



## **Technological change and the structure of the economy: the determinants and economic impact of ICTs**

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### **ABSTRACT**

In this paper we investigate the determinants and economic impact of ICT at the macro level for a panel of ten countries over the period 1992-2005. We argue that, since ICT is a General Purpose Technology, its diffusion can be understood only considering the interaction with organizational and structural change. The empirical results are in line with this view: facilitating factors such as changes in regulation, human capital and the structure of the economy are relevant determinants for increasing ICT expenditure. Moreover, in the context of a structural model linking ICT, business services, innovation and growth, we show that decreases in regulation, harmonization of regulation across countries and increases in human capital have a direct positive impact on ICT investment and an indirect positive impact on innovation, growth and business services.

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## 1. Introduction

During the 1990s the US experienced a record period of uninterrupted growth. After the 1980s and the first half of the 1990s in which the contribution of ICT services to growth was sluggish (the so-called “Computer productivity paradox”, Triplett, 1999), the “New economy”, thanks to its exceptional growth performance, has moved to the centre of the stage.

Many studies have attempted to assess the contribution of ICT to growth performance and empirical works have flourished both at the macro and at the micro level, finding overall a positive impact of ICT on productivity and growth (for a review see Guerrieri and Padoan, 2007).

In addition to the clean conclusion that ICT investment enhances productivity, the literature has shown that there are large differences across countries in the production and use of ICT. International comparisons of the role of ICT in industrial countries have shown that two, or possibly three, groups of national patterns can be identified (Schreyer, 2000). Within Europe, Daveri (2000) identifies laggards (Italy, Spain and to a lesser extent, Germany and France) and fast adopters (the UK, Netherlands, Sweden, Finland).

In this paper we argue that, in order to properly analyze the ICT “revolution” and to explain differences across countries in ICT adoption and diffusion, it is necessary to recognize that ICT is a General Purpose Technology (GPT).<sup>4</sup> In fact, it is easy to verify that ICTs satisfy the three key characteristics of GPTs identified by Bresnahan and Trajtenberg (1995): *commonness* (today, computers and related equipment are used in almost all industries of the economy); *technological dynamism* (improvements were not limited to the computers’ computational capacity, but range from the semiconductor to the Internet); and *innovational complementarities* with other forms of advancement (ICTs have seriously facilitated new ways of organising firms by inducing processes of decentralisation of decision making, of team production etc., Milgrom and Roberts, 1990; Brynjolfsson and Hitt, 2000; Bresnahan et al., 2002).

Furthermore, as it has been the case for many other GPTs, ICTs have been slow in fulfilling their potential for increasing productivity due to limited size of the ICT producing sector and, more relevantly, of the ICT capital good stock at the beginning of the 1990s. This means that the main contribution to economy-wide productivity growth of the late 1990s came from ICT *using* sectors rather than from sustained technical progress and TFP growth in the ICT *producing* sector, thus further qualifying ICTs as GPTs.

Lipsey, Carlaw and Bekar (2005), in the context of GPT, offer a Structuralist-Evolutionary (S-E) representation of the relationship between technology and the economy in which economic performance (not only GDP but also its distribution, total employment, pollution and other environmental effects) is determined by the

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<sup>4</sup> GPTs are radical new ideas or techniques that have the potential for important impacts on many industries in an economy. Bresnahan and Trajtenberg (1995) identified three key characteristics of GPTs: commonness (they are used as inputs by many downstream industries); technological dynamism (inherent potential for technical improvements); and innovational complementarities with other forms of advancement (meaning that the productivity of R&D in downstream industries increases as a consequence of innovation in the GPT).

interaction between inputs and the existing facilitating and policy structure. In the S-E approach natural endowments are the only exogenous inputs; the facilitating structure includes technology, infrastructure, physical capital, human capital, people, labour practices, and so on; while the policy structure is the set of realizations that provides the means of achieving public policies (public sector institutions, regulatory bodies, etc, including people that staff these organizations).

The complex interactions outlined by the GPT approach can help to explain why some countries have more problems in adopting a GPT as compared to others: the potential mismatches between technology, the facilitating structure and the policy structure may be weaker or stronger depending from country to country.

In order to analyze the impact of GPTs (hence of ICTs), it is thus necessary to abandon the framework of a production function typical of *Neoclassical* and *Endogenous* growth models (see Barro and Sala-i-Martin, 1995; and Aghion and Howitt, 1998 for comprehensive reviews) and to take into account the interaction between the new technologies, institutions, the structure of the economy and other “facilitating factors”.

Some attempts in this direction include taking a sectoral perspective by distinguishing between ICT producing, ICT using and non-ICT industries (van Ark *et.al*, 2002) and explicitly modelling the interaction between ICT, producer services and the structure of the economy (Guerrieri *et al.*, 2005).

This paper makes another step forward in this direction by analyzing the determinants of development and diffusion of Information and Communication Technologies (ICTs) within advanced countries, taking into account that ICTs are GPTs and, therefore, that their development is strongly linked to the “general business environment”, including the role of institutions, the regulatory environment, human capital, the sectoral composition of the economy. The study of the determinants of ICT spending has also relevant policy implications: increasing the ICT investment is one of the objectives set by the Lisbon Agenda. However, in order to reach this goal, it is necessary first to understand what are the factors that encourage/discourage ICT investments.

Moreover, the paper also addresses the issue of the impact of increasing ICT investment on the economy within a structural model (the SETI model developed by Guerrieri *et al.*, 2005) linking ICT, services (both domestic and imported), innovation and growth. In particular we simulate the impact of several policy interventions (decreasing regulation, homogenizing the level of regulation across European countries, increasing human capital) on ICT investment and on the other endogenous variables of the SETI model (services, innovation and economic growth).

The analyses have been carried out with yearly observations from 1992 to 2005 on a panel of ten countries (Austria, Denmark, Finland, Germany, Italy, the Netherlands, Sweden, the United Kingdom, the United States, and Japan). The empirical results are in line with the literature: facilitating factors are relevant determinants for the spread of general purpose technologies such as ICT to the extent that they influence the business environment. Human capital is a factor that increases ICT investments, while burdensome regulation tends to depress them. Also, the structure of the economy turns out to be a relevant factor to understand the different rate of investment in ICT; in particular, countries with a higher share of the service sector

(some categories of producer services) usually display higher ICT investment. Finally, besides the intuition that in order to make R&D profitable countries require updated IT equipments and software, no econometric robust conclusions can be driven on whether countries that invest more in R&D are also those who invest more in ICTs.

The policy simulations show that ICT investment is stimulated by a decrease in regulation, by harmonization of regulation across countries and by an increase in human capital. Moreover the joint effects of these measures are larger than the sum of the single effects of the measures undertaken separately. Both changes in regulation and increases in human capital have a positive impact on services (domestic and imported), innovation and growth. These effects tend to be small in the short-run but increasing over time. Finally changes in regulation are more effective on services while increases in human capital have the larger impact on technology and GDP.

The rest of the paper is organized as follows: section 2 reviews the empirical literature on ICT adoption, section 3 presents the empirical analysis on the determinants of investment in information and communication technologies, and section 4 presents policy simulations by augmenting the SETI model of Guerrieri *et al.* (2005) with the ICT equation. Finally section 5 draws the main conclusions.

