The Economics of Cloud Computing†

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The paper examines the economic impact of the diffusion of a new technology as cloud computing. This will allow firms to rent computing power and storage from service providers and to pay on demand, with a profound impact on the cost structure of all the industries, turning some of the fixed costs into marginal costs of production. Such a change will have a substantial impact on the incentives to create new business, and through this, on investments and macroeconomic growth, job creation in all industries and job reallocation in the Information and Communications Technology (ICT) sector, and public finance accounts, through the direct impact on the public sector spending and the indirect one on the tax revenues. The paper investigates the consequences of the diffusion of cloud computing on market structures and competition, and tries to disentangle the above-mentioned aspects with a particular focus on a simulation run for the European economy.

Introduction

Cloud computing is a general purpose technology of the IT field which became widely available in the late 2000. Vaquero *et al.* (2009) define it as "a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized Service Level Agreements."

The diffusion of this new technology appears to follow the pattern of older general purpose innovations. In the course of modern history, the introduction of new technologies has often created initial resistance (think of modern assembly lines), initial diffidence (think of early mobile phones), visionary ideas (think of Bill Gates' claims of bringing a PC

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to every house), a slow adoption at the beginning (even for electricity),[1] with a mix of clear general benefits and specific costs (think of new energy sources), and finally, a process of rapid and generalized adoption. Researchers often talk of a technology adoption life cycle model: the first group of agents to use a new technology is called 'innovators' (and they overcome technological or institutional or coordination barriers to the adoption of the new technology), followed by the 'early adopters' (that are typically forward looking), the majority (that simply follows a process of rent maximization), and the 'laggards' (that are relatively myopic). This leads to repeated processes of gradual and sometimes slow diffusion of new technologies, even when their net benefits for the society are large and generalized. With the new general purpose technology of the Information and Communications Technology (ICT) field, cloud computing, the path of adoption is likely to be similar, though different national policies in support of its adoption may induce variable speed of diffusion in different countries.[2]

Cloud computing is an Internet-based technology through which information is stored in servers and provided as a service and on-demand to clients. The impact of its diffusion may be quite relevant, as it happened for the diffusion of telecommunications infrastructures in the 1970s and 1980s (for a related econometric study on their economic impact, see Röller and Waverman, 2001) or the introduction of the Internet in the 1990s (for an interesting study on this technological revolution, see Varian *et al.*, 2002) and, in general, for the diffusion of computers in the last three decades. In an important work, Jorgenson (2001) has shown how substantial has been the contribution of the adoption of the computer for the accumulation of capital and for the growth process of the US since the 1980s.[3]

Through cloud computing, firms will be able to rent computing power (both hardware and software in their latest versions) and storage from a service provider, and to pay on demand, as they already do for other inputs as energy and electricity. This will have a profound impact on the cost structure of all the industries using hardware and software, and therefore it will have crucial consequences on:

- Business creation and macroeconomic performance;
- Job creation in all industries and job reallocation in the ICT sector; and
- Public finance accounts, through direct impact on public sector spending and the indirect one on the tax revenues.

In this study, we try to disentangle these three aspects of the impact of cloud computing with reference to the European economy in the next few years. The first aspect is in line with our earlier results derived in Etro (2009a) on the basis of recent research on endogenous market structures in macroeconomic models by Etro and Colciago (2010) and more recently

1 As noticed by David (1990), only with the reinvention of the production process in the factories (which took decades) was the potential of electrification fully realized.

2 The classic work by Parente and Prescott (1994) has emphasized how differences in the barriers to the adoption of new technologies can heavily affect the growth potential of different countries.

3 Jorgenson (2001) estimates that computers contributed to 32% of TFP growth, and software to 9% of it in the period 1995-1999.

Colciago and Rossi (2011): the diffusion of the new technology may create a few hundred thousand new European Small and Medium Size Enterprises (SMEs) with substantial impact on employment and a reduction of the unemployment rate by a few decimal points. Moreover, the net impact on employment derives from a ratio between new jobs in all sectors and lost jobs in traditional ICT employment of about eight to one. This suggests that the problem of reallocation of labor (within IT departments or between these and other IT-related sectors) may be quite limited. Finally, our simulation suggests that the corresponding impact on the deficit/GDP ratio should be around 0.1% in the pessimistic scenario and 0.2% in the optimistic one. Therefore, the introduction of a cost reducing technology as cloud computing can have a small but not negligible impact on public finances, even if it creates a marginal reduction of the costs of the public sector. This happens because public finances benefit on the one side from the direct reduction in costs, and on the other side from the additional tax revenue derived from the boost to the economic activity and the creation of new private business and jobs.

