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Economic Implications of Cloud Computing

A Report for Microsoft

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DIW econ GmbH

Dr. Ferdinand Pavel

Mohrenstraße 58
10117 Berlin
Germany

Phone +49.30.8 97 89 - 497
Fax +49.30.8 97 89 - 116

fpavel@diw-econ.de
www.diw-econ.de

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Executive summary

This report presents an economic assessment of cloud computing, a new frontier of the IT era where software solutions and hardware resources are provided by global server networks ("the cloud") and can be accessed online via the internet. Cloud computing can be described according to its service environment, its different organizational forms, and its diverse business models.

With respect to the service environment the so-called cloud computing stack consists of three different layers or service levels. Infrastructure on-demand services are located at the lower end of the stack and development platform services as well as software on-demand services at the higher end. From an organizational point of view, the two relevant forms are public and private clouds.

Since market participants can access each of the different service levels either on its own or in combination, cloud computing allows for a variety of new business models to emerge. This benefits in particular small and medium sized companies, as it allows them to enter new markets more easily with lower up-front and transaction costs. It also allows them to employ more flexible contracting solutions with respect to their IT infrastructure.

Cloud computing is also expected to have significant impacts on all levels of economic activity. From a firm-level point of view the most important benefit is the overall reduction of IT costs as well as a shift of fixed capital expenses to variable costs of IT-related services. This leads to a significant increase in flexibility, which benefits first and foremost small and medium sized enterprises. Therefore, the introduction of cloud computing is expected to enable the creation of many new start-ups as well as to increase productivity of existing firms.

Regarding the IT industry, the introduction and adoption of cloud computing offers many new business opportunities. New markets like Software-as-a-Service or Platform-as-a-Service evolve. Due to lower fixed costs, the markets will expand and many new customers will show increased demand for IT solutions.

The IT and cloud computing industry is also expected to face substantial changes. Cloud computing is characterized by platforms and thus two-sided markets. Such markets are

different from the standard text-book models of perfect competition because they are shaped by economies of scale and network effects. In the long run, these effects impede perfect competition and are likely to lead to differentiated, oligopolistic market structures.

A crucial factor in the evolution of cloud computing markets will be the pricing strategies that providers will follow as well as the specification of standards for exchanging data between different clouds and for inter-operability in general. With respect to pricing strategies, providers need to carefully consider the various benefits that application developers and end users enjoy as well as the network effects that emerge between both sides. With respect to inter-operability standards, it can be expected that providers of cloud computing solutions will opt for open standards during the early stage of development in order to attract as many users as possible. Once they have been introduced, open standards are likely to persist also during later stages of market development.

The rapid development of cloud computing markets leads to challenges for different stakeholders, such as firms, industry associations and market regulators as well as legislators. These challenges consist of technical reliability, market regulation issues and problems regarding data security and privacy.

Technical and environmental challenges call for a reliable regulatory environment which stimulates innovations and investments. In this respect, policy makers are required to ensure stable and transparent conditions.

The economic forces shaping the cloud computing markets could, in the long run, develop into oligopolistic market structures. Inter-operability is another important issue for market supervisors. If markets eventually evolve towards more concentrated structures, using proprietary standards may become a superior strategy in order to lock in customers. Therefore, market regulators will closely observe the related developments. However, the innovative nature of cloud computing requires that also the practices of competition policy and market regulation need to be reviewed and adjusted based on new theoretical insights.

Data security will be a major topic for market regulators. If large parts of private and business data are to move into the cloud, trust into the security and guaranteed privacy of these data is a prerequisite for a cloud computing market to evolve. However, markets for security often exhibit market failures. It is possible to mitigate this problem by designing standards for data security and enforcement mechanisms which can be implemented by industry associations or imposed by law.

Overall, the report finds that cloud computing will lead to significant benefits for individual firms and will also have a significant impact on economy-wide developments by increasing employment, economic growth and productivity. The rise of cloud computing will also alter the level of competition in the software industry. Just as this is a challenge for major industry players, it is one for policy makers who might face the need to assess competition levels and possibly to impose remedies. The analysis in this report demonstrates that the case for public intervention in cloud computing industries currently does not exist and that it is uncertain whether this will change in the future. Given the huge economic potential of this technology, policy makers and regulators should be open-minded to the industry’s concerns and help – where needed – through exchange of opinions or support in establishing specific standards.

1. Introduction

Cloud computing is expected to offer flexible and tailor made IT solutions for almost all possible needs of commercial and private customers. While the underlying idea of providing computing as a utility is not new, recent technological developments have caused the costs for providing large-scale computing and storage capacity to decline substantially. At the same time, the strong expansion of available network bandwidth has increased the accessibility of network-based services and solutions to potential users. As a result, cloud computing – often referred to as an old idea whose time has (finally) come (Armbrust et al. 2009) – has become the new frontier of the internet era. Indeed, cloud computing is already present in many internet applications that users employ for their everyday life activities. For instance, the web search engines and email services offered by Microsoft or Google are all based on cloud computing technologies so that they can be accessed and used via internet from around the world. Given the numerous technological and economic possibilities to develop, provide and employ cloud computing solutions, it is not surprising that the range of different options as well as the assessment of the various advantages and disadvantages are highly complex. Moreover, new obstacles and challenges, for example with respect to network security, data protection and the environment, have arisen.

The large technological and economic potentials of cloud computing possibly lead fundamental changes in established legal and regulatory principles. In order to enable a fast adoption and utilization of this new general purpose technology, a well-structured overview on the potential and benefits as well as on risks and challenges for all stakeholders is necessary. This report intends to provide a structured discussion along these lines. Starting from an overview of current and future developments of cloud computing and the associated business models (section 2) we will review the various economic implications (section 3), focusing on individual benefits at the firm level, overall benefits at the economy-wide level, as well as on the implications for industrial competition. With this assessment in mind, we will discuss technical, regulatory and other relevant challenges for further adoption of cloud computing (section 4).

2. Definitions of Cloud Computing

Cloud computing refers to the storage of information or programs (like on-demand-software) centrally rather than locally on a designated server. Data-access is possible via an infrastructure (the so-called cloud foundation) of several computers for example via the internet (on-demand-infrastructure). Cloud computing generally refers to a specific sub archetype of delivery platforms. In contrast to similar forms such as managed hosting, cloud computing describes a delivery environment where vendors provide storage and processing capacity as on-demand services (utility computing). While the term cloud computing includes a complex range of different solutions and proceedings, it is generally differentiated according to its service environment, organizational forms and business models. These are described in more detail in the subsequent sections.

2.1 Service Environment

Generally, the different types of services offered by cloud computing solutions can be thought of as different layers within a single stack, where infrastructure on-demand services are located at the lower and software on-demand services at the higher end. Following BITKOM (2009), this service stack can be divided into three different levels:

- **Software as a Service (SaaS),** where independent software vendors (ISVs) offer end user applications via the internet, represents the highest level of existing cloud services. An important feature of SaaS platforms is the one-to-many matching approach where the service provider administrates from a single platform all maintenance actions like software updates or upgrades. Together with features like pay-as-you-go or pay-on-demand as well as easy expandability, SaaS is currently the most popular form of cloud computing and paves the way for large usage of cloud computing applications. Common examples on this level are Windows Live Center, Google Apps for Business, salesforce.com and WebEx. A further development in this context is called Collaboration as a Service (ColaaS or CaaS) which responds to the need of globally dispersed business units to work online simultaneously on one document, calendar or address management tool (BITKOM 2009).

- The second level is **Platform as a Service (PaaS)**. Here, the IT infrastructure required for developing multiple-user applications is provided in a technical framework and can be accessed online. A characteristic feature of a PaaS platform is its multi-tenant architecture and the corresponding technical deployment features for new operating software. This service level is closely related with SaaS as it addresses ISVs who develop their applications as SaaS solutions. Companies that provide such platforms, like salesforce.com, Microsoft, IBM or Apple, often encourage and lend support to ISVs with special "business partner" programs. ISVs benefit from PaaS as they can focus on developing their own applications and no longer need to maintain an own application infrastructure for synchronization, security and data management.

- The third and lowest service level is **Infrastructure as a Service (IaaS)** which provides basic IT hardware. On this level companies can use platforms with server, storage, network and the rest of the computer centre infrastructure as virtualised service. Access is given via internet in a pay-as-you-go manner and has virtually all administrative rights of control. In contrast to related forms such as managed hosting, IaaS offers multi-tenant capability, full elasticity, various payment options and programmatic control allowing customization options of the used resources for development issues (BITKOM 2009).

