Modelling ICT as a General Purpose Technology

Evaluation Models and Tools for Assessment of Innovation and Sustainable Development at the EU Level

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SPECIAL EDITION

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PREFACE

This Special Edition of Collegium originates from a study entitled *Evaluation Models and Tools for Assessment of Innovation and Sustainable Development at the EU level* that resulted from a service contract drawn between the European Commission and the College of Europe's Development Office. The Final Report Paper (with Executive Summary) as well as the intermediary reports and appendices of the study can be found on: www.coleurope.eu/research/modellingICT

The study was conducted between December 2005 and October 2006, under the direction of Peter Johnston, (Head of Unit, DG INFSO C3, European Commission), by a project team including Paolo Guerrieri (Coordinator), Sara Bentivegna, Anna Rita Cardoni, Giuseppe Espa, Cecilia Jona, Giovanna Jona, Matteo Luciani, Bernardo Maggi, Valentina Meliciani and Pier Carlo Padoan.

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This publication presents all findings of the study including all their technical details and provides an in-depth overview of the methodology, the policy simulations, the underlying theoretical framework, and all literature references.

All opinions expressed are those of the authors and do not necessarily reflect the view of the European Commission, of the Steering Committee, or any of the experts consulted during the project.

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CHAPTER I

MODELLING ICT AS A GENERAL PURPOSE TECHNOLOGY: OVERVIEW AND SUMMARY

1 Introduction

The Lisbon Agenda, a comprehensive and interdependent set of reforms with the aim of making the EU the most dynamic and competitive knowledge-based economy, has been reassessed to put more emphasis on the country policy dimension in addition to the EU level dimension. Priority area in the Lisbon Agenda include promoting the use of Information and Communication Technologies (ICTs). Additional policy areas that are complementary to the previous one include completing the internal market for services, and creating a more supportive environment for business. Moving towards more operational specifications of policy actions, however, requires the capability to assess the potential impact of such actions on economic growth, job creation, and social inclusion in quantitative terms. This, in turn, must be based on models and methods to analyse and test the impact of innovation and ICT investment on growth, employment and social integration.

After a decade long record of empirical analysis of the relations between innovation, ICT, growth, and employment, a comprehensive evaluation of available models and methods is still lacking. In particular an assessment of how models can lead to improvements in policy design and analysis, both at national and EU levels, is required. Such an assessment is necessary to make progress in the implementation of the Lisbon Agenda and in promoting the role of ICT in fostering sustainable growth. Most of the existing models linking ICT to economic growth and employment, both at the macro and the micro level, do not provide a fully satisfactory analysis of the transmission mechanism of ICT to economic performance and do not take fully into account the response of different national systems of production and organisation, including the role of business services, to the development and diffusion of the new technologies.

A different response to a given effort can reflect different economic structures and sectoral compositions of production. Hence, taking structural and systemic aspects into account is crucial in assessing innovation and ICT impact. More progress is also needed in the analysis and empirical investigation of the determinants of ICT spending, which is largely if not completely determined by the private sector; a key element in the design and implementation of policies aiming at promoting ICT.

Finally, data limitations and the lack of appropriate sets of indicators have been a severe constraint in modelling the impact of ICT related policies. In most cases, improvements in modelling and policy assessments are possible only to the extent that data availability will allow.

The aim of the present study is to review the existing models focussing on the relationship between ICT investment, technological innovation and diffusion, and European performance in terms of growth, employment and social inclusion. To assess the usefulness for impact analyses we focus on both the economic content (richness and detail of relationships and feedback mechanisms included in the models) and the methodological aspects. In particular the main objectives of the study are:

- To identify models and tools that satisfy the requirements for evidence based impact assessment and evaluation of policies and programmes;
- To assess their capabilities for quantitative evaluation of the impact of research and investment in terms of growth, competitiveness, jobs and social inclusion;
- To identify which further developments and improvements of these models and tools are needed in terms of modelling and tooling capabilities and in terms of better satisfying innovation policy aims and design;
- To identify the needs for data and for appropriate systems of indicators and to suggest improvements where necessary.

2 ICTs are General Purpose Technologies

General Purpose Technologies are radical new ideas or techniques that have the potential to have an important impact on many industries in an economy. Their key characteristics are: pervasiveness (used as inputs by many downstream industries); technological dynamism (inherent potential for technical improvements) and; innovation 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). Thus, as general purpose technologies improve, they spread throughout the economy, bringing about overall productivity gains.

ICTs can be seen as *a General Purpose Technology*; since computers and related equipment are used in most sectors of the economy. ICTs have also displayed a substantial level of technological dynamism spurring not only radical improvement in computational capacity (following Moore's Law), but also a successive wave of new technologies (ranging from the semiconductor to the Internet). Moreover, ICTs have seriously facilitated new ways of organising firms, including the decentralisation of decision making, team production etc. Thereby ICTs have clearly exhibited innovation complementarities with other forms of technological progress.

The complex and rich causation mechanisms highlighted in this framework, however, cannot easily be translated into quantitative models. The impact of ICT cannot be modelled by simply considering it an additional factor of production. The literature usually distinguishes three ways in which ICT has impact on the economy:

1 ICT production. One way to grasp the economic importance of information and communication technologies is to consider the role of ICT producers on the economy's total value added or GDP. Such an approach focuses on the production process of ICT goods.
2 ICT as capital input. ICT industries provide only limited information about the contribution of ICT in production. Hence, this approach focuses on the importance of computers and information technology as an input in other industries.
3 ICT as a special capital input. In addition to their direct (and remunerated) contribution to output growth, ICTs generate spillovers or free benefits that exceed the direct returns to ICT capital. Such positive externalities are always characterised by a discrepancy between a private investor's rate of return and the rate of return for society as a whole.

A fully satisfactory way of modelling an ICT-driven growth requires a totally new modelling approach, a demanding long-term research project that deserves to be undertaken. However, some intermediate steps can be taken, if progress is to be made in the area of quantitative results and policy simulations. In addition, as long as these limitations persist, it is a useful strategy to complement the analysis carried out with existing large Computable General Equilibrium (CGE) models with other models that are flexible enough to provide additional information on the impact of ICT. The comparisons and simulation exercises carried out by the two categories of models are able to take into account some relevant elements of the impact of innovation in general, and ICT in particular, which are considered in GPT literature.

In chapter 2, starting from the idea that ICT is a GPT, we show how, in the context of an aggregate production function, the indirect effects of ICT on GDP are larger than the direct effect (the effect of ICT on GDP as a simple input). Moreover we show how regulation, the composition of the manufacturing sector and the interaction between ICT and producer services help explain the indirect (spillover) effects of ICT on GDP. These features are part of what can be classified under the terms of "facilitating structure" and "policy structure" in the GPT literature.

Chapter 3 contains a comprehensive review of data and indicators for the information society, as well as for benchmarking e-inclusion.

In chapter 4 through a comparative evaluation of eight CGE models, we present a preliminary assessment of the impact of policy actions to support ICT adoption. Simulation results with one of these models (InterFutures) are presented in chapter 5.

In chapter 6 we take into account the endogeneity of ICT and the elements that make it more profitable for countries to invest in the development and diffusion of these technologies. We carry out a number of alternative estimations of an ICT equation, one of which will be used to endogenize ICT in the structural model discussed in chapter 7, where a number of policy simulations are carried out. The rest of this chapter offers a more detailed description of the contents of this publication, as well as a number of policy implications and recommendations.

3 Information Society Technology: Data and Indicators

In chapter 3 we assess the system of ICT data and indicators by evaluating their ability to provide information on the relationship identified in the analytical models. We also provide answers to the main policy questions, and suggest improvements. We assess the extent to which data issues and appropriate systems of indicators put limitations to modelling ICT and economic performance and indicate directions for improvement.

In order to assess data quality, as a first step, a careful study of the technical notes related to each data source has been carried out. Combining this information with the data screening results and a deep coherence analysis leads to the following considerations:

1. The best structured data source is EUROSTAT. It is the best source for Human Capital information and the only one available for policy indicators. However time series are currently too short and therefore it is preferable to refer to this source only once the extension of timed series is increased, except for Human Resources in Science and Technology (HRST) measures. In this case, ICT data is derived from another source European Information Technology Observatory (EITO).
2. Groningen Growth and Development Centre (GGDC) is currently the best source for ICT variables and indicators since data come from official national statistical agencies with the highest available guaranty for quality and country coverage. However information on data quality is not entirely clear. Missing data are estimated but it is not indicated which values are actually missing. This leads to the drawbacks mentioned above.
3. OECD data are affected by many missing values and reveal several inconsistencies between databases that emerge only when deep analysis is carried out. These data can be safely used when they are extracted from the same Data Base (no inconsistent behaviour has been detected when working with a single Data Base).

Once data consistency is assessed, a Core Dataset is identified. It includes basic variables for growth empirics, ICT measures and R&D expenditures. Time series of selected variables have the minimum length of 10 years. The Core Dataset has been obtained as a combination of two data sources (GGDC and STAN OECD) with some overlap. In this case, our suggestion is to use preferably OECD data sources, because they are gathered directly from National Accounts without further elaboration. However, from a sectoral point of view, GGDC data provide a better coverage than OECD data. ICT variables are available only from GGDC, according to our selection criteria. For cross-country non-dynamic analysis, we recommend to refer to EUROSTAT.

As a general remark, it can be said that information on ICT is still sparse and of low quality in statistical terms. A great deal of work is still necessary to obtain a reliable dataset. At present, a large effort has been undertaken to create a database on measures of economic growth, productivity, employment creation and technological change at the industry level for all European countries, by the EUKLEMS project. Once it is completed the latter will be a considerable improvement in terms of data quality and availability, as it will provide an important input to policy evaluation, in particular for the assessment of ICT impact on economic growth.

As to the issue of e-Inclusion, it has gained new relevance and centrality within the scope of the strategic plan, i2010 – A European Information Society for growth and employment (CEC, 2005). This has followed the identification as a priority of the achievement of an Inclusive European Information Society promoting growth and jobs in a way consistent with sustainable development, and prioritising better public services and quality of life.
Attention has been drawn to the social impact of ICTs and the need to guarantee the benefits from their use by an ever-increasing number of citizens. Reference to various dimensions of access (both material and skill access), alongside the implementation of public services, indicates a distinctly richer and more structured interpretation of the themes of e-Inclusion than in the past. Meanwhile, the concept of e-Inclusion acquires new facets reflecting the complexity of the dimensions concerned and confirming its multiform nature.

In order to reach an interpretation of the concept of e-Inclusion articulated in these terms, a multi-focus approach is suggested:

- multi-perspective (referring both to individuals and to communities, to the overall population as well as target groups),
- multi-methodological (utilising both quantitative and qualitative tools)
- multi-dimensional (arising from the fragmentation of the concept into the dimensions of access, quality of life, participation and empowerment, and the separation of the indicators into the categories of 'background' and 'advanced').

The following dimensions may thus be considered:

- access
- quality of life
- empowerment.

The most serious problem associated with the different dimensions of the concept of e-Inclusion, is the uneven availability of data. In terms of the "acces" dimension, for example, there is a good quantity of data useful to understand trends; the same is true for the "quality of life" dimension. However, the dimension of "empowerment", which has only recently attracted attention of researchers and policy makers, is distinctly lacking. This asymmetry in terms of data availability inevitably limits the coverage of indicators to the dimensions of access and quality of life, while reference to the dimension of empowerment remains at a purely theoretical level.