## 2. Review of the Literature

In this section we will review the relevant empirical results on ICT adoption both at the macro and at the micro level.

The topic of ICT diffusion has received increasing attention. At the macro level, the literature has mostly concentrated on the *digital divide*, *i.e.* the striking difference in the adoption of information technologies between developed and developing countries. At the micro level, instead, the literature focused on the identification of those characteristics (both specific to the firm and to the environment in which the firm operates) that are able to influence firms' decisions to invest in ICT.

In this paper we try to understand what are the factors that boost/depress ICT investments at the macro level. This is something new in the literature. Despite that, this topic is somewhat related to both the micro literature and the *digital divide* literature.<sup>5</sup> In particular, this paper is closer to the micro than to the *digital divide* literature in considering ICT adoption from the point of view of the firm rather than of the consumer. Understanding what drives the single firm's behavior is crucial in order to understand the results at the aggregate level. At the same time, even though the *digital divide* literature puts attention to diffusion of ICTs in a broader sense than

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<sup>5</sup> It is important to point out that in the literature we review, the endogenous variable (*i.e.* ICT) has been measured by means of different variables: number of internet host per capita, computer per capita, internet connection per capita, internet users, mobile phones per capita, a dummy variable indicating if the firm uses computers, and other formulations. In what follows we do not make a distinction on the endogenous variable used, and we will generally call it ICT.

investment, we believe that these two concepts are closely related and therefore that our paper is also related to this strand of literature.<sup>6</sup>

There is a widespread agreement that the *digital divide* is mostly due to the difference in economic wealth of countries. Caselli and Coleman (2001), Balamoune-Lutz (2003), Chinn and Fairlie (2004), and Pohjola (2003), by analyzing a sample including both developing and developed countries, provide empirical evidence that income per capita is positively and significantly related to ICT adoption.<sup>7</sup> Hargittai (1999) by estimating a model on a sample of OECD countries, argues that income per capita *per se* is not sufficient to explain the digital divide, and suggests that income distribution need to be considered as well.

Another factor that is widely considered in the literature, both at the macro and at the micro level is Human Capital. From a theoretical point of view, the argument is that skilled (*i.e.* educated) workers are more capable of learning how to use new technologies, and that they are more flexible with respect to their job assignment. Because the adoption of ICT often requires a reorganization of the firm, a firm with a high percentage of skilled workers can implement more easily information technologies. In the macro literature, those authors who analyze samples including both developed and developing countries find mixed evidence (Chinn and Fairlie, 2004, and Balamoune-Lutz, 2003), whereas those who analyze OECD countries find a significant influence of the level of human capital on ICT adoption (Gust and Marquez, 2002, and Hargittai, 1999).<sup>8</sup> Studies at the micro level, instead, find a positive relationship between the general level of employee qualification and ICT use (Bayo-Moriones and Lera-Lopez, 2007, and Haller and Traistaru-Siedschlag, 2007).

The impact of regulation on the adoption of ICT has received much attention in the literature. In general, it has been argued that all kinds of restrictions, regulations or constraints that somehow limit the set of decisions of an economic agent, may drive the economy to a sub-optimal equilibrium. The question is if they also negatively influence the adoption of ICT. Gust and Marquez (2002) demonstrate that regulation in the labor market slows down the process of adoption, Dasgupta, *et al.* (2001) that competition policy matters, while Hargittai (1999) focuses on the influences of the structure of the telecom market (monopoly *vs.* competition). Some authors analyzing the *digital divide* have also included indices of property rights and/or of civil liberties that resulted to be important variables as well (Balamoune-Lutz, 2003, Chinn and Fairlie, 2004, and Caselli and Coleman, 2001).

Demographic factors such as the age structure of the population and the size of urban population have also been taken into account. The idea is that ICT have larger diffusion among younger people and that urban population tends to adopt more ICT (internet and computer) because of network economies. However, the empirical evidence is mixed. Regarding population age: Chinn and Fairlie (2004) argue that if

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<sup>6</sup> In fact, firms' investment in ICTs and their diffusion in the country are closely related. It is hard to imagine an economy where firms use PCs and the internet, and consumers (that after all are the labor force that uses this technology on the job) do not.

<sup>7</sup> On the other hand, Dasgupta, *et al.* (2001) find income per capita non significant in determining ICT.

<sup>8</sup> By starting from the consideration that the language of most web sites is English, some of these authors have also tested that, in addition to an education variable, English proficiency is a further explanatory variable for ICT adoption. However, other empirical results do not support this hypothesis (Hargittai, 1999, and Caselli and Coleman, 2001).

the developing countries had the same population age composition of the US, the divergence in adoption of ICT would have been even larger; on the other hand Bayo-Moriones and Lera-Lopez (2007) find no relationship between workforce age and ICT at the firm level. With respect to urban population: Dasgupta, *et al.* (2001) find a positive elasticity with ICT adoption and Chinn and Fairlie (2004) find it negative.<sup>9</sup>

Knowledge spillovers, network externalities, and competitive pressure are all factors that could play a relevant role in firms' (and thus countries') adoption of ICTs. Hollenstein (2004) argues that for firms being able to understand future benefits and costs of ICT investments is fundamental: therefore the possibility to absorb knowledge from other firms is a factor that influence firms adoption of ICTs. Haller and Traistaru-Siedschlag (2007) find that in Ireland firms located in the capital city region are those who adopt more ICTs, and Bayo-Moriones and Lera-Lopez (2007) find that competitive pressure encourages the adoption of ICT. At the macro level technological spillovers can derive for example from relationships with foreign (perhaps more advanced) countries. That is why many authors investigated the relationship between the degree of openness of an economy and ICT adoption. However, empirical evidence does not allow for a clean conclusion: Balamoune-Lutz (2003) and Caselli and Coleman (2001) find a positive relationship, while Pohjola (2003) and Chinn and Fairlie (2004) find it to be not significant.<sup>10</sup>

The economic structure of a country has shown to be relevant for ICT adoption. The empirical analysis mainly tried to answer two questions, namely: *i*) what are the Firm's specific characteristics that influence the adoption of ICTs? and *ii*) Does sectorial composition of a country play a role in terms of ICT performances? Many authors find that firm's size is a relevant variable for ICT investment decisions (Haller and Traistaru-Siedschlag, 2007): the larger the firm, the higher the probability of adopting new technologies.<sup>11</sup> Not only firms' size matters though. The organizational structure has shown to be relevant as well (Caroli and Van Reenen, 2001). Hollenstein (2004) suggests that team working and horizontal structure are organizational characteristics that encourage ICT adoption. Also the answer to the second question is positive: given that some sectors use more ICT than others, different sectorial composition determines different rates of investment in ICT. The literature emphasizes how the higher the share of the service, and of the manufacturing sector, the higher the ICT investment rate, while an inverse relation exists with agriculture and public sector (Caselli and Coleman, 2001, and Gust and Marquez, 2002).<sup>12</sup>

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<sup>9</sup> Chinn and Fairlie (2004) explain this result through the inclusion of a telephone line density variable: "this finding suggests *that after controlling for telephone line density* in a country, the Internet substitutes for the benefits accruing to operating in an urbanized environment" (p. 14).

