The Economic Impact of Cloud Computing on Business Creation, Employment and Output in Europe

An application of the Endogenous Market Structures Approach to a GPT innovation

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ABSTRACT

Cloud computing is a new general purpose Internet-based technology through which information is stored in servers and provided as a service and on-demand to clients. Adopting the endogenous market structures approach to macroeconomics, we analyze the economic impact of the gradual introduction of cloud computing and we emphasize its role in fostering business creation and competition thanks to the reduction of the fixed costs of entry in ICT capital. Our calculations based on a DSGE model show a significative impact for the European Union with the creation of a few hundred thousands new SMEs and a significant contribution to growth. Governments could enhance these benefits by subsidizing the adoption of cloud computing solutions.

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KEYWORDS Endogenous market structure, Cloud computing, Utility computing, General purpose technology, Firms' Entry, Business Cycle

I. Introduction

The introduction of a general purpose technology can provide a fundamental contribution to promote growth and competition,[2] and it can help the economy to recover from a severe downturn as the current one. In this article we employ the endogenous market structures approach (Etro, 2004, 2007a)[3] to study the economic impact of an innovation in the hardware-software field which is going to have a profound effect on the market structure of many sectors and on the global macroeconomic performance in the next years. This innovation is associated with cloud computing, the new frontier of the Internet era, a technology through which information will be stored in servers and provided on line as a service to clients in a pay-as-you-go manner. Firms will be able to adopt this service on demand, so as to avoid large up-front costs (that are currently necessary for hardware and software equipment) and spend in ICT according to their production necessities – see Dubey and Wagle (2007) and Armbrust *et al.* (2009) for early reviews of the topic. This will have a large impact on the cost structure and through it on the production possibilities of all firms, especially small and medium size enterprises (SMEs). Our focus will be mainly on the theoretical impact of this innovation on the creation of new firms and products, on the empirical evidence about the impact of its introduction for the European economy and on the implications for policies supporting cloud computing adoption. This allows us to apply the theory of endogenous market structures to examine a macroeconomic experiment that can be hardly approached within the neoclassical or New-Keynesian frameworks.

In the next Section II we will describe the nature of the general purpose technology represented by cloud computing, its genesis and its likely impact on the economy and on the structure of many markets. As we will see, the introduction of cloud computing is going to reduce drastically the fixed costs of entry and production, turning part of them into variable costs related to the production necessities. This will have a positive impact on entry and competition in all sectors where fixed ICT spending is crucial. The positive association between ICT innovations and competition is well known, and policymakers recognize that it may work in both directions: on one side competitive sectors adopt ICT innovations earlier and become more productive, on the other side ICT adoption enhances competition. For instance, the e-Business Watch of the European Commission (2008) notices that *while it seems obvious that increasing levels of competition can push companies to adopt and use ICT, the opposite might well also be the case. In fact, ICT and the usage of the internet have drastically impacted on certain sectors such as banking and reshaped the competitive scenario* (p. 42).

In Section III we will describe our approach to the estimate of the economic impact of cloud computing. We will adopt a standard macroeconomic model augmented with endogenous market structures and will simulate the impact of a gradual reduction of the fixed costs of entry. The experiment will be based on a dynamic stochastic general equilibrium model calibrated on the European economy and translated in empirical results on the basis of Eurostat data. In this sense, this paper provides a simple application of the endogenous market structures approach to macroeconomics. However its results should be only seen as preliminary and temptative: further work is needed to improve the match between our theoretical foundations and the empirical exercise.

Section IV will present the results. Starting from conservative assumptions on the cost reduction process, we obtain that the diffusion of cloud computing will provide a positive contribution to the annual growth rate (up to a few decimal points), contributing to create about a million new jobs through the development of a few hundred thousand new SMEs in the whole EU-27. We will present the results on business creation for each country and for each macro-area. The driving mechanism behind the positive contribution of cloud computing 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 up-front costs of entry, often associated with physical and ICT capital spending. Cloud computing allows potential entrants to save in the fixed costs associated with hardware/software adoption and with general ICT investment, and turns part of these costs into variable costs. 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. Again the e-Business Watch of the European Commission (2008) emphasizes this aspect clearly: *SMEs form significant industry segments in the EU and account for the majority share in EU employment. Thus, they require specific policy attention. While their strength lies in the flexibility with which they can adjust to changing market conditions, their small size makes them less able to face high up-front costs.* (p. 53).

Our analysis will emphasize a mechanism of propagation of the effects of cloud computing which depends on the endogenous market structures. Through business creation, the adoption of cloud computing is going to enhance competition in each sector and to increase production and lower mark ups. This will have a positive impact on consumption so as to contribute to the recovery of the EU economy. Most of all, part of these effects are going to be positively related to the speed of adoption of the new technology. Our results are only preliminary and future research should try to improve the calibration of a theoretical model or the estimation of an empirical model. Moreover, alternative methodologies would be helpful in cross-checking the validity of our results. Beside our quantitative results, our main contribution relies in the description of a mechanism through which cloud computing is likely to create a positive effect on GDP, employment and business creation. We need to notice that our approach neglects other positive effects exerted by the introduction of cloud computing, mainly the creation of new and multilateral network effects and the positive externalities due to energy savings,[4] whose consideration would be subject to excessive uncertainty. Therefore, we can look at our estimates of the impact of cloud computing on the economy as conservative estimates.

Section V discusses policy implications. Since a large part of the positive effects of cloud computing are positively related to its speed of adoption, our investigation suggests that policymakers should promote as much as possible a rapid adoption. For instance, governments could finance, up to a limit, the variable costs of computing for all the firms that decide to adopt a cloud computing solution. These policies may be easily tuned to optimize the process of adoption of the new technology and to strengthen the propagation of its benefits within the country. In a context as the European one, smaller countries would be able to obtain larger gains from similar policies at least in the initial phase, because they would easily attract foreign investments from the larger countries. In a period of increasing limits to other forms of fiscal competition, especially in the integrated market, a policy of subsidization of cloud computing could generate substantial capital flows toward smaller countries with good general infrastructures (think of Malta or Luxembourg in the E.U.).

The article draws the conclusions in Section VI. The Appendix contains an advanced treatment of the analysis.

II. Features and Implications of Cloud Computing

The term cloud computing refers to an Internet-based technology through which information is stored in servers and provided as a service (*Software as a Service*, or SaaS) and on-demand to clients (from the clouds indeed). Its impact will be spectacular on both consumers and firms. On one side, consumers will be able to access all of their documents and data from any device (the personal laptop, the mobile phone, an Internet Point..), as they already do for email services, and to exploit impressive computational capabilities.[5] On the other side, firms will be able to rent computing power (both hardware and software) and storage from a service provider and to pay on demand, as they already do for other inputs as energy and electricity: that is why we talk of *utility computing*. The former application will affect our lifestyles, but the latter will have a profound impact in terms of cost reductions on the software industry. According to Armbrust *et al.* (2009) this impact will be similar to the one that semiconductor foundries had on the hardware industry.[6] Moreover, cloud computing will also exert a fundamental impact on the cost structure of all the industries using hardware and software, and therefore it will have an indirect but crucial impact on their market structures.

In preparation to this new scenario, 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 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.

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), 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).