The paper is organized as follows: it reviews multiple aspects of the new technology, followed by its macroeconomic impact with a special emphasis on the labor market. Then it examines the social costs and benefits of the process of job creation and destruction associated with the diffusion of cloud computing, and the consequence for European public finances. Finally, the conclusion is offered.

A new general purpose technology as cloud computing can exert a number of effects on the economy. First of all, it can provide huge cost savings and more efficiency in large areas of the public sector, including hospitals and healthcare (especially to provide information and technologies in remote or poorer locations), education (especially for e-learning and universities), and the activity of government agencies with periodic spikes in usage.

A few examples from the European health sector are in order. We start from the most simple applications to move toward more relevant ones. One of the leading Italian hospitals, the Pediatric Hospital of Bambin Gesù in Rome, has recently switched to an online solution for the e-mail services of its 2,500 employees (the switch that took place in 2010, in less than four months, led to large cost savings and allowed IT specialists to focus on other more relevant tasks for the hospital). The Swedish Red Cross has improved the coordination of its intervention adopting a cloud computing solution which has reduced costs by about 20% and enhanced communication in real time between its employers. A Russian cardiovascular center, Penza, has adopted a cloud computing solution to coordinate activities, diagnosis and decisions on treatment and surgery between doctors around the country, with crucial gains for the patients. During the H1N1 pandemic, a global cloud computing tool was built and made available in a few days (based on the Microsoft's Windows Azure platform) to centralize and provide information on the diffusion of the flu.

Second, cloud computing can provide cost efficiencies in the private sector, whose exploitation in all industries is directly related to the diffusion of what Lanvin and Passman (2008) call e-business skills in the managerial environment (the capability of exploiting new opportunities provided by the ICT and to establish new business). Liebenau (2010) has been studying the relationship between the character of the cloud and the organizational, financial and managerial changes that businesses need to make to take advantage of what is on offer. He has focused on different kinds of ICT budget issues, noticing that "for many functions the up-front costs can be much lower, reducing the entry barriers for small firms and providing many companies new opportunities for experimentation, prototyping and containing risks. Organizations can shift from major ICT expenditure on capital goods to spending on operating costs, a change that will have meaning for more than accountants. Budgets that form part of planning and some of the ways incentives are structured are likely to change. This could have major effects upon how firm performance is measured and thereby how companies are valued, stocks traded and other financial services extended. A focus on innovation should become the most important element of these changes."[4]

Beyond cost efficiencies, on which we will return soon, substantial positive externalities are expected from cloud computing because of energy savings. The improvement of energy efficiency may contribute to the reduction of total carbon emissions in a substantial way. The introduction of cloud computing can also create multilateral network effects between businesses and increased productivity within businesses, and it can promote entry and innovation in all the sectors where ICT costs are relevant and are drastically reduced by the adoption of cloud computing.

Diffusion of Cloud Computing

In a recent research based on the works of Etro and Colciago (2010) and Colciago and Rossi (2011), we have simulated the economic impact of the diffusion of cloud computing in Europe through the incentives to promote business creation. The key point is that, somewhat surprisingly, a big portion of the benefits associated with the diffusion of the new technology derives from indirect mechanisms active in non-ICT sectors rather than from the direct efficiencies in the ICT sector. Here, we report some refinements of this study which take into consideration aspects that were neglected in the earlier work, namely, the decomposition of the process of job creation across countries and macrosectors and between job creation and job destruction, and the role of public finances.

