.

As for (1) data security and (2) personal data protection, items (b), (h) and (i) in Table 5 and items (b) and (e) in Table 6 would be relevant. In formulating policy measures concerning data security and/or personal data protection, it would be highly important to set a demarcation line of responsibility between service providers and service users. With the responsibility demarcation line, service providers can more realistically estimate the maximum market risk and required amount of investment to maintain such service levels. On the other hand, service users and potential service users can more easily make decisions on procuring service, knowing the risks involved and their responsibilities. These conditions would enhance competition and expand the market. Also, the advancement of data encryption technology, which is relevant to item (d) in Table 6, may decrease the risks of data access by unauthorized parties and may stimulate market demand as well.

As for (3) cloud portability, item (f) in Table 6 would be relevant and some Table 5 survey respondents who had concerns on cloud portability may have chosen item (i), because in Table 5 survey there were not available any items that explicitly correspond to cloud portability. In crafting policy measures concerning cloud portability, it would be imperative that service providers are required to transfer data from one service provider to another within a reasonable time and cost and to provide the exhaustive erasure of the user data after such a transfer. These requirements would allow service users to more easily switch from one service provider to another and encourage potential service users to start subscribing to cloud services. Also, it would introduce more competition and churn to the market. Thus, policy measures on cloud portability are pro-competition as well.

[20] Article 14.11 Cross-Border Transfer of Information by Electronic Means: "Each Party shall allow the cross-border transfer of information by electronic means, including personal information, when this activity is for the conduct of the business of a covered person."

[21] Article 14.13 Location of Computing Facilities: "2. No Party shall require a covered person to use or locate computing facilities in that Party's territory as a condition for conducting business in that territory."

[22] Article 14.17 Source Code: "1. No Party shall require the transfer of, or access to, source code of software owned by a person of another Party, as a condition for the import, distribution, sale or use of such software, or of products containing such software, in its territory."

[23] Article 8.70 Objective and general provisions: "1. The Parties recognise that electronic commerce contributes to economic growth and increases trade opportunities in many sectors. The Parties also recognise the importance of facilitating the use and development of electronic commerce."

[24] Article 8.73 Source code: "1. A Party may not require the transfer of, or access to, source code of software owned by a person of the other Party."

[25] Article 8.81 Free flow of data: "The Parties shall reassess within three years of the date of entry into force of this Agreement the need for inclusion of provisions on the free flow of data into this Agreement."

Table 5
Reasons for NOT using cloud computing service.

Reasons for NOT Using Cloud Computing Service	Percent
(a) Not in need	44.7
(b) Concern on data security, such as data breach	34.5
(c) Cannot find and/or judge its merit	22.5
(d) Huge modification cost of current system for the introduction	19.1
(e) Concern on network stability	10.2
(f) Concern on communications cost increase	9.0
(g) Cannot customize applications for cloud computing service	6.9
(h) Have conflict with its own firm's compliance rules	6.6
(i) Relevant laws and regulations are not well prepared.	3.3
(j) Others	6.7

Source: 2014 Communications Usage Trend Survey by the MIC.
Note 1: Asked to those who answered "Not used and no plans to use in the future" (n = 513).
Note 2: Multiple answers were allowed.

Table 6
Web-survey results on the question of "For each situation, to what degree do you think a shift from private to public cloud computing will occur?" (Unit: %).
Source: Web-survey conducted by the MIC in March 2014.

	Big shift	Some shift	No shift
(a) Public cloud becomes popular.	10.0	38.9	51.1
(b) Advancement of data security is expected. For example, proper regulation is introduced or is harmonized internationally.	5.9	42.0	52.1
(c) Private cloud becomes popular.	8.8	38.4	52.8
(d) Data encryption technology is advanced and data access from unauthorized personnel is not expected.	6.5	36.6	56.9
(e) Advancement of personal data protection is expected. For example, proper regulation is introduced or is harmonized internationally.	5.3	36.2	58.5
(f) Cloud portability becomes popular.	6.1	33.3	60.6

Once these policy measures (data security and personal data protection, data encryption technology and cloud portability) are implemented, it would be beneficial to both service providers and service users and potential service users, contributing to competition enhancement, demand stimulation and market expansion; the market, in this case, meaning the cloud computing market, ICT market and the whole country's economy. If these policy measures were more thoroughly implemented, the market entry cost would be maintained not unduly high and new entrants would continuously enter the market.