4 Technology, ICT and Performance: A Comparative Assessment of Computable General Equilibrium Models (CGE)

Chapter 4 considers a number of Computable General Equilibrium Models (CGE) to identify their ability to model and simulate the impact on economic performance of technology in general and ICT in particular. The purpose of the review is twofold. On the one hand, the evaluation is instrumental to choose the CGE model to be used for simulation exercises of the impact of ICT on economic performance that is carried out in chapter 5. On the other hand we suggest possible ways of introducing ICT in CGE models, taking into account the complexity of the transmission mechanisms present in the models. The models we have considered are the following:

1. NEMESIS, developed by the Research Group System's Analysis and MacroEconomics Modelling (ERASME) of the École Centrale Paris, the Belgium Federal Planning bureau, the Chambre de Commerce et d'Industrie de Paris, and the Institute of Computers and Communication Systems;
2. MULTIMOD, developed by the IMF;
3. WORLDSCAN, developed by the CPB (Netherlands Bureau for Economic Policy Analysis);
4. QUEST, developed by the European Commission;
5. NiGEM, developed by the National Institute of Economic and Social Research (NIESR).
6. International Futures (IFs), developed by Prof. Barry B. Hughes of the Graduate School of International Studies, University of Denver;
7. Oxford World Macroeconomic Model and the BAK Oxford New IIS (NIIS) Model of the Oxford Economic Forecasting;
8. GEM E-3 Model, developed by the National Technical University of Athens.

The list of these selected models cannot be considered exhaustive, but representative for the range of available CGE models. They have been selected because of their wide application and/or because of the endogenous treatment of innovation.

The criteria we use to compare and evaluate these models include: the richness of transmission mechanisms, methodological aspects, the number of relevant endogenous variables, the level of sectoral disaggregation and the endogeneity of technical change. More specifically we look at three aspects:

i performance variables;

ii structural specification and detail;

iii methodological approach.

With respect to the performance variable, the models are very similar. GDP is obviously a performance variable in all models (either computed in levels or in growth rates) while none of the models explains Total Factor Productivity.

On the contrary with respect to structural specifications and details, the models exhibit different characteristics. This is relevant for the purpose of the topic of this publication. As the literature points out, ICT has different impacts on economic sectors and a sectoral dimension is an important condition for a model to properly evaluate the impact of ICT. Models which include a structural dimension are WorldScan, NEMESIS, IFs and GEM E-3.

As far as the methodological approach is concerned, the models can be classified between calibrated and estimated models. Both are capable of analysing the impact of ICT investment on the economy.

With the exception of IF, none of the models considered include ICT as a variable, not even as an exogenous variable. Therefore, in order to obtain some information about the treatment of technology in the models, we examine the way in which technological change is modelled and, whenever possible, whether simulation exercises carried out with these models can shed some light on the process of innovation diffusion. We focus on the following criteria:

i Richness of transmission mechanisms;

ii Complexity of the factors affecting technology;

iii Degree of sectoral disaggregation;

iv Presence of domestic and foreign spillovers;

v Presence of diffusion effects

The models that offer the best mix between the different factors are the IF and the Oxford model. The former because of the results it provides at sectoral levels, linked with ICT, (which is not considered in other models); and the latter for the highly detailed sectoralisation, together with an appropriate (ECM) statistical tool.

5 ICT as a General Purpose Technology (GPT): Modelling its Impact on Performance using IFs

In chapter 5 we carry out a series of simulation exercises on the impact of ICT on economic performance, using the International Futures (IFs), model. We have chosen the IFs model to perform simulation exercises, since it includes a specific ICT sector and it allows ICT to exert its impact on the economy via different channels, rather than being modelled as a simple input in a standard production function.

The simulation exercises are examples of a larger set of possible exercises to be conducted with IFs and possibly other CGE models. Presenting the results, we concentrate on the impact in terms of *GDP*, but the exercise can be repeated for *employment* and other endogenous performance variables. The purpose of the simulations is to show that through the IFs model, it is possible to study the effects of ICT in a more complex way than by considering its impact on GDP as an input of the production function.

We consider the following scenarios:

Scenario A - This scenario explores the effect of a more productive capital factor in the ICT sector. We investigate, whether a more productive ICT sector in the model leads to widespread effects into the economic system.

Scenario B - This scenario considers a change in the time lag needed for the convergence of the services sector multifactor productivity (MFP) to the one of the ICT sector. The scenario evaluates the impact of a more rapid rate of adoption and diffusion of ICT in the service sector, which is typically a large user of ICT.

Scenario C - We simulate different regimes of adoption of ICT technologies in the economic system. We use the percentage of networked persons in the economic system as a proxy for ICT adoption rate.

Scenario D - This scenario explores the effects of a change in the elasticity of multifactor productivity of the ICT sector to the stock of network infrastructure in the economic system.

Scenario E - In this simulation, similarly to scenario D, we change the value of the elasticity of MFP of the ICT sector, to infrastructure in communication technology.

Scenario F - In this scenario we assume different regimes for the MFP of the ICT sector of the technological leader (USA) to evaluate the process of international diffusion of technological change.

The most significant results are the following:

i A more productive capital factor in the ICT sector, increases GDP, but only in the very long run;

ii A more rapid rate of adoption and diffusion of ICT in the service sector, leads to a different but rising trend-cycle profile of the MFP growth rate;

iii An increase in the percentage of networked persons in the economic system, a proxy for ICT adoption rate, leads to a positive impact on MFP and hence on GDP;

iv An increase in the elasticity of multifactor productivity of the ICT sector to the stock of network infrastructure in the economic system, leads to higher aggregate investments that, in turn, affect GDP;

v A higher elasticity of ICT MFP to communication infrastructure leads to higher GDP, only if the change is "big enough";

vi Finally, the increase in the MFP of the ICT sector for the system leader (The United States) has a positive effect on GDP of other countries through international diffusion.

From a quantitative point of view, our simulations produce results with relatively small effects for the relevant macroeconomic variables. This should not be interpreted as indicating a limited effect of the transmission channels of the ICT sector in the economic system, but rather as an indication that appropriate modelling as a GPT, requires a much more thorough analysis of what is inherently a highly pervasive phenomenon, which can hardly be embedded in the framework of a "super" model composed of seven blocks (socio-political, demographic, economic, technological, environmental, agricultural, energy) such as IFs.

With these limitations in mind, the IFs model can nevertheless offer some first useful insights on the transmission mechanisms of several ICT related policies. The simulation exercises allow to study the impact of policies aimed at facilitating ICT adoption (increasing the percentage of networked persons), or affecting the responsiveness of ICT productivity to the general environment (network infrastructure, infrastructure in communication technology). Moreover, they allow to study the interaction between ICT and services. These are elements of the "facilitating structure" that are emphasised in the GPT literature. Finally, the model can also offer some insights on the diffusion of the impact of ICT on performance across countries.

6 The Determinants of Adoption and Diffusion of Information and Communication Technologies

In the standard literature on CGE models ICT is usually considered as an exogenous variable. The qualitative literature on the determinants and effects of ICT has emphasised the crucial role played by the *"business environment"* in facilitating or hampering the adoption and diffusion of the new technologies. A report by Indepen (2005) underlined that simply increasing total investment in ICT will, in itself, not deliver improvements in productivity and economic growth. To be productive, this investment also requires complementary changes in the way organisations are structured and function, as well as in human capital. Hence investment in ICT by the private sector will be undertaken only to the extent that an appropriate environment is available to reap the benefits of ICT. Among the factors affecting such environment one can recall:

- obstacles in making investments in organisational change;
- employment protection;
- educational and skill levels;
- product market regulation;
- the degree of service market integration.

While several qualitative studies have stressed the importance of these factors, to our knowledge no attempt has been undertaken to model their impact on ICT investment and on ICT profitability. It is therefore important, when modelling the impact of ICT on economic performance, to take into account the interaction with organisational and structural variables.

In chapter 6 we present estimates of ICT equations taking into account the factors that promote (or prevent) the investments in information and communication technologies at a macro level. Our results are in line with the literature on the *digital divide*, which highlights the striking difference in the adoption of information technologies between developed and developing countries. In addition we highlight the role of facilitating factors as relevant determinants for the spread of general purpose technologies, such as ICT. Human capital and investments in R&D increase ICT investments, while burdensome regulation tends to lower them. The structure of the economy also turns out to be relevant in explaining the rate of investment in ICT; countries with a higher share of the service sector notably, are associated with higher ICT investment. A number of facilitating factors, including the degree of labour market flexibility and the absence of obstacles to start up firms, turn out to be important determinants of ICT, to the extent that they improve the business environment.

Of particular interest are the results on *human capital*. Our analysis has been carried out by using four different measures of human capital:

i total number of researchers over population;

ii science and technology graduates over population aged 20-29;

iii percentage of population aged 25-64 with at least an upper secondary degree; and

iv spending in human resources.

All of them perform well, except for *the science and technology graduates* variable. We are aware that this result is not in line with what was expected. Given that increasing the number of graduates in mathematics, science, technology and engineering is one of the EU objectives, this result requires a further analysis. On the other hand, in line with the EU objective of reaching a rate of 80% (of *the population aged 25-64*) *with at least a completed upper secondary degree*, this variable performed well: a 1% increase in the fraction of population with an upper secondary degree leads to a 0.5% increase in investment in software.

The variable *spending in human resources* is also significant in explaining ICT Given that in the EU most of the education is provided by the public sector, this result further supports the idea that general education matters a lot for ICT investment.
Finally, R&D expenditure is positively correlated with ICT investment. Since we include this variable in order to capture the propensity of a country to innovate we expected that countries that spend more on R&D would be those that invest more in ICT. Not surprisingly R&D expenditure is strongly correlated with the amount of human capital as the availability of researchers (i.e. educated people) is a necessary condition for R&D activities.

In conclusion, the amount of human capital, the expenditure on R&D, the intensity of regulation measured in a number of ways (business start up costs, product market regulation, and labour market protection), and the share of the dynamic services sector on the economy influence either negatively or positively investment in ICT. These results are in line with the idea that ICT is a general-purpose technology.

7 A Structural Model with Endogenous ICT

In chapter 7 we offer a complementary approach to modelling the impact of ICT, based on simulations carried out with a small structural model, SETI which has been modified to consider the endogenous determination of ICT. In SETI output growth is a function of (exogenous) labour and capital accumulation, as a well as of endogenous accumulation of technology and producer services, both domestic and imported. The introduction of producer services in the production function can be interpreted as the result of the decomposition of Total Factor Productivity (TFP) in presence of spillovers generated by the interaction among sectors in the economy.

Producer services can be treated as a production factor in the same way as intermediate goods. As a consequence the model can be seen as a way to endogenise the components of TFP and to take into account the feedback effects of output growth on the TFP components themselves. The relevance of technology in the production of services has been widely considered in literature.

In SETI, the link between services and technology is modelled and tested simultaneously with the relationship between technology and services. Producer services are also expressed as a function of the expenditure in information technology (ICT) and of the structure of the economy, according to how the manufacturing sector is oriented towards the use of services in production. Therefore some components of the facilitating structure are taken into account.

Technology, as captured by patents, grows with output, through services and through diffusion with foreign technology which contributes to human capital. Technology accumulation in each country depends both on domestic factors and on the diffusion of technology between countries. This, in turn, depends on the intensity of technology accumulation in other countries, on the impact of ”distance” between countries, as well as on the ability of importing countries to use the technology. Human capital in the receiving/importing country measures the capacity of absorption of technology by the recipient country, while human capital in the sending/exporting country measures the capacity of the latter to produce technology.