Starting from conservative assumptions on the cost reduction process associated with the diffusion of cloud computing over five years, we obtain that the diffusion of cloud computing could provide a positive and substantial contribution to the annual growth rate (up to a few decimal points), helping to create several hundred thousand new jobs every year through the development of a few hundred thousand new SMEs in the whole EU-27. The driving mechanism behind the positive contribution works through the incentives to create new firms, and in particular, SMEs. One of the main obstacles to entry in new markets is represented by the high upfront costs of entry, often associated with physical (and ICT) capital spending. Cloud computing allows potential entrants to save the fixed costs associated with hardware/software adoption and with general ICT

[4] On the financial aspects of cloud computing *see also* Jäätmaa (2010).

investment, and turns part of this capital expenditure into operative expenditure, which is a variable cost. This reduces the constraints on entry and promotes business creation. The importance of such a mechanism is well known at the policy level, especially in Europe, where SMEs play a crucial role in the production structure.

Cloud computing is currently developing along different concepts, focused on the provision of 'Infrastructure as a Service' (IaaS: renting virtual machines), 'Platform as a Service' (PaaS, on which software applications can run) or 'Software as a Service' (SaaS: renting the full service, as for e-mail). In preparation for its introduction, many hardware and software companies are investing to create new platforms able to attract customers 'on the clouds'. Cloud platforms provide services to create applications in competition with, or in alternative to on-premises platforms, the traditional platforms based on an operating system as a foundation, on a group of infrastructure services and on a set of packaged and custom applications. The crucial difference between the two platforms is that while on-premises platforms are designed to support consumer-scale or enterprise-scale applications, cloud platforms can potentially support multiple users at a wider scale, namely at Internet scale.[5]

Competition Issues in the Provision of Cloud Computing

The introduction of cloud computing is going to be gradual. Currently, we are in the middle of a phase of preparation with few pioneers offering services that can be regarded as belonging to cloud computing, often derived from internal solutions (turning private clouds into public ones). Amazon Cloud Computing was launched in October 2006, IBM's Blue Cloud in November 2007, followed by cloud solutions by Google and Microsoft. Meanwhile, many large high-tech companies as Amazon, Google, Microsoft, Saleforce.com, Oracle and others keep building huge data centers loaded with hundreds of thousands of servers to be made available for customer needs in the near future.[6]

[5] In the business literature, cloud computing has been seen as a step in the commoditization of IT investments (Carr, 2003), as the outcome of an evolution toward a utility business model in which computing capabilities are provided as a service (Rappa, 2004; and Brynjolfsson *et al*., 2010), as the core element of the era of Web 2.0, in which Internet is used as a software platform (O'Reilly, 2005), or simply as an application of the generativity power of the Internet (Zittrain, 2007). *See also* IDC (2008).

[6] The first mover in the field has been Amazon, that has provided access to cloud solutions with its 'Amazon Web Services' (initially developed for internal purposes). Through this cloud computing service, any small firm can start a web-based business on its computer system, add extra virtual machines when needed and shut them down when there is no demand: for this reason the utility is called Elastic Cloud Computing. Google is also investing huge funds in data centers, and 'Google App Engine' allows software developers to write applications that can be run for free on Google's servers. Even the search engine of Google or its mapping service can offer cloud application services: for instance, when Google Maps were launched, programmers easily found out how to use their maps with other information to provide new services. Microsoft is also investing a lot in new data centers. In January 2010, the leading software company has launched a cloud platform called 'Windows Azure' that is able to provide a number of new technologies: a Windows-based environment in the cloud to store data in Microsoft data centers and to run applications, an infrastructure for both on-premises and cloud applications (through .NET Services), and a cloud-based database (through SQL Data Services, which can be used by different users and from different locations). Moreover, 'Windows Azure' provides a browser-accessible portal for customers: these can create a hosting account to run applications, or a storage account to store data in the cloud, and they can be charged through subscriptions, per use fees or other methods. Another important player is Salesforce.com with its Force.com products. Also Oracle has introduced a cloud-based version of its database program.

Competition between these companies is probably going to reshape the ICT market structure, as PC distribution did in the 1980s. This may raise some concerns for competition and for the consequences on the users of cloud services.

On the one side, the strength of competition for the provision of cloud services suggests that multiple players (as those mentioned above and, possibly, others) would probably share the market for a while avoiding excessive concentration. The importance of cloud computing in changing the prevailing business model in ICT is determining wide investments in innovation by these same players, therefore the ultimate success in the cloud business will be associated with the creation of superior technologies rather than with the exploitation of network effects or barriers to entry.