2.2 Organizational forms

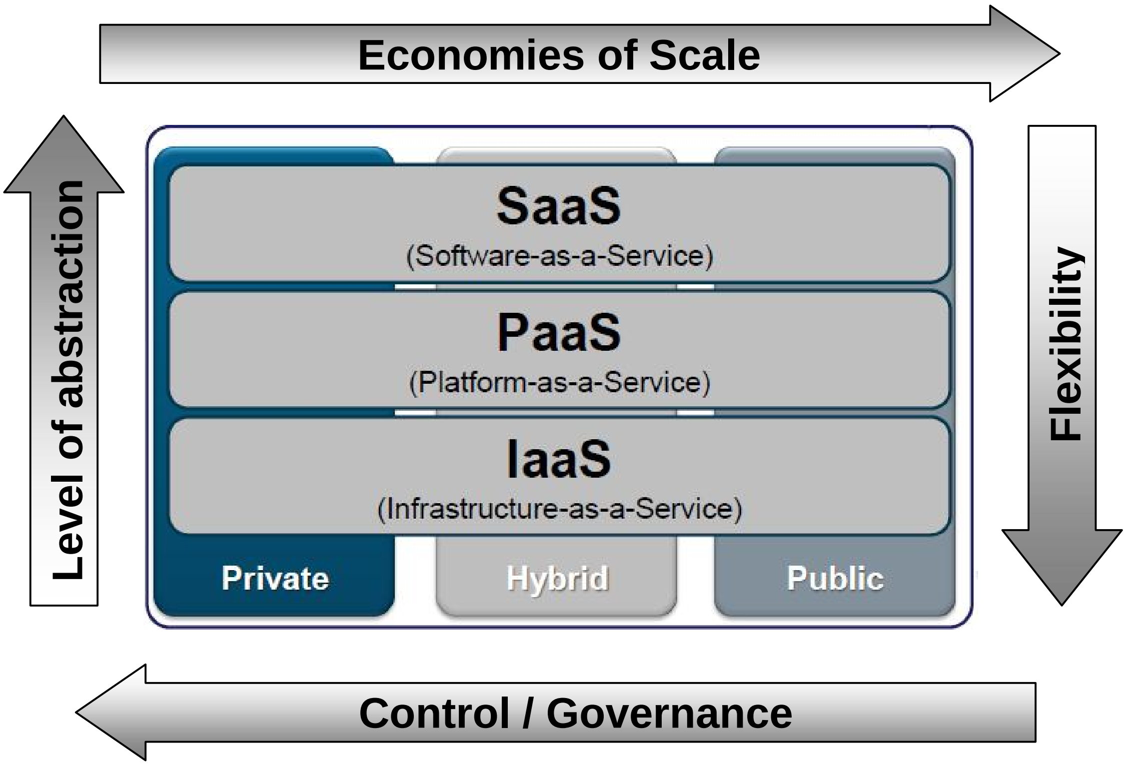
Apart from service levels, cloud computing systems can also be differentiated in an organizational, operational and legal way. Generally, the two main forms are private and public clouds (BITKOM 2009).

A public cloud is defined as a fast and highly flexible environment that can be accessed via the internet by an unlimited number of users on a pay-as-you-go basis. The datacenter is controlled, maintained and owned by a specific provider. In contrast, a private cloud is defined as an independent and in-house operating IT system that can be accessed by a limited number of users via intranet or a virtual private network. The datacenter of a private cloud is entirely hosted and owned by the company itself. Both types reveal two important differences: a public cloud offers large economies of scale and great resource flexibility with at the same time little governance and monitoring possibilities. For private clouds the opposite is the case. While it has only small economies of scale and its IT resources are fixed, it offers full governance, security and monitoring possibilities of internal data.

Between these two organizational forms, several sub-types – so-called hybrid clouds – are possible. Typically, they combine the best characteristics of both cloud types via outsourcing. For instance, a private cloud with an in-house datacenter can be maintained and administrated by an external service provider. In the same way it is possible for a company to use a service provider with an own datacenter and thereby choose a complete outsourcing solution for its private cloud environment. The major challenge for hybrid clouds is the harmonization of heterogeneous applications into one interlocked framework.

The trade-off between economies of scale and governance of private and public clouds is closely related to the three service levels of cloud computing. Following Grözinger (2010), the whole cloud stack can be distinguished in terms of technological abstraction and flexibility of usage, as shown in Figure 1. Technological abstraction refers to the degree of usability of the delivered services. If the abstraction level is high, the services are easier to use than in case of low abstraction where services are complex but very flexible in terms of customization possibilities. For example, SaaS solutions offer the highest level of technological abstraction with complete ready-to-use application frameworks for end users. At the same time, SaaS is characterized by low flexibility with respect to customization of components for individual needs. On the contrary, IaaS solutions deliver complex services with a low level of technological abstraction but offer high flexibility with respect to customization to individual needs. In-between, PaaS solutions offer a combination of flexibility and technological abstraction to allow for the development of applications, which are based on available development environments but customized to individual needs.

Figure 1: Main Levels and Organizational Forms of Cloud Computing



Source: Grözinger 2010

2.3 Business models

An important characteristic of cloud computing is that each individual service level can be accessed either solely or in combination. For instance, cloud computing enables ISVs to fully rely on PaaS and thus to avoid the whole decision process concerning the required computing resources. Alternatively, companies can also provide a combination of different service levels like infrastructure with development platforms. Based on the three types of service levels as described above, seven business models can possibly emerge: three stand-alone models on each service level as well as combinations between the different levels, i.e. IaaS & PaaS, PaaS & SaaS, IaaS & SaaS and IaaS & PaaS & SaaS (BITKOM 2009 p. 35).

A consequence of the flexibility of combinations of different types of cloud computing service levels is the formation of globally connected dynamic value-adding networks, where computing power, computing resources and cloud services are interlinked in multidimensional ways (BITKOM 2009). With the increasing adoption of cloud computing, they will increasingly replace the formerly linear IT value chains in which resources had to be built up gradually and on an individual basis.

Figure 2: Structure of Two Cloud Computing Platforms (selected examples at different service levels)

	Windows Azure	Google
SaaS	- Windows Live - Microsoft AdCenter - Online Services	- Google Analytics - Google Docs
PaaS	- SQL Azure - App Fabric	- App Engine - Web Toolkit
IaaS	- Storage/ Compute Service - Computing Power	- Storage (BigTable, Datastore API)

Source: DIW econ

Figure 2 shows examples for the combination of IaaS, PaaS and SaaS solutions as offered by two different cloud computing platforms:

- The first, Microsoft's Windows Azure, offers computing power, application storage as well as the rest of the computer centre infrastructure with a lot of technical experience as IaaS. At the PaaS level, Windows Azure features a relational database service (SQL Azure) as well as the App fabric tool for building connected applications. Finally, at the SaaS level Windows Azure offers cloud-based applications like Windows Live with a mail client and a messaging service and the Microsoft AdCenter, a management tool for search-based advertising campaigns on Bing, the web-search engine of Microsoft as well as Microsoft online services (see Box: Illustration of PaaS and SaaS provider).

- In comparison, Google's cloud platform provides Big Table and Datastore API for storage services on the IaaS level and the Google App engine as well as Web Toolkit for developing purposes at the PaaS level. Finally, Google offers Google Analytics to measure site performance and Google docs for office purposes at the SaaS level.

To illustrate how different service levels and business models of cloud computing can interact, the subsequent box discusses several examples from Microsoft's Windows Azure platform. For this purpose, Microsoft's Online Services[1] are of particular interest. As a SaaS solution, they offer access to various software products for different business purposes such as Exchange Online for e-Mailing, contact management and business appointments or Sharepoint Online for centralized data management and project planning. Microsof also offers a PaaS solution which enables SVPs to adjust these existing online applications to more specific purposes and requirements as well as to develop and deploy additional software components. Differences on the PaaS level arise as SVPs are focusing on different products as well as ranges of applications.

[1] For further information see http://www.microsoft.com/online/de-de/prodExchange.aspx

Box 1: Box: Illustration of PaaS and SaaS examples

PaaS case Study

As a major provider of PaaS solutions, Microsoft is maintaining its B2B relationships with ISVs via its Microsoft Partner Network[2]. Within this network it is possible for firms to reach different levels of partnership by extension of their competences and certifications. One of Microsoft's certified partners is the German IT company Parashare[3] with special focus on Microsoft's Sharepoint cloud solution. On behalf of customers from various industries the firm installs either a standard solution package or an individual extension beyond its standard functionalities. Therefore Parashare is developing an in-house range of extensions within the Sharepoint software. These extensions are able to solve industry-specific problems that companies have to deal with. For instance, Parashare implemented an individually tailored solution of the Sharepoint software for a large federal association in the public health insurance sector, taking into account the specific requirements of the customer (see the SaaS case study below).

Another PaaS partner is the German company IT-Improvement[4] with expertise in almost all fields of Microsoft's technologies like ASP, .Net, Silverlight or SQL 2008. With regard to cloud computing solutions, IT-Improvement focuses on the entire Microsoft Business Productivity Online Suite Standard (BPOS) that includes the messaging and collaboration solutions Exchange Online, SharePoint Online, Office Live Meeting, and Office Communications Online. IT-improvement is also developing new components for the entire BPOS that are adapted to the specific needs of their customers. These services are particularly interesting for customers that are active in IT and online related areas (see SaaS case study below), but can also be applied to other sectors. In this way both companies help their clients to reduce costs and to increase productivity levels. They also foster the further development and value of the Microsoft cloud service platform in general.

