Macroeconomic analysis of cloud computing in Japan

Soichiro Takagi*  Hideyuki Tanaka

Abstract
Cloud computing is becoming one of the major technological changes for business management in the last decade. From internal management to supply chain management, various services can be provided by cloud providers that locate somewhere in the world. However, despite its pervasive impact on business and economy, its understanding on the effect on economy is still in early stage. On the other hand, macroeconomic analysis with micro-foundation such as dynamic stochastic general equilibrium (DSGE) approach is heavily concentrated on financial and monetary analysis. This study fills in this gap and tries to construct macroeconomic model that incorporates specific technological change such as cloud computing. By the presented model, this paper tries to understand the impact of the diffusion of cloud computing comprehensively.

1. Background
Cloud computing has become one of the major topics among the information technology architecture. Cloud computing provides information services from centralized data centers so that firms do not need to invest in and own a huge computer resources. General consumers also benefit from cloud computing such as online storage. However, business sector started to use cloud services more thoroughly. For example, information technology services for email, human resource management, supply chain management, customer relationship management are now provided by cloud vendors.

These new types of services are penetrating rapidly in Japanese economy. IPA (2012) shows that use rate of SaaS (Software as a Service, one of the service models of cloud computing) has grown from 19.5% in 2010 to 33.7% in 2011. Information technology is referred as “General Purpose Technology” because it improves various aspects of business and products. Cloud computing reduce fixed cost to utilize information technology drastically for firms, so it is expected to promote economic growth when wider range of firms can benefit from IT that otherwise was not affordable. On the other hand, cloud computing is possible to be provided from anywhere in the world. In other

---

1 Ph.D Candidate, Graduate School of Interdisciplinary Information Studies, The University of Tokyo
2 Graduate School of Interdisciplinary Information Studies, The University of Tokyo
*Corresponding author. Email: qq096511@iii.u-tokyo.ac.jp
words, if the domestic provider is not competitive, Japanese economy may face the hollowing-out effect particularly in information services sector. Therefore, cloud computing has two-sided potential both of growth and challenge.

A certain amount of articles have been published on cloud computing, but the concerns and academic disciplines are scattered across literature. For example, some studies focus on technological architecture, and others discuss on security and privacy. Some studies argue market governance such as competition law and regulation. Despite the potential impact on business and economy, its effect on economy is not studied enough. Even if the scope is expanded to IT and economy in general, most of the empirical studies conduct analysis on firm or industry basis. Therefore, there has been a limit to understand the impact of technological innovation on economy as a whole.

On the other hand, from macroeconomics point of view, analysis with models with micro-foundation such as dynamic stochastic general equilibrium (DSGE) model or its foundation, real business cycle (RBC) model is becoming popular among literatures. However, its application is heavily concentrated on financial and monetary policy. Application of DSGE analysis on the specific technological innovation and macroeconomic variables is still yet fully utilized.

Therefore, this paper tries to construct a model to understand the impact of the diffusion of cloud computing in macroeconomic scale. It also reports the results of impulse response of macroeconomic variables when economy encounter the diffusion of cloud computing. The model would be a prototype for further development, but it tries to build a foundation for analysis on specific technological innovation and its economic implication.

2. Prior studies
From macroeconomics perspective, analytical framework and methodology have been developed drastically in the last decade. Emerging from analyzing the fluctuation of business cycle (Kydland and Prescott: 1982, Long and Plosser: 1983), macroeconomic analysis with micro-foundation became one of the dominant schools in literature. However, despite that one of the major concerns of the basic RBC model used to be technological innovation, RBC and DSGE have developed rapidly focusing on monetary and financial analysis. More recently, DSGE analysis started to be applied to wider range of topics such as the effect of immigration (Mandelman and Zlate, 2008), incorporation of On-the-job search (Macit, 2010), productivity and energy price (Dhawan et.al, 2008).