On the other side, the development of alternative cloud computing solutions could create the risk of being locked-in for potential customers. To avoid this, it is important to promote, especially in the initial phase, agreements between public authorities and industry leaders on a minimum set of technological standards and process standards to be respected in the provision of cloud services to guarantee data security, privacy and portability.

For sure, the diffusion of cloud computing is going to create a solid and pervasive impact on the global economy. The first and most relevant benefit is associated with a generalized reduction of the fixed costs of entry and production, in terms of shifting fixed capital expenditure (CAPEX) in ICT into operative costs (OPEX) depending on the size of demand and production. This contributes to reduce the barriers to entry, especially for the SMEs, as infrastructure is owned by the provider, it does not need to be purchased for one-time or infrequent intensive computing tasks, and it generates quick scalability and growth. The consequences on the endogenous structure of the markets with largest cost savings will be wide, with the entry of new SMEs, a reduction of the mark ups, and an increase in average and total production. In spite of the fact that the relative size of IT cloud services may remain limited in the next few years, they are destined to increase rapidly as a percentage of total IT revenues and to have a relevant macroeconomic impact, especially in terms of creation of new SMEs and of employment. Cloud platforms and new data centers are creating a new level of infrastructures that global developers can exploit, especially SMEs that are so common in Europe. This will open new investment and business opportunities, currently blocked by the need for massive upfront investments. The new platforms will enable different business models, including pay-as-you-go subscriptions for computing, storage, and/or IT management functions, which will allow small firms to scale up or down to meet the demand needs. This mechanism is going to be crucial in Europe because of the large presence of SMEs and of the higher risk aversion of the entrepreneurs compared to their American counterparts (largely because of the differences in the capital and credit markets and in the venture capital market). Reduction of the fixed costs may reduce the risk of failure and promote entry even more.

Evaluating the Impact of Cloud Computing

To evaluate the impact of cloud computing, we have adopted a macroeconomic approach emphasizing the effects that this innovation has on the cost structure of the firms investing in ICT and consequently the incentives to create and expand new business, on the market structure and on the level of competition in their sectors, and ultimately on the induced effects for aggregate production, employment and other macroeconomic variables. The methodology is based on a dynamic stochastic general equilibrium calibrated model augmented with endogenous market structures in line with recent developments in the macroeconomic literature. The model follows the framework introduced by Etro and Colciago (2010) and recently extended to include the dynamics of the labor market by Colciago and Rossi (2011), and it has been augmented with a public sector producing goods and services and, for the sake of simplicity, being financed with labor income taxation.[7] Such a model is perturbed with a realistic structural change to the cost structure, with the purpose of studying the short and long-term reactions of the economy.

Our experiment is focused on Europe, taking as given the rest of the world (which is an additional conservative hypothesis). Therefore, all our data were derived from the official EU statistics (Eurostat), mainly for the number of firms, which is basically equivalent to the number of SMEs, employment and GDP. In particular, we used data for most of the EU member countries. Moreover, we focused on a few aggregate sectors for which we have detailed and comparable EU statistics: manufacturing, wholesale and retail trade, services, including hotels and restaurants, transport storage and communication, real estate and other financial and business activities. These aggregate sectors cover the majority of firms in terms of number (more than 17 million firms) and a large part of employment for the European countries (about 114 million workers), and include all the sectors where the effects emphasized in our analysis are relevant, namely, manufacturing and service sectors, where the use of ICT capital, the role of entry costs, and competition effects are more relevant.[8]

Two key factors for the impact of cloud computing are, on the one side, the size of the cost savings in ICT spending and, on the other side, the reduction of the fixed costs of production. On the first point, the business literature emphasizes large savings. IDC (2009) estimated a total cost reduction of about 50% or more in the private sector, but a more prudential estimate in a negative scenario could go down to 20%. Estimates for the public sector are more limited, ranging between a reduction in total costs of 10% in a pessimistic scenario and of 30% in an optimistic one [but West (2010) suggests a range between 25% and 50% in successful cases]. One should also keep in mind that the portion of these potential benefits that will be translated on the private sector will also depend on the level of competition in the provision of cloud services. As mentioned above, while discussing

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7 *See* Ghironi and Melitz (2005), Bilbiie *et al.* (2007, 2008a and 2008b), Etro (2007), Cecioni (2010), Etro and Colciago (2010), Faia (2010), Lewis and Poilly (2010), Colciago and Rossi (2011), and Totzek (2011). *See* Etro (2009b) for a survey.