The introduction of cloud computing is going to be gradual. Currently we are only in a phase of preparation with a few pioneers offering services that can be regarded as belonging to cloud computing. Meanwhile, many large high-tech companies are building huge data centres loaded with hundreds of thousands servers to be made available for customer needs in the near future.[7]

Amazon has been the first mover in the field, providing access to half a million developers by way of 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.[8] For instance, Animoto, an application that produces videos from user-selected photos and music, has been a successful business of this kind. When Animoto was launched on the leading social network Facebook, it was forced by exponentially increasing demand to bring the number of machines used on the Amazon Web Services from 50 to 3500 within three days, something that would have been impossible without relying on a cloud platform.

Google is also investing huge funds in data centres.[9] Already nowadays Google provides word processing and spreadsheet applications online, while software and data are stored on the servers. 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 – for instance the location of houses from the rental and sales listings of Craiglist.

Microsoft has started later but with huge investments in the creation of new data centres. In the fall of 2008, the leading software company has introduced a cloud platform called Windows Azure, currently available only in a preview version. Azure is able to provide a number of new technologies: a Windows-based environment in the cloud to store data in Microsoft data centres and to run applications; an infrastructure for both on-premises and cloud applications (through .NET Services); a cloud based database (through SQL Data Services, which can be used from different users and different locations); and an application tool to access Live Services which allows to synchronize and constantly update data across systems joined into a mesh (for instance all the personal devices as the PC, the office's computer, the mobile phone and so on). 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.[10]

Other software and hardware companies have been actively investing in cloud computing (3Tera and Saleforce.com are particularly active).[11] Social networks have moved in the same direction turning into social platforms for consumer based applications, with Facebook in the front road. Yahoo! is developing server farms as well. Oracle has introduced a cloud based version of its database program and has bought Sun Microsystems to prepare further expansion in the field.

The battle for the clouds between these companies is going to reshape the ICT market structure as PC distribution did in the 80s. But according to the Economist (2008):

> cloud computing is unlikely to bring about quite such a dramatic shift. In essence, what it does is take the idea of distributed computing a step farther. Still, it will add a couple of layers to the IT stack. One is made up of the cloud providers, such as Amazon and Google. The other is software that helps firms to turn their IT infrastructure into their own cloud, known as a 'virtual operating system for data centres' Will this prospective platform war produce a dominant company in the mould of IBM or Microsoft that is able to extract more than its fair share of the profits? Probably not, because it will be relatively easy to switch between vendors… Nor is it likely that one firm will manage to build a global cloud monopoly. Although there are important economies of scale in building a network of data centres, the computing needs of companies and consumers vary too widely for one size to fit all.

Most important, the need of creating network effects in the development of a cloud platform will keep low the margins for a while and will maximize the speed of diffusion of cloud computing between firms at the global level. Therefore, in the long run, we expect a rather competitive situation on the supply side of cloud computing.

In front of these rapid evolution, it is crucial to understand the economic impact of the introduction of this general purpose technology. 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 in ICT into operative costs depending on the size of demand and production. This contributes to reduce the barriers to entry especially for 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 entry of new SMEs, a reduction of the mark ups, and an increase in average and total production.

Another important benefit is associated with the creation of multidimensional network effects due to the new possibilities of product creation in the clouds, that is between companies exploiting in different ways the potentialities of cloud computing through the same platform or different ones. This is related to another new possibility, the rapid adoption of changes: it is not uncommon, that applications in the clouds are modified on a daily base (to accommodate new requirements, or enable new economic venues), which is impossible with on-premise solutions. It is important to notice that the aggregate role of these network effects can be relevant but it is extremely difficult to measure.

Finally, cloud computing is going to introduce the possibility of a) sharing resources (and costs) among a large pool of users, b) allowing for centralization of infrastructures in areas with lower costs, and c) allowing for peak-load capacity increases (generating efficiency improvements for systems that are often only 10-20% utilized). These features will lead to additional savings in energy and to greater environmental sustainability, whose measure, however, is again subject to large uncertainty.[12]

A recent study of the International Data Corporation (2008) has examined the role of IT cloud services across five major product segments representing almost two-thirds of total enterprise IT spending (excluding PCs): business applications (SaaS), infrastructure software, application development & deployment software, servers and storage. Out of the $ 383 billion that firms have spent in 2008 for these IT services only $ 16.2 billion (4%) could be classified as cloud services. In 2012 the total figure was expected to be at $ 494 billion and the cloud part at $ 42 billion, which would correspond to 9% of customer spending, but also to a large part of the growth in IT spending. The majority of cloud spending is and will remain allocated to business applications, with a relative increase of investment in data storage.

Even if the relative size of IT cloud services may remain limited in the next few years, it is destined to increase and to have a relevant macroeconomic impact, especially in terms of creation of new SMEs and of employment. In times of global crisis, this could be an important contribution to promote the recovery and to foster growth. Cloud platforms and new data centres 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 of massive up-front 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. As the Economist (2008) claims, *the internet disrupted the music business; Google disrupted the media; cloud-based companies could become disrupters in other inefficient industries.*

The macroeconomic impact of the diffusion of this new general purpose technology may be quite large, as it happened for the introduction of the Internet in the 90s.[13]

III. Evaluating the Economic Impact of Cloud Computing: Methodology and Data

Our approach in the evaluation of the impact of the diffusion of a new general purpose technology as cloud computing is based on macroeconomic theory and macroeconomic data. We emphasize the effect 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 the induced effects for aggregate production, employment and other macroeconomic variables.

Our methodology is based on a dynamic stochastic general equilibrium (DSGE) calibrated model augmented with endogenous market structures in line with recent developments in the macroeconomic literature (see Etro, 2009, for a survey). This model is perturbed with a realistic structural change to the cost structure, with the purpose to study the short and long term reactions of the economy. Therefore, our methodology is based on a solid theoretical framework and provides results that can be easily replicated by economists. However, it has some limitations that we need to point out. First of all, while the methodology is useful to estimate the aggregate impact of a shock on the macroeconomy, it is less so at the microeconomic level. Second, the experiment we present is highly speculative because the nature of the cost shift (due to the introduction and diffusion of cloud computing) can only be conjectured (it will depend on many future macroeconomic and policy factors), and also because we are in a moment of high macroeconomic uncertainty. For this reason, we will focus on the net expected impact of cloud computing on the economy, meaning the expected additional impact above and beyond the cyclical behavior of the macroeconomic variables (associated with any other motivations). Moreover, we will present estimates for different scenarios – of slow and rapid adoption of the new technology – that should cover the range of possible outcomes with a good approximation. Third and last, our approach neglects some of the positive effects exerted by the introduction of cloud computing, mainly the creation of new network effects and the positive externalities due to energy savings. Their consideration would be subject to excessive uncertainty, but because of this we can look at our estimates of the impact of cloud computing on the economy as conservative estimates.

In the rest of this section we briefly describe our baseline model, our data sources and the experiment associated with the introduction and diffusion of cloud computing. Further analytical details on the model are provided in the Appendix. The results of the numerical exercise are presented in the next section.

For our estimates, we develop a DSGE model calibrated on the EU economy in the traditional way.[14] The infinite horizon model accounts for the dynamics of output, consumption, working hours (as an endogenous factor of production), and accumulation of ICT capital (as a reproducible factor of production)[15] in a standard way. The production of final goods in different sectors derives from Cobb-Douglas functions with constant returns to scale in labor and in the stocks of hardware and software, which jointly determine the stock of ICT capital. The aggregate production function reads as:

$$Y_t = AL_t^{\alpha} H_{t-1}^{(1-\alpha)\gamma} S_{t-1}^{(1-\alpha)(1-\gamma)} \tag{1}$$

where Y_t is output, A is total factor productivity, which is assumed exogenous in our analysis (its growth would not change our qualitative results), L_t are total labor hours, H_t is the aggregate stock of hardware and S_t is the aggregate stock of software, while $\alpha \in (0,1]$ is the labor share, whose realistic value is around 2/3, and $\gamma \in [0,1]$ represents the elasticity of ICT capital to the stock of hardware, with a realistic value between 3/4 and 9/10 (hardware represents the main share of ICT spending compared to software). Notice that physical capital of a different nature could be added without loss of generality, but the details of this extension are beyond our current interests.