In terms of prior studies on cloud computing, literature on the economic aspect is relatively scarce. Among the scarce studies, the series of studies of Etro (2009, 2011) are the most close to the topic of this paper. These studies have focused on the cost reduction effect of cloud
computing and analyzed its macroeconomic impact by simulation based on DSGE model. Underlying perception of these studies on cloud computing is that cloud computing turns IT cost from fixed costs into marginal costs of production. These studies assume the following effects. First, cost reduction of IT investment lowers initial barrier of entry for new firms and foster the establishment of small and medium size enterprises (SME). Second, the increase of SME would have a positive effect on employment and GDP. Third, they also analyze the impact on public accounts arguing that public spending is lowered and tax income is increased by the diffusion of cloud computing. Etro (2009, 2011) constructed the model that is augmented specifically with the increased number of firms, and conducted simulation on EU countries. The results show that the diffusion of cloud computing boosts GDP by 0.05% to 0.15% in short term, and 0.1% to 0.3% in medium term. The estimates on business creation and job creation are shown in Table 1.

<table>
<thead>
<tr>
<th>Speed of diffusion</th>
<th>Short term</th>
<th>Medium term</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>Slow</td>
<td>+0.05</td>
<td>+0.1</td>
</tr>
<tr>
<td></td>
<td>Rapid</td>
<td>+0.15</td>
<td>+0.3</td>
</tr>
<tr>
<td>Business Creation</td>
<td>Slow</td>
<td>+73,256</td>
<td>+83,478</td>
</tr>
<tr>
<td></td>
<td>Rapid</td>
<td>+378,640</td>
<td>+430,973</td>
</tr>
<tr>
<td>Job Creation</td>
<td>Slow</td>
<td>+300,000</td>
<td>+70,000</td>
</tr>
<tr>
<td></td>
<td>Rapid</td>
<td>+1,000,000</td>
<td>or +700,000 more</td>
</tr>
</tbody>
</table>

Notes: Impact on GDP and business creation is taken from Etro (2009), and impact on job creation is taken from Etro (2011). Source: Etro (2009) and Etro (2011)

Etro (2009, 2011) draw implications for various aspects such as GDP, business creation and job creation, but the basic idea is that cloud computing lowers entry cost and promotes entrepreneurship. Its model is developed carefully incorporating endogenous growth model, but in other words, it is not easy to expand to include other aspects because of the specialized development into entry costs.

Besides the analysis with DSGE model, Cudanov et al. (2011) point out the benefit of flexible scalability of cloud computing. They argue that IT investment does not meet the actual
demand of ICT because it is difficult to expect actual demand perfectly, and investment is conducted once a certain terms, not daily basis. Because of this gap of demand and investment, excessive investment happens under low demand and opportunity loss happens under high demand period. Culdanov et al. (2011) did not present the ways to measure the amount of these losses, but these flexibleness certainly is one of the benefits of cloud computing.

On the impact on employment, Ross (2011) discussed impact on ICT workers in user firms. From user firms’ point of view, introduction of cloud computing is similar to outsourcing because these firms utilize resources outside the firms. Ross (2011) argues that along with the transition from in-house operation to utilization of cloud computing, jobs and the role of ICT workers in user firms would be affected. It has pointed out that the role of ICT workers shifts from “a technical to more of a liaison role as they engage with external service providers”.

As seen in this section, several studies provide the perspectives on the effect of cloud computing, but they rather pick up various aspects partially and far from understanding the phenomenon comprehensively. There is also a missing point in previous studies such as negative effect of reduced revenue for domestic ICT firms. For example, if firms do not build their own software and computer systems, the revenue that ICT firms used to earn by creating those systems would be reduced. In addition, it is possible that Japanese firms import foreign cloud services instead of utilizing domestic services.

Economic analysis of cloud computing is in the initial stage and there is a large opportunity for research. This paper tries to construct a model to incorporate multiple effects of cloud computing, thus provide a basis for macroeconomic analysis of technological innovation such as cloud computing.

3. Models

The main purpose of this study is to implement the impact of cloud computing into macroeconomics models. The base model in which the cloud is incorporated is conventional RBC model with monopolistic competition, which is widely used in macroeconomics literature. The base model follows Griffoli (2011) which describe the behavior of household and firms.