8 We ignored other aggregate private sectors (as electricity, gas and water supply), where we believe that our mechanisms are either weaker or absent, or sectors where comparable data were not available. Country-specific heterogeneity and sectoral differences were taken into consideration on the basis of statistics on the labor market and the entry/competitive conditions at the level of EU countries and their aggregate sectors.

the potential antitrust issues, we have reasons to believe that competition in the field will be strong enough to conjecture a wide translation of the cost savings.

On the second point, Carr (2003) suggests that about half of capital expenditure of modern firms is ICT related, and therefore a large part of it may be eliminated and (partially) turned into operative expenditure. While this may be true in a number of sectors and for advanced companies, following Etro (2009a), we adopted a more conservative assumption for our macroeconomic investigation. One of the best reviews of the state of ICT in Europe is provided by the e-Business Watch of the European Commission. The 2006 e-Business Report provided a comprehensive survey of ICT adoption and spending, showing that 5% of total costs is spent in ICT. Since only a part of the total cost corresponds to fixed costs of production, the average ICT budget must be more than 5% of the total fixed costs of production. Of course, only a part of ICT spending represents fixed costs, and only a part of it will be cut even after the adoption of cloud computing in alternative to a fully internal solution. For this reason, we decided to adopt a conservative assumption and to consider a range of reduction in the fixed costs in the long run between 1% and 5%. The same cost reduction is assumed to take place in the production of goods and services of the public sector. Our main purpose is to show that even such a limited technological change due to cloud computing delivers substantial effects at the macroeconomic level. Needless to say, larger shocks will be associated with wider effects.

Macroeconomic Impact of Cloud Computing: What Is the Contribution to the Reduction of the Unemployment Rate?

In this section we report the results of our simulation for the introduction and diffusion of cloud computing in the European economy. We focus on the impact on GDP, business creation and employment (the role of the public sector will be considered in more detail in a subsequent section) in the short term, which is defined as a period of one year since the beginning of the process of adoption of cloud computing (say in 2012), and in the medium term, that is after five years (say in 2016). Two scenarios are considered: slow adoption corresponds to the case of a slow diffusion of the new technology leading to a 1% reduction of the fixed cost, and rapid adoption leading more rapidly to a 5% rapid reduction in the fixed costs. The calibration of the model and of the shock is the same as adopted in Etro (2009a).

The contribution to GDP growth can be hardly differentiated between countries and sectors, therefore we simply summarize our average estimates to the European countries. The range is between 0.1% a year in the short run under slow adoption, and 0.4% in the medium run under fast adoption of cloud computing.

Before entering further details, it is worthwhile to sketch the main mechanism emphasized in our model. The gradual introduction of cloud computing reduces the fixed costs needed to enter in each (non-ICT) sector and increases the incentives to enter. This increases the current and future competition in each market and tends to reduce the markups and increase production. The associated increase in labor demand induces an upward pressure on wages that induces workers to work more (or new agents to enter in the labor force). The current and expected increase in output affects the consumption/savings behavior. In the short run, the demand of new business creation requires an increase in savings, which may induce a temporary negative impact on consumption. However, in the medium and long run, the positive impact on output leads to an increase in consumption toward a higher steady-state level. Of course, a faster adoption exerts a large impact on business creation and therefore on output and employment as well.

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The simulation confirms our earlier result of a permanent creation of about 400, 000 new SMEs. The largest impact is expected to occur in the aggregate sectors of wholesale and retail trade (about 160,000 new firms in the medium run under fast adoption) and of real estate and other financial and business activities (plus 150,000 new SMEs). Our empirical exercise shows a strong impact on the creation of new SMEs, in the magnitude of a few hundreds of thousands in the whole EU (again, this is additional to a normal situation without the introduction of cloud computing). Incidentally, this is consistent with the conclusions of studies like IDC (2009) that argue that cloud services could add $800 bn in net new business revenues between 2009 and 2013. Notice that the effect is permanent and tends to increase over time: the creation of new SMEs is not going to vanish, but it is going to remain over time with a permanent impact on the structure of the economy. Moreover, the effect is deeper in countries where the diffusion of SMEs is particularly strong (as in Italy) or where ICT adoption has been generally rapid (as in the UK).