Consumer preferences are logarithmic in the consumption index C_t with a constant elasticity of labor supply:

$$U = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \log C_t - \chi \frac{L_t^{1+1/\varphi}}{1+1/\varphi} \right\} \quad \chi, \varphi \geq 0 \tag{2}$$

where L_t is employment of the representative agent and $\beta < 1$ is the discount factor. These assumptions are the traditional ones and deliver standard consumption and labor supply functions. We assume for simplicity homogenous goods within each sector. However, since our focus is on the impact of shocks on the market structure and through that on the economy, we augmented the model with endogenous market structures as recently introduced by Ghironi and Melitz (2005), Bilbiie *et al.* (2007, 2008,a,b), Etro (2007a), Etro and Colciago (2007) and Colciago and Etro (2008).[16] New firms can be created with an initial fixed investment: since this is expressed in terms of the final good, it implicitly requires the use of labor, hardware and software. Once active in a sector, each firm competes with a number of rivals in the choice of the production level. In the Cournot-Nash equilibrium, the aggregate production is inversely related to the equilibrium mark up and price and positively related to the number of firms (which affects mark ups in turn). The number of competitors in each sector N_t, and therefore the concentration of each sector is endogenized through the process of business creation, which operates by equating in each period the stock market value of a firm to the entry cost. Entry and ICT capital accumulation occur gradually over time because of the business creation/destruction process and of the investment/depreciation process. Jointly, they determine the market structure and its dynamic evolution, in terms of how many firms are active in each sector, how much each firm produces and which one is the equilibrium mark up in each sector and in each period.[17]

We assume homogenous goods in each sector, which implies the following mark up:

$$\mu_t = \frac{N_t}{N_t - 1} \tag{3}$$

which is decreasing in the number of firms. The latter follows the equation of motion:

$$N_{t+1} = (1-\delta)\left(N_t + N_{E,t}\right)$$

where $N_{E,t}$ is the number of new firms and δ is the rate of business destruction. The real value of a firm V_t is the present discounted value of its future expected profits, or in recursive form:

$$V_t = (1-\delta)E_t\left[\frac{V_{t+1} + \pi_{t+1}(N_{t+1})}{1+r_{t+1}}\right] \qquad (4)$$

where $\pi_t(N_t)$ is the profit function depending on the number of firms and r_t is the interest rate. Endogenous entry of new firms equates this value to the fixed cost of entry η_t in each period. Notice that a reduction of the entry cost due to a reduction in the fixed investment in ICT capital promotes entry, and with it competition, which reduces the mark up and increases aggregate production, employment and consumption. This mechanism is at the core of our analysis.

Our experiment is focused on Europe. Therefore, all our data derive from official EU statistics (*Eurostat*), mainly for the number of firms, which is basically equivalent to the number of small and medium size enterprises (SMEs), employment and gross domestic product. In particular, we used data for most of the EU member countries and Norway for which we had complete data. Moreover, we focused on a few aggregate sectors for which we have detailed and comparable EU statistics:

- Manufacturing
- Wholesale and retail trade (WRT)
- Hotels and restaurants (HR)
- Transport storage and Communication (TSC)
- Real estate renting and business activities (REB)

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 (more than 113 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 and the role of entry costs and competition effects are more relevant. We ignored other aggregate private sectors (as electricity, gas and water supply) and the public sector, where we believe that our mechanisms are either weaker or absent, or sectors where comparable data were not available (as part of the financial sector). All the results are based on the numerical simulation of a calibrated model (see the Appendix for details). However, country specific heterogeneity and sectorial differences were taken in 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.

A main aspect of our empirical exercise concerns the nature of the shock affecting the economy. The introduction of cloud computing allows firms from all sectors to reduce fixed costs in ICT and turn part of them into variable costs. In our analysis we focus on the reduction in the fixed cost associated with the introduction of cloud computing. The increase in the marginal cost of production is endogenous and depends on the technological choices of the firms, which decide how much hardware and software (or, generally speaking, ICT capital) to use according to their production necessities, and on the endogenous rental rate of ICT capital. In general, this depends on the market structure of the hardware and software sectors, which we will assume to be perfectly competitive. One may augment the analysis with an increase in the unitary cost of production (a reduction of A) associated with the cloud computing technology, but here we will ignore this aspect and assume that this technology reduces the fixed costs of production only.[18]

The reduction in fixed ICT spending is gradually exploited by the new and existing firms, and the speed of adoption of the new possibility remains an unknown variable for us. It will depend on a number of macroeconomic and microeconomic factors and on policymaking as well. Moreover, it will be characterized by important strategic complementarities: adoption for a single firm is crucial if many firms are expected to adopt it, but it is not if they are not, which means that multiple equilibria could emerge (with slow or rapid adoption and with limited or deep adoption). For this reason we will adopt a reduced form model of adoption based on a gradual reduction of the costs of entry and we will differentiate the simulations for cases of slow and rapid adoption to evaluate the range of results.

The general specification of the process of cost reduction that we assume in the simulations works as follows. Define η_t as the fixed cost of entry in a sector, which constraints business creation at time t. The fixed cost of entry at time $t+1$ is given by:

$$\eta_{t+1} = \rho\tilde{\eta} + (1-\rho)\eta_t$$

where $\rho \in (0,1)$. The above formula for the future cost is a weighted average of the current cost and a long run cost $\tilde{\eta}$. The dynamic path of η_t depends on two parameters. The first parameter, $\tilde{\eta}$, is the steady state level of the fixed cost, which is going to be lower than the initial one. The second parameter, ρ, represents the speed of diffusion or adoption of the new technology. Changes in these two parameters allow us to depict scenarios with slow or rapid adoption and to parametrize the absolute size of the shock. It turns out that changes of the speed of adoption within a realistic range, from fast adoption ($\rho \simeq 1$) to slow adoption ($\rho \simeq 0.5$), have a limited impact on the aggregate effects (because of the forward looking nature of the firms and agents behavior), while the long run size of the cost reduction is crucial.

A key factor for the impact of cloud computing is the size of fixed cost savings. The business literature emphasizes large savings. Dubey and Wagle (2007) conjecture large reductions in the cost of ownership for typical business services.[19] Carr (2003) suggests that about half of capital expenditure of modern firms is ICT related. While this maybe true in a number of sectors and for advanced companies, we prefer to adopt 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 provides a comprehensive survey of ICT adoption and spending, showing that 5% of total costs is spent in ICT. Figure 1 shows the variability of this figure across a few key sectors on which European Commission (2007) has focused its analysis, while Figure 2 shows the little variability between firms of different sizes.