SETI is a multi country model and assigns an important role to the diffusion of technology across countries. In this respect, it assumes that producer services operate as an attractor of technology in that the more developed the service sector in the recipient country is, the larger the demand for technology will be. In this way ICT, as a *General Purpose Technology*, carries a supranational, European dimension.

In its original version SETI treats ICT as an exogenous variable; therefore it was not able to take the full interaction between performance and ICT into account. However, as discussed above, ICT determination can be made endogenous and the original SETI model has been enlarged accordingly through the addition of an equation determining ICT spending. The enlarged version has been used to carry out a number of policy simulations. The following scenario exercises were carried out:

- elimination of the impact of regulation on services;
- deeper EU integration in the market for services;
- halving of diffusion costs as represented by distance;
- increase of 5% in the level of human capital in both receiving and sending countries;
- a combination of first & fourth scenario
- doubling the impact of R&D spending on ICT;
- elimination of the impact of the administrative burdens on start ups;
- a combination of the latter two above

Results confirm that services are a powerful driver of growth and that deeper integration in the European market for producers of services does indeed significantly contribute to growth. In fact, the scenario of 'deeper integration in the market for services' shows the highest relative performance in output and services (both domestic and imported), with respect to other scenarios. Producer services (and therefore growth) are also boosted by a reduction of diffusion costs (scenario d), elimination of the impact of regulation (scenario a), as well as a combination of the two measures.
Technology accumulation is enhanced especially by human capital accumulation. The stock of technology is higher with respect to baseline, when the stock of human capital (both in sending and receiving countries) is increased. The ultimate driver of growth is technology accumulation and the latter is strongly supported by human capital accumulation. However, for such a mechanism to produce significant effects, a rather lengthy transmission mechanism is needed. In addition a larger stock of human capital enhances technology accumulation (and therefore growth) since it allows to exploit the benefits of knowledge diffusion across countries.

Stronger ICT accumulation enhances technology accumulation and therefore growth over a long time horizon. In the medium term, growth is more effectively supported through a stronger diffusion of existing technology and a stronger contribution of services to the process.

The impact of ICT on growth is in turn dependent on the impact of variables affecting ICT on the production of the latter. Policy can impact ICT only indirectly in a number of ways. More human capital is the single most effective measure in boosting ICT, followed by R&D, and the elimination of administrative burdens on start-ups. Higher investment in education, which can be considered a key public policy strategy, boosts human capital accumulation, and therefore ICT, and consequently producer services and growth. Human capital also supports growth through technology accumulation.

8 Conclusions and Recommendations

Modelling ICT as a general purpose technology involves a high degree of complexity. Factors determining ICT investment and diffusion are numerous; regulatory and business environment ("facilitating factors") are of crucial importance, however they are difficult to translate into a quantitative analysis. We have nevertheless offered a number of preliminary steps towards a more appropriate modelling of ICT. First we have emphasised the importance of indirect effects of ICT, which are more relevant than direct effects and also complex to model. Secondly, we have carried out modelling of ICT impact on performance using the IFs. Thirdly we have presented results of the estimation of an ICT equation. Finally we have used a structural model which includes an endogenous determination of ICT to perform policy simulations. Our results confirm that these two classes of models (CGE and small structural models) should be seen as complemenatry tools in evaluating the impact of ICT. In addition, we have considered three databases and identified a core dataset.

8.1 Main Findings

Modelling ICT as a GPT requires a multi step procedure:

- When disentangling TFP several elements must be taken into account. We concentrate on three elements: i) the relationship between GPT (ICT in our case) and specific technology accumulation, ii) the relationship between ICT and the structure of the economy, iii) the relationship between ICT and the "facilitating structure".
- The relationship between ICT and specific technology accumulation. One central feature of a GPT (such as ICT) is that its impact on productivity and hence performance is "indirect" rather than direct. More specifically ICT increases the productivity of direct knowledge accumulation (e.g. investment in R&D), which would otherwise exhibit decreasing returns.
- The relationship between ICT and the structure of the economy is crucial to understand the channels through which such an indirect effect takes place as well as how strong such an impact will be. As the use of ICT takes different intensities according to the sectors in which it is applied, a given increase in ICT investment will generate a different impact according to the presence in the economy of sectors in which ICT can be better combined with other factors and/or in which organisational improvements can be more easily introduced. For example business services are intensive ICT users therefore a widespread presence of such services in the economy enhances the impact of ICT on performance.
- The relationship between ICT and the facilitating structure is crucial in understanding the extent to which the economic system is prepared to receive and use a GPT such as ICT. Precisely because of its nature, ICT introduction requires not only a specific investment in ICT equipment but, even more importantly, a number of facilitating factors that generate the appropriate environment for ICT adoption.
- Elements mentioned above interact in generating a virtuous circle of ICT sustained growth and the impact of positive spillovers. ICT enhances the productivity impact of technology accumulation, which facilitates structural and organizational change towards more ICT intensive activities. This, in turn, facilitates the introduction of ICT.

Policy simulations carried out both with the IF model and with SETI confirm some of the characteristics of ICT as a GPT, namely:

- due of its pervasiveness, ICT investment can be increased only indirectly, i.e. by acting upon the characteristics of the environment in which it develops;

- due to its role as a facilitator of direct technology accumulation as well as a complement to it (e.g. such as R&D expenditure), increases in ICT are only noticable with some (possibly long) lag;
- in order to fully appreciate the impact of ICT (a comprehensive analysis of its policy impact), it should be evaluated in conjunction with other policy measures.

8.2 Policy Recommendations and Implications

The IFs platform, like other CGE models, contains useful features to simulate the effects of key parameter changes on the economic system related to the introduction and diffusion of ICT. The magnitude of the effects on performance is dependent on the highly complex set of inter-connections among the building blocks of Ifs.

From a qualitative point of view, simulations with a CGE lead to reasonable results, namely:

- a more productive capital factor in the ICT sector increases GDP, but only in the very long run;
- a more rapid rate of adoption and diffusion of ICT in the service sector leads to a different but rising trend-cycle profile of the MFP growth rate;
- an increase in the percentage of networked persons in the economic system (a proxy for ICT adoption rate) leads to a positive impact on GDP;
- an increase in the elasticity of multifactor productivity of the ICT sector to the stock of network infrastructure in the economic system leads to higher aggregate investments which, in turn, affect GDP;
- a higher elasticity of ICT MFP to communication infrastructure only leads to higher GDP, if the change is “big enough”;
- finally, the increase in the MFP of the ICT sector for the system leader (the United States) has a positive effect on GDP of other countries through international diffusion

The simulation exercises allow us to study the impact of policies aimed at:

- facilitating ICT adoption (increasing the percentage of networked persons)
- affecting the responsiveness of ICT productivity to the general environment (network infrastructure, infrastructure in communication technology).

These measures do have an impact on ICT and hence on growth. Moreover, they also allow us to study the interaction between ICT and services. These are elements of the “facilitating structure” that are emphasised in the GPT literature. Finally the model can offer some insights also on the diffusion of the impact of ICT on performance across countries.

These results are strengthened by the simulation results carried out with a small structural model which includes ICT as an endogenous variable.

Results with the SETI structural model confirm that

- services are a powerful driver of growth and that deeper integration in the European market for producers of services does indeed significantly contribute to growth
- technology accumulation is enhanced especially by human capital accumulation, but also because a larger stock of human capital enhances technology accumulation and hence growth, since it allows to exploit the benefits of knowledge diffusion across countries

ICT investment can be boosted by a number of policy strategies such as:

- more investment in human capital
- lower start up costs for business and lower barriers to labour mobility
- more investment in R&D

Stronger ICT accumulation enhances technology accumulation, and hence growth, over a long time horizon. In the medium term, growth is more effectively supported through a stronger diffusion of existing technology and a stronger contribution of services to the process.

ICT spending increases growth indirectly by boosting services. This is in turn dependent on the impact of variables affecting ICT on the production of the latter. Higher investment in education, which can be considered a key public policy strategy, boosts human capital accumulation, and hence ICT, and hence producer services and growth.

In summary, our results show that EU output growth can be significantly increased if the availability of business services and the accumulation of knowledge and ICT diffusion are enhanced. These results can be obtained both through an improved regulatory environment, through deeper integration in service markets, and a stronger impact of technology diffusion.

CHAPTER II

ICT AS A GENERAL PURPOSE TECHNOLOGY

1 Introduction

In this chapter we review the literature on the pervasive effects of Information and Communication Technologies (ICT) on the economy and we report some evidence consistent with the view that ICTs are General Purpose Technologies (GPTs).

The importance of the institutional framework, organisational issues, public policies, etc., in facilitating or hampering the development, adoption and diffusion of ICT has thoroughly been discussed within the framework of techno-economic paradigms and General Purpose Technologies (GPT). The complex and rich causation mechanisms highlighted in these frameworks cannot be easily translated in quantitative models. However, since the main purpose of this book is to provide quantitative tools for assessing the impact of innovation in general, and ICT in particular, on the economy, the simulation exercises conducted in the following chapters will aim at taking into account some of the elements that are present in known theories.

After having discussed the literature on the pervasive impact of ICT (Section 2), we will first present some ideas on how to implement the concept of ICT as a GPT in estimation and simulation exercises (Section 3). Then we will present some evidence consistent with the view that ICT is a GPT (Section 4). In particular we will show how, in the context of an aggregate production function, the indirect effects of ICT on GDP are larger than the direct effect (the effect of ICT on GDP as a simple input of the production function). Moreover we will show how regulation, the composition of the manufacturing sector and the interaction between ICT and producer services help explaining the indirect (spillover) effects of ICT on GDP.

These elements are part of what can be classified under the terms of "facilitating structure" and "policy structure" in the GPT literature. We will come back to the specific role of these factors in other parts of this volume and in particular in Chapter 7, when carrying out simulations with the SETI model.

2 ICTs are General Purpose Technologies

2.1 Techno-Economic Paradigms

One of the fundamental insights provided by Schumpeter (1939) is that technological innovations are not evenly distributed over countries, industries and time. Extending on this insight, already in the 1980s, neo-Schumpeterian authors, following a historical approach, introduced the concept of a techno-economic paradigm. The concept has been used to refer to a set of guiding principles, which become managerial and engineering common sense for each major

phase of development (Perez, 1983). Perez (1983, 1985, 1988) and Freeman and Perez (1988) explain Schumpeter's long cycles as a succession of techno-economic paradigms.
A change in paradigm involves many clusters of radical and incremental innovations and has pervasive effects throughout the economy, spreading from the initial industries where it starts to the whole economy. Moreover it implies not only major product and process innovation but also organisational and social change. Each paradigm has its own key factors in a particular input or in sets of inputs that satisfy the following conditions:

- i low and rapidly falling relative cost;
- ii Apparently almost unlimited availability of supply;
- iii potential of widespread use in many products and process throughout the economic system.

Such characteristics may be found in different waves of development in coal, steel, oil, and nowadays in microelectronics and telecommunications.