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[2] For further information see https://partner.microsoft.com/germany/Partner
[3] For further information see http://www.parashare.de/
[4] For further information see http://it-improvement.com/

SaaS case study

Microsoft offers its Business Productivity Online Suite Standard (BPOS) to SaaS cloud computing customers. BPOS presents an ensemble of tools for efficient process management like calendar, web-conferencing or instant messaging. For implementation of these services Microsoft receives further support from its PaaS partners from the Microsoft Partner Network. One of Microsoft's SaaS clients is the AOK federal association, which is one of the biggest German health insurance funds consisting of 14 separate agencies. AOK is using a cloud solution on basis of Microsoft online services. One of the major requirements was to integrate a solution that could deliver a consistent system for working across different locations in Germany. The individual SaaS solution for the AOK is based on Microsoft's Sharepoint Online and has been implemented in cooperation with Microsoft's IT Partner Parashare. During implementation, the IT partner could add self-developed components of Sharepoint Online for an individual adjustment to meet the specific requirements of AOK. In addition to fast availability, flexibility and broad security aspects, a key advantage of this SaaS solution is the seamless connection with existing Microsoft office software packages. This guarantees the possibility of switching back easily to the classic on-premise platform. Moreover, the application is easy to use for all employees within a short amount of time and thereby reduces the amount of training units.

Another example of a SaaS customer is the German IT service provider Advantics. In cooperation with the Microsoft partner IT-improvement, the BPOS system was installed for this customer. The core requirement for Advantics was to obtain a reliable and efficient IT system structure. Furthermore, the requirement of virtual cooperation could be fulfilled via Microsoft's Sharepoint and Office Live Meeting solutions. As a growing medium-sized enterprise, Advantics benefits from the flexibility of the cloud computing system. New employees as well as freelancers can easily be integrated into ongoing projects and processes. Necessary resources can be added on-demand and in a cost-efficient way. Documentation and organisation within projects with multiple team members and partners can be improved and information flows be accelerated.

3. Economic impact of Cloud Computing

The preceding chapter has illustrated the different service levels, organizational forms and business models that define cloud computing. Generally, the specific needs of individual firms in different sectors and of different size classes as well as those of private consumers are very different. However, cloud computing will prove to be a general purpose technology that offers new business possibilities and advantages like increased flexibility and lower fixed costs for all market participants. Therefore, the introduction and adoption of cloud computing will have a major impact on all levels of economic activity.

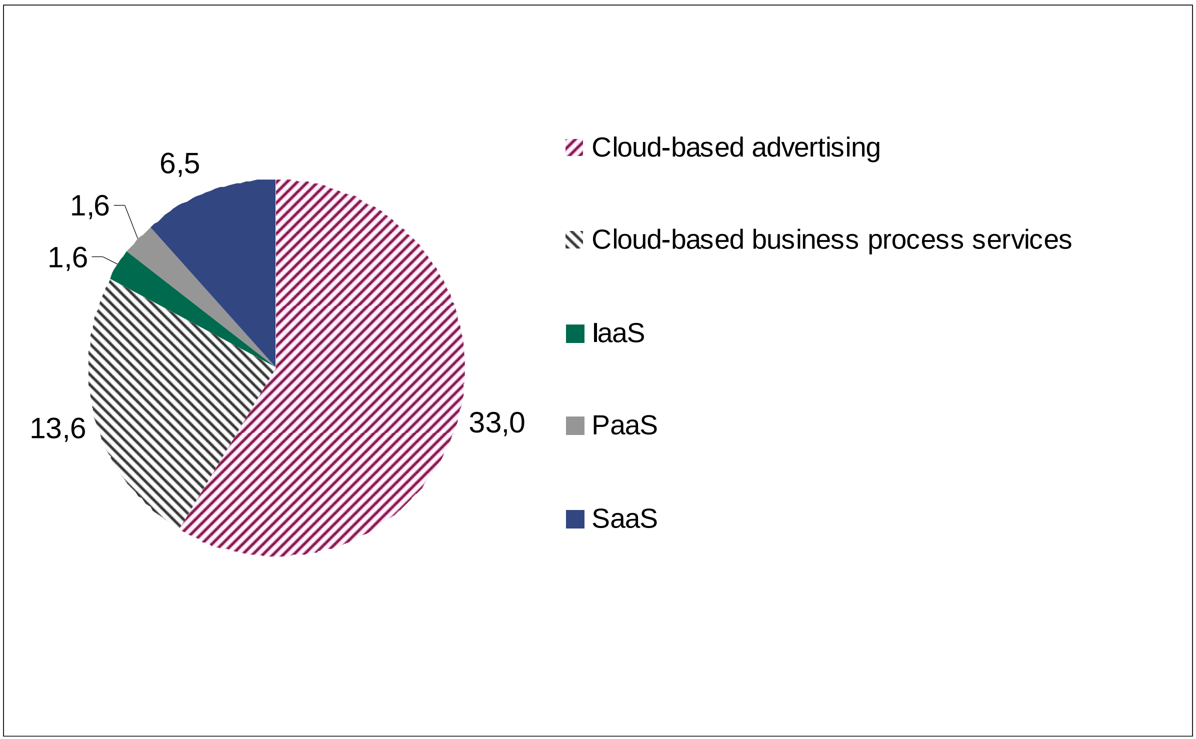
In this chapter, different aspects concerning the economic impact of cloud computing will be assessed. Section 3.1 starts with a presentation of the current structure of the cloud computing market. Section 3.2 continues with a discussion of benefits at the level of individual firms. Against this background, section 3.3 presents related impacts at the economy wide level. Finally, section 3.4 discusses which factors and economic forces will shape the different markets for cloud computing.

3.1 Current market structure

Providing a first overview on the current structure of cloud computing markets requires a clear definition. Typically, analysts differentiate between the provision of cloud computing services and cloud-based business process services. While the former is further divided into IaaS, PaaS and SaaS (as defined in section 2), the latter comprises cloud-based advertising as well as other types of cloud-based business process services.[5] For 2009, the combined revenues that these cloud computing markets generated worldwide are estimated at a total of 56 billion US$ or 40.1 billion € (Gartner 2009, see Figure 3). The most valuable market segment is cloud-based advertising, which accounts for 33 billion US$ (59% of the overall revenues), followed by other business process services with 13.6 billion US$ (24% of overall revenues). Hence, total revenues generated by cloud-based business process services are about five times higher than those of cloud computing services, indicating the high potential of this technology. Among the latter, SaaS accounts for much larger revenues (6.5 billion US$ or 12%) than PaaS or IaaS (1.6 billion US$ or 3% each).

[5] Cloud-based business process services are defined as business processes delivered as a service via the internet if service providers offer a one-to-many business process platform for its customers. E-commerce for example includes online retail services but not online retailing. Further types of cloud-based business process services are human resources, payment processing and others.

Figure 3: Revenues from worldwide cloud services, 2009 (in billions of US$)



Source: Gartner (2009)

According to Gartner (2009), global cloud computing markets are expected to grow at high rates in the next years till 2013. Especially the services for cloud-based advertising are expected to run up to 77 billion US$ in terms of revenues and those for cloud-based business process management services up to 42 billion US$. Within the market for cloud computing services, revenues from SaaS will more than triple to 20 billion US$ in 2013, those from IaaS will increase even stronger to about 8 billion US$, those from PaaS to about 2 billion US$.

In Germany, the market for SaaS accounted for revenues of about 380 million € in 2009 and is expected to grow at an annual rate of 20% till 2011 (Experton Group 2009). For PaaS and IaaS, Bitkom (2009) estimates the revenues in 2009 at 128 million € and 94 million €, respectively. These segments are expected to grow during the next years at an annual growth rate of more than 36 %.

3.2 Micro level benefits

The Planning and design of required computing and storage volume, as well as the administration and monitoring of even more complex IT infrastructure is an important task for all firms, independent of their respective size and the industry they are operating in. For firms in the IT sector like software vendors and application developers or companies with needs for large data processing or storage capacities, these issues even constitute major management problems.

Given its potential for cost-reduction and flexible pricing models on all levels of IT services, cloud computing is capable of providing competitive solutions to these issues. For instance, fixed costs associated with initial investments in the development and construction of IT infrastructures will be significantly lower than before, because resources are available on demand, up-front commitments are no longer necessary and resources can be increased when needed (Armbrust et al. 2009). In fact, since elastic cloud computing operations adapt automatically to fluctuations with respect to utilization, long-term resource planning for IT infrastructure is no longer necessary. This is particularly important for small and medium-size enterprises (SMEs) and for start-ups that have to react flexibly in fast-paced markets. Here cloud computing (especially SaaS) creates new options and opportunities.

The strong potential for cost reductions is illustrated by the so-called cost-associativity for end-users, according to which the use of 1000 servers for one hour costs no more than using one server for 1000 hours (Armbrust et al. 2009). For example, batch processing activities can be executed externally in a datacenter with far more resources and faster performance than on local desktop computers.