Since only 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%. Our main purpose is to show that even such a limited technological change

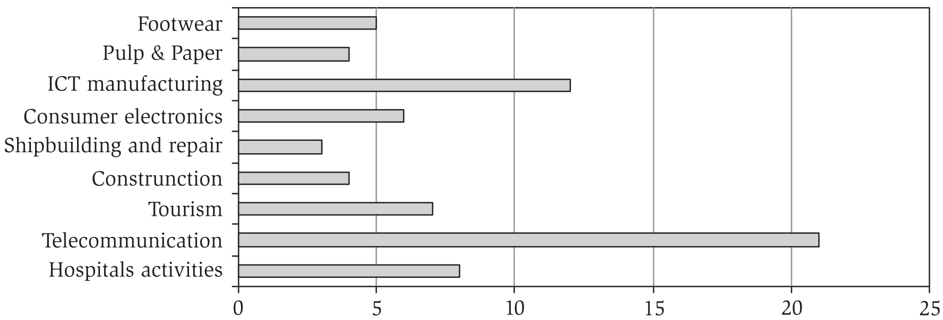

Figure 1. Average share of the ICT budget as % of total costs (by sector).

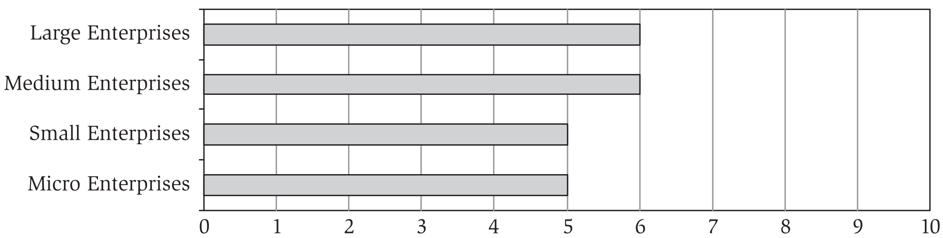

Figure 2. Average share of the ICT budget as % of total costs.

due to cloud computing will deliver substantial effects at the macroeconomic level. Needless to say, larger shocks will be associated with wider effects.

IV. Evaluating the Economic Impact of Cloud Computing: Results for EU Countries

In this section we report the results of our experiment on the introduction and diffusion of cloud computing in the European economy. We focus on the impact on GDP, business creation and employment in the short term, that is after one year, and in the medium term, that is after 5 years. Two scenarios are considered: slow adoption corresponds to the case of a 1% percent slow reduction ($\rho \simeq 0.7$) in the fixed costs of entry and rapid adoption to a 5% rapid reduction ($\rho \simeq 1$) in the fixed costs – further details are in the Appendix.

Table 1. Additional output variation in Europe.

	Short Term		**Medium Term**	
	Slow	**Fast**	**Slow**	**Fast**
Output	*0.05*	*0.15*	*0.1*	*0.3*

The contribution to GDP growth can be hardly differentiated between countries and sectors, therefore we simply summarize our average estimates to the European countries. As shown in Table 1, the range is between 0.05% in the short run under slow adoption and 0.3% in the medium run under fast adoption of cloud computing. These results are derived in terms of percentage variation from a steady state value in a stationary model, but since growth is expected to be about zero in 2010, these percentage deviations can be approximately interpreted in terms of additional contribution to the growth rate. Given the conservative assumptions on the size of the shock, these are remarkable contributions to GDP growth, and they have a direct counterpart in the effects on employment.

One should take the estimates on the impact on employment with care. Even if we took in consideration 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 found that the introduction of cloud computing could create, on average, about a million additional jobs in Europe. About two thirds of job creation is expected to occur in the six largest countries (United Kingdom, Germany, France, Poland, Italy and Spain), but each country could enjoy a temporary increase in the work force. Of course this increase is going to vanish over time because the structural features of the economy lead employment toward its natural level, which is affected only in a small measure from the reduction of the fixed costs. However, the short run impact can be quite strong and, in a period of crisis as the one depicted for the forthcoming years, it can contribute to limit the increase of the unemployment rate in a substantial way. Our estimates of the reduction of the unemployment rate in the European countries due to the introduction of cloud computing are around 0.5% in the short run and 0.2-3% in the medium run.[20]

Before entering in further details, it is worthwhile to sketch the mechanism emphasized in our model. The gradual introduction of cloud computing reduces the fixed costs needed to enter in each sector and increases the incentives to enter. This increases current and future competition in each market and tends to reduce the mark ups 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 consumption/savings behavior. In the short run, the demand of new business creation requires and 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.

Given this overview of the main results in terms of GDP and employment, it is now time to present our full results in terms of estimates of new business creation for each country and each one of the aggregate sectors we took in consideration: manufacturing, wholesale and retail trade, hotels and restaurants, transport storage and communication and finally, real estate renting and business activities. Figures 3-4 provide our estimates on the creation of new SMEs. The largest impact is expected to occur in the aggregate sectors of wholesale and retail trade (plus 156 thousand firms in the medium run under fast adoption) and of real estate and other business activities (plus 144 thousand new SMEs). While the reader can easily look at the results divided by aggregate sectors in each country, we will not comment on the emerging differences across sectors because we do not want to overemphasize the limited predictive power of our exercise at this level of detail and also because we did not find substantial heterogeneity in the results in terms of percentage contributions.

Nevertheless, our empirical exercise shows a strong impact on the creation of new SMEs, in the magnitude of a few hundred of thousand in the whole EU (again this is additional to a normal situation without the introduction of cloud computing). 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

	M		WRT		HR		TSC		RES		Total	
Countries	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**
Belgium	155	799	564	2913	180	932	74	383	470	2429	1443	7457
Bulgaria	125	645	na	na	96	498	81	420	139	717	441	2281
Czech Republic	636	3285	913	4719	212	1094	198	1022	1064	5497	3022	15618
Denmark	79	406	212	1094	57	297	63	325	312	1615	723	3737
Germany	838	4332	2019	10438	766	3958	405	2094	2642	13655	6670	34477
Estonia	23	121	60	313	7	39	15	78	55	286	162	836
Ireland	19	97	135	699	56	289	30	156	148	767	388	2008
Greece	398	2055	1314	6794	442	2284	304	1571	606	3132	3064	15836
Spain	938	4847	3478	17975	1212	6267	976	5044	2748	14202	9351	48335
France	1083	5597	3007	15540	966	4994	420	2169	2686	13885	8162	42185
Italy	2191	11327	5310	27445	1148	5936	666	3445	4512	23323	13829	71476
Latvia	34	176	98	507	11	59	22	112	99	512	264	1366
Lithuania	72	374	224	1158	16	82	29	152	118	611	460	2378
Hungary	262	1354	643	3325	136	704	152	784	821	4241	2014	10407
Netherlands	199	1026	701	3624	156	807	119	615	676	3493	1851	9565
Austria	122	632	341	1762	196	1014	67	345	363	1874	1089	5627
Poland	828	4280	2591	13391	240	1238	607	3138	1158	5988	5424	28036
Portugal	417	2157	1272	6574	373	1926	126	651	952	4922	3140	16230
Romania	251	1296	877	4534	88	453	137	706	358	1850	1710	8840
Slovenia	76	395	97	503	31	159	39	200	98	504	341	1762
Slovakia	34	178	90	466	7	39	10	52	60	312	202	1046
Finland	108	556	204	1057	46	237	102	527	241	1244	700	3620
Sweden	261	1350	536	2769	109	563	136	705	966	4993	2008	10380
United Kingdom	645	3334	1623	8389	561	2902	348	1800	2745	14186	5922	30612
Norway	82	425	237	1227	43	223	99	511	414	2140	876	4526
EU 25 counties	9876	51047	26547	137215	7157	36994	5225	27006	24451	126378	73256	378640

Creation of SMEs firms in the short term
Legenda: Slow *stands for slow adoption of the new technology, white* Fast *stands for fast adoption*
Sectors: M (manufacturing), WRT (Wholesale arid Retail Trade), HR (Hotels and Restaurants)
TSC (Transports Storage and Communications), REB (Real Estate and Business Activities).