<sup>10</sup> Caselli and Coleman (2001) also investigate if the source of imports matters and find that actually it does: in fact, they find that imports from OECD countries are significant while imports from non-OECD are not.

<sup>11</sup> The rationale often used to justify this result is that larger firms face less financial constraints thus being less risk adverse with respect to new technologies.

However, Hollenstein (2004) find that firm size matters only for firms with more than 200 employees, and that the explanatory variables of the model play a different role for *small* firms and for *large* firms, in particular with *small* firms that look for a quick return on investments.

<sup>12</sup> The rationale for this result is that the public sector often lacks the incentive to obtain high productivity standard, thus to innovate, and so to adopt ICT.

Finally, there is not yet agreement on the use of a price index as a determinant of ICT use. The straightforward idea is that if price fall the quantity demanded increases. Pohjola (2003) includes a price index in his regression and finds it to be significant, while Chinn and Fairlie (2004) argue that given that prices exhibit a downward trend they should not be included in the analysis.

### 3. Empirical Analysis

As we have seen in the review of the literature there are many factors that may influence ICT investment/expenditure/adoption such as Economic Wealth, Regulation/Policy, Sectorial Composition, Openness to Trade and Foreign Investment, Human Capital, Demographic Factors, and others. As ICT is a general purpose technology it is not surprising that among the explanatory factors used in the literature several relate to the set of “facilitating factors”, *i.e.* variables influencing the general business environment. We have chosen a number of such variables in addition to those more directly related to ICT activities.

The endogenous variable is the ratio of ICT investment to Value Added (henceforth *ICT*).<sup>13</sup> ICT investments are computed as the sum of Gross fixed capital formation of IT equipment, Communication equipment, and Software.

To proxy the sectorial composition of the economy we have considered the share of some categories of producer services on the economy (*service*). These are: Post and Telecommunications, Finance, Insurance, Real Estate and Business Services<sup>14</sup>. We have chosen these services since in previous studies (Guerrieri and Meliciani, 2005; and Guerrieri et al., 2005) we have shown that their production and trade is strongly linked to investments in ICT. Given that these services are heavy users of information technologies, we expect that, *ceteris paribus*, countries with a higher share of these activities have a higher rate of investment in ICTs.

Guerrieri et al. (2005) have developed and estimated a structural model (SETI) of the co-evolution of technology, domestic and imported services and GDP<sup>15</sup>. In the next section we will run simulations by augmenting the SETI model of Guerrieri, *et al.* (2005) with the ICT equation. Therefore, in estimating the ICT equation, we have to take into account for the endogeneity of services. We will do this by estimating the ICT equation with instrumental variables, where we use as instruments the other exogenous variables and the one period lag of the variable *services*.

In order to capture the propensity to innovate of a country we have included the ratio of Gross Expenditures on Research and Development (*GERD*) on GDP. The rationale for including this variable is to investigate whether ICT and R&D are complementary. This should be the case according to the GPT literature that stresses the importance of innovation complementarities: on the one hand in order to make R&D profitable countries require updated IT equipments and software and on the

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<sup>13</sup> Data for both variables are taken from the EU-KLEMS database. For a detailed description of the variables see the Appendix.

<sup>14</sup> Data are taken from the EU-KLEMS database. *services* is computed as the ratio of the value added of Post and Telecommunications, Finance, Insurance, Real Estate and Business Services on the value added of all industries. In what follows, for simplicity, we will refer to this variables as Business Services although it includes a wider category of advanced producer services.

<sup>15</sup> For a description of the SETI model see the Appendix.

other high R&D efforts favor the development and diffusion of new technologies such as ICTs.

In accordance with the literature, we include in the model a measure of human capital. The first measure we consider is the share of researchers in total employment (henceforth *researchers*) that is the same variable that is also included in the SETI model. This variable captures a very “sophisticated” kind of human capital. Moreover, as it was to be expected, it is strongly correlated with *GERD* (Table 1 – lower triangle). Therefore we consider also other proxies for measuring human capital. First, we took data from Eurostat on Spending on Human Resources (*shr*) that it is not highly correlated with other exogenous variables (Table 1 - upper triangle). However, it is necessary to point out that *shr* is not a variable commonly used in empirical analyses as the empirical literature always measures Human Capital from an “education-based” point of view, rather than a “cost-based” point of view (Le, Gibson & Oxley, 2005). Eurostat defines *shr* as “total public expenditure on education” and given that in the EU education is in large part provided by the public sector, we believe it is worth considering this variable too. Secondly we used the share of population having completed at least upper secondary education. The limit of this variable is that it is available only for European countries and only starting from 1998 and that it has a low variability across countries for the sample of advanced countries included in this study.

The introduction of different indicators of human capital should also help assessing whether for stimulating ICT investment it is more important to achieve a satisfactory level of general education or to focus on more specific highly educated human resources.

Finally, in order to take into account for the impact of the business environment on firms’ ICT expenditure, we introduce some variables that capture the national degree of regulation. In particular, the level of regulation is measured by three different indices: an index of Regulatory Conditions in Seven Non-Manufacturing Sectors (*Regulation*) constructed by Conway and Nicoletti (2006), an Index of Administrative Burdens on Start-ups (*absu*) taken from Conway *et al.* (2005), and an index of Employment Protection Legislation (*epl*) taken from the OECD Employment Outlook 2004.<sup>16</sup> The *regulation* index attempts to capture restrictions to competition in seven industries (Airlines, telecoms, electricity, gas, post, rail, and road freight); it is computed as an average of five “low-level” indicators: 1) *barriers to entry*, 2) *public ownership*, 3) *vertical integration*, 4) *market structure*, and 5) *price controls*. The *epl* indicator, instead, tries to capture the strictness of employment protection legislation. It is the result of the aggregation of many indices that can be grouped in two broad areas: permanent contracts and temporary contracts. For permanent contracts three fields of regulation are considered: 1) the *procedural requirements* from the decision to lay off to the actual termination of the contract, 2) the *notice and trial period*, and 3) the *direct cost of dismissal*. The legislation of temporary contracts is described by means of the *definition of types of labour and*

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<sup>16</sup> The index *regulation* has both a time series and a cross sectional dimension, whereas *absu* and *epl* are characterized mainly by a cross sectional dimension. This is because *regulation* has been computed every year, while *absu* and *epl* have not. In particular, *absu* has been computed only for 1998 and for 2003. Regarding *epl*, with some exceptions, it has been computed for 1990, 1998, and 2003.

*procedures*, the *maximum number of successive renewals*, and the *maximum cumulated duration of the contract*. Finally, the *absu* index measures the *administrative burdens on the creation of Corporations* and the *administrative burdens on the creation of sole proprietor firms*.

Although the three indices all measure the tightness of regulation, they focus on different aspects: respectively restriction to competition, administrative burdens and flexibility of the labour market. We think that assessing whether these different forms of regulation have different impacts on incentives to adopt new technologies has important policy implications since it allows to discriminate what kind of deregulation (if any) works better in stimulating ICT.