2.1.1 The ICT Paradigm

Innovations in the field of microelectronics have led to a technological revolution that has directly affected some industries (computers, electronic components, telecommunications) and indirectly the whole economic system of the leading industrial countries. Moreover it has involved organisational and social changes to the extent that we can properly talk of a new techno-economic paradigm. Freeman and Soete (1987) analyse the growing impact of ICT by considering its uneven diffusion from a few leading sectors to the economy as a whole. They report that:

- i the sectors with the highest rates of growth in labour and capital productivity are the electronic industries and in particular the computer and the electronic component industries, which can be described as the 'carrier' branches of the new paradigm;
- ii a group of industries that has made widespread use of microelectronics both in product and process technologies experiences a considerable increase in labour productivity and some increases also in capital productivity: this is the case of scientific instruments and telecommunications;
- iii the sectors that have started to use microelectronics in the last fifteen years but where old technologies, still prevail and have experienced uneven increases in productivity across firms and countries, with examples including printing machine-building and clothing industries;
- iv within sectors producing homogeneous goods in large plants, there has been a tendency towards low increase in labour productivity and decline in capital productivity despite the introduction of information technology in the production process. This effect can

be explained by the thought that they have suffered from the exhaustion of the energy- and material-intensive mass production paradigm (in some cases labour productivity increases within these industries have been achieved through plant closures and rationalisation). This applies to the petrochemical, oil, steel and cement industries;

v there is a group of service sectors based on information technology that are among the fastest growing but they still account for only a small (although rapidly increasing) proportion of total service output and employment (software, databanks, computerised information services, design, etc.);

vi there is another group of service sectors that has also been affected by information technology with uneven increase in labour productivity among firms and countries. Those are the banking, insurance and retail services (this phenomenon is particularly important since it shows that gains in productivity are not necessarily higher within the manufacturing sector);

vii the majority of service sectors have not been able to achieve major gains in labour productivity due to the lack or very limited diffusion of information technologies.

Overall the new paradigm linked to information technologies has unevenly affected the different sectors of the economy; however its impact does appear to have had a pervasive nature. Moreover the development and diffusion of the new technologies has interacted with the organisation of production, the working of national institutions and public policies. The diffusion of ICT in the economic system and its impact on performance cannot be fully understood if these elements are not taken into account.

2.2 General Purpose Technologies

The notion of General Purpose Technologies (GPTs) was first introduced by Bresnahan and Trajtenberg in a conference contribution in 1991 , which was later published as Bresnahan and Trajtenberg (1995). GPTs are radical new ideas or techniques that have the potential for important impacts on many industries in an economy. Bresnahan and Trajtenberg 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). Thus, as GPTs improve they spread throughout the economy, bringing about general productivity gains.

In the book *"General Purpose Technologies and Economic Growth"*, edited by Helpman (1998) the concept of GPT is compared to that of techno-economic paradigms (TEP). It argues that the concept of TEP is much broader than that of GPT since it covers the entire economic system surrounding any set of pervasive technologies actually in use. However, there are important complementarities between the two concepts since a GPT is an innovation that fundamentally alters the relationships among various technologies and between technology and the other elements of TEPs.

2.2.1 ICT as a GPT

The recent ICT "revolution" can be seen to be one such GPT, since today, computers and related equipment are used in most industries of the economy. ICTs have also displayed a substantial level of technological dynamism spurring not only radical improvement in computational capacity (following Moore's Law), but also a successive wave of new technologies (ranging from the semiconductor to the Internet). Moreover, ICTs have seriously facilitated new ways of organising firms, including the decentralisation of decision making, team production etc. (Milgrom and Roberts, 1990; Brynjolfsson and Hitt, 2000; Bresnahan et al., 2002). Thereby ICTs have clearly exhibited innovational complementarities with other forms of advancement[1].

One of the main issues analysed within the GPT literature has to do with the attempt to understand why GPTs are mostly, if not always, slow in fulfilling their potential for increasing productivity. The "Solow-paradox", in the context of ICT, is a recent and famous example of a slow realisation of a GPT's potential. Bresnahan and Trajtenberg (1995) suggest three possible explanations for the observed paradox. One explanation lies in the possibility that GPT industries and user industries face a coordination problem, producing "too little, too late innovation" (p. 94). Moreover, difficulties in forecasting the technological developments of the other side (GPT producers and users) tend to lower technical advance in all industries of the economy.

Finally, Bresnahan and Trajtenberg point to the importance of the match between GPTs and specific institutions that facilitate or hinder GPTs in playing out their roles as engines of growth. If institutions show a disinterest in new technologies, an economy with the "wrong" institutions may prove inadequate for supporting GPTs, including the application industries (p. 104).

2.2.2 ICT and GPT: Going beyond the Production Function

The broad literature on technological change and its impact on economic performance (only to quote major contributions, see Dosi et al. 1988 and, more recently, the Oxford Handbook of Innovation edited by Fagerberg, Mowery and Nelson, 2005) has stressed how innovation is a complex phenomenon that goes beyond an increase in R&D expenditures and whose impact cannot be understood in the framework of a production function. This literature has emphasised the wider systematic setting, which influences innovation, the role of institutions and

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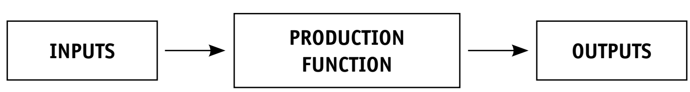
1 It can be noted that the Bresnahan-Trajtenberg model is a partial model, while subsequent contributions (such as Helpman and Trajtenberg, 1998; Jacobs and Nahuis, 2002) have applied explicit general equilibrium frameworks.

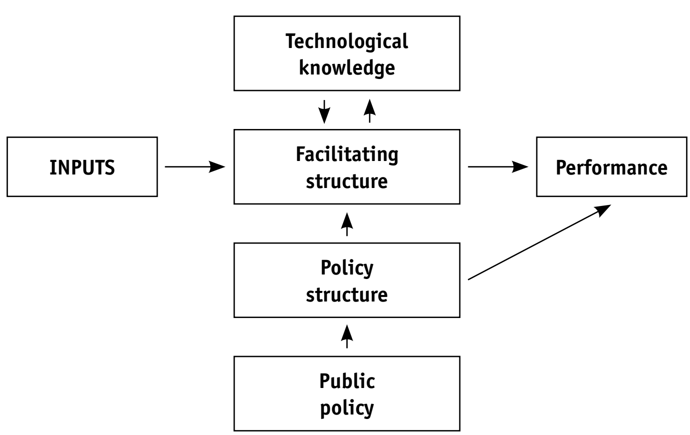
organisations in this context and the diversity in the working of innovation over time and across different sectors of the economy. This view has been shared by Lipsey, Carlaw and Bekar (2005) in the context of GPT, offering a Structuralist-Evolutionary (S-E) representation of the relationship between technology and the economy that goes beyond the production function. This includes the interaction between technological knowledge, the facilitating structure, the policy structure, public policy and performance (see Figure 1). In the S-E approach technology (that includes product, process and organisational technologies and that have elements of both tacit and codifiable knowledge) is embodied in the facilitating structure. This includes physical objects, people and structures such as all physical capital, human capital, infrastructure, private-sector financial institutions, labour practices, consumer durables, research units and educational institutions. Natural endowments are the only exogenous inputs that are fed into the productive system that is embedded in the facilitating structure and are transformed by capital and labour into outputs, thus creating the performance variables. Public policy includes both its objectives as expressed in legislation, rules, regulations, procedures, etc. and the means of achieving them as expressed in the design and command structure of public sector institutions. The policy structure is the set of realizations that provides the means of achieving public policies (public sector institutions, regulatory bodies, etc, including people

Figure 1: ***Alternative representations of the link between technology and performance***

a The neoclassical aggregate production function



b The Structuralist-Evolutionary decomposition



that staff these organizations). Economic performance (not only GDP but also its distribution, total employment, pollution and other environmental effects) is determined by the interaction between inputs and the existing facilitating and policy structure. These in turn are affected by technological knowledge and public policy. Moreover technologies are themselves affected by the facilitating structure. Changes in technology have no effect on performance until the elements of the facilitating structure have been adjusted to fit the new technologies.

The complex interactions outlined by the GPT approach (see Figure 1) can help to explain why some countries have more problems in adopting a GPT as compared to others, since the potential mismatches between technology, the facilitating structure and the policy structure may be weaker or stronger depending from country to country. As a consequence countries' ability to achieve low rates of unemployment, high rates of growth and international competitiveness are likely to be connected to the extent to which they are able to produce and use new technologies.
In fact the literature on the impact of ICT on growth and productivity has shown that there are large differences across countries in the production and use of ICT. Several studies have shown how the USA performs better than Europe regarding the contribution of ICT to sectoral productivity growth (see for instance, Inklaar et al., 2005). Other studies have argued that the problems that Europe faces in terms of low rates of growth, high rates of unemployment and losses in export shares in R&D based industries are partly linked to the unsatisfactory performance of European countries in science-based industries and in particular in ICT (Fagerberg, Guerrieri and Verspagen, 1999).

Finally, also within Europe, there are important differences in the contribution of ICT to economic growth. In particular Daveri (2000) finds that the contribution of new technologies has been substantial in some countries (such as the UK and the Netherlands), increasing over time in other countries (the Nordic European countries), while the new technologies contributed less in large continental countries (such as France and Germany) and very little in Italy and Spain.
The crucial question then becomes to identify the factors that explain different degrees of ICT diffusion and different impact of ICT expenditures on economic performance in different countries.

2.2.3 Formal Theories of GPT

The complexity of the concept of GPT cannot be easily translated from appreciative theorising to formal models. Lipsey, Carlaw and Bekar (2005) is one of the most recent attempts in this direction. They recognise the trade-off between generality and explanatory power: the more general a theoretical formulation, the less it is able to explain events for which specific local conditions matter. Nevertheless they provide some models that aim at capturing some specific features of sustained growth processes in industrial countries, with given specific institutions and where the growth process has already taken place. In this framework they provide models that differ from traditional neoclassical growth models (with exogenous or endogenous technological change) for various aspects that make them more similar to evolutionary theories (e.g. Nelson and Winter, 1982). These are:

i the use of a non-stationary equilibrium concept;

ii the dismissal of a single aggregate production function;

iii the use of simulation rather than careful analytical solutions;

iv the assumption of no perfect foresight

In the baseline model that they propose there are three sectors: a) a single consumption good; b) R&D that produces applied knowledge which is used to develop applications of each GPT for specific purposes; c) fundamental research that produces pure knowledge, which leads to new GPT. These assumptions allow to focus the attention on technological complementarities and modelling knowledge that grows irregularly. To make the baseline model more tractable a flat technology is assumed in each sector described by each sector's single production function. The complex structure of technology is thus found in the relations across sectors. Research generates the knowledge that develops into a GPT once a lucky strike occurs with its potential efficiency depending on the amount of research that went into it and a random disturbance. The potential raises the efficiency of applied R&D through a logistic diffusion process. Finally the output of applied knowledge raises efficiency in the consumption and pure research sector. The model generates the stylised facts of economic growth such as sustained growth at a varying rate, a constant ratio of knowledge stock to output, a falling ratio of labour to output and non-stationarity of growth rates over time.

In order to capture more features of the historical facts and to bring the modelling closer to an S-E-type model of GPT driven growth, the baseline model is enriched along the following dimensions (Lipsey, Carlaw and Bekar, 2005, p. 495-496):

- introducing a logistic diffusion of the productivity enhancing effects of GPTs on applied R&D;
- allowing an existing GPT to be cut off by a new rival GPT causing productivity slowdowns;
- allowing a GPT to arrive very late in the stage of an incumbent's evolution, thus following on from a productivity slowdown;
- imposing additional behavioural structure on the model, which explains why GPTs might have to accumulate a minimum amount of pure knowledge before entering the system;

- modelling historical scale effects, which give a temporary burst to growth but do not show up as permanent increasing returns in an aggregate production function;
- beginning the process of modelling the facilitating structure;
- allowing for externalities that feed back from applied research results to assist pure research;
- disaggregating the model into several production lines within the three broad production sectors in order to model technological complementarities;
- allowing more than one GPT to exist simultaneously.