3.1 Base model

Representative household follows the utility function:

\[ E_t \sum_{t=0}^{\infty} \beta [log C_t + \psi log (1 - l_t)] \] (1)
where $C$ is consumption, $l$ is a unit of labor therefore $1-l$ means the time used for leisure. Household maximize the equation (1) under the following budget constraint:

$$c_t + k_{t+1} = w_t l_t + r_t k_t + (1 - \delta)k_t$$  \hspace{1cm} (2)

where $k$ is capital, $w$ is wage, $r$ is interest rate, $\delta$ is depreciation rate of capital. $w_t l_t + r_t k_t = y_t$, where $y$ is output under perfect competition. Note that:

$$i_t = k_{t+1} - (1 - \delta)k_t$$  \hspace{1cm} (3)

where $i$ represent the flow of investment. Therefore,

$$i_t = y_t - c_t$$  \hspace{1cm} (4)

From first order condition of (1) under budget constraint (2), Euler equation for consumption is obtained as:

$$\frac{1}{c_t} = \beta E_t \left[ \frac{1}{c_{t+1}} (1 + r_{t+1} - \delta) \right]$$  \hspace{1cm} (5)

and first order condition for $w$ is:

$$\psi \frac{c_t}{1-l_t} = w_t$$  \hspace{1cm} (6)

In terms of the firm section, each firm $i$ produces output following Cobb-Douglas function with Harrod-Neutral technological progress:

$$y_{it} = k_{it}^{\alpha} (e^{z_{it} l_{it}})^{1-\alpha}$$  \hspace{1cm} (7)

where $z$ is the level of technology. Profit of firms is described as follows:

$$k_{it}^{\alpha} (e^{z_{it} l_{it}})^{1-\alpha} - w_t l_t + r_t k_t$$  \hspace{1cm} (8)
Optimal capital labor ratio is obtained from first order condition for $k$ and $l$:

\begin{align}
    k: \quad & \alpha k_t^a (e^{\alpha l_t})^{1-a} = r_t \quad (9) \\
    l: \quad & k_t^a (1 - \alpha) (e^{\alpha l_t})^{-\alpha} = w_t \quad (10)
\end{align}

Dividing (9) by (10) yields optimal capital to labor ratio:

\[ k_t r_t = \frac{\alpha}{1 - \alpha} w_t l_t \quad (11) \]

In terms of pricing, under the monopolistic competition, price is determined by:

\[ p_{it} = \frac{\epsilon}{\epsilon - 1} mc_t p_t \quad (12) \]

where $p_{it}$ is firm-specific price, $mc_t$ is marginal cost, and $\epsilon$ is the elasticity of substitution. For simplification, individual firms take market price $p_t$, therefore $mc_t = \frac{\epsilon - 1}{\epsilon}$. Combining marginal cost and production function, the following conditions are obtained:

\begin{align}
    w_t &= (1 - \alpha) \frac{\nu_{it}(\epsilon - 1)}{k_{it}(\epsilon)} \\
    r_t &= \alpha \frac{\nu_{it}(\epsilon - 1)}{k_{it}} \frac{1}{\epsilon}
\end{align} \quad (13) \quad (14)

\[ \textbf{3.2 Implementing cloud computing} \]

As discussed in previous sections, there are several ways by which cloud computing affects macroeconomics variables. In this study, three paths are identified and incorporated into the base model. Before going into the identification of paths, the diffusion of cloud computing is described as follows:

\[ \text{cloud}_t = \omega \text{cloud}_{t-1} + e\text{cloud}, \quad 0 < \text{cloud}_t < 1 \quad (15) \]

where $e\text{cloud}$ is white noise with zero means and normal distribution, and in this context, it is the temporary shock to start the diffusion. $\text{cloud}_t$ is defined as penetration rate which is $0 < \text{cloud}_t < 1$. The diffusion speed follows the process of auto regressive one (AR(1)), with $\omega$ assumed as 0.95. In
this setting, additional diffusion of cloud computing decreases over time as shown in Figure 1.

![Graph showing supposed diffusion of cloud computing](image)

Figure 1. Supposed diffusion of cloud computing. Vertical axis is penetration rate of cloud computing, horizontal axis is year.