Figure 3. The impact of cloud computing on business creation in the short run.

	M		WRT		HR		TSC		REB		Total	
Countries	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**	**Fast**
Belgium	176	910	642	3316	205	1061	85	436	535	2764	1644	8488
Bulgaria	142	735	na	na	110	567	93	478	158	816	503	2596
Czech Republic	724	3739	1040	5372	241	1246	225	1163	1212	6257	3443	17776
Denmark	90	463	241	1246	65	338	72	370	356	1838	824	4254
Germany	955	4931	2301	11880	873	4505	462	2384	3010	15542	7601	39243
Estonia	27	138	69	356	9	44	17	89	63	325	184	952
Ireland	21	111	154	795	64	329	34	177	169	872	443	2285
Greece	453	2339	1498	7733	503	2599	346	1789	690	3565	3491	18025
Spain	1069	5517	3963	20459	1382	7133	1112	5741	3131	16165	10656	55015
France	1234	6371	3426	17688	1101	5684	478	2468	3061	15804	9300	48015
Italy	2497	12892	6051	31238	1309	6756	759	3921	5142	26547	15758	81355
Latvia	39	201	112	577	13	67	25	127	113	583	301	1555
Lithuania	83	426	255	1318	18	94	33	173	135	696	524	2707
Hungary	299	1541	733	3784	155	801	173	892	935	4827	2295	11846
Netherlands	226	1168	799	4125	178	918	136	700	770	3976	2109	10887
Austria	139	720	388	2005	223	1154	76	393	413	2133	1241	6404
Poland	944	4872	2952	15241	273	1410	692	3572	1320	6816	6181	31910
Portugal	475	2455	1449	7483	425	2192	143	741	1085	5602	3578	18473
Romania	286	1476	1000	5161	100	516	156	804	408	2105	1949	10061
Slovenia	87	449	111	573	35	181	44	228	111	574	389	2006
Slovakia	39	202	103	530	9	44	11	59	69	355	231	1190
Finland	123	632	233	1203	52	270	116	600	274	1416	798	4121
Sweden	298	1537	610	3151	124	641	155	802	1101	5683	2288	11815
United Kingdom	735	3795	1850	9549	640	3303	397	2049	3128	16147	6749	34843
Norway	94	484	270	1396	49	254	113	582	472	2436	998	5152
EU 25 Countries	11254	58103	30251	156180	8156	42107	5954	30739	27862	143845	83478	430973

Creation of SMEs firms in the short term
Legenda: Slow *stands for slow adoption of the new technology, white* Fast *stands for fast adoption*
Sectors: M (manufacturing), WRT (Wholesale arid Retail Trade), HR (Hotels and Restaurants)
TSC (Transports Storage and Communications), REB (Real Estate and Business Activities).

Figure 4. The impact of cloud computing on business creation in the medium run.

in countries where the diffusion of SMEs is particularly strong or where ICT adoption has been generally rapid. In absolute terms, Italy is estimated to have the largest impact in terms of new business (with 81 thousand new SMEs in the medium run under fast adoption), followed by Spain (plus 55 thousand), France (48 thousand), Germany (39 thousand), United Kingdom (35 thousand) and Poland (32 thousand).

We have also examined the impact on employment in each country with a distinction between aggregate sectors. In absolute terms, the largest impact is expected for the manufacturing sector and also for the sector under the label hotels and restaurants, and this is not surprising given the high number of workers in these aggregate sectors. Overall, the impact on employment is more limited compared to the impact on business creation for a simple reason. One of the main advantages of cloud computing is an induced change in the market structure of many sectors, with the creation of more firms and an increase in the level of competitiveness (associated with a reduction in prices as well). This change in the market structure associated with larger efficiency induces a re-allocation of jobs that does not increase by much the number of workers. Anyway, also in this case we are talking about a few hundreds of additional workers (or a corresponding lower number of unemployed agents) at the European level. Notice that our simulation emphasizes a slow reduction of the net impact on employment in the medium run compared to the short run: this is normal because the absolute impact on the labor force tends to vanish in the long run. According to our estimates, United Kingdom is going to exhibit the larger impact in terms of new workers (with 240 thousand new workers in the short run under fast adoption), followed by Germany (160 thousand), France (100 thousand), Poland (94 thousand), Italy (76 thousand) and Spain (69 thousand). Overall, the results country by country 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, and in the regulatory framework and in the competitive conditions of the goods markets, that create the conditions for quick business creation. Without overemphasizing our quantitative results, we notice that, in percentage terms, countries as United Kingdom, Finland, Poland, Czech Republic and Slovakia are expected to perform better than average, while countries as Hungary, Italy, Austria and Spain are expected to perform more poorly than average.

V. Policy Implications

Cloud computing is a new general purpose Internet-based technology through which information is stored in servers and provided as a service and on-demand to clients. In this paper we analyzed the economic impact of its gradual introduction in the next years and we emphasized its role in fostering business creation and competition in all the markets thanks to the reduction of the fixed costs of entry in ICT capital. Our calculations for European countries show a significative medium term impact of the diffusion of cloud computing on entry of SMEs, employment and growth. Starting from conservative assumptions on the cost reduction process, the analysis shows that the diffusion of cloud computing will provide (in a medium term range of five years) a positive impulse to the annual growth rate, contributing to create about a million new jobs through the development of a few hundred thousand new SMEs in the countries under investigation.

Part of the positive effects of cloud computing are going to be positively related to the speed of adoption of the new technology. For this reason, our investigation suggests that policymakers should promote as much as possible a rapid adoption of cloud computing. Concrete possibilities include fiscal incentives and a specific promotion of cloud computing in particular 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.[21] Moreover, they could introduce business friendly rules for the treatment and movement of data between their country and foreign countries. These policies may be studied in such a way to optimize the process of adoption of the new technology and to strengthen the propagation of its benefits within the country.

Moreover, in a context as the European one, smaller countries would be able to obtain larger gains from similar policies at least in the initial phase, because they would easily attract foreign investments from larger countries. In a period of increasing limits to other forms of fiscal competition (especially in the integrated market), a policy of subsidization of cloud computing (without discrimination across firms of different member countries) could generate substantial capital flows toward smaller countries with good general infrastructures. For instance, early adoption of these policies by small E.U. countries as Luxembourg or Malta could attract large investments by foreign firms (looking for subsidies to adopt the new business model) and create wide effects in terms of output growth and job creation in these countries.

Of course, international policy competition for the subsidization of cloud computing solutions would generate positive spillovers across countries, and some coordination at the E.U. level would be welcome.

VI. Conclusion

The main contribution of this paper is an empirical application of the endogenous market structures approach to a real world phenomenon, the introduction of a general purpose technology which is not directly augmenting total factor productivity, but that is reducing the fixed costs of entry and production in the economy. The theoretical part of the paper develops an extension of the framework introduced by Colciago and Etro (2008) and other related works of the recent literature on endogenous entry and macroeconomics, assuming that entry costs are in units of the final good, and they follow a deterministic process depending on the speed of adjustment toward a long run level. Further work may generalize this theoretical framework and the cost reduction process. The empirical part of the paper translates the impact of a cost reducing innovation on the European economy. Future work may also improve the calibration of the theoretical model and the translation of the numerical simulation in empirical estimates with additional information on labor and good markets at the national and sectorial level. Moreover, alternative methodologies for the estimate of the impact of cloud computing would be welcome to crosscheck the validity of our results. Beside our quantitative results, our main contribution remains in the description of the competitive mechanism through which cloud computing is likely to create a positive effect on business creation, GDP and employment.