Since these policy measures are pro-competitive, they would work against a market shift to one with oligopolistic characteristics and offset the utility-based social welfare loss. Having said this, since the cloud computing service market itself possesses network externalities, low marginal cost and economies of scale, even if there is not any market entry cost increase, the market may shift to one with oligopolistic characteristics and induce utility-based social welfare loss.

Also, these policy measures may not only expand the market but also encourage service providers to offer a larger variety of service choices to service users and potential service users. Some services may use cutting edge technologies, be provided at cheaper prices and integrate with other relevant service layers, such as the network layer, package software layer, SI (System Integration) service layer and consulting service layer. This means that these policy measures may induce dynamism and churn in the market.

It should be noted that while implementing these policy measures would be beneficial for sure, the actual style of policy measures to be implemented would vary from country to country, depending on each country's policy decision-making. During this policy decision-making, several factors would be considered, possibly including the stage of development of the cloud computing market, expected role of cloud computing market within the country's whole economy, and policy priority order/balance among elements, such as market growth, fair competition, tolerance to the shift of the market to a market with oligopolistic characteristics, and fostering SMEs. Also, the implementation of the policy measures would vary as well; some countries may prefer behavioral guidelines to regulatory framework and some may prefer the opposite. Further, in order to formulate these policy measures properly and to allow them to function to their fullest potential, they should be formulated and revised through close and continuous discussion between industry and government. Since input from service users and potential service users (both corporate and private) would make the policy measures more effective, they should also be kept well informed and should have the opportunity to contribute.

3.3. Discussion

To the best of our knowledge, there do not exist any research papers that cover the cloud computing market, utility-based social welfare and DSGE model-based simulation simultaneously and that makes this research paper the first in this topic. Etro (2009), Takagi and Tanaka (2014), Tamegawa et al. (2014) and Tamegawa et al. (2015) are the research papers in which the DSGE model was applied to the cloud computing market. Also, Mendicino and Pescatori (2004) covered utility-based social welfare and DSGE (but not cloud computing) and Feng et al. (2014) covered cloud computing and monopolistic, duopolistic and oligopolistic markets (but not DSGE).

Etro (2009) discussed the impact of the diffusion of cloud computing and its positive contribution to GDP, employment and business creation in 27 European countries. In our modeling, we followed, among other papers, Etro (2009). However, we introduced the investment adjustment cost function in order to reflect the effect of the nature of stickiness (persistency) of investment, following Christiano, Eichenbaum, and Evans (2005). In this respect, we departed from Etro (2009)'s model (see Appendix A).

Takagi and Tanaka (2014) discussed the impact of the diffusion of cloud computing on a macroeconomic scale, assuming three paths of (1) cloud computing increases productivity of firms because lower IT costs enable more firms to benefit from IT; (2) cloud computing lowers entry cost for new firms and thus increases the number of firms, raising productivity by intensifying the competition among firms and promoting innovation, and transferring resources to more productive sectors; (3) cloud computing reduce the output of the domestic information services industry by intensified international competition. However, Takagi and Tanaka (2014) assumed the fixed trend of cloud computing diffusion that takes 16 years to reach 20% share with marginal diffusion decrease over time. This means that their simulations calculated the behaviors of macroeconomic variables without considering their interaction with the diffusion of cloud computing. On the contrary, our model does not adopt such assumptions. Also, Takagi and Tanaka (2014) treated all the sectors of Japan's economy equally with common macroeconomic variables and parameters, while we considered the usage rate of cloud computing services by six industrial categories of (1) Construction, (2) Manufacturing, (3) Transport and Postal Activities, (4) Wholesale and Retail, (5) Finance and Insurance and (6) Service and Other Industries (see Appendix B). Further, Takagi and Tanaka (2014) took the values of parameters, such as labor share, discount factor and market exit rate of firms, from Griffoli (2011) in which calibration was obviously not made for the Japanese market. By contrast, we calibrated parameters for the Japanese market (see Appendix A).