The analysis is carried out on a panel of ten countries (Austria, Denmark, Finland, Germany, Italy, the Netherlands, Sweden, the United Kingdom, the United States, and Japan) with yearly observations from 1992 to 2005.<sup>17</sup>

Before going to the results, it is however necessary to point out that we chose not to fill missing values by interpolation or any other methodology. This choice has decreased substantially the number of observations available in particular for the variables *GERD* and *researcher* (graph 3 and 4). Hence we end up with an unbalanced panel of ten countries over the period 1992-2005.<sup>18</sup>

Graph 1 to 8 show the variables that have been considered in the empirical model. As we can see from graph 1, it is possible to identify three groups of countries that exhibit almost the same dynamics in ICT investments: Sweden, the UK, and the US are the countries that invested the most and that have increased more rapidly their share of ICT investment during the nineties; Finland, Japan, and the Netherlands exhibit a slow increasing pattern during the nineties, and overall show values around 3%; Austria, Germany and Italy are the countries that performed poorly with values below 2.5%; finally, Denmark cannot be inserted in any of these groups as it is the only country that exhibits an increasing pattern after 2000.

Graph 2 shows the share of services. In all countries the share of these services in the economy has increased during the sample period, with the US and the UK showing the highest values and Italy, the Netherlands, and the UK exhibiting the most relevant increase. Graph 3 shows the performance of the countries in terms of expenditure in R&D. Most of the countries have maintained a stable GERD/GDP ratio, with Austria, Denmark, Finland, and Sweden being the only countries exhibiting increasing patterns. This variable shows the highest values in the Nordic countries (Sweden and Finland) and in Japan, while Italy shows remarkably lower levels with respect to the other countries included in the sample. Not surprisingly, the same things can be said about our first measure of human capital, that is the share of researchers in total employment (graph 4). Regarding *shr* (figure 5) none of the countries exhibit a noteworthy pattern; the only interesting thing is that Scandinavian

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<sup>17</sup> The choice of countries to include in the sample has been driven by the need of being consistent with SETI. The countries included in the analysis are, thus, the same as in the SETI model but for the exclusion of France for which data on ICT investment are not available yet. On the other hand, the time period is different as in SETI the sample covers 1988 through 1998. However, we believe it is necessary to extend the time period in order to include the years after 1995 characterized by the highest gains in productivity due to the use of ICTs.

<sup>18</sup> This, in the end, has constrained our empirical analysis to econometric techniques that have good small sample properties.

countries are those who spend a higher share of GDP in human resources, while Japan the smallest. Finally also with respect the share of population having completed at least upper secondary education (figure 6) none of the countries exhibit a noteworthy pattern and the variable does not vary much across the countries included in the sample with the notable exception of Italy that shows the lowest values.

Finally graphs 7, 8 and 9 show the regulation indicators. For administrative burdens on start ups and employment protection legislation, due to the low variability of the series over time, we have reported averages over the periods 1992-1995, 1996-2000 and 2001-2005. From the graphs we can observe that regulation in seven non-manufacturing industries has decreased almost everywhere and, at the same time, its dispersion across countries has also decreased (one thing that will be relevant for the results of policy simulations we will show later). Nonetheless the UK and the US, that had the lower levels of regulation in 1992, continue to show the lowest values also in 2003 (with the UK becoming the less regulated country), while Italy, despite the sharp decrease in the index, remains the most regulated country in the sample. Comparing the three regulation indicators, we can observe that as far as administrative burdens on start ups are concerned the less regulated countries are the UK, the US and the North European countries, while in the case of employment protection the UK and the US have again the lowest values, but the other European countries tend to have similar values (at the end of the period Sweden and Finland appear among the countries with the higher values of employment protection). Finally as far as restrictions to competition in seven non manufacturing industries are concerned, again the less regulated countries are the UK and the US, while Nordic countries are in a middle position. This different pattern across countries of regulation of the labor market compared to the presence of administrative burdens and degree of competition is an interesting feature that should be kept in mind when looking at regression results.

Table 2 shows estimates of a random effect model for ICT investment.<sup>19</sup> Panel *a*, and *b* of table 1 present IV Random Effect Estimates with different human capital measures: respectively *researchers*, and *shr*, whereas the three columns within each panel present different specifications with respect to the regulation variables: the first including the *regulation* index, the second including the *absu* index, and the third including the *epl* index. In all regressions we have also included three time dummies to capture the economy slowdown that followed the 9/11.

In all estimations we found a positive relation between *ICT* and *services*: a 1% increase in the share of business services on the economy leads to a 0.48-1.34% increase of the ICT/GDP ratio.

The results for human capital are mixed: we found a positive and significant relation between human capital and *ICT* when human capital is measured with *researcher* while when it is measured with *shr* the coefficient is not significant. This result is not surprising. Indeed, as we have already pointed out, *shr* is a “cost-based” indicator of human capital, and usually “education based” indicators are supposed to be more appropriate for macroeconomic analyses. We thought, however, it was worth considering this variable as it can be considered as an indicator of “general”

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<sup>19</sup> All variables are log transformed.

human capital. In fact, one interesting issue to address is whether, in terms of ICT diffusion, it matters more *scientific* human capital or *general* human capital. That is a relevant question in terms of EU policy as two of the objectives of the Lisbon agenda are of increasing the number of graduates in mathematics, science, technology and engineering, and of reaching a rate of 80% of the working age population with at least a completed upper secondary degree.

To measure *general* human capital we also considered the percentage of working age population with at least an upper secondary degree (*education*). Unfortunately, data on *education* are available from Eurostat for European countries only and starting from 1998. This limitation in the sample has created serious problems in estimation. We run regressions with this variable and we obtained mixed results (the variable is not significant in the model with random effects but it is positive and significant in the model with fixed effects).<sup>20</sup> We believe that this is due to the limited variability of this variable in the sample, and, in particular, to the limited variability *between* countries (graph 6). In fact, in a recent work Luciani and Padoan (2007), by estimating a model for software investment on a sample of fifteen European countries, found a positive and significant coefficient for *education*. In our sample, all countries but Italy exhibit similar values of *education*, whereas the sample used by Luciani and Padoan (2007) includes also countries with low levels of human capital such as Portugal, Spain, and Greece (graph 5 - series with filled dots). The presence of this set of countries increases the variability of *education* thus making significant the coefficient for this variable.

Somehow linked to the performance of the human capital indicators is the performance of *GERD*. In fact, when the human capital is *researcher* the variable *GERD* is not significant (probably due to the high correlation between *researcher* and *GERD*), whereas when the human capital indicator is *shr* the variable enters the equation with a positive and significant sign.

Overall it appears that what matters more for ICT investment across advanced countries is not the general level of education (probably also because this is very similar across these countries) but having a high share of researchers. This result may also depend on the fact that, differently from many other studies reviewed in Section 2, we are not looking at ICT adoption by households but at ICT investment by firms.