3 Implementing the Concept of ICT as a GPT in our Estimation and Simulation Exercises

Simulating the impact of ICT on performance along similar lines that have been used to simulate the impact of R&D on performance is not satisfactory considering that ICTs are General Purpose Technologies.

In particular our aim is to shed some light into the black box of the production function and to capture the interactions between ICT, the facilitating structure, public policy and performance. Again, since the purpose of the study is to have quantitative predictions we will not be able to fully capture the complexity of interactions and transmission mechanisms that have been described in the literature.

More specific descriptions of the transmission mechanisms of ICT on performance in the simulation exercises will be given in the following Chapters; here we want to highlight our general assumptions. These are:

1. The impact of ICT on performance depends on its interaction with the "facilitating structure" that affects its development and diffusion;
2. Some crucial elements of the facilitating structure are: human capital, regulation, the sectoral composition of the economy;
3. Some producer sector services, such as knowledge intensive business services, communication services, finance and insurance, are potentially major users of ICT and the interaction between these sectors and the ICT sector can have an important impact on aggregate performance;
4. R&D is a crucial ingredient for the generation of new technologies (ICTs) and the productivity of R&D is itself affected by the diffusion of ICT;
5. ICTs are pervasive technologies. Therefore, in order to study their impact on performance, their diffusion throughout the economy must be taken into account.

Finally a satisfactory attempt to simulate the impact of ICT on the economy must take into account the endogeneity of ICT and the elements that make it more profitable for countries to invest in the development and diffusion of these technologies.

Some of these features will be taken into account in the next Chapters when using formal models to simulate the impact of ICT on performance. In particular, in Chapter 5 we will use the International Futures (IFs) model to perform simulation exercises since it has a specific ICT sector and it allows ICT to exert its impact on the economy via different channels rather than being modelled as a simple input in a standard production function.

Moreover, in order to better take into account the role of the facilitating structure, in Chapter 7 we will use the SETI model. This model has been developed with the purpose of studying the interaction between ICT, technology accumulation and diffusion, business services and economic growth and we think that the explicit modelling in SETI of the link between ICT and producer services can offer new insights on the relationship between ICT and performance that cannot be studied within other multi-equation models reviewed in Chapter 4. The results of the simulations using the SETI model with endogenous ICT expenditures will be presented in Chapter 7.

4 The Impact of ICT on Performance: Direct and Spillover Effects

In this section we will show how the simple treatment of ICT as an input in the production function leads to an underestimation of the impact of ICT on GDP.

To analyse the contribution of information and communication technology (ICT) to economic growth, Paul Schreyer (2000) uses a well-established growth accounting framework and considers three ways in which ICT can influence economic growth:

1 *ICT production* – One way to grasp the economic importance of information and communication technologies is to consider the role of ICT producers on the economy's total value added or GDP. Such an approach focuses on the production process of ICT goods.
2 *ICT as capital input* – Looking at ICT industries provides no information about the contribution of ICT in production. Hence this approach focuses on the importance of computers and information technology as an input in other industries. In this case, computers and information equipment can be seen as a specific type of capital good in which firms invest in together with other types of capital and labour to produce output. This approach treats ICT capital goods as all other types of capital goods.
3 *ICT as a special capital input* – Part of the discussion about the new economy is based on the claim that ICTs produce benefits that go beyond those pertaining to investors and owners. In fact, in addition to their direct (and remunerated) contribution to output

growth, ICTs generate spillovers or free benefits that exceed the direct returns to ICT capital. Such positive externalities are always characterised by a discrepancy between a private investor's rate of return and the rate of return for society as a whole. In other words, ICT equipment generates benefits above and beyond those reflected in its measured income share.

To translate the three aspects of the role of ICT into a well-established growth accounting framework, Schreyer considers a production function relating economy's output growth to labour and capital input and to multi-factor productivity (MFP). The growth contribution of each input is obtained by weighting its rate of change with a coefficient that represents each factor's share in total cost. This can be expressed as:

$$\hat{Q} = s_L \hat{L} + s_{KC} (1 + \theta) \hat{K}_C + s_{KN} \hat{K}_N + \hat{A} \tag{1}$$

where Q is output, L is labour input, K_C is ICT capital, K_N is all other capital and A is disembodied technical change (hatted variables indicate rates of change). In expression (1), spillovers can be picked up by θ, which adds to the growth effects of ICT capital. Other coefficients denote each factor's share in total cost. Under constant returns to scale, total costs equal total revenue and the weights also represent income shares.

The presence of term θ in the production function is justified by the growth accounting framework. This model refers to Solow's considerations that a combined increase of labour and capital inputs doesn't explain, alone, the aggregated output growth. In fact, there is a residual (Solow residual) captured but not explained by the productive factors' rise and that represents the multi-factor productivity increase due to technological progress.

According to Schreyer (2000), in presence of additional effects, the MFP calculation captures both the externality generated by ICT capital and the overall rate of technical change. This can be seen from the following expression that shows the effects of calculating MFP residual in presence of spillovers:

$$MF\widetilde{P} = \hat{Q} - s_L \hat{L} - s_{KC} \hat{K}_C - s_{KN} \hat{K}_N = s_{KC} \, \theta \, \hat{K}_C + \hat{A} \tag{2}$$

As shown in equation (2), rates of changes in MFP are obtained residually by deducting the growth contributions of capital and labour from the rate of output growth. In this equation, if ICT generates positive externalities, these effects should be picked up by a conventionally measured multi-factor productivity residual.

Schreyer doesn't calculate spillover effects separately. His equation shows that the growth accounting framework loses much of its effectiveness in dealing with s_{KC} and even more with θ. We try to overcome this problem by attempting to estimate θ directly. Moreover, we evaluate spillover effects with another method. Namely, we consider factors that can influence, positively or negatively, the impact of ICT. To clarify this aspect, consistently with the notion of ICT as a GPT, we assume that regulation (as part of the determinants of "business environment") can weaken the impact of ICT. We consider the role of other factors that contribute to the adoption and diffusion of ICT such as the weight of manufacturing industries that are large users of producer services as well as producer services themselves, given the large penetration of ICTs in some service industries.

4.1 Technological Progress and ICT

To evaluate the direct effects of ICT on economic growth, we modify equation (1). In our version, expressed in levels, we consider total capital input, we omit the term θ, and introduce a trend variable to consider time effects on output. We have:

$$Q_{tj} = L_{tj}^{sL} \; K_{tj}^{sK} \; C \; e^{a\,t} \; E_{tj} \qquad (3)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

In equation (3), K_{tj} is total capital input, t is time, C is the constant term, E_{tj} are residuals, and s_L, s_K and a are the coefficients (subscript t and j refer to period and countries respectively). If we use lower-case letters to denote the same equation in logarithms, we have:

$$q_{tj} = s_L \, l_{tj} + s_K \, k_{tj} + c + a \, t + \varepsilon_{tj} \qquad (4)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

where ε_{tj} is $\ln(E_{tj})$.

Regression results, obtained with a GLS estimator, are the following:

Table 1: ***Estimates of the Production Function***

	Coefficient	***P* > |*z*|**	**Std. Error**
s_K	0,6	0,00	0,04
s_L	0,5	0,00	0,04
a	0,01	0,00	0,00
C	0,39	0,13	0,25
R^2	**within** **between** **overall**	0,91 0,99 0,99	
Wald χ^2 (3) **Prob > χ^2**		5470,64 0,00	
sigma_u **sigma_e** **rho**		0,11 0,06 0,76	

Table 1 shows a strong link between output and capital and labour inputs. We must note that the sum value of s_{KC} and s_L coefficients is equal to 1.1. The positive and significant a value leads to investigate on other factors -related to technical progress- different from capital and labour to explain GDP. Following this consideration and the positive trend coefficient we try a second regression to analyse separately ICT and non-ICT effects (see table 2):

$$q_{tj} = s_L\, l_{tj} + s_{KC}\, k_{Ctj} + s_{K\,N}\, k_{Ntj} + c + a\, t + \varepsilon_{tj} \qquad (5)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

Table 2: ***The Direct Impact of ICT on GDP***

	Coefficient	$P > \|z\|$	Std. Error
s_{KC}	0,6	0,00	0,02
s_{KN}	0,5	0,00	0,03
s_L	0,5	0,00	0,04
a	0,01	0,00	0,00
C	0,39	0,00	0,27
R^2	within between overall	0,92 0,99 0,99	
Wald χ^2 (4) Prob > χ^2		6079,32 0,00	
sigma_u sigma_e rho		0,11 0,06 0,80	

Results in table 2 confirm that ICT represents an important factor in sustaining growth. Once ICT is introduced in the production function, the trend variable appears to account for other factors affecting output growth and not to technological progress since its coefficient is now negative and statistically significant.

4.2 Spillovers

To evaluate the indirect ICT effects, on the ground of Schreyer's theory and referring to Berger (1993), we introduce the following assumption. We assume that the ICT random effect related to time is null and that the ICT spillover influence is related to the random effect interaction among countries. In this case, the production function becomes:

$$q_{tj} = s_L\, l_{tj} + s_{KC}\, k_{Ctj} + s_{KN}\, k_{Ntj} + c + \mu_{t\,j} \qquad (6)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

the term $\mu_{t\,j}$ includes two effects as described below:

$$\mu_{t\,j} = \varepsilon_{tj} + spillovers_{t\,j} \qquad (7)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

Where $spillovers_{t\,j}$ is represented by $s_{KC}\ \theta_j\ k_{Ctj}$.

Under our assumption, the residuals' average with respect to time is equal to 0, and so we can write:

$$\Sigma_t\ (\mu_{t\,j}/T) = \Sigma_t\ (\varepsilon_{tj}/T) + \Sigma_t\ (spillovers_{t\,j}/T) = 0 + \Sigma_t\ (spillovers_{t\,j}/T) = E_t\ (spillovers_{t\,j}) \quad (8)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

where E_t $(spillovers_{t\,j})$ is the mean value of $spillovers_{t\,j}$ over time.
From E_t $(spillovers_{t\,j})$ we can derive the estimate for θ_j. In fact, we have:

$$\Sigma_t\ (\mu_{t\,j}/T) = E_t\ (spillovers_{t\,j}) = s_{KC}\ \theta_j\ \Sigma_t\ (k_{C\,t\,j}/T) \quad (9)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

and so:

$$\theta_j = (1/s_{KC})\ [1/\Sigma_t\ (k_{C\,t\,j}/T)]\ \Sigma_t\ (\mu_{t\,j}/T) \quad (10)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

Using this last formula and referring to the regressions of table 2, θ_j takes on average the value of 7.97. The contribution of spillovers to economic growth, measured by $s_{KC}\ \theta_j$ is 1.35. Comparing these results with the values of the respective coefficients s_{KC}, we find that the indirect contribution of ICT to output production is greater than the direct contribution of ICT. This supports the notion of ICT as a GPT.

Another way to grasp the spillovers effects is to consider factors that can facilitate or delay their impact. First, we consider regulation. We consider an indicator of regulation in OECD countries (see Nicoletti, Scarpetta e Boylaud, 2000). The relevant equation is:

$$q_{tj} = s_L\ l_{tj} + \beta_{REG}\ REG_{tj} + s_{KC}\ k_{Ctj} + s_{KN}\ k_{Ntj} + c + \varepsilon_{tj} \quad (11)$$

$$t = 1,\ldots,T \qquad j = 1,\ldots,n$$

β_{REG} captures the impact of regulation (*REG*) in terms of spillovers.