Tamegawa et al. (2014) and Tamegawa et al. (2015) discussed the relationship between cloud computing adoption rate increase and productivity increase. In their model, firms were divided into two groups (firms using cloud computing and firms not using cloud computing), and a different production function was prepared for each group of firms. However, Tamegawa et al. (2014) and Tamegawa et al. (2015) fixed the share of those using cloud computing as 0.1 throughout their simulation. This means that their simulations calculated the behaviors of macroeconomic variables without considering their interaction with the diffusion of cloud computing. Also, similar to Takagi and Tanaka (2014), Tamegawa et al. (2014) and Tamegawa et al. (2015) treated all the sectors of Japan's economy equally with common macroeconomic variables and parameters. In addition, Tamegawa et al. (2014) and Tamegawa et al. (2015) doubted the effectiveness of applying Etro (2009)'s modeling approach to the cloud service market in Japan, referring to Ukai (2013)'s findings that Japanese SMEs were not particularly interested in cloud computing. However, since the MIC noted an upward trend in cloud computing use in firms with less than 1 billion JPY[26] capital in its 2016 Communications Usage Trend Survey (see footnote 3), we take the position that Etro (2009)'s modeling approach is effective for the cloud service market in Japan.

The fact that Mendicino and Pescatori (2004) focused on utility-based social welfare and DSGE (but not cloud computing) and that Feng et al. (2014) analyzed cloud computing and monopolistic, duopolistic and oligopolistic markets (but not DSGE) would be a good indication of the importance of welfare-based evaluation in a DSEG model-based simulation setting and the importance of analysis of cloud service markets with oligopolistic characteristics, respectively.

4. Conclusions

The impact of the shift of the cloud computing market to a market with oligopolistic characteristics on the Japanese macroeconomy and its utility-based social welfare were quantitatively estimated and analyzed, utilizing DSGE model-based simulation. Based on the understanding that the purpose of a policy would be to enhance social welfare and that utility-based social welfare would be one of the most suitable indicators for policy measure evaluation, utility-based social welfare, rather than GDP, was chosen to be calculated in this paper. It was demonstrated that as the degree of oligopolistic characteristics increases, the utility-based social welfare decreases (the utility-based social welfare loss increases). Under the scenario in which the market entry cost v increases sharply 9.6% due to the applied shock and then maintains its steady-state value in a constrained market, the number of firms n increases at the early stage; however, it then gradually decreases and reaches its steady-state value, which is 5% smaller than its initial value. As n decreases, the market becomes less competitive and the degree of oligopolistic characteristics increases, resulting in 37.3% utility-based social welfare loss in terms of consumption in the system comprised of a single sector of cloud computing service and 0.204% utility-based social welfare loss in terms of consumption in the whole Japanese economy.

Since there were several significant assumptions made when applying the DSGE simulation results to the whole Japanese economy, it would be difficult to immediately utilize these findings for policy formulation purposes. However, the introduction of a regulation was modelled and its impact on Japanese economy simulated and the dynamic interaction of the macroeconomic variables within the endogenous market structure were illustrated.