In this analysis, it is assumed that cloud computing affect mainly three variables: First, cloud computing increases productivity of firms. Because cloud computing reduces deployment cost of IT, more firms can enjoy the benefit of IT. Positive effect of IT on productivity has been reported by vast amount of studies such as Jorgenson (2002), Jorgenson and Motohashi (2005), Miyazaki et. al (2012). Overall productivity is supposed to be improved with the reduction of IT cost.

Second, as seen in prior studies, cloud computing can lower entry cost for new firms thus increase the number of new firms. Etro (2009) focuses on this effect and develops the model that depends specifically on the entry cost and number of firms. On the other hand, the present study assumes that increased number of firms can intensify the competition among firms, and promote innovation. Newly developed SMEs also can promote innovation, and transfer of employment from less productive to more productive sector. Therefore, this study assumes the increased number of firms can increase the productivity of economy.

Thirdly, cloud computing can reduce the output of information services industry. As discussed earlier, cloud computing reduces deployment cost drastically by sharing computing resources. Traditionally, firms needed to develop its own computer systems that support their businesses by outsourcing the design and development of systems to ICT sector. Reduction of IT cost has the inverse effect to reduce the revenue of IT service firms that used to develop computer systems
for user firms. This negative effect on output is assessed directly by subtracting the corresponding amount from production function.

These three effects are incorporated to the base model as follows. Productivity level $z_t$ is determined by the level of previous year (AR(1)) and the diffusion of cloud computing, $\text{cloud}_t$ and the number of firms, $n_t$:

$$z_t = \rho z_{t-1} + \phi \text{cloud}_t + \phi_n n_t$$

(16)

where $\rho, \phi$ and $\phi_n$ are parameters that are calibrated in the next section.

Entry cost $\eta_t$ is defined as the penetration rate that is the change ratio from steady state and $1 < \eta_t < 1$. It is reduced by the diffusion of cloud computing:

$$\eta_t = \rho \eta_{t-1} - \theta \text{cloud}_t, \quad -1 < \eta_t < 1$$

(17)

And this entry cost can increase the number of firms through:

$$n_t = \gamma \left( n_{t-1} + \frac{\nu t}{e^{\eta}} \right)$$

(18)

where $\nu$ is the ratio of investment into new firms among total investment, $t. \eta$ is the change ratio from steady state, therefore its initial value is 0. In order to make entry cost as non-zero value, entry cost is expressed as $e^{\eta}$, exponential of $\eta$. By dividing investment into new firms by entry cost, $\frac{\nu t}{e^{\eta}}$ represents the number of new firms. Following Etro (2009), a certain rate of business is destructed by $1 - \gamma$.

Finally, subtracting the negative effect of reduced revenue in ICT sector from (7):

$$y_{it} = k_{it}^\alpha (e^{z_t}l_{it})^{1-\alpha} - \mu \times \text{cloud}_t$$

(19)

Figure 2 shows the relations of endogenous variables. Diffusion of cloud computing affects the variables by three paths. However, because endogenous variables also affect each other, for example, number of firms ($n$) affects productivity ($z$), capital ($k$) affects output ($y$), and investment ($i$) affects number of firms ($n$). Therefore, the diffusion does not simply affect economy by three paths but also affect through intertwined systems of variables.
3.3 Calibration

In this section, parameters are categorized as structural parameters of base model and operational parameters which are used to define the extent of effects of cloud computing. Structural parameters of the base model are taken by Griffoli (2011) as shown in Table 2. $\rho$ describes the stickiness to prior period and is also applied on the equations for the impact of cloud computing such as (16) and (17).

![Figure 2. Relationship of endogenous variables](image)

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\delta$</th>
<th>$\psi$</th>
<th>$\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.33</td>
<td>0.99</td>
<td>0.023</td>
<td>1.75</td>
<td>0.95</td>
</tr>
</tbody>
</table>

In terms of operational parameters, each parameter is calibrated so that each path has reasonable impact on the overall equation system. The aim of this study is to identify the paths of the impact of cloud computing on economy and to draw the dynamic response of macroeconomic variables. In this regards, precise estimation of parameters and the quantifying the impacts are beyond the scope of this study. Parameters on the impact of cloud computing are calibrated based on the method that are described as follows.