Finally, as it was to be expected, tighter regulations depress ICT investment. With the exception of *epl* that is never significant, the other two indices perform well, with *regulation* being able to capture better the *within* dynamics, and *absu* being able to explain better the *between* differences. This result cannot be interpreted from an economic point of view as it is probably due to the fact that the *absu* index has almost only the cross-section dimension, whereas *regulation* has also the time series dimension. Besides that, the performance of both indices is not surprising. In fact, on the one hand the *regulation* index measures the level of regulation of seven non-Manufacturing sectors. However, two of these seven sectors (namely Post and Telecommunications) are also included in the variable services. As it has been shown, these services are heavy users of ICTs, thus not surprisingly the tighter the regulation in these markets, the lower are the investments in ICTs. On the other hand, the literature on the effects of regulation on the economy has reached the conclusion

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<sup>20</sup> Results of these regressions are not reported but are available upon requests.

that countries where (controlling for other factors) firms face more entry barriers perform poorly, both in terms of GDP growth and in terms of innovation and technological progress (R&D expenditures).<sup>21</sup> Accordingly with this conclusion, the *absu* parameter is negative and significant. Finally, the fact that the degree of flexibility in the labor market does not affect ICT investment is an interesting result since it suggests that not all kinds of “deregulation” exert the same impact on ICT investment and that deregulation policies aimed at increasing ICT investments should be devoted to foster competition in services and to reduce administrative burdens on start ups rather than to reduce employment protection.

In order to test the robustness of our estimation, on table 3 we present IV Fixed Effects Estimates. Due to poor time series dimension in *epl* and *absu* this estimation is provided only for the equation including the *regulation* variable. As in table 2, columns *a* and *b* show results with different human capital variables. Qualitatively (sign and significance of parameters) the results are similar to those obtained with Random Effect. Quantitatively only the parameter of the variable *services* is substantially different: FE estimation predicts a stronger relation between *ICT* and *services*. Finally, by means of an Hausman (1978) test, in the bottom line of table 3 we test random *vs.* fixed effect in the model. The test clearly indicates that a random effect model is preferred.

To sum up: the results are in line with the literature. What our estimation adds is the consideration *a)* of different measures of regulation, *b)* of different measures of human capital, *c)* of the complementarity between ICT and R&D and *d)* of the endogenous relationship between *services* and ICT investment. Moreover, with respect to the macro studies on the digital divide, our sample includes only advanced countries but over a longer time span. Finally, as in the micro studies, we focus on ICT expenditure from the perspective of the firm and thus we use as endogenous variable the “investment” in ICT.

#### 4. Policy Simulations

As we said in the introduction, ICT is a General Purpose Technology. In the context of the GPT paradigm it is meaningless a model that explains ICT diffusion but that performs poorly when it interacts with the other macroeconomic variables. In this section we augment the model of Guerrieri *et al.* (2005) (henceforth SETI) with our equation and present policy simulations.

SETI is a continuous time model of endogenous growth, business services and technology diffusion. We choose the SETI model to perform our exercise because it allows to identify important structural links that help to better understand the role of ICT as a GPT. In particular, SETI allows modelling the facilitating factors which, as we have seen in the previous sections, are crucial in explaining the introduction and diffusion of a GPT such as ICT. Such facilitating factors include the role of national and Europe wide regulation, the time–evolving role of distance (which is a proxy for the role of infrastructure in facilitating innovation diffusion), the availability of

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<sup>21</sup> For a review of the literature on the economic effects of regulation see Schiantarelli (2005).

human capital. The model has been estimated on several European countries, Japan, and the US.<sup>22</sup>

In our estimation we could not ensure data consistency with SETI in particular concerning our endogenous variable  $ICT$ . This is due both from a logical reason and a technical reason. First, SETI has been estimated on data from 1988-1998 and we think it would be a weakness for our estimate not to include the most recent observations. Second, the endogenous variable used in SETI is the share of IT expenditure on GDP taken from Eurostat. Unfortunately, this variable is available from Eurostat only up to 2001<sup>23</sup>. Thus, in order to estimate the model on recent observations we were forced to change the source of data.

Furthermore, in order to augment the SETI model with our equation we need to modify our estimates by switching from a discrete time formulation to a continuous time formulation:

$$\Delta \log ICT_{it} = \delta(\log ICT_i^* - \log ICT_{it-1}) \quad (1)$$

$$\log ICT_i^* = \alpha + \beta \mathbf{Z}_{it} \quad (2)$$

Here we have that the growth rate of ICT investments (*i.e.* the diffusion rate) is a function of the difference between the steady state equilibrium level of ICT investments (the so called post-diffusion level), and the level of investment in the previous year, with  $\delta$  representing the adjustment speed to the equilibrium level. The equilibrium level of investment is a linear function of a set of exogenous variables  $\mathbf{Z}$ .<sup>24</sup> By plugging (2) in (1) we obtain:

$$\Delta \log ICT_{it} = \delta\alpha - \delta \log ICT_{it-1} + \delta\beta \mathbf{Z}_{it} + \eta_i + \varepsilon_{it} \quad (3)$$

that is an estimable equation.

To estimate our continuous time specification we use GMM estimator proposed by Arellano and Bond (1991).<sup>25</sup> The vector of variables  $\mathbf{Z}$  characterizing the steady state equilibrium include the variables *services*, *GERD*, *researchers*, and *regulation*. In addition, three time dummies were included to account for the world economy slowdown following the 9/11. The choice of the variables follow from the analysis of the previous paragraph. As we have seen between the two human capital measures *researchers* is the one that performs better. On the other hand, the choice of the

<sup>22</sup> Detailed information about the SETI model can be found in the appendix.

<sup>23</sup> This variable was indeed not produced by Eurostat, rather by the European Information Technology Observatory (EITO). Eurostat has started developing a new ICT indicator from 2002 that unfortunately cannot be linked to the one computed by EITO.

<sup>24</sup> This model has been originally proposed by Chow (1967) and applied in the ICT diffusion literature by Balamoune-Lutz (2003), and by Kiiski and Pohjola (2002) among others.

<sup>25</sup> Indeed, estimating this equation with GMM is not a choice but a necessity. In fact GLS random effect estimation leads to inconsistent estimates because, due to the dynamic nature of the equation, the assumption that the country specific effects are uncorrelated with the right hand side variables is necessarily violated. To show that, let us add from both the LHS and the RHS of equation (3)  $\log ICT_{it-1}$  to obtain:  $\log ICT_{it} = \delta\alpha + (1 - \delta) \log ICT_{it-1} + \delta\beta \mathbf{Z}_{it} + \eta_i + \varepsilon_{it}$ . That is an ordinary panel equation with an autoregressive component. Here  $ICT_{it-1}$  is necessarily correlated with  $\eta_i$ , in fact:  $E(\eta_i, ICT_{it-1}) = E\{\eta_i(\delta\alpha - (1 - \delta) \log ICT_{it-2} + \delta\beta \mathbf{Z}_{it-1} + \eta_i + \varepsilon_{it-1})\} \neq 0$  because at least  $E(\eta_i^2)$  is  $\neq 0$ .

regulation variable was obliged. In fact, the Arellano Bond estimator is a first difference estimator and given that both *absu* and *epl* have a limited time series dimension we had to focus on *regulation*.