The different service levels of cloud computing offer new business models and opportunities for many different firms and end-users:

- SaaS is particularly interesting for end users of software applications, independently of whether they require standardized applications like office software or specific, tailor-made solutions. At this level a flexible pricing model on basis of utilized resources, features or users allows clear cost control and business planning. Commercial customers or private end-users can also benefit from additional features like easy updating and combinations with other service levels like IaaS, so that compute-intensive desktop applications can run in the cloud and thereby deliver time savings and lower computing cost. Key requirements of SaaS users are reliability of the provider or well defined interfaces for integration and migration purposes.

- PaaS is particularly interesting for application developers and software vendors as it offers access to large customer bases as well as to well-established development platforms. This allows firms to focus on key issues like programming and development of new software in an easy-to-use environment. PaaS platforms typically provide large IT resources and automatic scalability of frameworks together with development tools, an application server, quality and life cycle tools and process automation software. The service provider, rather than the developer, has full responsibility for administration and software management and ensures that the latest upgrades and patches for utilized software are installed. Another important advantage for PaaS users are large developer communities using the same platform and promoting intercommunication and knowledge exchange. In combination with PaaS often a SaaS interface is available and facilitates later deployment and sales activities of the software.

- IaaS offers a large potential for reduction of fixed IT costs. Instead of buying a datacenter with servers, networks and storage, it is possible to employ a service provider with large server farms and experienced IT staff. Hence, initial investments in the development and construction of IT infrastructures will be significantly lower than before. Service providers offer flexible pricing models in a pay-as-you-go manner on a short- or long-term basis. For instance, if further storage resources are needed, they can be added in a fast and easy way. Finally, the risks of loss of data or server downtimes can be dramatically reduced by employing a service provider.

From the perspective of an individual firm, the first important question with respect to cloud computing is to determine the point at which it is worth moving into the cloud rather than using your own IT infrastructure. Armbrust et al. (2009) illustrates this for the case of a firm with large data storage requirements. Obviously, the firm would move into the cloud as soon as the cloud solution generates a higher net revenue than the solution with an own datacenter.

Formally, this can be illustrated as follows:

$$\text{UserHours\_cloud} \times (\text{revenue}_{hour} - \text{Cost\_cloud}_{hour})$$
$$\geq \text{UserHours\_datacenter} \times (\text{revenue}_{hour} - \text{Cost\_datacenter}_{fixed} / \text{Utilization})$$

In this case, a crucial parameter to determine the break even point is the level of utilization of the own datacenter. Since the costs for the data center are fixed, high utilization levels are required to ensure economic operations. In practice, however, the capacity of a datacenter can rarely be exhausted and the lower the level of utilization, the higher the costs of operating an own datacenter. The cloud solution, on the contrary, does not suffer from this problem since – thanks to its flexibility and appropriate pricing models – the firm purchases only the utilized computing resources, independently of how CPU intensive its operations are.

More generally, parameters that must be compared to assess the savings from employing a cloud-based solution depend on individual specificities. These typically include the costs of WAN bandwidth per month, CPU hours and required disk storage. In addition, non-monetary aspects such as risk diversification must be accounted for (Armbrust et al. 2009). To illustrate the economic potential of cloud computing solutions, McKinsey (2008) compares the costs that a customer spends for a standard on-premise application like Customer Relationship Management (CRM) to the total costs of software for developing, deploying and integrating this application. They also include the costs of all software, hardware and labour for hosting it – henceforth defined as total platform costs. Under a traditional solution – where a software vendor develops an on-premise application and the customer deploys and integrates it and either hosts the application itself or uses a managed service provider – McKinsey (2008) estimates total platform costs at 60-70 Dollars per 100 Dollars spent on the application itself. However, if the software vendor operates with a PaaS solution on a massive scale (1 million users on its delivery platform) to develop, integrate, deploy and host the same CRM application (and hence, offers a SaaS solution), total platform costs decline to only 20-30 Dollars per 100 Dollars spent on the same application. Hence, cloud computing enables the vendor to either offer the same CRM application at lower costs to the customer or, alternatively, to offer a superior application (e.g. with more features and functions) at the same costs.

As these examples demonstrate, firm-level benefits from cloud computing are rather different and depend mainly on the specific types of activities that a firm is engaged with. Overall, however, the general impact is that cloud computing allows for increased efficiency in terms of utilization of existing IT resources. In other words, the fundamental impact of cloud computing solutions is that it permits firms to shift the typically fixed capital expenses for IT hard- and software to variable operating expenses. Hence, this technology appears to be particularly well-suited for SMEs, for which high fixed costs of IT systems have so far been a major impediment for ICT uptake.

3.3 Economy wide level

Since cloud computing is expected to generate significant benefits for individual firms, it appears reasonable to expect that it will also have significant impacts on economic developments at the economy-wide level. Generally, this relates to the broader question of the overall impact of information and communication technologies (ICT) on key economic variables such as the gross domestic product (GDP) or productivity growth. Until the mid-1990s, a significant link to the diffusion and usage of ICT could not be established. Inspired by this apparent paradox, Nobel laureate Robert Solow (1987, p.36) famously stated that "you can see the computer age everywhere but in the productivity statistics". Since that time, the importance of ICT for economic performance has become much clearer. In fact, ICT needs to be understood as a general purpose technology which enables firms to develop and implement various types of innovations and stimulates productivity. There is, for example, strong empirical evidence that diffusion and usage of ICT has had a crucial impact on the strong productivity surge that the US economy experienced during the turn of the century (van Ark et al., 2008; Jorgenson et al., 2003; Stiroh, 2002). Also, for Europe, several recent studies identify a significant and positive impact of ICT on innovations and productivity (Timmer and van Ark, 2005; DIW econ 2008).

Given the difficulties in identifying the overall impact of ICT on economic performance during the early years of its diffusion, it is hardly surprising that empirical evidence on the economy-wide impact of cloud computing as a very recent ICT phenomenon is so far not available. However, in an early assessment on this topic, Etro (2009a) uses a macroeconomic model to simulate the expected developments under alternative scenarios that differ by the adoption speed of cloud computing. Based on the micro-level observation that cloud computing essentially allows for (partly) converting capital expenses (fixed costs) into operational expenses (variable costs), Etro applies a theoretical framework where the level of fixed up-front costs for setting up a firm determines the number of firms that operate in the market. In this context, cloud computing can be modeled as a shift of fixed IT cost that a firm typically faces when entering a market to variable costs of a cloud computing solution. In this way, cloud computing allows for additional market entry and thus, the creation of new firms. In turn, market entry of new firms increases competition and production levels, which will also increase labor demand and thus job creation.

Embedding this endogenous market structure approach into an established economy-wide simulation model for 25 member states of the European Union, Etro estimates the macroeconomic impact of a gradual introduction of cloud computing technologies. Particular emphasis is given to the contribution to GDP growth as well as to firm and job creation. Using information on IT capital costs in different sectors (manufacturing, wholesale and retail trade, hotels and restaurants, transport storage and communication and real estate renting), the model is also capable of distinguishing sector-specific differences.

In different simulations, Etro estimates the effects on a short term (after one year) as well as on a medium-term basis (after five years). Furthermore, the results vary depending on the speed of adoption of new cloud computing technologies (either a 1 or 5 percent reduction in the fixed costs of entry). Overall, the study finds an average contribution of cloud computing to GDP growth in the EU in a range between 0.05% after one year (assuming a slow adoption) and 0.3% after five years and fast adoption. Given the rather conservative assumptions used to model the impact of cloud computing, the author considers these to be remarkable contributions.

The projected increase in GDP is the result of substantial creation of new SMEs with the strongest impact expected to occur in wholesale and retail trade (plus 156,000 firms in the EU 25 in the medium run under fast adoption). On a country level, the impact of cloud computing on SME creation increases with the general share of SMEs in a country as well as with the general level of ICT adoption. Here, the strongest impact is expected to occur in Italy (with 81,000 new SMEs in the medium run under fast adoption), followed by Spain (plus 55,000), France (48,000), Germany (39,000), United Kingdom (35,000) and Poland (32,000).

With respect to employment, the manufacturing sector as well as hotels and restaurants are expected to show the largest increases. At the country level, results depend on the impact of cloud computing on SME creation as well as on specific labor market conditions that affect the ability of a country's economy to create new jobs in reaction to positive economic shocks. Overall, about two thirds of job creation is expected to occur in the six largest member states. Etro expects the largest impact on job creation in the UK (with 240,000 new workers in the short run under fast adoption), followed by Germany (160,000), France (100,000), Poland (94,000), Italy (76,000) and Spain (69,000). With reference to the current economic and financial crises, a fast adoption of cloud computing could thus lead to a significant reduction of unemployment in the EU.