Appendix

The structure of the economy simulated in the experiment is an extension of the model with endogenous market structures developed by Etro and Colciago (2007) and Colciago and Etro (2008) with investment in terms of final good. Consider a representative consumer with utility:

$$U = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \log C_t - \chi \frac{L_t^{1+1/\varphi}}{1+1/\varphi} \right\} \quad \chi, \varphi \geq 0 \tag{5}$$

where $\beta \in (0,1)$ is the discount factor, L_t is labor and C_t is a consumption index. Ideally, this index would aggregate consumption bundles of multiple sectors with a constant elasticity of substitution, but our assumptions allow us to normalize the number of sectors to one without loss of generality.[22] The representative sector is characterized by different firms $i = 1, 2, \ldots, N_t$ producing the same good in different varieties. A general formulation for the consumption index C_t of the representative sector is based on Dixit and Stiglitz (1977):

$$C_t = \left[\sum_{i=1}^{N_t} C_t(i)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{6}$$

where $C_t\,(i)$ is the production of firm i of this sector, and $\theta \in (1, \infty)$ is the elasticity of substitution between the goods produced in the sector. The distinction between different sectors and different goods within a sector allows one to separate limited substitutability at the aggregated level, and high substitutability at the disaggregated level. When $\theta \to \infty$ we are in the case of homogenous goods within sectors, which will be our baseline case.

In each period, total consumption C_t is allocated across the available goods according to the inverse demand functions:

$$p_t(i) = \frac{C_t(i)^{-\frac{1}{\theta}} E_t}{\sum_{j=1}^{N_t} C_t(j)^{\frac{\theta-1}{\theta}}} \qquad i = 1, 2, \ldots, N_t \tag{7}$$

where E_t is total expenditure. Each good is produced in each period at a constant marginal cost common to all firms. Under the different forms of competition, we obtain a symmetric equilibrium mark up $\mu_t > 1$ depending in general on the kind of competition (in prices or quantities), on the degree of substitutability between goods θ and on the number of firms N_t. A Cournot equilibrium generates the equilibrium mark up:

$$\mu_t = \frac{\theta N_t}{(\theta - 1)(N_t - 1)} \tag{8}$$

The markup remains positive for any degree of substitutability, since even in the case of homogenous goods, we have:

$$\lim_{\theta \to \infty} \mu_t = \frac{N_t}{N_t - 1}$$

This allow us to consider the effect of strategic interactions in an otherwise standard setup with perfect substitute goods (which has been traditionally studied only under perfect competition in the neoclassical tradition). The individual profits in units of consumption can be expressed as:

$$\pi_t(N_t) = \frac{(N_t + \theta - 1)C_t}{\theta N_t^2} \tag{9}$$

which are clearly decreasing in the number of firms and in the substitutability between goods. In what follows, we will adopt the parametrization of Colciago and Etro (2008) and focus on the case of Cournot competition with homogenous goods, therefore we will set $\theta \to \infty$ so that $\mu_t = N_t / (N_t - 1)$ and $\pi_t(N_t) = C_t / N_t^2$. The results can be easily generalized to imperfect substitutability and other forms of competition as Bertrand or Stackelberg competition.[23]

In this model, households choose how much to save in riskless bonds and in the creation of new firms through the stock market. The number of firms follows the equation of motion:

$$N_{t+1} = (1-\delta)\left(N_t + N_{E,t}\right) \tag{10}$$

where $N_{E,t}$ is the number of new firms and δ is the exogenous rate of exit. The real value of a firm V_t is the present discounted value of its future expected profits, or in recursive form:

$$V_t = (1-\delta)E_t\left[\frac{V_{t+1} + \pi_{t+1}(N_{t+1})}{1+r_{t+1}}\right] \tag{11}$$

where r_{t+1} is the real interest rate. We experimented a model without capital and with capital interpreted as ICT capital, adopting the latter in the simulations. However, for illustrative purposes we first describe the simpler model and subsequently augment it with capital accumulation.

The Model without Capital Stock

Consider first the model where there is not accumulation of capital and production is linear in labor:

$$y_{i,t} = Al_{i,t} \tag{12}$$

where A is total factor productivity, kept constant in all our analysis, and $l_{i,t}$ is the quantity of labor demand by each individual firm i.

The aggregate budget constraint reads as:

$$V_t N_{E,t} + C_t = \pi_t N_{t-1} + w_t L_t \tag{13}$$

Total consumption plus investment in new firms must be equal to total income $\pi_t N_{t-1} + w_t L_t$, where π_t are profits of an individual firm. The first order condition for labor supply is:

$$L_t = \left(\frac{w_t}{\chi C_t}\right)^{\phi} \tag{14}$$

while the Euler equation for shares is:

$$V_t = \beta(1-\delta)E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(V_{t+1}+\pi_{t+1}(N_{t+1})\right)\right] \tag{15}$$

We assume that a new entrant has to pay η_t units of output at time t in order to start production. Thus, the endogenous entry condition reads as:

$$V_t = \eta_t \tag{16}$$

Profits are:

$$\pi_t(N_t) = \left(1-\frac{1}{\mu_t}\right)y_{i,t} = \left(1-\frac{1}{\mu_t}\right)\frac{Y_t}{N_t} \tag{17}$$

which is $\pi_t(N_t) = Y_t / N_t^2$ in case of homogenous goods.

Consider the Euler equation for shares and plug in the endogenous entry condition to obtain:

$$\eta_t = \beta(1-\delta)E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\eta_{t+1}+\left(\frac{C_{t+1}}{C_t}\right)^{-1}\pi_{t+1}(N_{t+1})\right] \tag{18}$$

Next, notice that $N_{E,t} = (Y_t - C_t)/\eta$, thus the dynamic path of the number of firms follows:

$$N_{t+1} = (1-\delta)N_t + (1-\delta)\frac{(Y_t - C_t)}{\eta} \tag{19}$$

Given the aggregate relations $w_t = A/\mu_t$ and $Y_t = AL_t$, and the labor supply schedule, it follows that:

$$Y_t = \left(\frac{1}{\mu_t \chi C_t}\right)^{\varphi} A^{1+\varphi} \tag{20}$$

Therefore, we obtain a system in two variables (C_t, N_t) and two equations which are given by:

$$\eta_t = \beta(1-\delta)E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(\eta_{t+1}+\frac{Y_{t+1}}{N_{t+1}^2}\right)\right] \tag{21}$$

(recall that $Y_t = C_t + \delta\eta N_t / (1-\delta)$) and by:

$$N_{t+1} = (1-\delta)N_t + \frac{(1-\delta)\left[(\mu_t \chi C_t)^{-\varphi} A^{1+\varphi} - C_t\right]}{\eta} \tag{22}$$

given a process for η_t this can be solved for C_t and N_t and thus we can get all the other variables. In particular we can get the dynamic of the real wage, hours, mark up, output and the number of new entrants.

The steady state with a constant fixed cost of entry can be easily derived. In case of exogenous labor supply ($\varphi = 0$) equal to one, we can solve for the number of firms and consumption as:

$$\tilde{N} = \sqrt{\frac{\beta(1-\delta)A}{[1-\beta(1-\delta)]\eta}} \tag{23}$$

and

$$\tilde{C} = A - \frac{\delta\eta}{1-\delta}\sqrt{\frac{\beta(1-\delta)A}{[1-\beta(1-\delta)]\eta}} \tag{24}$$

Notice that the number of firms is increasing and concave in productivity A relative to the fixed cost η, and consumption is increasing in A and decreasing in η. The steady state mark up is:

$$\tilde{\mu} = \frac{\sqrt{\beta(1-\delta)A}}{\sqrt{\beta(1-\delta)A} - \sqrt{[1-\beta(1-\delta)]\eta}} \tag{25}$$

which is decreasing in the ratio A/η. This fully characterizes the steady state endogenous market structures.