Due to our *non-treatment* of missing values this estimation is done on a sample of eight countries (Denmark, Finland, Germany, Italy, the Netherlands, the UK, the US, and Japan) with early data from 1992 to 2003.<sup>26</sup> Again, given that in the SETI model one of the endogenous variables is a service sector variable, in order to overcome a problem of endogeneity, we have considered the variable *services* as pre-determined.<sup>27</sup>

Table 4 shows the results of Arellano-Bond GMM estimation for the ICT equation. Results are qualitatively in line with those obtained with IV random effect: *services* enter positively and significantly the equation albeit with a considerable lower magnitude, while the coefficients of both *regulation* and *researchers* are pretty stable. Even in this new estimation the parameter of *GERD* turns out not to be significant. These results are encouraging. In fact, estimating an equation with GMM on just 64 observations might not give reliable estimates. However, given that the results we have obtained are close to those we get with IV random effects, we feel comfortable of using this equation in the simulation exercise.

In particular we will focus on simulating the impact of changes in regulation and in human capital on ICT and on the other endogenous variables of the SETI model (*services*, *innovation* and *GDP*).

Other studies, recently, have looked at similar issues. The European Commission (2007) has investigated the causes of the lower performance of European countries with respect to the US in terms of TFP growth and has identified three policy areas that can contribute increasing simultaneously growth and jobs in Europe. These are: (i) knowledge building; (ii) strengthening competition forces; and (iii) enhancing flexibility. In particular, using the QUEST model, they have shown that: (i) actions to support R&D investment could significantly raise economic and productivity growth in Europe; ii) competition is crucial for both the level and growth rate of productivity; iii) enhanced flexibility is needed to smoothly adjust production structures towards further specialisation and diversification into new areas of relative comparative advantage.

Previous studies by the IMF (2002) and by Bayoumi, Laxton and Pesenti (2004) had also shown the importance of decreasing regulation for EU growth, while simulations by the European Commission (2003) have shown that deregulation alone (i.e. bringing the level of EU product market regulation down to the US level) would not be enough but should be accompanied to an increase in R&D spending, education and ICT in order to fill the European gap with the US in terms of per capita GDP. Finally, Guerrieri et al. (2005) have shown that in the long run growth in Europe is best supported through stronger technology accumulation, itself supported by larger availability of human capital, while in the medium term a better regulatory environment, more ICT investment and a deeper integration can provide a stronger boost to growth.

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<sup>26</sup> Arellano-Bond estimation requires more data than OLS/GLS estimation, as it requires at least three consecutive observations for all the variables included in the model.

<sup>27</sup> Technically this implies making use of the moment condition  $E(\varepsilon_{it}/s_{i1}, \dots, s_{iT}) = 0$  instead of the stronger moment condition  $E(\varepsilon_{it}/s_{i1}, \dots, s_{iT}) = 0$ .

The results of the policy simulations just reviewed are all based on models with exogenous ICT expenditure. However, as we have shown in this paper, firms' incentives to adopt new technologies depend on the business environment in which they operate, the level of human capital and complementary R&D expenditure, the structure of the economy (e.g. its sectoral composition). In what follows we will use the SETI model, enriched with our endogenous representation of ICT, in order to simulate the impact of changes in regulation and human capital on ICT investment, services (domestic and imported), innovation and growth in Europe.

We think that the Lisbon Agenda's goal of increasing ICT investment can be addressed only through a deep understanding of the synergies between the new technologies and the so called "facilitating factors". Moreover the overall impact of such changes in the economy must take into account of the simultaneous evolution of ICT, innovation, services and GDP.

The methodology for the simulations is the following<sup>28</sup>. Given the historical starting values of the variables (the last available value for all the variables), and the parameter estimates, we run a baseline scenario. Then we construct three different possible scenarios plus two combinations of them and we compare each of these scenarios with the baseline.

The three different scenario we construct try to account for the following questions: *a)* what happens if the level of regulation decreases of 20% in all European countries? *b)* What happens if there is an homogenization in the regulation within Europe? Finally, *c)* what happens if there is a 5% increase in the level of human capital in all European countries? The composite scenarios are: *d)* What is the impact of a simultaneous decrease in regulation and increase in human capital? *e)* What is the impact of a simultaneous harmonization of regulation and increase in human capital?

To implement scenario *a* we have simply decreased of 20% the starting values of *REG* for all European countries; similarly, to implement scenario *c* we have simply increased of 5% the starting values of *hc* for all European countries. To implement scenario *b* we have decreased the value of *REG* so that the sum of *REG* within European countries is the same as in scenario *a*. However, in this scenario, we have not decreased the value of *REG* in all countries, rather we have started decreasing the value of the country with tighter regulation, then we have decreased the value of the second country with tighter regulation, and so on up to the point where the value of *REG* in Europe was 80% of the original value. Basically, the magnitude effect on scenario *a* and *b* is the same, the difference is that in scenario *a* regulation decreases uniformly everywhere, while in scenario *b* it decreases in some countries so that the variance of the variable across countries decreases (harmonization in regulation). Finally scenarios *d* and *e* are respectively the sum of scenario *a* and *c* and of scenario *b* and *c*.

Figure 10 reports the results of the policy simulation exercise on the endogenous variables of the SETI model. The impact of all measures on ICT is sharply increasing over the first five years and then tends to stabilize. The magnitude of changes in regulation is much higher than the impact of the increase in human capital. Both

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<sup>28</sup> For a detailed description of the SETI model and for an explanation of the methodology used for simulate the model, see the Appendix.

decreasing regulation and homogenizing regulation across Europe lead to about a 10% increase in ICT, while increasing human capital leads to an increase in ICT of about 2%. It is also interesting to observe that, when the two measures are taken simultaneously, their joint impact is larger than the sum of the two effects taken separately.

The effect of the various policy measures on the other endogenous variables is much smaller (in particular in the case of technology) but it is increasing over time. It is interesting to observe that the two regulation measures outperform changes in human capital when we consider the impact on domestic and imported services, while the increase in human capital has a much larger impact (compared to changes in regulation) on technology. Finally, both changes in regulation and in human capital affect output growth indirectly through their impact respectively on services (domestic and imported) and on technology. Both policy measures have a negligible impact at the beginning (for about the first five years), but this impact is increasing over time. Overall the effect of the increase in human capital (that operates via its positive impact on technology) on GDP is larger than the change in regulation (that operates via its positive impact on services).

Again the simultaneous decrease (harmonization) in regulation and increase in human capital exerts the larger impact on all the endogenous variable.

Another interesting result is that, although the decrease in regulation and the harmonization of regulation across Europe tend to have a similar impact (recall that the magnitude of the change in regulation is the same in the two scenarios), harmonization outperforms simple deregulation in its impact on services (and, in particular, on imported services), while deregulation is more effective than harmonization in its impact on technology. Finally the impact of the two measures on GDP is similar. This result is consistent with the idea that there are important benefits for harmonization especially for the production and trade of services, an area that remains subject to different legislations and degrees of protection across Europe. On the other hand, in order to affect innovation, deregulation works better than harmonization.

## **5. Conclusions**

In this paper we have investigated the determinants of ICT investment across European countries over the period 1992-2005. In line with the literature on GPT, and with the view that ICT is a GPT, we have found that a set of variables affecting the “general business environment” in which firms operate play a strategic role in firms’ decision to invest in the new technologies. Among these variables the regulatory environment, human capital and the sectoral composition of the economy appear as important determinants of ICT investment. In particular, human capital and a high share of business services in the economy are factors that increase ICT investment, while burdensome regulation tends to depress it.