First, steady state of base model is calculated. Based on the steady stated, each parameter is calibrated so that the diffusion of cloud computing has a reasonable impact on economy. In terms of $\phi$, that describes the impact of cloud computing on productivity, it is assumed that 1% increase of the
diffusion of cloud computing leads to 0.1% of productivity increase. $\phi_n$ is calibrated so that 1% increased number of firms can lead to 1% increase of productivity. $\theta$ describes the impact on entry cost. Etro (2009) estimated that cloud computing can lower entry cost 1% or 5% depending on the speed of diffusion. Taking the moderate estimation from Etro (2009), this study assumes the entry cost is lowered 1% by the diffusion of cloud computing. For convenience, this study sets the target of diffusion to reach 12.83% in 20 years from equation (15) and Figure 1. Therefore, $\theta$ is calibrated so that entry cost is reduced 1% in 20 years.

$\mu$ adjusts the reduced revenue of ICT sector, and it is calibrated from the share of the related industry and decreased revenue. According to MIC (2012), Software and Information sharing/providing industry are together comprise 4.1% of GDP of Japan. It is assumed that 20% of the revenue of those industries are reduced by 20 years. $\mu$ is calibrated to fulfill this assumption. In summary, operational parameters and related parameters used to implement cloud computing are calibrated as Table 3.

<table>
<thead>
<tr>
<th></th>
<th>$\phi$</th>
<th>$\phi_n$</th>
<th>$\theta$</th>
<th>$\mu$</th>
<th>$\gamma$</th>
<th>$\nu$</th>
<th>$\omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
<td>0.0168</td>
<td>0.08</td>
<td>0.058773439</td>
<td>0.97</td>
<td>0.1</td>
<td>0.95</td>
</tr>
</tbody>
</table>

4. **Results of impulse response analysis**

Figure 3a and 3b show the results of impulse response analysis with the 0.01 standard error shock on $e_{cloud}$. Horizontal axis is period (year), and vertical axis is the difference from steady state that is shown in Table 4. Note that the movement of variables in percentage in the following sections refers to the ratio from this steady state.
Table 4. Steady state of endogenous variables

<table>
<thead>
<tr>
<th>Endogenous variable</th>
<th>Steady state value</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>1.15602</td>
</tr>
<tr>
<td>c</td>
<td>0.917453</td>
</tr>
<tr>
<td>k</td>
<td>10.3724</td>
</tr>
<tr>
<td>i</td>
<td>0.238565</td>
</tr>
<tr>
<td>l</td>
<td>0.302733</td>
</tr>
<tr>
<td>y_l</td>
<td>3.81861</td>
</tr>
<tr>
<td>w</td>
<td>2.30262</td>
</tr>
<tr>
<td>r</td>
<td>0.033101</td>
</tr>
<tr>
<td>z</td>
<td>0.259177</td>
</tr>
<tr>
<td>n</td>
<td>0.771361</td>
</tr>
<tr>
<td>eta</td>
<td>0</td>
</tr>
<tr>
<td>cloud</td>
<td>0</td>
</tr>
</tbody>
</table>

As seen in the third panel of Figure 3a, the diffusion of cloud computing (cloud) has jumped 0.01(1%) and gradually decreased. As discussed earlier, cloud represents the additional diffusion of cloud computing, so overall penetration increases over time by decreasing amount.

First panel of Figure 3a show the number of firms (n). It has decreased in the earlier stage to -0.00077 that can be translated as 0.1% below its steady state but increased afterwards. In 20 years, it reaches 0.57% above steady state. Entry cost (eta) is decreased continuously to 0.6% on 20 years, and gradually rises afterwards.

Figure 3b shows the impulse response on key macroeconomic variables. Output (y) has decreased in first term by 0.17% but turns positive after 3 years and continues to rise up to 0.69% above steady state in 20 years. Output (y), capital (k), investment (i), labor supply (l) and also interest rate (r) decrease in the initial stage and start to rise after several years.