In the field of multilateral and bilateral inter-government trade negotiations, the awareness of electronic commerce's potential contribution to economic growth and to trade opportunities in many sectors has grown and thus some countries have begun signing trade treaties. The TPP 11 Agreement and the Japan-EU Economic Partnership Agreement are examples of these treaties that include electronic commerce chapters with articles to avoid unnecessary barriers to use and development of electronic commerce. Cloud computing plays a vital role in electronic commerce. However, if those trade barriers were introduced, the market may be more

[26] Equivalent to 9.41 million USD (Exchange rate as of the end of March 2018 is used: 1 USD = 106.24 JPY).

constrained and less competitive, the market entry cost may be higher and the market may take on oligopolistic characteristics. The DSGE simulation and analysis conducted in this paper would be relevant to these global trends and would provide some useful quantitative information in evaluating the importance of those trade treaties that include articles to avoid the introduction of these trade barriers.

Also, some common concerns of service users and potential service users for NOT using cloud computing service are identified: data security and personal data protection, data encryption technology and cloud portability), and some remarks are made concerning possible counter policy measures that the industry and government can take. They would be beneficial to both service providers and service users and potential service users, contributing to the enhancement of competition, demand stimulation and market expansion.

This paper has merits pointed out thus far, but it possesses some limitations which can be addressed by further research. Various further works are expected, including a more detailed analysis of cloud computing using firms' behavior that would make both the simulation and analysis of relationship between the simulation results and whole Japanese economy more accurate.

This paper focused on cloud computing service. One of the services that affect our society on a larger scale would be the online platform service.[27] As ICT progresses and a huge amount of data is being generated and accumulated, innovative services are being created and their markets are rapidly expanding. One of the benefits of the online platform service would be the providing of opportunities (platforms) for matching between service providers and service users. Since both service providers and service users can be either B or C, a variety of services are being initiated though the platform. For example, B2X (B2B or B2C) includes searching services, online shopping malls, application markets, contents services (video, music and E-books), reservation services, sharing economy platforms, video-clip sharing services and E-payment services. C2C includes internet auctions, free online markets and SNS (social networking services). Leading online platformers are so-called GAFA (Google, Apple, Facebook and amazon).[28] These online platform services are beneficial in many ways. For instance, from the viewpoint of business participants (B), online platforms enhance their market access. This is especially true for SMEs and startups. From the viewpoint of consumers (C), online platforms expand the choices of goods and services and provide places for secure transactions. On the other hand, as online platform service plays a bigger role in our economy, there would be several issues which we need to consider to make sure it properly serves our society and enhances our economy. These issues include its tendency to shift to a market with oligopolistic characteristics due to, among other factors, the network externalities,[29] low marginal cost and the economy of scale.[30] [31] [32] In this regard, online platform service is similar to cloud computing service. Since the business model of cloud computing service is becoming more highly value-added (shifting from simple data storage service to SaaS, PaaS and IaaS) and there are many firms that are providing both services, cloud computer service may overlap with online platform service more in the future. Accordingly, once online platform service is more recognized as a service that tends to shift to a market with oligopolistic characteristics, what was discussed and analyzed in this paper for cloud computing service could be used for online platform service analysis.

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[27] "Online platform service" does not seem to have a commonly acknowledged definition. For example, the EU's report "Online Platforms and the Digital Single Market Opportunities and Challenges for Europe" published in May 2016, does not define "online platform service" and simply lists its representing services and features, instead.

[28] In the world ranking of company market capitalization as of the end of March 2018, GAFA companies ranked high; Apple, in first place, is about 851 billion USD; Alphabet (Google), in second place, is about 7,190 billion USD; Amazon, in fourth place, is about 700 billion USD; Facebook, in eighth place, is about 464 billion USD.

[29] In the case of online platform service, due to the nature of its multi-faceted market, there are two kinds of network externalities in play: direct network externality and indirect network externality. Direct network externality can be observed at the same layer (for example, the benefit of SNS increases as the number of SNS users increases) and indirect network externality can be found between layers (for instance, the benefit of an online shopping mall increases as the number of consumers at the online shopping mall increases.).