Estimation results are the following:

Table 3: ***ICT Spillovers and Regulation***

	Coefficient	$P > \|z\|$	Std. Error
s_{KC}	0,10	0,00	0,01
s_{KN}	0,47	0,00	0,03
s_L	0,48	0,00	0,03
β_{REG}	-0,14	0,00	0,06
C	1,34	0,00	0,24
R^2	within between overall	0,92 0,99 0,99	
Wald χ^2 (4) Prob > χ^2		6662,27 0,00	
sigma_u sigma_e rho		0,09 0,06 0,72	

As expected, results confirm that regulation has a negative impact (see the negative and significant estimation results for β_{REG}).

To investigate further the role of the spillovers, in table 4, we consider two other factors: producer services and the structure of the manufacturing sector in each country, given that manufacturing industries are large users of producer services, and the manufacturing sector itself is a large user of ICT. The consideration of these two variables, therefore takes into account the role of structural connections and interdependencies that are crucial to understand the role of ICT as GPT. For this purpose, we have used an indicator that measures specialisation in manufacturing weighted by the use of services by manufacturing industries (Guerrieri, Meliciani, 2005). Structure orientation to services justifies the consideration of the combined effects of these two factors. The reason for the omission of the indicator of regulation from this estimation is that, given the missing data on economic structure, we use a panel of 11 years (1988-1998) for which we consider not appropriate the impact of regulation which would require a larger panel. In fact the regulation coefficient turned out as not significant when estimated over the shorter period.

To analyse the spillover effects with respect to services (*SER*) and economic structure (*STR*) we have estimated, respectively, the parameters β_{STR} and β_{SER} included in the following specification:

$$q_{tj} = s_L\, l_{tj} + \beta_{STR}\, STR_{tj} + \beta_{SER}\, SER_{tj} + s_{KC}\, k_{Ctj} + s_{KN}\, k_{Ntj} + c + \varepsilon_{tj} \qquad (12)$$

$$t = 1,\dots,T \qquad j = 1,\dots,n$$

The results are presented in the table below:

Table 4: ***ICT Spillovers, Business Services and the Composition of the Manufacturing Sector***

	Coefficient	$P > \|z\|$	Std. Error
s_{KC}	0,04	0,11	0,02
s_{KN}	0,49	0,00	0,08
s_L	0,49	0,00	0,06
β_{STR}	77,25	0,00	27,70
β_{SER}	8,17E-0,8	0,01	3,20E-0,8
C	-0,74	0,46	1,00
R^2	**within** **between** **overall**	0,86 0,99 0,99	
Wald χ^2 (5) **Prob > χ^2**		2671,50 0,00	
sigma_u **sigma_e** **rho**		0,08 0,03 0,85	

Table 4 shows a positive link between manufacturing structure, services and growth[2]. Moreover, results suggest that, with the introduction of β_{STR} and β_{SER}, the direct effect of ICT disappears (the value for s_{KC} is not significant).

Finally we consider a specification to further investigate the transmission channels of ICT externalities. To do this we consider a cross effect, usually neglected in the growth accounting framework. We have further specified the production function with a second order effect

2 Note that the coefficients β_{STR} and β_{SER} cannot be interpreted as elasticities.

as represented by $s_{KC}\beta_{SER}$ that captures the impact of ICT through services. We present the specification described by equation (13) after having carried out a regression that contained β_{SER} and β_{STR} separately. Only in the regression which includes β_{STR} the ICTs direct effect is not significant. We consider the result as an indication that the non significant ICT direct effect is due to β_{STR}. This result confirms the idea that the economic structure, as weighted by high-technology ICT services, captures the impact of ICT, again confirming the role of ICT as a GPT. To further investigate the relationship between the economic structure and ICT, we consider a version to evaluate the ICT transmission channel through services.

Our reference equation then becomes:

$$q = s_L \ K_{Lt} + s_{KC}\,\beta_{SER} \ k_{C\,t-1} \ SER_t + s_{KC} \ K_{Ct} + s_{KN} \ k_{N\,t-1} + C + \varepsilon_t \tag{13}$$

where SER_t are services (some categories of producer services, namely communication, business and finance and insurance) at the t time and $s_{KC}\,\beta_{SER}$ is the cross effect (computed by multiplying the ICT capital input by services) that captures the spillovers impact due to services. In other words, β is function of services and the ICT capital.
The specification of $K_{C\,t-1}\ SER_t$ is:

$$_{t-1}k_C \ \ _tSER = (_{t-1}k_C - ln\ E(k_C)) * (_tSER - ln\ E(SER)) \tag{14}$$

where E indicates the mean value. Table 5 presents the estimates of the parameters of equation (13):

Table 5: ***The Interaction between ICT and Business Services***

	Coefficient	$P > \|z\|$	Std. Error
s_{KC}	0,20	0,00	0,01
s_{KN}	0,04	0,00	0,01
s_L	0,77	0,00	0,03
$s_{KC}\beta_{SER}$	0,01	0,02	0,00
C	3,35	0,00	0,24
R^2	**within** **between** **overall**	0,93 0,99 0,99	
Wald χ^2 (4) **Prob > χ^2**		2409,11 0,0000	
sigma_u **sigma_e** **rho**		0,09 0,05 0,76	

As shown in table 5, services represent an important vehicle of the (direct and indirect) impact of ICTs on output growth.

5 Concluding Remarks

This Chapter has reviewed the literature on ICT as a GPT and has suggested some possible ways of capturing the complexity of transmission mechanisms highlighted in the literature with quantitative models. Moreover it has provided some evidence that ICT is indeed a GPT. In fact spillover (indirect) effects of ICT on GDP have been shown to be larger than direct effects. This gives support to the theoretical hypothesis of ICT as a general purpose technology that emphasises the role of ICT externalities and the necessity to overcome the view of ICT as an input in the production function. The analysis carried out in this Chapter also suggests that regulation represents an obstacle to the impact of ICT on economic growth. Moreover, services and the production structure of the economy have been identified as two important channels that account for the positive influence of ICT on growth. In the next Chapters these ideas will be further developed, also with the support of structural macroeconometric models.

CHAPTER III

INFORMATION SOCIETY AND E-INCLUSION: DATA AND INDICATORS

1 Introduction

The rapid development of the Information Society and the identification of ICT as a key driver for innovation, productivity, competitiveness and growth lead to the recognition that policy has a fundamental role to stimulate and promote ICT diffusion. Additionally the developments of the information society can coincide with European and national policies in areas such as the regulatory environment for telecommunication services, innovation and technology policy, education and labor market policy and patenting law and trade regulations.

These developments emphasize the necessity for a common international approach in monitoring the information society. Indeed, ICT data and indicators are important instruments for policy in a number of ways. First, quantitative data are needed to map the status quo, and to compare the degree of technological diffusion across regions or countries. Second, data are compulsory to understand and assess the improvements of information society and to monitor the progress achieved over time (E-business watch, 2005).

The first aim of this chapter is to provide an overview of the availability of official ICT data and indicators and to identify a *core dataset* to be used in modelling the impact of ICT on growth performance and employment both at macro and industry level. This raises the need to assess the availability of data and indicators from official data sources, in terms of variables type and data consistency in time[1] and space[2].

Another goal is to explore available data in order to asses which type of information can be "consistently" used in the implementation of multivariate studies on ICT diffusion. In other words, by applying several statistical techniques, an attempt is made to study the evolution of ICT investment over time and across countries. The objective is to get some insights on how to exploit the information contained in the above mentioned core dataset to develop simple policy tools to monitor technological diffusion in time and across space. It is widely known that composite indicators have become very popular in several policy areas, including those

1 Time series length.

2 Country coverage.

related to information society, mainly because of their promise to capture and reduce complexity of multi-dimensional concepts[3].

As to the issue of e-Inclusion it has gained new relevance and centrality within the scope of the strategic plan, *i2010 – A European Information Society for growth and employment* (CEC, 2005), due to the identification as a priority the achievement of an *Inclusive European Information Society* promoting growth and jobs in a manner consistent with sustainable development, and prioritising better public services and quality of life. Attention has clearly been drawn to the social impact of ICTs and the need to guarantee the advantages deriving from their use by an ever-increasing number of citizens. Reference to various dimensions of access (both material and skill access), alongside the implementation of public services, indicates a distinctly richer and more structured interpretation of the themes of e-Inclusion than in the past.

Meanwhile, the concept of e-Inclusion acquires new facets reflecting the complexity of the dimensions concerned and confirming its multiform nature. In order to arrive at an interpretation of the concept of e-Inclusion articulated in these terms, a multi-focus approach is suggested: that is, *multi-perspective* (referring both to individuals and to communities, to the overall population as well as target groups), *multi-methodological* (utilising both quantitative and qualitative tools) and *multi-dimensional* (arising from the division of the concept into the dimensions of access, quality of life, participation and empowerment, and the sub-division of the indicators into the categories of 'background' and 'advanced'). The available indicators do not always permit such an interpretation. However, starting out from current data sets, it is possible to construct indices to record the existing imbalances relating to the contribution of ICTs to the quality of life and empowerment of citizens.

2 Data Screening

In the literature on economic growth three effects of ICT on productivity and growth are distinguished. First, ICT investment contributes to overall capital deepening thus helping to raise labour productivity. Second, fast technological progress in the production of ICT goods and services may contribute to more rapid multifactor productivity (MFP) growth in the ICT-producing sector. Third, larger use of ICT may help firms increase their overall efficiency, and thus raise MFP. All these effects can be measured and analysed at different levels of aggregation, i.e. at the macro-economic level, the industry level and the firm level. Table 1 reports a schematic representation of this type of information (Jorgenson et al. 2005).

3 The strengths and risks of compound indicators are extensively discussed in the E-Business Watch Report (2005). Policy makers are well advised to use the figures of compound indicators mainly as a starting point for asking questions and to trigger public debate about policy objectives.

Table 1: ***Information required to start ICT Impact Evaluation (Macro and Industry Level)***

	Amount			
Labour	Hours worked, full time equivalent, wages	Age, gender	Education	Type of contracts
	Price and Quantity			
Investment	Computers, office and accounting equipment	Own and purchased software	Communication equipment	Non ICT capital goods
Capital Services	Computers, office and accounting equipment	Own and purchased software	Communication equipment	Non ICT capital goods
Capital Stock	Computers, office and accounting equipment	Own and purchased software	Communication equipment	Non ICT capital goods
Innovation	Research and Development (expenditure)			
Output	Value added, Gross output			

The first step of the data screening has been the identification of those countries that publicly provide data on ICT investment both at the aggregate and at the industry level as well as by type of capital goods (hardware, software and communication equipment). Many OECD countries now provide estimates of ICT investment, as well as on the ICT sector and on the service sector, although important gaps still remain (OECD, 2004) especially as far as the distinction between ICT and capital goods is concerned. Indeed, this distinction can be very useful in quantifying the contribution of each capital good to output growth (Jorgenson and Stiroh, 2000). At the same time it is necessary to assess the availability of data on labour, capital (no ICT), output and R&D expenditure that are the primary variables in growth empirics.

The task of building a core dataset for ICT studies can be classified under the general statistical problem of *Data Integration*. This label identifies all situations in which it is necessary to gather information coming from different sources and then from different surveys into a single database. Working at national and annual level and referring to European data sources should make this task a lot easier then usual, as the most common issues are supposed to be automatically solved and one can generally assume a high quality in terms of sampling, representativeness, and analysis (E-business Watch, 2005).

The screening procedure was applied to the following databases: the Total Economy Growth Accounting[4] and the 60-Industry database of the Groningen Growth and Development Centre (GGDC); the OECD STAN database for Industrial Analysis and the OECD Main Science and Technology Indicators (MSTI); EUROSTAT, R&D and National Accounts database (more description)[5]. In principle, the best coverage in terms of variables/indicators and countries is given by EUROSTAT data. Time-series length however is too often below 10 years which in the present context is considered the minimum time-span necessary for dynamic analysis. Nevertheless, it is clear that in the future the EUROSTAT database will play the central role which it cannot have in the present study.