We have also examined the impact on employment in each country with a distinction between aggregate sectors. Overall, the country-by-country results are similar to those found in our earlier study and are in part affected by differences in labor market conditions that tend to affect the ability of the economy to react to a positive change through job creation in the regulatory framework and in the competitive conditions of the goods markets (which create the conditions for a quick business creation).

One should take the estimates on the impact on employment with care. Even if we take into consideration the country-specific factors related to the labor market conditions, our basic simulations emphasize the impact in terms of hours worked, whose translation in new jobs depends on a number of institutional and structural features of the labor markets and their country-specific regulation. Keeping this in mind, we confirm the spirit of the results of our earlier study. The introduction of cloud computing could create hundreds of thousands of new jobs in a permanent way. Our simulation at the EU level suggests an initial creation of about 300,000 new jobs under the scenario of a slow adoption and more than a million new jobs under our positive scenario. The positive contribution to employment would be reduced in the following years, with a range between 70,000 and 700,000 new jobs created in the fifth year of the adoption process. About two-thirds of job creation is expected to occur in the six largest countries (UK, Germany, France, Poland, Italy and Spain), but each country could enjoy an increase in the workforce. The positive contribution of cloud computing to the net creation of new jobs can be translated into a quicker path of adjustment toward the long-run equilibrium of the labor market, that is, into a more rapid reduction of the unemployment rate. Our estimates of the reduction of the unemployment rate in the European countries due to the introduction of cloud computing remain between 0.1% and 0.3% in the short run, and between 0.05% and 0.2% in the medium run. In other words, the process of adjustment of the unemployment rate toward its long-run level in the next years could be substantially accelerated by a rapid adoption of the new technology throughout the economy.

While the nature of our experiment (a simulation) suggests that these results should be taken *cum grano salis*, the results also suggest the relevance of the mechanism underlying the diffusion of cloud computing. Most of the new jobs are expected in the manufacturing sector (31% for our countries), followed by the sector of wholesale and retail trade (28%) and the real estate and finance and other business activities (23%), with only a minor contribution by the sector related to transport and communication (10%) and the one including hotel, restaurants, and related activities (8%). Nevertheless, the process of business creation is going to be highly differentiated across countries, for instance, with a predominance of the manufacturing sector in industrial countries such as Germany and Italy, but also in Eastern European countries with a less developed tertiary sector, of the financial sector in the UK and of trade and services in a country as Greece. Not by chance, 36% of the new jobs in Germany, 34% in Italy and percentages above 40% in the Czech Republic, Slovakia and Romania, are expected from the manufacturing sector. At the same time, only 19% of the new jobs estimated in the UK derive from manufacturing, while 29% of them are expected in the macrosector, including real estate, finance and other business activities. Finally, Greece can expect 56% of the new jobs from wholesale and retail trade and from services, including hotels and restaurants.

Job Creation and Job Destruction: How Large Are the Social Costs of the Process of Job Creation and Destruction?

The results of our simulation on employment refer to the net creation of jobs, which is the difference between new (non-ICT) jobs created in the economy and (ICT) jobs possibly lost during the process of technology adoption. This leads to crucial questions on the decomposition of these figures between gross job creation and job destruction.

First of all, we need to emphasize that the social problems associated with the crowding out of ICT jobs may be much lower than one may expect. A first reason for this is implicit in the same nature of our results: as mentioned, a crucial benefit of the diffusion of cloud computing is associated with the push of the economy due to new business creation, which, in turn, by definition is creating new firms with the new technology, without destroying any jobs associated with the old technologies. For this reason, a lot of the benefits of the adoption of cloud computing are completely unrelated to the process of job destruction.

A second reason is that cloud computing generates a range of innovation opportunities that can only be exploited by ICT departments after a fundamental change of tasks. As noticed by Brynjolfsson *et al*. (2010), "the real strength of cloud computing is that it is a catalyst for more innovation. In fact, as cloud computing continues to become cheaper and more ubiquitous, the opportunities for combinatorial innovation will only grow. It is true that this inevitably requires more creativity and skill from IT and business executives."