[30] In this regard, in Japan in July 10, 2018, the METI, the Fair Trade Commission (JFTC), and the MIC jointly launched the Study Group on Improvement of Trading Environment surrounding Digital Platform Business, which is comprised of experts from a variety of fields, including competition, information and consumer policies, and one of its agenda items being to consider the possible rules that respond to the rise of platform businesses.

[31] In its policy paper titled "Fundamental Principles for Rule Making to Address the Rise of Platform Businesses" dated December 18, 2018, the Study Group of the METI, the JFTC and the MIC states that digital platforms provide multi-faceted markets that accommodate participants from multiple layers and are said to tend to progress monopolization and oligopolization through their characteristics, such as network effect, low marginal cost and scale economy.

[32] While Japan is in the stage of considering possible rules, the EU has gone much further. On April 26, 2018, the Directorate-General for Communications Networks, Content and Technology (DG CONNECT) put forth the "Proposal for a Regulation of the European Parliament and of the Council on promoting fairness and transparency for business users of online intermediation services" with the purpose of enhancing transparency and introducing prompt dispute resolution mechanisms for online intermediation services and online search engines. It was adopted by the European Commission on September 19, 2018 and currently is being deliberated at the European Parliament and the European Council.

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Appendix A. The Model and parameter calibrations

A.1 The Model

A system comprised of a single sector of cloud computing is considered and a model with an endogenous market structure is built for DSGE simulation. A number of models with endogenous market structure were introduced in several papers, such as Etro (2009), Colciago and Etro (2010) and Bilbiie, Ghironi, and Melitz (2012). Etro (2009) focused on cloud computing and others have dealt with markets in general.

The model in this paper utilizes ICT capital. On the demand side many of the market participants may consume only cloud computing services and do not have to possess ICT hardware; however, on the supply side many of the market participants need to have facilities, such as data centers, to provide cloud computing services.

In modeling the system comprised of a single sector of cloud computing, we basically follow, among other papers, Etro (2009)'s model with ICT capital. However, we introduce the investment adjustment cost function in order to reflect the effect of the nature of stickiness (persistency) of investment, following Christiano et al. (2005).

The following is a summary of the model.

A.1.1 Households

The representative household supplies L_t hours of work and consumes C_t at time period t for the wage rate w_t. By assuming Constant Relative Risk Aversion (CRRA), the expected lifetime utility function of the representative household is described as $U_t(C_t, L_t) = E_0\left[\sum_{t=0}^{\infty}\beta^t\left\{\ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}}\right\}\right]$, where $E_t[\cdot]$ denotes the mathematical expectation operator at discrete time period t, β $(0<\beta<1)$ represents the subjective discount factor, χ (>0) represents the weight of the disutility of labor and φ (≥ 0) represents the Frisch elasticity of labor supply to wages.

This household's aggregate budget constraint holds that total expenditure that is comprised of consumption, investment of existing firms, investment of market entrants and capital investment should be equal to total income, and thus $C_t + IK_t + ne_t v_t = \pi_t n_t + r_t K_t + w_t L_t$, where IK_t represents ICT investment, v_t represents market entry cost, ne_t represents the number of market entrants, π_t represents the profit of the representative firm, n_t represents the number of existing firms, r_t represents the interest rate (cost of capital) and K_t represents the ICT capital.

The representative household maximizes U_t under the household's aggregate budget constraint. By applying the transition equation of the number of firms (A5) and the transition equation of capital (A8), both of which will be introduced later, we have the following equations of (A1) to (A4):

$$v_t = \beta(1-\delta)E_t\left[\frac{C_t}{C_{t+1}}(v_{t+1}+\pi_{t+1})\right] \tag{A1}$$

$$L_t = \left(\frac{w_t}{\chi C_t}\right)^{\varphi} \tag{A2}$$

$$g_t\beta(1-\delta^k) + \beta\frac{r_t}{c_t} = g_{t-1} \tag{A3}$$

$$\frac{1}{C_t} = g_t\left\{1 - S\left[\frac{IK_t}{IK_{t-1}}\right] - \frac{IK_t}{IK_{t-1}}S'\left[\frac{IK_t}{IK_{t-1}}\right]\right\} + g_{t+1}\beta\left(\frac{IK_{t+1}}{IK_t}\right)^2 S'\left[\frac{IK_{t+1}}{IK_t}\right] \tag{A4}$$