Currently the above mentioned DBs are the most frequently used in the empirical research on ICT and growth and they have been chosen because they are primarily based on national accounts of individual countries. In all the DBs the industries are classified according to the International Standard Industrial Classification (ISIC) revision 3, which is very close to the European NACE rev1 classification system. The maximum industry coverage is given by the GGDC 60 providing data for 56 industries in total. The industry division is more detailed, than in STAN, allowing a focus on industries characterised by high ICT-investment shares and/or ICT-goods production.

Due to the peculiar structure of the considered data sources, it has been necessary to choose a specific screening protocol to be applied to each of them and to restructure databases schemes in order to include all information in the core dataset[6].

The 60-Industry and the Total Economy Growth Accounting databases, delivered by **GGDC**, cover the period 1979-2004 so that in this case the screening procedure is very simple. Indeed, reported variables are complete in terms of time and industry coverage. As can be deduced from the methodological GGDC notes, when data are not available in a given year, they are estimated. Subsequently a simple counting of existing data is sufficient to quantify the DBs coverage.

The **OECD** DBs have been screened constructing several types of synthetic coverage indexes, given the multidimensional structure (time, space, industry and variable) of the databases.

Specific attention has been given to **EUROSTAT** as it reports data on EU-27 even if with a short time-coverage. The complete screening is reported in the appendix to this publication that is available on-line (see www.coleurop.eu/research/modellingICT).

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4 We also looked at the Industry Growth Accounting database but we did not include it in our screening because it covers only 5 countries (US, France, Germany, Netherlands and UK).

5 Detailed information on the DBs can be found at the following addresses: www.ggdc.net for the GGDC databases; www.oecd.org/sti/stan and www.oecd.org/sti/msti for the OECD databases; http://epp.eurostat.cec.eu.int for EUROSTAT data.

6 Remark that not all EU-27 countries are covered in each DB. For instance GGDC sources include up to 20 countries (no data on Cyprus, Malta, Estonia) while EUROSTAT covers all EU-27 countries.

2.1 Data Quality Evaluation

Data comparability and databases coherence have been checked following the EUROSTAT quality framework for statistical output, (see OECD/JRC, 2005) data comparability and databases consistency. The results of the analysis lead to the following considerations:

1. The best structured data source is EUROSTAT. It is the best source for Human Capital information and the only one when policy indicators are concerned. However, time series are currently too short. Therefore, except for the measures of Human Resources in Science and Technology (HRST), it would be preferable to refer to this source in the future. ICT data are from EITO sources.
2. GGDC is currently the best source of ICT variables and indicators since data come from official national statistical institutes with the highest guarantees of quality and country coverage. Nevertheless the information on data quality is insufficient and lacks clarity. Missing data are estimated but there is no indication of which values were missing. It should be stressed however that the GGDC work is at present invaluable as they are the main source for long time series on ICT.
3. OECD data are affected by many missing data but, at this stage, it is the preferable data source because they are gathered directly from National Accounts without any further elaboration.

As a general remark, it can be said that information on ICT is still sparse and of low quality in statistical terms. A great deal of work is still necessary to obtain a reliable dataset. At present a main effort has been undertaken to create a data base on measures of economic growth, productivity, employment creation and technological change at the industry level for all European countries, by the EUKLEMS project. The latter will be a considerable improvement in terms of data quality and availability, as it will provide an important input to policy evaluation, in particular for the assessment of ICT impact on economic growth. The first release of the EUKLEMS database will be done in March 2007. Notice that the present analysis has been done on a sub-set of ICT data that will be included in the EUKLEMS DB and that it is most likely that data of other countries will be available from EUKLEMS allowing a deeper understanding of EU technological development.

3 The Core Data Set

Once data consistency has been assessed, a core dataset has been identified. It concerns basic variables for growth empirics, ICT measures and R&D expenditures. As already stated time series of selected variables have the minimum length of 10 years[7]. The Core Dataset has been obtained as a combination of two data sources (GGDC and STAN OECD) with some overlapping.

7 10 years has been considered by the authors the minimum length necessary to perform growth empirics.

ICT variables are available only from GGDC according to our selection criteria. However, for cross country non dynamic analysis it is recommendable to refer to EUROSTAT data.

Table 2 illustrates the core dataset in a variable by country representation. From this table it can be established which country coverage and which variables are suitable for models evaluation.

As far as innovation is concerned it has been necessary to define a second core dataset. Indeed data on R&D expenditure and patents are available at a substantial detail so that they have to be analysed by themselves.

Table 2: ***Basic and ICT Variables Core Dataset***

	Countries																			
Variables	AU	BE	CzRe	DK	FI	FR	GE	GR	HU	IR	IT	LUX	NL	PO	PG	SLO	SP	SW	TK	UK
Consumption of fixed capital	x	x		x	x	x	x				x	x	x					x		
Employees Full-time equivalent	x					x					x		x							
Employees Persons	x			x	x	o	o				x	x	o	x			x			o
Exports of goods																				
Gross capital stock (volume)		x		x	x	x	x				x						x			x
Gross fixed capital formation	x	x		x	x	x	x		x	x	x		x	x	x		x	x		x
Gross fixed capital formation (volume)	x	x		x	x	x	x			x	x		x	x	x		x	x		
Hours worked	+	+	+	o	o	o	+	+	+	+	+	+	+	+	+		+	o		+
Imports of goods																				
Intermediate inputs	x		x	x	x	x	x		x		x	x	x		x		x	x		x
Intermediate inputs (volume)	x			x	x	x	x				x	x						x		
Labour compensation of employees	x	x	x	x	x	o	o		x	x	x	x	o	x	x		x	x		o
Net capital stock (volume)				x		x	x				x						x			
Operating surplus and mixed income	x			x	x	x	x		x		x	x	x					x		x
Production	x		x	x	x	x	x		x		x	x	x	x	x		x	x		x
Production (volume)	x			x	x	x	x				x	x						x		
Total employment Full-time equivalent	x					x					x		x							
Total employment Persons	x	x		x	x	x	x		x	x	x	x	x	x	x		x	x		x
Value added	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o		o	o		o
Value added (basic prices)	x	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x		x
Value added (producer's prices)				x		x					x		x							
Value added (volume)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x
Wages and salaries	x				x	x	x		x		x	x	x	x				x		
IT-equipment	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x
Communication equipment	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x
Non ict equipment	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x
Transport equipment	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x
Non residential structures	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x
Software	x	x		x	x	x	x	x		x	x	x	x		x		x	x		x

Legend: **+** GGDC only, **x** STAN only and **o** is GGDC+STAN.

Table 3 shows a sample of the complete innovation core dataset reported in the appendix, which is available on-line (see www.coleurop.eu/research/modellingICT).Here again two data sources (MSTI and EUROSTAT) have been combined. As it is clear from the table the variable coverage is rather extended and almost all variables come from MSTI.

Table 3: ***Innovation Variables Core Dataset (Sample)***

	Countries																			
Variables	AU	BE	CzRe	DK	FI	FR	GE	GR	HU	IR	IT	LUX	NL	PO	PG	SLO	SP	SW	TK	UK
GERD (million current PPP $)	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
1.a. GERD (million national currency - for the euro area pre-EMU euro* or EUR)	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
13. Percentage of GERD financed by industry	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
14. Percentage of GERD financed by government	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
15. Percentage of GERD financed by other national sources	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x
16. Percentage of GERD financed by abroad	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
17. Percentage of GERD performed by the Business Enterprise sector		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
18. Percentage of GERD performed by the Higher Education sector		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
19. Percentage of GERD performed by the Government sector		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
21. Total researchers (headcount)			x						x					x	x		x			
21.a. Women researchers (headcount)									x											
....	....																			
....	....																			
R&D Expenditures of Foreign Affiliates																				
R&D Personnel (FTE)			x			x			x					x		x			x	
Researchers (headcount)																				
....	....																			
....	....																			
68. Number of patent applications to the EPO in the biotechnology sector (priority year)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
68.a. Number of patents granted by the USPTO in the biotechnology sector (priority year)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

On the basis of the above results it is now possible to choose the geographical, temporal and detail extent of the database to be used in modelling the ICT impact on growth.

4 Statistical Analysis towards the Understanding of ICT Information Extraction

As mentioned above, this section is devoted to the examination of the core dataset. The final aim is the exploration of statistical techniques to aggregate individual indicators into synthetic measures to be used as simple policy tools in monitoring ICT diffusion. The first step is to explore space (across country) and time variability of each indicator, in order to identify the relationships between them. Then, by applying appropriate multivariate statistical techniques, the joint behaviour of indicators is investigated. Finally, the results of these techniques are examined in order to understand if a unique synthetic index can be identified.
The analysis focused on the following elementary ICT and R&D variables:

BERD, GERD	Business Enterprise and Gross Domestic Expenditures on R&D as a percentage of GDP (Source OECD)
COMEQ	Communication equipment's expenditure (Source GGDC)
SOFT	Software expenditures (Source GGDC)
TEQ	Telecommunication equipment's expenditures (Source GGDC)
ITEQ	IT equipment's expenditures (Source GGDC)

In order to take into account the dynamics of the above variables each of them has been analysed and grouped according to the following criteria:

1 first the maximum indicator's value per country has been computed;
2 then countries have been ranked according to these maxima;
3 finally, ranked countries have been divided in 4 groups

Most studies on Information and Communication Technology analyse ICT investment as a whole without distinguishing between IT and CT assets[8]. Here instead one of the objective of the analysis is to investigate if both categories of ICT assets (IT and CT) have an analogous performance that justifies the analysis of ICT expenditure as a whole or if it points for substantial differences between them. This is why Figure 1 and Figure 2 report respectively the time series comparison of IT and CT investment expenditure over GDP[9] for the four groups of countries ranked in increasing order. The first group describes the time behaviour of countries with the lowest share of IT investment while the forth that of countries with the highest share. The blue dashed line in the graphs represents the group's average.

8 This is also because information on ICT asset types is still scarce in most countries.
9 Variables are in constant prices, year 2000.