Despite the significance of these findings, they only provide a partial assessment of the economy-wide effects that cloud computing is expected to induce. In fact, while Etro's analysis focuses on the impact on business and employment creation, a key benefit that cloud computing is expected to deliver is the reduction and increased flexibility of IT costs in general, that is not only for newly created but also for existing firms. In turn, this will permit more firms using advanced ICT solutions. While international comparisons typically show that a relatively high share of large-scale companies in Europe and the US already employs various types of ICT systems, it is especially the small and medium-sized enterprises that hesitate in taking up these technologies.[6] Among the main reasons for this observation are the high and largely fixed costs of adopting IT systems as well as the costs of operating and maintaining them, in particular with respect to human resources (DIW econ 2008). Given key features such as on-demand pricing and flexible IT support, cloud computing is particularly well suited to provide economic solutions for SMEs. Hence, another significant impact of this technology will be increased adoption of ICT adoption by SMEs which in turn can be expected to enable further innovations and thus, productivity growth.

In the remainder of this section we will provide a first quantitative assessment of the potential impact of cloud computing on ICT uptake by SMEs. The analysis is based on information on the use of different ICT applications by German and French companies of three different size classes, small, medium and large,[7] that were presented in a study on behalf of the EU Commission (DIW econ 2010). In particular, the following types of applications are considered (see Box: e-Business Technologies for short descriptions):

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[6] For empirical evidence, see the various studies on ICT uptake in different countries and sectors by the "Sectoral e-Business Watch" of the European Commission (www.ebusiness-watch.org).

[7] Following the standard classification used by the European Commission, the size of an enterprise is determined by the number of employees, where small firms employ up to 49, medium size firms up to 249 and large ones 250 and more employees.

- Enterprise resource planning software (ERP):
- Sales force automation software (SFA)
- Marketing automation software (MAS)
- Supply chain management systems (SCM)
- Order management systems (OMS)

Box 2: e-Business Technologies

Enterprise resource planning software manages all information about an enterprise and its functions in a centralised database. It is used to streamline various divisions of an enterprise and is usually involved with finance, asset management, risk and compliance.

Sales force automation records all data regarding sales and includes a client database. This provides a firm with a large database of client demographics and thereby enables more efficient marketing research.

Marketing automation software is used to simplify tasks related to marketing campaign management, lead generation, marketing resource management, planning, and branding and awareness.

Supply chain management systems manage all aspects of supply chain transactions. These include procurement or sourcing software, warehouse management software as well as transportation management software.

Order management systems are used for order entry and processing. This software collects customer and order data as well as specific account information.

Table 1 shows the percentage of large, medium and small firms in Germany and France that already used these ICT applications by 2008. Generally, the pattern of firm size classes in both countries is very similar with small ones accounting for 97% and medium ones for 2% of all firms. With respect to the adoption of ICT applications, the overall picture is again similar in the sense that in both countries, large companies are the most intensive users of the analysed ICT applications and adoption shares of medium-sized firms are typically higher than those of small firms. While adoption levels of large firms for each ICT application are rather similar in both countries, those for small- and medium-sized firms are rather different. Moreover, small firms in Germany tend to have higher shares than those in France.

Table 1: Shares of firms that have already implemented a specific type of ICT system by 2008

	Size classes:		
	Small	**Medium**	**Large**
Share of firms in Germany…			
... using ERP	8%	13%	31%
... using SFA	17%	7%	17%
... using MAS	17%	7%	17%
... using SCM	8%	13%	19%
... using OMS	8%	13%	21%
Share of firms in France…			
... using ERP	21%	36%	38%
... using SFA	11%	27%	25%
... using MAS	5%	18%	17%
... using SCM	5%	27%	29%
... using OMS	32%	73%	33%

Source: DIW econ (2010)

In general, cloud computing solutions are capable of providing benefits for all these applications. First, they generally allow for cost reduction and increased efficiency. Moreover, they can help reducing the complexity of different applications for end-users since all applications can be a combination of solutions from a single provider and because software maintenance and administration can be fully outsourced to an external service provider.[8] Consequently, it can be assumed that the availability of new, cloud-based solutions will in particular increase the adoption levels of small and medium-sized firms for all five types of applications, e.g. due to lower up-front costs, flexible payment schemes and minimised requirements for IT skills. As a concrete starting point we presume that for each application, the availability of cloud computing will shift adoption levels of firms of a given size class to that of firms in the next higher size class. For example, the share of small firms in Germany that use ERP will increase to that of medium-sized ones, i.e. from 8% to 13%. Given a

[8] Nevertheless, there are naturally differences in the degree to which certain systems are more or less capable of embodying cloud computing solutions. For example, applications like ERP or SFA systems are built upon large databases that typically contain valuable and sensitive information and are thus less suited to be moved into the cloud. On the other hand, systems like MAS are easier to move into a cloud environment where they might even benefit from specific features such as the ability to constantly update key functions like campaign management or lead generation. However, given the flexibility of different cloud computing solutions, it appears reasonable to assume that this technology will be capable of providing at least partial solutions for all types of ICT applications.

moderate speed of cloud computing adoption, this can be understood as a period of 3-5 years.

Table 2: Impact of cloud computing on the adoption of different ICT systems by SMEs in Germany and France

	Small and Medium sized Firms (share of all Small and Medium sized Firms)		
	Before adoption of cloud computing	**After adoption of cloud computing**	**Factor of growth**
Number of firms in Germany…			
... using ERP	204.295 (8%)	331.880 (14%)	1,6
... using SFA	397.974 (16%)	403.622 (17%)	1,0
... using MAS	397.974 (16%)	403.622 (17%)	1,0
... using SCM	204.295 (8%)	325.756 (13%)	1,6
... using OMS	204.295 (8%)	326.776 (14%)	1,6
Number of firms in France…			
... using ERP	253.739 (21%)	431.470 (36%)	1,7
... using SFA	129.373 (11%)	323.245 (27%)	2,5
... using MAS	65.938 (6%)	215.497 (18%)	3,3
... using SCM	68.442 (6%)	323.602 (27%)	4,7
... using OMS	385.615 (33%)	861.986 (73%)	2,2

Source: DIW econ (2010)

The implication of this presumption on the adoption of different ICT applications by SMEs in Germany and France is shown in Table 2. In Germany, the number of SMEs that use ERP, SCM and OMS applications will increase by a factor of 1.6 while the impact on adoption of SFA and MAS will be very moderate. In turn, this will lead to strong increases in the adoption levels of SMEs for ERP, SCM or OMS, while those of the other two applications will remain almost unchanged. In France, these effects are much stronger, mainly driven by the fact that the shares of small firms having adopted an ICT applications by 2008 are relatively low (Table 1). Hence, for all five applications the number of SMEs that use them will increase sharply with the strongest change for SCM and MAS and the lowest one for ERP. Accordingly, adoption levels for French SMEs will increase much stronger than those for German ones.

Overall, the analysis supports the expectation that SMEs are a major market for cloud computing solutions. Based on a simple, one-size-fits-all model, the specified changes in adoption levels of different applications cannot be simply translated into increases in economic key variables such as value added and productivity. However, the strong empirical evidence on the impact of ICT on economic competitiveness and growth (Timmer and van Ark 2005, DIW econ 2008, Enterprise LSE 2010) suggests that the modeled expansion in ICT adoption levels of SMEs would surely generate substantial economic benefits that have to be understood as additional to other potential effects of cloud computing, e.g. those quantified by Etro (2009).

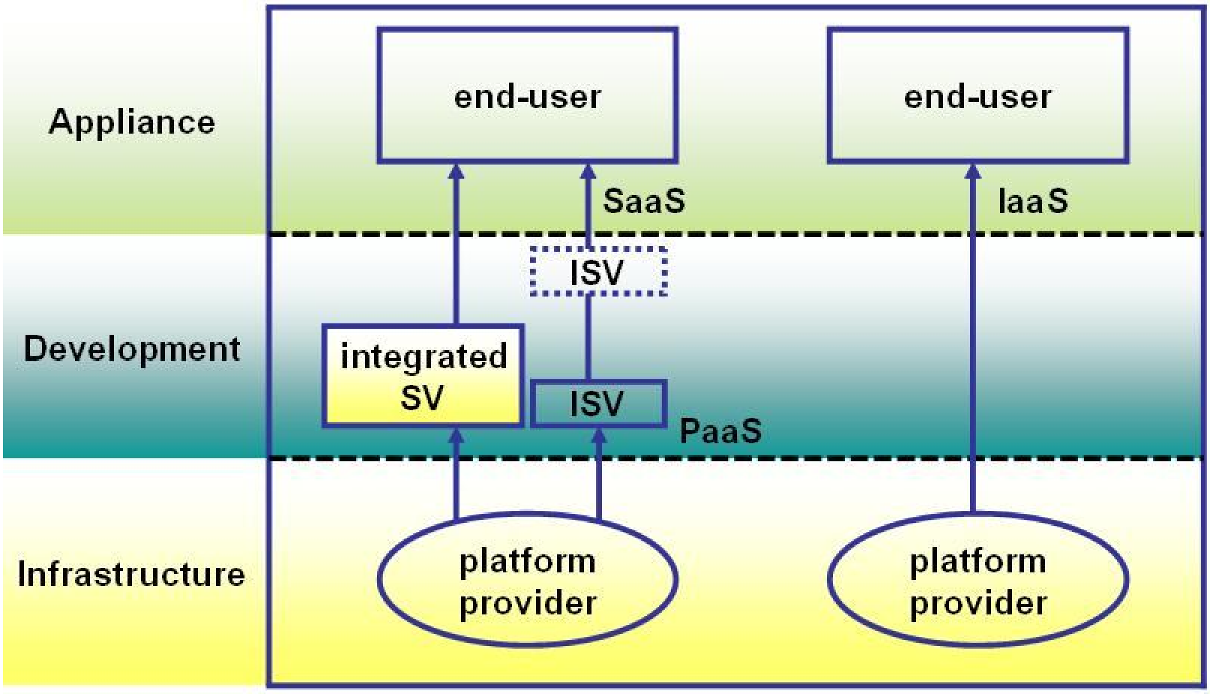
3.4 Implications for industrial competition