The Model with ICT Capital in the Production Function

Let us now move to the more general model with accumulation of a factor of production. We assume that firms need both labor and ICT capital to produce goods. The latter is composed of hardware and software. Let us define H as the stock of harware and S as the stock of software. We can assume that ICT capital K is composed by a combination of them, and that aggregate production requires this and labor L. Notice that we refer only to ICT capital to focus on our main interest, but total capital may include physical capital as well.

In particular, aggregate output of final good derives from the following Cobb-Douglas production function:

$$Y_t = AL_t^{\alpha}K_{t-1}^{1-\alpha} \tag{26}$$

where $\alpha \in (0,1]$ is the labor share. The stock of ICT capital derives from the following Cobb-Douglas aggregator of the stocks of hardware and software:

$$K_t = H_t^{\gamma}S_t^{1-\gamma} \tag{27}$$

where $\gamma \in [0,1]$ represents the elasticity of ICT capital to the stock of hardware. This implies that the aggregate production function can be written as:

$$Y_t = AL_t^{\alpha}H_{t-1}^{\gamma(1-\alpha)}S_{t-1}^{(1-\gamma)(1-\alpha)}$$

which exibits constant returns to scale in labor *L*, hardware *H* and software *S*.

The firm production function is:

$$y_{i,t} = A\left(l_{i,t}\right)^{\alpha}\left(k_{i,t-1}\right)^{1-\alpha} \tag{28}$$

In a symmetric situtation with $l_{i,t} = l_t$ and $k_{i,t} = k_t$ for any *i* we have $K_t = N_t k_t$ and $L_t = N_t l_t$. Firms decide on the investment in hardware and software and on the allocation of labor and ICT capital to minimize costs, and on the production choices.

We assume that the stock of both ICT components depreciates at the rate $\delta^{\kappa} \in (0,1)$, with a realistic value of 10% a year. This allows us to focus on the dynamic evolution of the stock of ICT capital without expliciting the allocation of resources between hardware and software. The path for ICT capital accumulation reads as:

$$K_t = \left(1-\delta^k\right)K_{t-1} + I_t \tag{29}$$

where I_t is the time-*t* investment in ICT capital. The aggregate budget constraint reads as:

$$C_t + V_t N_{E,t} + I_t = \pi_t N_{t-1} + r_t^k K_{t-1} + w_t H_t \tag{30}$$

Total consumption plus investment in new firms and the physical capital must be equal to total income $\pi_t N_{t-1} + w_t L_t$, where π_t are profits of an individual firm.

The first order condition for labor supply and the Euler equation for shares are unchanged. The Euler equations for ICT capital is:

$$1 = \beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(1 + r_{t+1}^k - \delta^k\right)\right] \tag{31}$$

The cost minimization problem is:

$$\min_{K,L} r_t^k K_{t-1} + w_t L_t + mc_t \left(Y_t - A \left(K_{t-1} \right)^{1-\alpha} \left(L_t \right)^{\alpha} \right) \tag{32}$$

where mc_t is the marginal cost, which implies:

$$L_t \ : \ w_t = \alpha A \left(K_{t-1} \right)^{1-\alpha} \left(L_t \right)^{\alpha-1} mc_t = \alpha \frac{Y_t}{L_t} mc_t$$

and

$$K_{t-1} \ : \ r_t^k = \left(1-\alpha \right) A \left(K_{t-1} \right)^{-\alpha} \left(L_t \right)^{\alpha} mc_t = \left(1-\alpha \right) \frac{Y_t}{K_{t-1}} mc_t \tag{33}$$

Profits maximization implies:

$$\mu_t = \frac{1}{mc_t}$$

The equation of motion for the number of firms remains the same. We assume again that a new entrant has to pay η_t units of output at time t in order to start production. Thus, the endogenous entry condition reads as:

$$V_t = \eta_t \tag{34}$$

Notice that individual profits are always $\pi_t(N_t) = Y_t / L_t^2$ in case of homogenous goods.

Considering the Euler equation for shares and plugging in the endogenous entry condition, we obtain:

$$\eta_t = \beta(1-\delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \left(\eta_{t+1} + \frac{Y_{t+1}}{N_{t+1}^2} \right) \right] \tag{35}$$

Next, consider the dynamics of the number of firms. Notice that $N_{Et} = (Y_t - C_t - I_t) / \eta_t$ thus we have:

$$N_{t+1} = (1-\delta) \left(N_t + \frac{Y_t - C_t - I_t}{\eta_t} \right) \tag{36}$$

These equations with those for the wage, the interest rate, ICT capital accumulation and the Euler equation provide a system of seven equations for seven endogenous variables (K, C, L, I, N, w, r^k).

Calibration and Shock

Calibration of structural parameters is standard and follows King and Rebelo (2000). The time unit is meant to be a quarter. The discount factor, β, is set to 0.99, while the rate of business destruction, δ_N, equals 0.025 implying an annual rate of 10%. The value of χ is such that steady state labor supply is constant and equal to one. The Frish elasticity of labor supply is φ, and we fix it at four. The labor share α is set equal to 0.7. We set productivity to $A = 1$. The baseline value for the entry cost is set to $\eta = 1$. Notice that the combination of A and η affects the endogenous level of market power because a low entry cost compared to the size of the market leads to a larger number of competitors and thus to lower markups, and *viceversa*. However, the impulse response functions are marginally affected by values of η within a reasonable range. The baseline mark up μ is set at 20%, as usual.

The model outlined above has been disturbed with a general cost shock that reproduces the introduction of the technological innovation analyzed in this paper. Here we describe the formal way to introduce this kind of shock. The aim is to simulate a gradual reduction of the costs of entry and production which reflects the gradual diffusion and adoption of the new technology, whose consequence is ex-

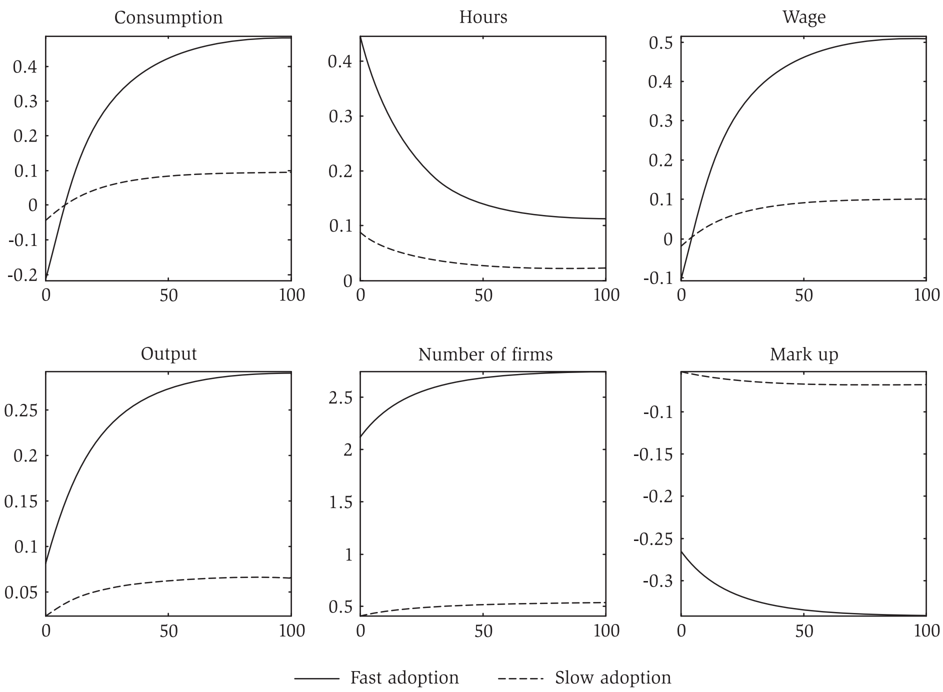

Figure 5. Response of the main macro-variables ($\rho \simeq 1$)