In this model, it takes approximately 200 terms to return to its original steady state.
Figure 3a. Impulse response on endogenous variables on the diffusion of cloud computing

Figure 3b. Impulse response of key macroeconomic variables. y_l is y divided by l.
5. Discussion

Impulse response introduced in previous section is the result of comprehensive impact and interaction between variables that is shown in Figure 2. In this analysis, three major paths are identified and incorporated in the model.

The model that incorporates these comprehensive effects into RBC model suggests overall effect on economy becomes positive during approximately 5 to 20 years. Output and consumption are increased, wage rises, and labor supply is also increased. As discussed in calibration section, this research set the temporary target of diffusion of cloud computing as 20 years later to reach 12.83\%. After 20 years, each endogenous variable reaches as shown in Table 5. From this analysis, GDP reaches 0.7\% above its initial steady state. However, these quantitative results heavily depend on the calibration of operational parameters. Therefore, the precise amount of the effect may change depending on calibration.

One of the major findings from the present model is that it takes several years until the diffusion of cloud computing has a positive effect on economy. In order to explore the contribution of three paths, impulse response from each path is examined and shown in Appendix. The basic idea is to decompose the three paths and conduct impulse response analysis one by one.

As shown in Figure A1, the impulse responses of the productivity path resemble those of comprehensive analysis particularly on its growth path. On the other hand, negative effect through reduced sales in ICT sector that is shown in Figure A2 shows that it has a counter effect on the positive result through productivity. Reduction of entry cost and increased number of firms also has a negative effect in initial stage but turns positive afterwards. Therefore, it is inferred that overall growth could be achieved mainly from productivity growth, but it is lowered by the negative effect of reduced revenue in the initial stage. From practical point of view, the results of the model suggests that economy can suffer from the reduction of revenue in ICT sector in the initial stage of diffusion, but gradually enjoy the positive effect of the rise of productivity and promotion of entrepreneurship.
Table 5. Change of variables after 20 years

<table>
<thead>
<tr>
<th>Endogenous variable</th>
<th>Change from steady state after 20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>0.70%</td>
</tr>
<tr>
<td>c</td>
<td>0.48%</td>
</tr>
<tr>
<td>k</td>
<td>0.27%</td>
</tr>
<tr>
<td>i</td>
<td>1.55%</td>
</tr>
<tr>
<td>l</td>
<td>0.15%</td>
</tr>
<tr>
<td>y/l</td>
<td>0.54%</td>
</tr>
<tr>
<td>w</td>
<td>0.54%</td>
</tr>
<tr>
<td>r</td>
<td>0.015% points</td>
</tr>
<tr>
<td>z</td>
<td>3.05%</td>
</tr>
<tr>
<td>n</td>
<td>0.57%</td>
</tr>
<tr>
<td>eta</td>
<td>-0.60%</td>
</tr>
<tr>
<td>cloud (culminated penetration rate)</td>
<td>12.83%</td>
</tr>
</tbody>
</table>

6. Conclusion

This paper tries to construct the model to analyze the economic impact of cloud computing. It identifies three paths for cloud computing to affect macroeconomic variables, and incorporates them into standard RBC model. Given the practical concern and scarcity of the prior study in the field, this study fills in the gap in this point. Compared to Etro (2009, 2011), this paper proposes more simplified but comprehensive way to understand technological innovation and its implication on economy.

However, this study is in the initial stage of modeling and there are various kinds of challenges and space for further improvement. First, the model is simple and straightforward, but rather primitive. There would be the space for more sophistication so that the model itself can provide a significant implication. Parameters are also temporarily calibrated based on the rough estimation. Cloud and productivity, cloud and entrepreneurship, cloud and revenue of ICT sector are all topics that should be investigated separately to assess the precise relationship. The present study tries to understand the mechanisms and movement of variables comprehensively, but ideally, it is better to be based on the empirical foundations.

This paper provides the first step to construct the foundation to understand the important technological change and its implication on macroeconomics, and it is ready for further improvement.
Acknowledgement

The authors thank Yasuyuki Muradate for helpful comments. All errors remain the authors'. 
Appendix

Impulse response on each path

Figure A1. Impulse response only through the effect on productivity
Figure A2. Impulse response only through the effect of reduced revenue in ICT sector
Figure A3. Impulse response only through the effect of reducing entry cost