Beyond this, the simulation can provide further results on the decomposition of the process of job creation. Since the experiment simulates a reduction in fixed costs, which is partially due to lower capital investment and partially due to lower labor employment in maintenance and administration of the ICT equipment, we can estimate the ratio between jobs created and job lost in the different scenarios. This ratio gives an idea of the social costs that the introduction of the new technology can create in the short run and of their size relative to the social benefits. Of course, a large portion of the jobs lost in ICT departments would be easily reallocated to similar positions within the same firms for the administration of cloud computing solutions, and for the development of new solutions for new IT tasks (this is most likely to be the case in medium and large companies, and of course in the public sector). However, purely for simplicity, let us assume that all the lost jobs in the IT departments of the existing firms will not be reallocated in the same firms. In other words, let us assume that the job destruction is at its maximum possible level as a consequence of the technological change.

To estimate the ratio between job creation and job destruction, we need to make some assumptions on the percentage of labor costs in the total fixed ICT costs. This is not likely to be particularly high, since a large part of the ICT is in hardware and software; however, let us assume that it is in line with the average labor intensity of the rest of the economy. Under these conservative assumptions, we have estimated the ratio between new jobs and lost jobs in the two extreme scenarios. The range is between 5 to 1 and 10 to 1.

In conclusion, the impact of the technological change on employment derives from a ratio between new jobs in all the sectors and lost jobs in the traditional ICT employment of about eight to one. As noticed, this is the result of very conservative assumptions, since a big portion of the lost jobs in IT departments are likely to be reallocated to different tasks within the same firms, and most of the time to more mission-critical tasks (think of the switch of focus of IT departments once e-mail services are outsourced).

In countries with a more rigid labor market, short-run costs of reallocation may emerge, and policy intervention in these cases may be useful. However, the results suggest that the problem of reallocation of labor following the diffusion of a new technology as cloud computing may be quite limited.

The Impact on Public Finances: What Will Be the Impact on the Deficit/GDP Ratio?

The adoption of cloud computing in the public sector can also have a fundamental role in the near future. A few business studies have investigated this aspect (see, West, 2010) emphasizing the potential for a large impact on cost savings, though lower than in the private sector.

In the US, interesting examples are available both for local and central public authorities. The city of Los Angeles has switched to a Google-based online solution for its e-mail services in 2009: the estimated cost reduction was around 25%, only nine jobs were gradually eliminated and almost 100 servers were relocated to a different use within the city administration. A similar switch took place in Washington, DC with estimated cost savings of around 50%. At a smaller level, the switch to a Microsoft-based online solution of the e-mail services of the Californian town of Carlsbad created cost savings of 40% per year (West, 2010). Even higher were the savings associated with the adoption of a cloud computing solution for service hosting and mapping technologies of the city of Miami, which also allowed the local authorities to introduce a new and more efficient system of control of the urban area. A Salesforce.com solution was employed by the US State Department for budget information, which led to cost reductions of around 75%, while private clouds have been adopted by NASA and the US Air Force. In September 2009, the Obama Administration has instituted the Federal Cloud Computing Initiative (FCCI), with the purpose of promoting standards and rules for the adoption of online services to reduce the $76 billion spending of the American government in IT.

In Europe, the most advanced country in terms of the adoption of cloud computing in the public sector is definitely the UK, which is trying to move to the cloud its IT assets at a rate of 10% a year, a wise gradual approach to reduce the £16 bn spending of the British government in IT. Many other local public authorities and central ministries have started to switch to cloud computing solutions. For instance, in 2010, the Ministry of Health of Belgium adopted the SharePoint platform hosted by Microsoft to organize the entire activities of the Presidency of the European Union in the second semester of the year. This has induced high cost efficiency and better organization. Other examples are abundant in public health and education. As mentioned above, in 2010, one of the leading Italian hospitals, the Pediatric Hospital of Bambin Gesù has switched to an online solution for the e-mail services of its 2,500 employees. At the same time, a similar switch took place in a university center based near Florence, the European University Institute (a EU-sponsored research center in social sciences), which moved to the cloud, mailboxes of about 2,500 researchers, students and other staff. The switch took about four months, led to a 100 times more storage space and an improved web-based experience at substantial savings (estimated to be 43% by EUI).[9]

The cost savings associated with these experiences in the public sector should not be seen as the typical ones because of an endogeneity problem: the early adopters are naturally those who benefit the most. Nevertheless a range of cost savings between 10% and 40% appears reasonable in the public sector.