actly to reduce the fixed costs in ICT capital expenditure. This allows firms to expand their variable investments in ICT as a function of their production level. A general specification of the process of cost reduction is the following:

$$\eta_{t+1} = \rho\tilde{\eta} + (1-\rho)\eta_t \tag{37}$$

where the dynamic behavior of the fixed cost depends on two parameters. The first parameter, $\tilde{\eta}$, is the final level of the fixed cost, which will be lower than the initial one. The second parameter, $\rho \in (0,1]$, represents the speed of diffusion or adoption of the new technology. The case of $\rho = 1$ allows to reproduce a permanent shock to the fixed cost, while lower levels of ρ allow us to replicate more gradual processes.

Figures 8 reproduces the impulse response functions to different cost shocks with $\rho = 1$. They emphasize the impact on consumption, hours of work, wage level, output, number of firms and mark up. Further details are available from the author.

NOTES

1. University of Milan, Bicocca, Department of Economics. Piazza dell'Ateneo Nuovo 1, 20126, Building U6, Office 360. Email: federico.etroatunimib.it. I am extremely grateful to Andrea Colciago for excellent research assistance on the simulations, to Sara Pancotti for data analysis, to seminar participants at the University of St Andrews and Charles University (Prague) and to two anonymous referees.
2. See Aghion and Griffith (2005), Aghion and Howitt (2009) and Acemoglu (2009).
3. This approach takes into account the strategic interactions between competitors in realistic markets where competition is not perfect, and the (endogenous) incentives to enter in these markets, which in turn affect the strategic interactions. See Etro (2009, 2010) for recent developments.
4. The improvement of energy efficiency may contribute to the reduction of total carbon emissions in a substantial way (ICT is responsible for 2% of carbon emissions in Europe, 1.75% due to the use of ICT products and services, and 0.25% to their production).
5. To provide an example that is familiar to economists, the last version of Matlab is able to use cloud computing to perform expensive and complex evaluations.
6. At one time, leading hardware companies required a captive semiconductor fabrication facility, and companies had to be large enough to afford to build and operate it economically. However, processing equipment doubled in price every technology generation. A semiconductor fabrication line costs over $3B today, so only a handful of major merchant companies with very high chip volumes, such as Intel and Samsung, can still justify owning and operating their own fabrication lines. This motivated the rise of semiconductor foundries that build chips for others, such as Taiwan Semiconductor Manufacturing Company (TSMC). Foundries enable fab-less semiconductor chip companies whose value is in innovative chip design: a company such as nVidia can now be successful in the chip business without the capital, operational expenses, and risks associated with owning a state-of-the-art fabrication line. Conversely, companies with fabrication lines can time-multiplex their use among the products of many fab-less companies, to lower the risk of not having enough successful products to amortize operational costs.

Similarly, the advantages of the economy of scale and statistical multiplexing may ultimately lead to a handful of Cloud Computing providers who can amortize the cost of their large datacenters over the products of many 'datacenter-less' companies (Armbrust *et al.*, 2009, p.3).

7. Locations are chosen strategically to minimize energy and cooling costs (cold regions are favorite), but also international legal issues associated with the global movement of information may be crucial in the future.
8. Amazon launched S3 in March 2006 and EC2 in August 2006. The former provides unlimited storage capacity at the price of 10 Euro cents per Gigabyte/month. The latter provides elastic computing capability at a price between 10 and 50 Euro cents per hour.
9. One of Google's futuristic plans includes centres located on ships to exploit the energy derived from the motion of the water!
10. While many applications and services can perform well either on-premises or in the cloud, Microsoft envisions a wider range of combinations, enabling developers and customers to manage applications and data in the cloud, or on-premises, or via some combination of the two that provides the best outcome in terms of functionality and other concerns such as security or privacy (this approach is defined as *Software plus Services*).
11. Notice that cloud computing implies outsorcing of both software and hardware, therefore it should not be surprising that hardware producers like Dell, HP and IBM are investing in the field as well.
12. While the above elements play in favor of a rapid adoption of cloud computing, there are many obstacles that could limit this process of adoption in the next years. Armbrust *et al.* (2009) provide a deep discussion of these obstacles and of the possible ways to overcome them.
13. This would be in partial solution to the Solow productivity paradox fo which You can see the computer age everywhere but in the productivity statistics (Solow, 1987).
14. Standard references include Christiano *et al.* (2005) and Galì (2008).
15. We refer only to ICT capital to focus on our main interest, but total capital may include physical capital as well.
16. Other works in this tradition include Chatterjee and Cooper (1993), Cooper (1999), Devereux *et al.* (1996), Etro (2004, 2008b) and Elkhoury and Mancini Griffoli (2007). For empirical evidence in support of the endogenous market structure approach see Broda and Weinstein (2007) and Etro (2009).
17. The main difference compared to Ghironi and Melitz (2005), Bilbiie *et al.* (2007, 2008, a,b), Etro (2007a) and Colciago and Etro (2008) relies on the presence of fixed cost of entry in units of consumption good (as opposed to fixed costs in units of labor).
18. We experimented with a double shock to both the fixed cost of production and the aggregate productivity without changing the qualitative results of the paper.
19. They suggest that the cost of ownership could be 30% lower in case of a customer relationship management delivered through software as a service.
20. Further details are available from the author.
21. Another useful policy is the direct adoption of cloud computing solutions in the public sector (that, however, may generate legal problems for the handling of reserved data). We should remark that the adoption of cloud computing in the public sector generates gains from cost savings, but does not generate gains from endogenous business creation that characterize the adoption in the private sector.
22. Formally, one can think of this index as aggregating consumption in a continuum of sectors $C_t = \left[\int_0^1 C_{kt}{}^{(\omega-1)/\omega} dk\right]^{\omega/(\omega-1)}$, where $\omega \in (1,\infty)$ is the elasticity of substitution between the consumption bundles of the different sectors C_{kt}. Under the assumption that firms in each sector choose their strategies taking as given total expenditure in their sec-

tor, the degree of substitutability between sectors does not affect competition within sectors. Moreover, notice that the aggregate price index would be $P_t = \left[\int_0^1 P_{kt}^{1-\omega} dk\right]^{-1/(\omega-1)}$, with P_{kt} price index of sector k. Under logarithmic preferences, total expenditure is indeed equalized between sectors ($P_{1t}C_{1t} = P_{2t}C_{2t} = ..$), and the symmetry of the model implies $P_t = P_{kt}$ and $C_t = C_{kt}$ for any k and t. Therefore we can normalize the number of sectors to one without loss of generality.

23. For recent advances in the industrial organization literature on endogenous entry under different forms of competition see Etro (2007b, 2008a).

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