Among human capital variables, we have found that a high share of researchers in total population is what matters most, while spending on human resources and having a high percentage of working age population with at least an upper secondary degree do not discriminate. This result may depend upon the sample of countries included in this paper that is composed of European countries with very similar

levels of general education (with the exception of Italy) and on the fact that we are concentrating on adoption by firms. In order to stimulate ICT investment across the most advanced European economies, efforts should be devoted to strengthening human capital at its highest levels more than to increasing the general level of education.

Among the regulation variables tight regulatory conditions in non-manufacturing sectors and high administrative burdens on start-ups have a negative impact on ICT investment, while employment protection legislation is not significant. This result qualifies the conclusions reached by other studies on the role played by “deregulation” in stimulating ICT investment by showing that not all kinds of deregulatory measures have the same impact, but concentrating on reducing administrative barriers and on liberalising service industries can be more effective than introducing higher degrees of flexibility in the labour market.

Finally, in this paper we have used a structural model of endogenous growth, innovation and business services, in order to simulate the impact of changes in regulation and human capital on the economy. We have found that ICT investment is stimulated by a decrease in regulation, by harmonization of regulation across countries and by an increase in human capital. We have also found that these measures have a positive impact on services (domestic and imported), innovation and growth that are small in the short-run but increasing over time. While changes in regulation are more effective in stimulating the growth of business services (domestic and imported), increases in human capital have a larger impact on technology and GDP.

Increasing ICT investment is one of the objectives set by the Lisbon Agenda. In this paper we have shown that this result can be reached only through deep changes in the general environment in which European firms operate. This is not surprising since ICTs are technologies that affect almost all industries of the economy and have important repercussions on firms’ organisation, therefore, their virtuous interaction with the so called “facilitating factors” is crucial not only for ICTs to exert their positive impact on the economy, but also for creating the incentives for firms to adopt the new technologies.

#### **REFERENCES:**

- Aghion, P. and P. Howitt (1998), *Endogenous Growth Theory*. MIT Press, Cambridge MA.
- Arellano, M. and S. Bond (1991), "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economic Studies*, 58(2), 277-97.
- Arvanitis, S. (2004), “Information Technology, Workplace Organization, Human Capital and Firm Productivity: Evidence for the Swiss Economy”, in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.
- Baldwin, J. R. Sabourin, D. and D. Smith (2004), “Firm Performance in the Canadian Food Processing Sector: The Interaction Between ICT, Advance Technology Use and Human Resource Competencies”, in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.

- Baliamoune-Lutz, M. (2003), "An analysis of the Determinants and Effects of ICT Diffusion in Developing Countries," *Information Technology for development*, 10, 151-169.
- Barro, R. and X. Sala-i-Martin (1995), *Economic Growth*. McGraw-Hill: New York.
- Bayo-Moriones, J.A. and F. Lera-Lopez (2007), "A Firm Level Analysis of Determinants of ICT Adoption in Spain", *Technovation*, 27, 352-366.
- Bayoumi, T. Laxton, J. and P. Pesenti (2004), "Benefits and Spillovers of Greater Competition in Europe: A Macroeconomic Assessment", *NBER Working Paper n. 10416*.
- Bresnahan, T.F. Brynjolfsson, E. and L.M. Hitt (2002), "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence", *Quarterly Journal of Economics*, 117, 339-376.
- Bresnahan, T.F. and M. Trajtenberg (1995), "General purpose technologies: Engines of growth", *Journal of Econometrics*, 65, 83-108.
- Brynjolfsson, E. and L. Hitt (2003), "Computing Productivity: Firm-level Evidence," *Review of Economics and Statistics*, 84, 793-808.
- Caselli F. and W.J. Coleman II (2001), "Cross-Country Technology Diffusion: The Case of Computers," *American Economic Review*, 91, 328-335.
- Caroli, E. and J. van Reenen (2001), "Skill-biased organisational change? Evidence from a panel of British and French establishments", *Quarterly Journal of Economics*, 116, 1449-1492.
- Chinn, M. D. and R. Fairlie (2004), "The Determinants of the Global Digital Divide: A Cross-Country Analysis of Computer and Internet Penetration," *NBER Working Papers n. 10686*.
- Chow, G.C. (1967), "Technological Change and the Demand for Computers", *American Economic Review*, 57, 1117-1130
- Conway, P., Janod, V. and G. Nicoletti (2005), "Product Market Regulation in OECD Countries, 1998 to 2003", *OECD Economics Department Working Paper n. 419*.
- Conway, P. and G. Nicoletti (2006), "Product market regulation in non-manufacturing sectors in OECD countries: measurement and highlights", *OECD Economics Department Working Paper n. 530*.
- Dasgupta, S. Lall, S. and D. Wheeler (2001), "Policy reform, economic growth, and the digital divide - an econometric analysis," *Policy Research Working Paper Series n. 2567*.
- Daveri, F. (2000), "Is growth in Europe an ICT story too?", *IGIER Working Paper n. 168*.
- European Commission (2003), *The EU Economy 2003 Review*.
- European Commission (2007), *The EU Economy 2007 Review*.
- Gretton, P. Gali, J. and D. Parham (2004), "The Effects of ICTs and Complementary Innovations on Australian Productivity Growth." in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.
- Guerrieri, P Maggi, B. Meliciani, V. and P.C. Padoan (2005), "Technology diffusion, services and endogenous growth in Europe. Is the Lisbon strategy useful?", *Rivista di Politica Economica*, 95, 271-317
- Guerrieri and Padoan (2007) (eds), "Modelling ICT as a General Purpose Technology" *Collegium*, 35, 147-171.

- Gust, C. and J. Marquez (2002), "International comparisons of productivity growth: the role of information technology and regulatory practices," *International Finance Discussion Papers n. 727*, Board of Governors of the Federal Reserve System (U.S.).
- Haller, S. and I. Traistaru-Siedschlag (2007), "The Adoption of ICT: Firm-Level Evidence from Irish Manufacturing Industries", *Economic and Social Research Institute (ESRI) Working Paper n. 204*.
- Hargittai, E. (1999), "Explaining Differences in Internet Connectivity Among OECD Countries," *Telecommunications Policy*, 23, 701-718.
- Hausman, J.A. (1978), "Specification Tests in Econometrics", *Econometrica*, 46, 1251-1272
- Hempell, T. van der Wiel, H. and G. van Leeuwen (2004), "ICT, Innovation and Business Performance in Services: Evidence for Germany and the Netherlands", in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.
- Hollenstein, H. (2004), "Determinants of the Adoption of Information and Communication Technologies", *Structural Change and Economic Dynamics*, 15, 315-342.
- Kiiski, C. and M. Pohjola (2002), "Cross country diffusion of the Internet", *Information Economics and Policy*, 14, 297-310.
- International Monetary Fund (2002), *World Economic Outlook*: Washington.
- Lipsey, R.G. Carlaw, K.I. and C. Bekar (2006), *Economic Transformation*. Oxford University Press
- Luciani, M. and P.C. Padoan (2007), "Endogenizing ICT: Quantitative Results", in Guerrieri and Padoan (ed.), "Modelling ICT as a General Purpose Technology" *Collegium*, Vol. 35, p. 147-171.
- Maliranta, M. and P. Rouvinen (2004), "Ict and Business Productivity: Finnish Micro-Level Evidence", in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.
- Milana, C. and A. Zeli (2004), "Productivity Slowdown and the Role of ICT in Italy: A Firm-Level Analysis", in OECD (ed.), *The Economic Impact of ICT, Measurement, Evidence, and Implications*: Paris.
- Milgrom, P. and J. Roberts (1990), "The Economics of Modern Manufacturing Technology, Strategy and Organization", *American Economic Review*, 80, 511-528.
- Pohjola, M. (2003), "The adoption and diffusion of ICT across countries: Patterns and determinants", in D.C. Jones (ed.), *New Economy Handbook*. Elsevier-Academic Press: San Diego.
- Schiantarelli, F. (2005), "Product Market Regulation and Macroeconomic Performance: A Review of Cross-Country Evidence," *Boston College Working Papers in Economics* 623.
- Schreyer, P. (2000), "The contribution of information and communication technology to output growth: a study of the G7 countries", *OECD Science, Technology and Industry Working Papers n. 2000/2*.
- Trinh, L. Gibson, J. and L. Oxley (2005), "Measures of Human Capital: A Review of the Literature", *New Zealand Treasury Working Paper 05/10*.