As of today, the market for cloud computing is not yet fully developed. Therefore, the future structure of this market is unknown. Nevertheless, economic theory can provide insights into how the market will evolve. This section will analyse the overall market environment as well as the relevant forces that are expected to shape the market for cloud computing. The main questions addressed in this section are:

- What type of competition will evolve among platform providers?
- How can platform providers influence this competition?
- Which strategies will be followed?

Specific economic literature that exclusively focuses on cloud computing is only developing at the moment. Hence, this literature does not yet offer general insights that would be capable of answering the questions listed above. There is, however, one strand of economic literature that can give insights into the economics of cloud computing: the economics of networks and two-sided markets. Armstrong (2006), Economides and Katsamakas (2006) and Rochet and Tirol (2006) are major contributions to this field and serve as basis for the discussion in this section.

Figure 4: Structure of the Cloud Computing Market



Source: DIW econ

The literature on the economics of two-sided markets describes market environments that are shaped by platforms which enable different types of players, such as buyers and sellers, to interact. Typical examples for such platforms include credit card firms that ease the interaction between customers and shop owners, shopping malls that bring together customers and shops and operating systems for computers that link software vendors and computer users. Similarly, many cloud computing solutions can be regarded as platforms that enable providers of applications and end-users to interact. Therefore, cloud computing solutions are two-sided markets. From an economic perspective, such two-sided markets have special properties which regard the strategic interaction of the specific players. This section will discuss the most important market forces that are likely to shape the development of the cloud computing industry.

Generally, there are three groups of agents (players) in the market (see also Figure 4):

- The first group of agents are application providers.[9] They utilize the development environment offered by a certain platform (PaaS) to develop applications that add features to the basic functions of the platform and therefore generate additional value for other platform users.[10] The application providers can either be independent vendors (ISV) or subsidiaries of a platform provider. Since cloud computing lowers the fixed costs connected to developing software and therefore eases market entry, a large number of software vendors are expected to enter the market.
- The second group are end-users who use the different services that a platform offers, like storage and computing power (IaaS), typically together with specific software (SaaS). Also for end-users, cloud computing decreases the fixed costs of using IT services, so that the number of end-users will be higher as on traditional software markets.
- The third group are platform providers who offer combinations of IaaS, PaaS and SaaS.[11]

While the following analysis based on the economics of networks and two-sided markets is of course not capable of delivering final answers to the questions raised above, it still allows to depict the relevant forces that shape the markets and to discuss the relative strength of different developments.

What type of competition will evolve among platform providers?

In contrast to the text-book models of perfect competition, there are two important features of cloud computing platforms that impede the competition between platform providers:

- *Economies of scale*. There are high fixed costs connected to the development and set-up of a cloud computing platform combined with the fact that variable costs tend to be small. Therefore, there are economies of scale, so that average costs decrease with an increasing number of agents active on the platform. This limits entry into the market

[9] In special cases this could also be hardware providers which sell complementary devices (such as mobile phones for wireless access to the cloud).
[10] These providers do not necessarily develop applications for end-users only. They might also provide software solutions for general tasks that are in turn further customized by other application developers.
[11] Obviously, the case of a pure IaaS provider as depicted on the right side of Figure 4 refers to a specific situation where – from an economic perspective – the market transaction resembles the standard model of supplier and consumer rather than a two-sided market (platform). However, IaaS is more likely to be an integral part of cloud computing platforms which also offer other services like PaaS and SaaS, so that the model of two-sided markets clearly applies.

because a large platform incurs lower average costs than a smaller one and is therefore more competitive.

- *Economies of scope*. These are network effects that can be differentiated in cross-group and intra-group network effects:
  - *Intra-group* network effects arise if an agent benefits from a high number of agents from the same group on a platform. For example, a developer on a given platform benefits from sharing experience with other developers on that platform.
  - *Cross-group* network effects arise if the agents of one group in a two-sided market benefit from a high number of agents of the other group. For example, end-users benefit from a large variety of application providers on a platform. Vice versa, application providers benefit from a large number of end-users, or rather potential customers.

How relevant are these forces in shaping the pattern of future competition? Economies of scale are decreasing with the number of agents on a platform. Hence, in the case of cloud computing, this effect is likely to impede market entry of new players. However, once several platforms of significant size operate in the market, scale effects play only a minor role in the competition between those large players, just as it is the case in other industry settings with large fixed costs, such as the chemical or steel industry.

However, while the scale effects caused by a critical mass of developers or users are important, it is reasonable to assume that additional *intra-group* network effects will be of only minor importance in many cloud computing settings. In fact, once a critical mass has been achieved, the additional benefit from an additional developer on other developers is likely to be marginal.[12] Moreover, the use of open source software and open technical standards allows for developers to interact even across different platforms and thus decreases *intra-group* network effects within the same platform further.

In contrast, the *cross-group* network effects caused by end-users on application providers (that is the benefit of additional end-users for application providers) are rather high and non-decreasing in the number of end-users. In fact, every additional end-user (and his/her

[12] A standard example for a market with strong *intra-group* network effects are telecommunication networks, where – according to Metcalfe's law – the value for each user increases above proportional with every additional user, since she allows for an increasing number of new possible connections.

demand) adds to the benefit to the group of application providers. Conversely, the cross-group networks effects of additional application providers (on the benefit of end-users) are probably lower and decreasing in the number of application providers. That is, the first available application generates more benefit for the end-users than the thousandth.

Theoretically, the combination of economies of scale and economies of scope tends to lead towards a winner-takes-it-all competition, because end-users and application providers will decide to use the platform with the lowest costs and the highest value, which is a self-enhancing effect. In praxis, however, several factors prevent such a monopoly to evolve. Firstly, there are differing consumer preferences and requirements. Therefore, different platforms provide different solutions which suit some end-users or application providers in a better way (“product differentiation”). Secondly, the market for cloud computing platforms is not a homogeneous market but has to be regarded as segmented. For example, the competition between a cloud computing platform aimed at business clients and a platform offering entertainment services for private consumers will be limited. Further market segmentation can arise from cultural and linguistic differences or technical incompatibilities.

At the moment, the market for cloud computing is in an early stage of development. Competition is very intense as many incumbents from the IT market as well as new players enter the market. Attracting end-users and market share is the main objective for the players in this evolving market. Therefore, price competition and open standards are currently the dominant strategies.

In the long run, cloud computing markets will be shaped by economies of scale and network effects which lead to oligopolistic or even monopolistic market structures. Eventually, there will be several separate cloud computing markets, each with one or very few platforms serving the different needs of small business clients, large multinational enterprises, private customers, etc. Most probably, once introduced, open standards that are accepted and demanded by end-users and developers, will persist, even if large players aim at introducing proprietary standards.

How can platform providers shape this competition?

The main factor a platform provider can influence is the price it sets for entering and using the platform. In this context, the term “price” is used in a broad sense and includes all financial transactions between providers, developers and users such as fees for developers, prices of applications, licence fees, charges for cloud services, etc. A platform provider can set different prices for end-users and application providers (just like a developer can set prices for its customers). These prices may also be negative, so that a platform provider can chose to subsidise a group of agents in order to attract more of them.[13]

How should the agents be priced?

The relative size of the cross-group network effects determines the price a platform provider tends to charge from the agents of a specific group (end-users and application providers). Since the cross-group network effects of end-users are likely to be higher than the respective effects of application providers, end-users are more valuable to the platform. That is, a platform can maximize its profits if it attracts many end-users (by offering low prices or even subsidies) and sets relatively high prices to application providers. The application providers are willing to pay this price because they can benefit from the large number of end-users on the platform. Therefore, it can be expected that most platforms will tend to charge end-users less than application providers.

When is it optimal to subsidise one group of agents?