where δ represents the market exit rate of existing firms and market entrants during the time period t, δ^k represents the physical depreciation rate, g_t is one of two Lagrange multipliers[33] in Lagrangian $\mathscr{L} = \sum_{t=0}^{\infty}\beta^t\left[\ln(C_t) - \chi\frac{L_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}} - f_t(C_t + IK_t + v_t ne_t - \pi_t n_t - r_t K_t - w_t L_t) - g_t\left\{K_{t+1} - (1-\delta^k)K_t - IK_t + S\left[\frac{IK_t}{IK_{t-1}}\right]IK_t\right\}\right]$ and $S\left[\frac{IK_t}{IK_{t-1}}\right]$ represents the investment adjustment cost function.

A.1.2 Firms and market clearing

Let us suppose that cloud computing goods have a variety of ω and that cloud computing goods are produced by capital and labor. By supposing that at time period t, there are n_t existing firms and ne_t market entrants enter the market, and by the time period $t+1$ some of the existing firms and new market entrants exit the market at the rate of δ, we have:

[33] The other Lagrange multiplier f_t turns out to be $f_t = 1/C_t$.

$$n_{t+1} = (1-\delta)(n_t + ne_t) \tag{A5}$$

We can divide the output Y_t into existing firm portion YC_t and new market entrant portion $ne_t v_t$ and divide the hours of work L_t into existing firm portion LC_t and new market entrant portion $ne_t\frac{v_t}{w_t}$:

$$Y_t = YC_t + ne_t v_t \tag{A6}$$

$$L_t = LC_t + ne_t\frac{v_t}{w_t} \tag{A7}$$

ICT capital K_t is accumulated as ICT investment IK_t is made. We have the following transition equation of capital:

$$K_{t+1} = (1-\delta^k)K_t + IK_t - S\left[\frac{IK_t}{IK_{t-1}}\right]IK_t \tag{A8}$$

In many cases, the transition equation of capital is described as $K_{t+1} = (1-\delta^k)K_t + IK_t$; however, in order to reflect the sticky nature of investment (investment amount cannot be changed in the short term) and to avoid a situation in which investment amount jumps to its value in a steady state without a transition period, the investment adjustment cost function $S[x]$ is introduced. $S[x]$ satisfies the three following properties: (1) $S[x]$ is connected smoothly at $x = 1$; (2) $S[x]$ has minimum value of 0 at $x = 1$; and (3) $S[x]$ is a downward-convex function. These properties are equivalent to $S[1] = S''[1] = 0$ and $S''[1] = \frac{1}{ss}$, where ss (> 0) is a constant that governs the degree of stickiness of investment adjustment cost. With these properties, $S[x]$ has the following two characteristics:

(i) When IK is in a steady state, $IK_t = IK_{t-1}$ and thus $S\left[\frac{IK_t}{IK_{t-1}}\right] = S[1] = 0$. Therefore, equation (A8) becomes $K_{t+1} = (1-\delta^k)K_t + IK_t$.

(ii) When IK is not in a steady state, $IK_t \neq IK_{t-1}$ and thus $S\left[\frac{IK_t}{IK_{t-1}}\right] > 0$. However, equation (A8) and $K_{t+1} = (1-\delta^k)K_t + IK_t$ are connected smoothly at $x = 1$.

In this paper, the investment adjustment function is defined as $S[x] \equiv \frac{1}{2}\left\{e^{\frac{1}{\sqrt{ss}}(x-1)} + e^{-\frac{1}{\sqrt{ss}}(x-1)} - 2\right\} = \frac{1}{2}\left\{e^{\frac{1}{2\sqrt{ss}}(x-1)} - e^{-\frac{1}{2\sqrt{ss}}(x-1)}\right\}^2 (\geq 0)$. Therefore, for any x, $S[x]$ is equal to or more than zero.