- Triplet, J.E. (1999), "The Solow computer paradox: what do computers do to productivity?", *Canadian Journal of Economics*, 32, 309-334.
- van Ark, B. Inklaar, R. and R.H. McGuckin (2003), "Changing Gear Productivity, ICT and Service Industries: Europe and the United States", in Christensen, J.F. and P. Maskell (ed.), *The industrial dynamics of the new digital economy*. Edward Elgar: Cheltenham.
- White, H. (1980), "A Heteroscedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity," *Econometrica*, 48, 817-838.

### ***Appendix 1: Data Definitions and Sources***

- ICT* = Nominal gross fixed capital formation of *Computing equipment* + *Communications equipment* + *Software* divided by Gross value added at current basic prices. Source: EUKLEMS Database
- services* = Ratio of the Gross value added at current basic prices Post and Telecommunications, Finance, Insurance, Real Estate, and Business Services Gross value added at current basic prices in all industries (01-99). Source: EUKLEMS Database
- GERD* = Gross Domestic Expenditure on R&D (national currency) over Gross Domestic Product at Market Prices (national currency). Sources: MSTI database, OECD.
- researchers* = Ratio of Total Researchers (Full Time Equivalent) to total Employment. Sources: MSTI Database, OECD.
- shr* = Spending on Human Resources Total public expenditure on education as a percentage of GDP. Source: Eurostat.
- education* = Total population having completed at least upper secondary education, Population aged 25 to 64 (%). Source: Eurostat.
- absu* = Index of Administrative Burdens on Start-ups. Sources: Conway *et al.* (2005).
- regulation* = Index of Regulatory Conditions in Seven Non-Manufacturing Sectors: airlines, telecoms, electricity, gas, post, rail, and road freight. Source: Conway & Nicoletti (2006).
- epl* = Overall Employment Protection Legislation. Source: OECD Employment Outlook 2004.

### ***Appendix 2: The SETI Model (Guerrieri et al., 2005)***

SETI is a continuous time model of endogenous growth, business services and technology diffusion. In the original version, the model consists of four differential disequilibrium equations in: *i*) output (*Y*), *ii*) domestic (*Sh*) and *iii*) imported (*Sm*) business services, and *iv*) technology (*T*). The dependent variable of each equation is the growth rate of the endogenous variable, with the growth rate that is a linear function of the difference between the actual value *x* and the partial equilibrium level  $x^*$ .

Output is a function of labour ( $L$ ) and capital ( $K$ ) accumulation, as a well as of accumulation of technology and services.<sup>29</sup> Services, both domestic and imported, grow with output, with technology, with the expenditure in information technology ( $ICT$ ), and with the structure of the economy ( $STR$ ); in addition, services decrease with higher levels of regulation ( $REG$ ). Finally, technology grows with output, services and human capital ( $hc$ ).<sup>30</sup>

The augmented version of SETI model that we use for simulation consists of the four equations that we just described plus our continuous time specification of the  $ICT$  equation where the share of information technology is positively related to business services and human capital, and it depends negatively on regulation. By simplifying, for each country the model can be described by means of the following five equations:

$$\begin{aligned}
 1 - \partial Y &= \delta^Y(Y^* - Y) & Y^* &= \alpha_0 + \alpha_1 T + \alpha_2 Sh + \alpha_3 Sm + \alpha_4 K + \alpha_5 L \\
 2 - \partial Sh &= \delta^{Sh}(Sh^* - Sh) & Sh^* &= \beta_0 + \beta_1 Y + \beta_2 T + \beta_3 STR + \beta_4 ICT + \beta_5 REG \\
 3 - \partial Sm &= \delta^{Sm}(Sm^* - Sm) & Sm^* &= \gamma_0 + \gamma_1 Y + \gamma_2 T + \gamma_3 STR + \gamma_4 ICT + \gamma_5 REG \\
 4 - \partial T &= \delta^T(T^* - T) & T^* &= f(hc, Sh, Sm, Y, dist) \\
 5 - \partial ICT &= \delta^{ICT}(ICT^* - ICT) & ICT^* &= \theta_0 + \theta_1 Sh + \theta_2 REG + \theta_3 hc
 \end{aligned}$$

where all variables are natural logs,  $dist$  is a variable that measure the distance between two countries, and  $f(\dots)$  is a non linear function characterizing the process of technology accumulation.<sup>31</sup>

With this augmented SETI there are two possible ways to run policy simulation. The first is by comparison of different steady states. In this model steady states are characterized by a set values for all parameters, and by a set of initial conditions and of growth rates that describe the evolution of the exogenous variables. This way entails computing the steady state of the model, changing some parameter that characterize this steady state, and finally looking at the transition dynamics to the new steady state level. However, it is not guaranteed that we are on the steady state.

Indeed, in running policy simulations we are interested in evaluating what happened if some policy is implemented today, *i.e.* where we actually are not at the steady state. This brings us to the second option that in the end we have followed.

We have run simulations starting from the last available value for all the variables in the model. Given this (historical) starting values, and the parameter estimates, we have run a baseline scenario. Then we have constructed several different possible scenarios and we have compared each of these scenarios with the baseline. This methodology provides simulation that are more reliable in the short/medium-run (15-25 years), than in the long run, because long run dynamics depends by the adjustment process towards the steady state. On the contrary, analyzing the transition from one steady state to another provides good long run simulations but with possibly poor results for the medium/short run.

<sup>29</sup> In this framework services are treated as a production factor in the same way as intermediate goods.

<sup>30</sup> Moreover, in order to take into account the process of diffusion of knowledge, technology accumulation also grows with foreign technology; hence, in each country the process of accumulation depends both on domestic factors and on the diffusion of technology between countries.

<sup>31</sup> For detailed information on the model, and in particular for the technology accumulation process summarized by  $f(\dots)$ , we refer the reader to Guerrieri *et al.* (2005).