It can be a superior strategy for a platform provider to subsidise one of the agent groups and even sell its services at below costs level.[14] This is the case if the cross-group network effects of one group, most likely end-users, are very high and an additional end-user generates very high benefits for the application providers. Then, a platform can extract higher additional benefits from application providers than it has to pay as subsidy to end-users. It is therefore plausible to assume that end-users could be subsidised in some settings. For example, several platforms distribute the access software to the platforms for free, even though they incurred development costs. This is a subsidy.

Which strategies will be followed?

a) Intra-platform competition between application providers

An application provider offering a certain kind of product (say a finance application) has an interest in being the only provider of such a product on a given platform. Therefore, the provider would be willing to pay a higher price to the platform in return for a monopoly

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[13] For example, mobile phone companies subsidise mobile phone sales.
[14] However, competition regulation or anti-dumping laws may restrict this.

position. However, end-users enjoy higher benefits if there are more providers of financial applications. Hence in the case of a monopoly for a certain provider on a given platform, fewer end-users will be using the platform. What is the best strategy for the platform provider? If end-users can be charged, there is an incentive to allow competition between application providers, because a large variety of application providers will attract many paying end-users. If end users cannot be charged, the platform will tend to “sell” monopoly power to application providers. Further, if competition between platforms is intense (as it is the case at the early stages of market development), platforms will try to attract as many end-users as possible. Hence, high competition limits the platforms’ ability to sell monopoly power to application providers. However, in the later stages markets of market development when oligopolistic market structures prevail, competition between platforms may be less intense and platform providers may therefore be able to sell monopoly power for certain applications or services.

b) Vertical integration

Vertical integration means that a platform provider also acts as (non-independent) application provider, e.g. as a software vendor. In this case, an application may be sold below its marginal price, for example provided for free to end-users. This is a useful strategy to stimulate demand for the platform and is an optimal strategy when there is a relatively strong demand for the platform itself compared to the applications. In this case, the extra profit the integrated platform/software firm makes from selling the platform offsets the cost of subsidising the use of the application.

c) The role of open source software and open standards

Open source software is comprised of software platforms and applications that are deployed for free, that is without licence fees or similar charges. A well-known example is Linux, a free operating system that can be used to run and administer computer networks. In the context of cloud computing, open source software plays an important role as well. There are initiatives like OpenStack that develop open source operating systems for cloud computing platforms. However, these examples cannot be readily compared to the standard cases of open source software platforms like Linux. The main difference is that in the cloud computing context, end-users use complex services that combine application software, development environments as well as underlying hardware services. Since at least the hardware operation causes real costs, cloud computing providers will eventually need to charge application providers or end-users, or both. However, as described above, there might be several constellations possible where some users even receive subsidies such as free software access as long as others players can be charged at higher levels. Hence, the relationship between service provision and respective charges can be rather indirect (and less visible), in particular in an open source environment.[15]

Therefore, pure-play open source solutions are unlikely to evolve in cloud computing markets. However, there are some lessons that can be learned from the economic literature on open source. This mainly concerns open standards. One of the main concerns of potential cloud computing users are fears of a data lock-in problem, meaning that data extraction out of the cloud and data transfer to alternative providers is impossible due to proprietary standards. Therefore end users have a strong preference for open standards. At the recent stage of market development, competition for end-users is high, therefore cloud computing platforms offer open standards. Once open standards are introduced, it is likely that they will persist.

There are some similarities between open source software and the introduction of open standards in cloud computing at the moment. Open source software is characterized by the public availability of the source code. Everyone is free to use the software, to change its code and to add features as long as the result is distributed as open source software in turn. Therefore, a developer of open source software cannot charge users and he cannot exclude specific users from using the software. This is – although in a limited way – similar to open standards. If a platform maintains open standards and open source operating software, it cannot exclude others from using the same standards and it can charge users only for the services it supplies, not for the software.

From a static perspective, open-source and open standard solutions are welfare maximising. That is the number of application providers and end-users on a platform are at a maximum. Large cross-group network effects increase the benefits to both groups. However, in a dynamic view, incentives for innovation and investment are a crucial issue. In proprietary systems, innovative activity is conducted by private investment. There are several legal mechanisms such as patents and copyrights that give private innovators some limited, exclusive rights on the use of their innovation. This enables innovators to benefit from the returns of their innovation and gives them incentives to innovate. In the software and cloud

[15] The complexity might be even further increased if an additional party such as an online advertiser is involved to finance the entire operation.

computing context, this is a producer-driven view of innovation. In an open source environment, innovators are not able to appropriate the returns from their innovations because open source solutions are distributed for free. This in turn, should lead to low incentives to innovate and consequently fewer innovations. However, empirical evidence shows that many innovations take place even though exclusive proprietary rights are lacking. Many contributors are users (in contrast to profit-oriented firms) who provide solutions for specific problems for free. This is referred to as user-driven kind of innovation.

One incentive for profit-maximising firms to invest into open source software development could be to ensure the compatibility between their proprietary software and open source solutions (von Hippel and Korgh 2003). Open source applications running on cloud platforms may be complementary to a proprietary application. Therefore, the owner of this proprietary software has an incentive to invest into to the open-source software and ensure compatibility between the open-source software and his proprietary product. This way, the free open source application attracts many end-users who then employ the standards shared by both applications. The use of the open source application is free. However, if the end-user needs more features or better support, he will need to licence the proprietary software. In this way, a profit-oriented firm can appropriate the returns from an investment into open source software.

How will the market eventually evolve? Will open standards and open source software prevail or will proprietary platforms and proprietary standards dominate? It seems most likely that neither of the two systems will dominate the cloud computing markets. Cloud computing is a highly complex system of services. Therefore, it is plausible that many different standards for the interaction between the various layers of service and between the different players in the market will exist. Some of these standards will be open, some proprietary. If a platform itself has a high value (which could, for example, be due to lifestyle elements in B2C environments), the platform provider will try to appropriate a larger share of this value and will try to maintain proprietary standards. Competition between platform providers will limit the ability to introduce such proprietary standards. So-called hybrid systems which use a mix of open and proprietary standards are likely to become the dominant form of cloud computing solutions.

4. Challenges for further adoption

Cloud computing offers a large variety of business opportunities and an enormous potential for cost reduction. However, in order to tap the full potential of cloud computing, market conditions, the regulatory framework, the political environment as well as legal technical terms and conditions must be optimal. Therefore, policy makers and business leaders face challenges in several areas.

4.1 Technological challenges

Armbrust et al. (2009) classify technical challenges for cloud computing in two different categories.

- The first refers to adoption challenges of the new technology. From a technical point of view a major challenge lies in the reliability of the technology. Any breakdown of an important service can be damaging for firms' businesses and therefore represents a central concern.
- The second category refers to the growth potential of cloud computing technologies and solutions. Due to its multi-tenancy possibilities, cloud computing providers are confronted with entirely new dimensions of computing that may provoke data transfer bottlenecks, performance unpredictability, scalable storage bugs, bugs in large-scale distributed systems as well as the scaling speed. To meet these requirements cloud computing may use latest developments of internet and cloud computing technologies like virtual machine techniques and flash memory hardware for performance unpredictability.

In order to meet these technical challenges, further technological progress and innovations are necessary. However, firms will only invest into research and development and take the risks of introducing innovations, if there is a stable and sound market environment. Therefore, policy makers need to focus on providing reliable investment conditions such as appropriate regulatory environments. In addition to the cloud computing industry per se, this also includes related areas such as telecommunications that provide necessary infrastructure such as internet access. Here, the current struggle to roll out modern access networks (e.g. based on glass fiber) that allow for the necessary bandwidth is a relevant example of how the lack of appropriate investment incentives can distort the development of innovative technologies.

4.2 Challenges for market regulation

A major regulatory concern will be the development of competition in cloud computing markets. Presently, competition is strong as many new players enter the market at different levels so that there is currently no need for regulation or market intervention. However, as described in section 3.4, economies of scale and network effects are likely to lead to higher levels of market concentration while other factors such as product differentiation and the use of open standards tend to reduce the potential monopoly power. To which extent these different factors will eventually shape competition levels remains to be seen. It will, however, be closely monitored by competition authorities and market regulators. But the evolution of ICT markets such as cloud computing also poses new challenges to competition policy. In particular, current practices such as the determination of a dominant position, the definition of relevant markets or the assessment of uncompetitive conduct need to be adjusted in the light of the insights gained from relevant theories such as the economics of two-sided markets.

Inter-operability is another important issue for market supervisors. At the current early stage of market development, most cloud computing providers try to gain market share by using open standards to ensure inter-operability. In later stages of market development, when the markets will be more concentrated, using proprietary standards might become a beneficial strategy in order to lock-in customers. From a market surveillance perspective this reduces welfare. Hence, market authorities may try to ensure open standards and might impose it as a remedy against uncompetitive conduct. In monitoring and analysing the markets, regulators will again need to consider the specific properties of two-sided markets. For example, it will be difficult and thus unlikely, that platform providers will be able to change once introduced open standards to proprietary ones. However, by imposing open standards where proprietary standards have been established, a market supervisor may lower incentives for innovations and investment. Hence, a trade-off between open standards (connected with higher welfare in a static comparison) and dynamic innovation incentives may occur and must be addressed.