Under the market clearing condition, we have:

$$YC_t = C_t + IK_t \tag{A9}$$

By assuming a Cobb-Douglas production function, the production function of firm j ($j = 1, 2, \ldots, n_t$) at time period t can be described as $yc_{j,t} = A(lc_{j,t})^{\alpha}(k_{j,t})^{1-\alpha}$, where $yc_{j,t}$ represents the output of firm j, $lc_{j,t}$ represents the hours of work of firm j, $k_{j,t}$ represents the ICT capital of firm j and A represents Total Factor Productivity (TFP), which is assumed constant in this paper, and α represents labor share. By multiplying n_t by both sides of the production function of firm j above, by assuming symmetry across firms of firm 1 to firm n_t, and by using the relationships of $YC_t = yc_{j,t}n_t$, $LC_t = lc_{j,t}n_t$, $K_t = k_{j,t}n_t$, we have the following equation:

$$YC_t = A\cdot(LC_t)^{\alpha}\cdot(K_t)^{1-\alpha} \tag{A10}$$

Since TFP A and labor share α remain constant, the increase in output can be achieved by the increase in LC_t and K_t. This means that the contribution of cloud computing diffusion to output is modelled and achieved not by TFP but by GPT (General Purpose Technology).

By minimizing the total production cost of firms at the time period t ($r_tK_t + w_tLC_t$), we get the following equations:

$$w_t = \alpha\cdot\frac{YC_t}{LC_t}\cdot\frac{1}{\mu_t} \tag{A11}$$

$$r_t = (1-\alpha)\cdot\frac{YC_t}{K_t}\cdot\frac{1}{\mu_t} \tag{A12}$$

where μ_t represents price markup in which $\mu_t = \frac{1}{mc_t}$, and where mc_t represents marginal cost.

In order to avoid extreme cases, such as a monopoly or perfectly competitive market, in which in a steady state both the profit of the representative firm and market entry cost equal zero, we introduce the Cournot equilibrium. Under the Cournot equilibrium, the number of firms in the market and the market structure are set endogenously and each firm decides on the amount of its production based on the given information of other firms' production amount. Since price markup μ_t holds $\mu_t = \frac{\theta}{\theta-1}\cdot\frac{n_t}{n_t-1}$, where θ represents the degree of substitutability across goods with a variety of ω, when $\theta \to \infty$, we can treat cloud computing goods as homogenous and we have:

$$\mu_t = \frac{n_t}{n_t-1} \tag{A13}$$

Under the Cournot equilibrium, the profit of the firm j $\pi_{j,t}$ can be described as $\pi_{j,t} = \left(1-\frac{1}{\mu_t}\right)\frac{yc_{j,t}}{n_t}$ and by assuming symmetry across firms and by using the relationships of $\mu_t = \frac{n_t}{n_t-1}$ and $YC_t = yc_{j,t}n_t$, we have:

$$YC_t = \pi_t\cdot n_t^2 \tag{A14}$$

Since at time period 1 the system undergoes a sudden shock of e_t that makes the market entry cost v_t increase and maintain that value, we assume the following equation:

$$v_t = v_0 + e_t \tag{A15}$$

A.1.3 Summary of the Model

Now we have 15 endogenous variables of: output Y_t, consumption C_t, hours of work L_t, ICT capital K_t, ICT investment IK_t, output contributed by existing firms YC_t, hours of work of existing firms LC_t, wage rate w_t, interest rate r_t, number of firms n_t, number of market entrants ne_t, profit of the representative firm π_t, price markup μ_t, market entry cost v_t and Lagrange multiplier g_t. On the other hand, we also have a set of 15 simultaneous equations.

A.2 Calibration

Table A1 tabulates the parameters and calibrated values for the simulation.