The introduction of the public sector and of labor taxation in our theoretical model allows us to derive a few more implications. First of all, the mechanism of propagation of

[9] *See* http://www.microsoft.com/casestudies/Microsoft-Active-Directory-Domain-Services/European-University-Institute/University-Avoids-345-233-in-Messaging-Upgrade-Gains-100-Times-More-Storage/4000009020.

the effects of the new technology is slightly different. Following standard assumptions, a fixed part of the initial income (before the introduction of the cost reducing technology) is destined to the production of public goods (20% as in standard macroeconomic simulations). The introduction of the cost saving technology makes public spending more efficient, which translates in direct savings (of spending needed to create the same amount of public goods), but does not create a multiplier effect (as in the private sector). However, the adoption of distortive taxation needed to finance public spending introduces new and more realistic mechanisms in the model. In particular, it strengthens the propagation of the technology change (because of a classic substitution effect: higher net wages enhance labor supply) and creates changes in public finance accounts. Since we assume budget balance to start with (which sets the initial tax rate at the level needed to finance the initial amount of public spending), the simulation allows one to derive the impact of the introduction of a cost reducing technology on public finances. As for the simulation of the impact on GDP, we are not able to provide differentiated results for countries and sectors, but we can simply derive a summarized result.

It is useful to remind the reader of the tough experiment we have performed. The gradual introduction of cloud computing creates an expansion in the economy through new business creation, additional employment and additional income. For a given tax rate, this increases the tax revenues, which create a surplus in the public accounts (that is assumed to be redistributed to the consumers). The sum of the direct savings from the adoption of cloud computing and the increased tax revenues represents the additional amount that the public sector redistributes to the private one (which in turn is consumed and contributes to strengthen the expansion). This sum, expressed as a percentage of total income, can be interpreted as the improvement in the deficit/GDP ratio due to the introduction of the general purpose technology, which is what we are ultimately interested in.

We focus again on the impact in the short term, that is after one year, and in the medium term, that is after five years, in our two scenarios. The model suggests that the corresponding impact on the deficit/GDP ratio is about 0.1% in the pessimistic scenario and 0.2% in the optimistic one. In other words, the introduction of a cost reducing technology as cloud computing can have a small but not negligible impact on public finances, even if it only leads to a marginal reduction of the costs of the public sector. This happens because public finances benefit on the one side from the direct reduction in costs, and on the other side, on the additional tax revenues derived from the boost to the economy and to the creation of new private business.

A back-of-the-envelope calculation confirms these numbers: if ICT spending is about 4% of GDP and a quarter of this (1%) is within the public sector, a cost reduction between 10% may imply an impact of 0.1% of GDP that could be moderately increased because of the indirect impact of the expansion of the private sector on taxation.

Conclusion

A part of the positive effects of cloud computing is going to be positively related to the speed of adoption of the new technology. Of course, there are a number of factors that may slow down this adoption, such as a lack of understanding of the cloud by firms, systemic risk, security, privacy[10] and interoperability issues, reliability, jurisdictional complexity, data governance, loss of IT control, and general *status quo* inertia. For this reason, our investigation suggests that policy makers should promote as much as possible a rapid adoption of cloud computing. Concrete interventions include (beyond the expansion of the broadband capacity, of course):

- International agreements in favor of unrestricted flow of data across borders (since data centers are located in different countries with different privacy laws, data portability remains a key issue for the diffusion of cloud computing);
- Agreements between EU authorities and industry leaders on a minimum set of technological standards and process standards to be respected in the provision of cloud computing services to guarantee data security, privacy and portability, and promote a healthy diffusion of the new technology;
- Introduction of fiscal incentives for the adoption of cloud computing and a specific promotion, particularly in dynamic sectors (for instance, governments could finance, up to a limit, the variable costs of computing for all the domestic and foreign firms that decide to adopt a cloud computing solution); and
- Introduction of public support to the reallocation of employment within the IT field (from IT departments, especially of small firms toward different destinations in the IT sector).

These policies may be studied in a way to optimize the process of adoption of the new technology and to strengthen the propagation of its benefits.

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