Finally, market regulators will observe the market for cloud-based applications. Cloud computing platform providers have multiple instruments to exercise monopoly power at the expense of software vendors. If platforms have enough market power, they can impose rules on ISVs concerning how to sell their applications, at which price and under which conditions. Provided that ISVs are locked-in with a specific platform, market regulation could be called for. Again, in the context of cloud computing, the definition of the relevant market will be crucial and insights from modern economic theory and empirical evidence will have to serve as a basis.

4.3 Data security

Cloud computing offers entirely new ways of processing, storing, collecting and managing data in global networks spanning many countries. Moreover, new relations between firms and customers like multi-tenancy systems arise. However, most laws regulating these relations are effective only in a single country. Thus the globalisation of computing needs to be backed by international laws which are consistent with these changes and provide a sound framework for doing business beyond national borders.

Data security will be a main topic for market regulators. If large parts of private and commercial data are to move into the cloud, trust into the security and guaranteed privacy of these data is a prerequisite for a cloud computing market to evolve. However, markets for security often exhibit market failures. That is, the positive effects of providing security usually benefits all agents in a market, not only the one who provides (and pays for) security. In the cloud computing context, some large, well-established players could invest into cloud security and establish end-user confidence into cloud computing in general. Other platform providers then have an incentive to free-ride and offer cheaper but insecure cloud solutions and thus misuse their customers' trust. Spectacular cases of lost or leaked data could subsequently lead to customers' mistrust into cloud computing as a whole. The magnitude of this problem depends on how well customers can distinguish between secure and insecure cloud computing providers. It is possible to mitigate this problem by establishing standards for data security and enforcement mechanisms. These can be implemented by industry associations (cf. Microsoft's proposition for a foundation regarding data privacy protection, 2010) or in cases of severe market failures by market regulators.

4.4 Environmental challenges

Over the past years IT-related energy consumption has become an important issue for firms in the cloud computing industry. In fact, energy consumption from large server farms has doubled between 2000 and 2005 from 0.5 percent to 1 percent of world total electricity consumption (Technological Review 2009). By virtue of the economic expansion in emerging markets like India and China, demand for ICT services will quadruple by 2020 and cause a significant and rapidly growing energy- and carbon footprint of the ICT industry (Greenpeace 2010). Nevertheless, ICT in general and cloud computing in particular also offer substantial potential for reductions of total energy consumption and thus emissions of greenhouse gases of entire economies by enabling more energy efficient production processes in general as well as a more efficient use of IT resources in particular (DIW econ 2009, Climate Group 2008).

Generally, from an economic point of view, it is and should be the energy and environmental policy framework as established by national governments that shapes the ecological footprint of cloud computing. Just as for all sectors of an economy, firms active in the cloud computing industry will try to maximize their profits while taking this framework as given. Such profit maximization is necessary for the efficient allocation of resources and the maximization of social welfare. As long as the use of electrical energy causes environmental damages that are not accounted for, it is therefore the task of energy and environmental policy to ensure that the interaction of demand and supply will lead to socially-efficient price levels. Therefore, the related environmental challenge is neither a specific one for cloud computing, nor should it be part of the regulatory concerns that matter with respect to this general purpose technology. Rather, it is the most important task for environmental policy makers to ensure that all negative externalities that are caused by the use of energy are efficiently internalized into the energy price. Instruments capable to achieve this such as a tax on carbon emissions or a trading scheme for emissions permits have already been established and are ready to be used.

5. Conclusions

This report presents an economic assessment on cloud computing, a new frontier in the IT era in which software solutions as well as hardware resources are provided by global server networks (“the cloud”) and data-access via the internet rather than locally on personal computers and on-site servers.

Overall, the report finds that cloud computing will lead to significant benefits for individual firms, mainly due to lower IT costs per se as well as due to a shift of fixed IT expenses to variable costs of IT services. Naturally, this will also impact economy-wide developments and increase employment, economic growth and productivity. On the other hand, the rise of cloud computing will also alter the level of competition in the software industry. Just as this is a challenge for major industry players, it is one for policy makers who might face the need to assess competition levels and possibly to impose remedies. However, the analysis in this report demonstrates that the case for public intervention in cloud computing industries currently does not exist and that it is uncertain whether this will change in the future. In fact, a crucial element for sustaining a sufficient level of competition is the use of open standards.

The report finds a number of challenges for further developments of cloud computing with respect to technical and regulatory issues and data security. As the discussion emphasizes, these challenges mainly affect the industry itself rather than policy makers. Hence, there is currently no need for significant public interventions into the development of this industry. On the other hand, given the huge economic potential of this technology, policy makers and regulators should be open-minded to the industry's concerns and help – where needed – through exchange of opinions or support in establishing specific standards.

6. References

van Ark, B., O'Mahony, M. and Timmer, M. P. (2008): "The productivity gap between Europe and the United States: trends and causes", Journal of Economic Perspectives, Vol. 22, No. 1, pp. 25-44.

Armbrust, M., A. Fox, R. Griffith, A.D. Joseph, R. Katz, A. Konwinsky, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia. (2009): "Above the Clouds: A Berkeley View of Cloud Computing", UC Berkeley RAD Laboratory, http://radlab.cs.berkeley.edu/.

Armstrong, M. (2006): "Competition in two-sided markets", RAND Journal of Economics, Vol. 37, No. 3, pp. 668–691.

BITKOM. (2009): Cloud Computing – Evolution in der Technik, Revolution im Business. Download: http://www.bitkom.org/files/documents/BITKOM-Leitfaden-CloudComputing_Web.pdf.

Climate Group (2008): "SMART 2020: Enabling the low carbon economy in the information age", A report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI).

Detecon Consulting (2010): „Wer klaut in der Cloud? Chancen und Risiken des Cloud Computings", Opinion Paper, July 2010.

DIW econ (2008): "An Economic Assessment of ICT Adoption and its Impact on Innovation and Performance. European Commission", Study Report 10/2008.

DIW econ (2009): "ICT Impact on Greenhouse Gas Emissions in Energy-Intensive Industries", Impact Study No. 03/2009, Sectoral e-Business Watch on behalf of the European Commission.

DIW econ (2010): "A Single Market for an Information Society – Economic Analysis", The Report for the Directorate General Information Society and Media.

Dubey, A., J. Mohiuddin, and A. Baijal (2008): "Emerging Platform Wars in Enterprise Software", McKinsey & Company.

e-business watch (2008): "An Economic Assessment of ICT Adoption and its Impact on Innovation and Performance", European Commission, DIW Berlin, Final Report.

Economides and Katsamakas (2006): “Two-Sided Competition of Proprietary vs. Open Source Technology Platforms and the Implications for the Software Industry”, Management Science, Vol. 52, No. 7, pp. 1057–1071.

Enterprise LSE (2010): The Economic Impact of ICT, Report on behalf of the European Commission.

Etro, F. (2009a): “The Economic Impact of Cloud Computing on Business Creation, Employment and Output in Europe”, Review of Business and Economics, Vol. 54, No. 2, pp. 179-218.

Etro, F. (2009b): Endogenous Market Structures and the Macroeconomy, Berlin: Springer 2009

Experton Group (2009): Software as a Service, Marktzahlen Deutschland 2009 – 2011.

Gartner (2009): “Forecast: Sizing the Cloud; Understanding the Opportunities”, in: Cloud Services, Gartner Inc.

Gray, J. (2008): “Distributed computing economics”, Queue 6, 3 – 2008, 63-68.

Greenpeace (2010), Make IT green – Cloud Computing and its contribution to climate change, Greenpeace International March 2010.

Grözinger, M. (2010). Cloud Computing – Eine Einführung, BITKOM 2010.

von Hippel, E. and G. von Krogh (2003): “Open Source Software and the ‘Private-Collective’ Innovation Model: Issues for Organization”, Organization Science, Vol. 14, No. 2, pp. 209-223.

Jorgenson, D. W., M. Ho and K. J. Stiroh (2003): “Growth of U.S. Industries and Investments in Information Technology and Higher Education”, in: Corrado, Haltiwanger, and Sichel (eds.) Measuring Capital in a New Economy, University of Chicago Press: Chicago.

Microsoft (2010): Ideenpapier zum Konzept einer Stiftung Datenschutz, o.O.

Rochet, J.-C. and J. Tirol (2006): “Two-sided markets: a progress report”, RAND Journal of Economics, Vol. 37, No. 3, pp. 645–667.

Stiroh, K. (2002): “Are ICT Spillovers Driving the New Economy?”, Review of Income and Wealth, Vol. 48, No. 1, pp. 33-58.

Solow, R. (1987): “We’d better watch out”, New York Times Book Review, July 12 1987.

Technology Review (2009): http://www.technologyreview.com/business/23520/.

Timmer, M. and B. van Ark (2005): "IT in the European Union: A driver of productivity divergence?", Oxford Economic Papers, Vol. 51, No. 3.