Table A1
The parameters and calibrated values for the simulation.

Parameter	Value	Source
Labor share α	0.389	The MIC and the Ministry of Economy, Trade and Industry (METI), "2017 Basic Survey on the Information and Communications Industry (Performance in FY2016)"
Discount factor β	0.998	[1]
TFP (Total Factor Productivity) A	1	Normalized and set to 1.
Market exit rate of firms δ	0.0308	[2]
Physical depreciation rate δ^k	0.100	[3]
Market entry cost at the initial Cournot equilibrium v_0	1	Normalized and set to 1.
Weight of the disutility of labor χ	0.966	[4]
Frisch elasticity of labor supply to wages φ	0.85	[5]
Constant that governs the degree of stickiness of investment adjustment cost ss	0.309	Christiano et al. (2005) and many subsequent papers

Note: χ varies depending on the simulation setting, because χ is set so that the steady state value of the hours of work L_* equals one.

[1] The discount factor β is set to 0.998, which is equivalent to an annual rate of 1%, based on the recent yields of a newly issued 10-year Japanese Government Bond.

[2] The market exit rate of existing firms and new market entrants δ is set to 0.0308, which is equivalent to the annual rate of 12.3%, because according to the 2014 Economic Census for Business Frame by the MIC and the METI, in the category of the business of services incidental to Internet, during the 29-month period from February 1, 2012 to July 1, 2014, the number of continued establishments was 2,889 and that of closed establishments was 1,225. This means that 1,225 establishments out of a total 4,114 (=2,889 + 1,225) establishments closed in 29 months (1,225 × (12/29)/4,114 = 0.1232).

[3] The physical depreciation rate δ_k is set to 0.100, which is equivalent to the annual rate of 0.401, because according to Research Report on Economic Analysis on ICT in FY2016 by the MIC, in FY2015 ICT stock was 28,786 down from 28,997 in the previous year, and ICT investment was 11,408 (all are in billion JPY). Therefore, δ_k is estimated as 0.401 by applying these statistics into the equation of $K_{t+1} = (1 - \delta^k)K_t + IK_t$ (δ^k = {(11,407-(28,786–28,997)}/28,997 = 0.4006).

[4] The weight of the disutility of labor χ is set so that the steady-state value of the hours of work L_* is normalized and equals 1. Therefore, the value of χ varies depending on the simulation setting (In many cases, the value of χ is slightly smaller than one).

[5] The Frisch elasticity of labor supply to wages φ is set to 0.85, because according to Kuroda and Yamamoto (2008), the Frisch intertemporal elasticity of substitution in labor supply in Japan fell within the range of 0.7–1.0.

Appendix B. The relationship between a system comprised of a single sector of cloud computing and the whole Japanese economy

In Appendix A, the set of model equations that are used for the simulation is applied to a system comprised of a single sector of cloud computing. In Appendix B, with several assumptions, an attempt is made to apply the simulation results to the whole Japanese economy based on Japan's published macroeconomic statistics and the results of a web-survey targeting business people conducted by the MIC in March 2014.

For each of the six industrial categories of (1) Construction, (2) Manufacturing, (3) Transport and Postal Activities, (4) Wholesale and Retail, (5) Finance and Insurance, and (6) Service and Other Industries, three kinds of cloud computing user groups of Group A (firms using cloud computing service), Group B (firms not using cloud computing service, but may use in the future) and Group C (firms not using cloud computing service and have no plans to use in the future) are considered, depending on their current cloud computing use style and on their likeliness of cloud computing use in the future. For each of the six industrial categories, the possible room for expansion of cloud computing use is considered, adding up all the cases of three cloud computing user Groups. By taking into account government statistics, such as ICT investment rate in total investment in Japan, and by calculating weighted average across the six industrial categories, the coefficient of the contribution of the impact of advancement of cloud computing in a system comprised of a single sector of cloud computing to the whole Japanese economy is estimated, which yields 5.48×10^{-3}.

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