Figure 1: ***Time Series Comparison for IT Equipment as a Percentage of GDP (the dashed horizontal line denotes the group's average)***

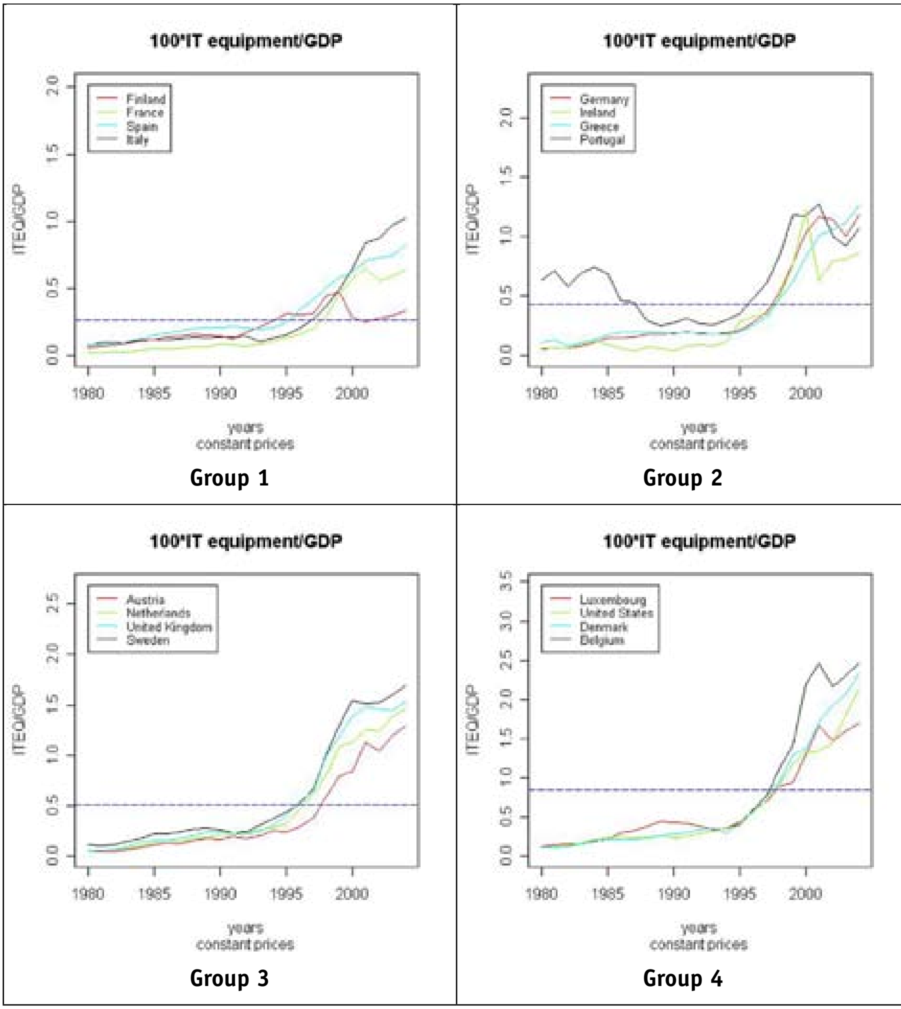
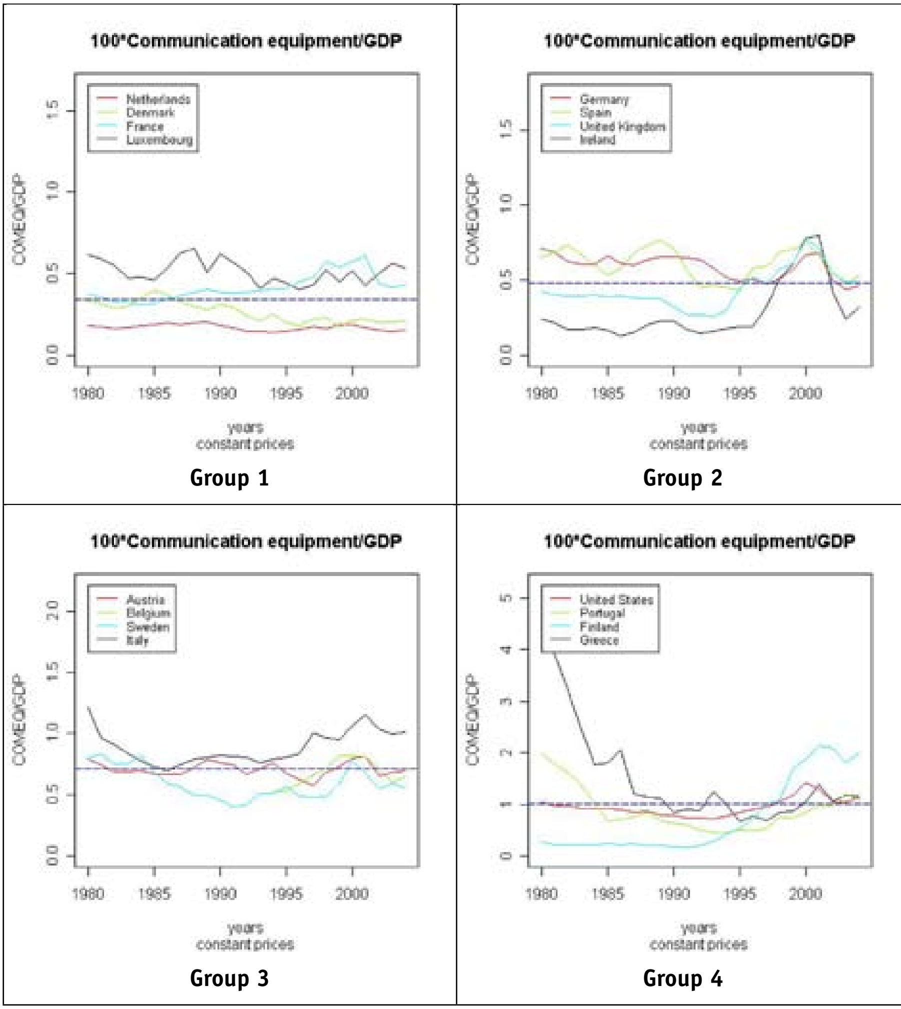


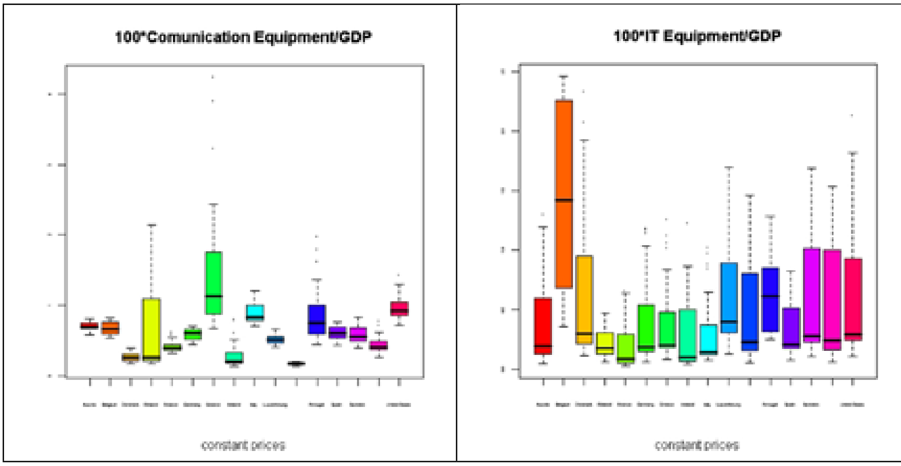
Figure 2: ***Time Series Comparison for Communication Equipment as a Percentage of GDP (the dashed horizontal line denotes the group's average)***



The graphical analysis above draws attention to the remarkable variability of IT expenditure across countries. With the exception of Sweden, Denmark and the United States belonging always to the fourth group, the remaining countries rank in different groups in relation to the selected indicator. Netherlands, for example, goes in the fast IT adopter group but in the slow CT adopter group, thus underlining the different features of IT and CT expenditures.

Country diversity emerges also looking at the boxplots reported in Figure 3 showing the shares of IT and CT expenditures over GDP by country in the time span 1980-2004.

Figure 3: ***Boxplot of IT and Communication Equipment Expenditures as a Percentage of GDP by Country (1980-2004)***



However it is well-known that during the last twenty years the rates of ICT adoption (as a whole) have varied considerably across countries. As shown in the previous graphs, since the second half of the nineties the share of IT investment has been particularly high in the US, Sweden, Finland and the United Kingdom. In contrast, IT investment in some continental European countries (Italy, France) has been substantially lower. Many reasons can be addressed for these differences ranging from industry specialisation, gaps in workers' skills to the degree of market regulation. Indeed Conway et al (2006) provide evidence that anti-competitive product market regulation has a strong negative effect on ICT investment.

The above evidence points to a deeper analysis of the relationship between ICT investment and the degree of product market regulation made, preserving the distinction IT and CT expenditures. This is a necessary step to develop a technological synthetic indicator. In fact, it might be very important to identify all those factors influencing (positively or negatively) technological diffusion.

To this end the shares of IT and CT over GDP are plotted against the indicator of product market regulation[10] by country, using years as plotting symbols. The graphical analysis suggests that:

- IT plus software expenditure has a quite strong linear relationship with the regulatory index in most countries for most years. A negative correlation is evident for all coun-

10 See Conway et al (2006) for a description.

tries. However, several differences can be noticed in terms of levels and speed of growth of the IT expenditure. Several countries show varying level of expenditure with constant regulation at the beginning of the considered time window.

- The relation between Communication equipment and Regulation is more variable across countries. Some countries (like Finland and Sweden) show an almost linear relationship (with negative correlation), but no common patterns for all countries can be found.

In order to explore in much more detail the linear linkage between IT expenditure and the degree of market regulation, a linear model has been fitted to each country. Results are reported in Table 4.

Table 4: ***Results of the Estimated Linear Models between IT+Soft/GDP and Product Market Regulation Index by Country***

Country	R^2	Intercept and confidence interval	Regulation's coefficient and confidence interval
Austria	0.95	**3.83** (3.58 - 4.08)	**-0.75** (-0.81 - -0.69)
Belgium	0.89	**5.89** (5.12 - 6.66)	**-1.15** (-1.39 - -0.92)
Denmark	0.97	**5.19** (4.97 - 5.41)	**-0.85** (-0.9 - -0.8)
Finland	0.80	**3.04** (2.77 - 3.3)	**-0.36** (-0.42 - -0.3)
France	0.89	**3.05** (2.75 - 3.34)	**-0.48** (-0.54 - -0.42)
Germany	0.92	**2.68** (2.5 - 2.87)	**-0.44** (-0.49 - -0.4)
Greece	0.85	**5.31** (4.63 - 5.99)	**-0.87** (-1 - -0.75)
Ireland	0.45	**1.91** (1.4 - 2.42)	**-0.27** (-0.37 - -0.17)
Italy	0.90	**2.66** (2.44 - 2.87)	**-0.36** (-0.4 - -0.32)
Netherlands	0.91	**3.57** (3.3 - 3.83)	**-0.54** (-0.6 - -0.48)

Country	R^2	Intercept and confidence interval	Regulation's coefficient and confidence interval
Portugal	0.15	**1.56** (0.99 - 2.12)	**-0.13** (-0.25 - -0.02)
Spain	0.93	**2.6** (2.44 - 2.75)	**-0.39** (-0.43 - -0.36)
Sweden	0.85	**5.47** (4.9 - 6.05)	**-1.06** (-1.22 - -0.9)
United Kingdom	0.89	**3.09** (2.86 - 3.33)	**-0.62** (-0.69 - -0.54)
United States	0.89	**5.82** (5.28 - 6.35)	**-1.96** (-2.2 - -1.72)

Notice that in all countries [11] the presence of a strong negative linear relationship between IT expenditures and product market regulation is confirmed.

The need to identify common joint behaviours of all indicators can now be addressed by pursuing the application of standard multivariate statistical techniques. In the next section two types of Multivariate analysis are illustrated: a principal component analysis and a cluster study. Both techniques can return sythe classifications and ordering of countries with respect to the analysed variables. What is necessary to assess, is the level of insight that these approaches are able to convey to the interested user.

4.1 Principal Component Analysis

The Principal Component Analysis (PCA) takes into consideration the following set of elementary indicators:

List of variables for the PCA

BERD	BERD as a percentage of GDP (Source OECD)
GERD	GERD as a percentage of GDP (Source OECD)
REGREF	Market Regulation Index (Source OECD)
COMEQ	Communication equipment's expenditure (Source GGDC)

11 Exception made for Ireland and Portugal where the linearity is less strong with an R2 of 0.45 and 0.15 respectively. However if we consider different time windows (1997-2003 Ireland and 1988-2003 Portugal) we find a very strong linear relation between the two indicators.

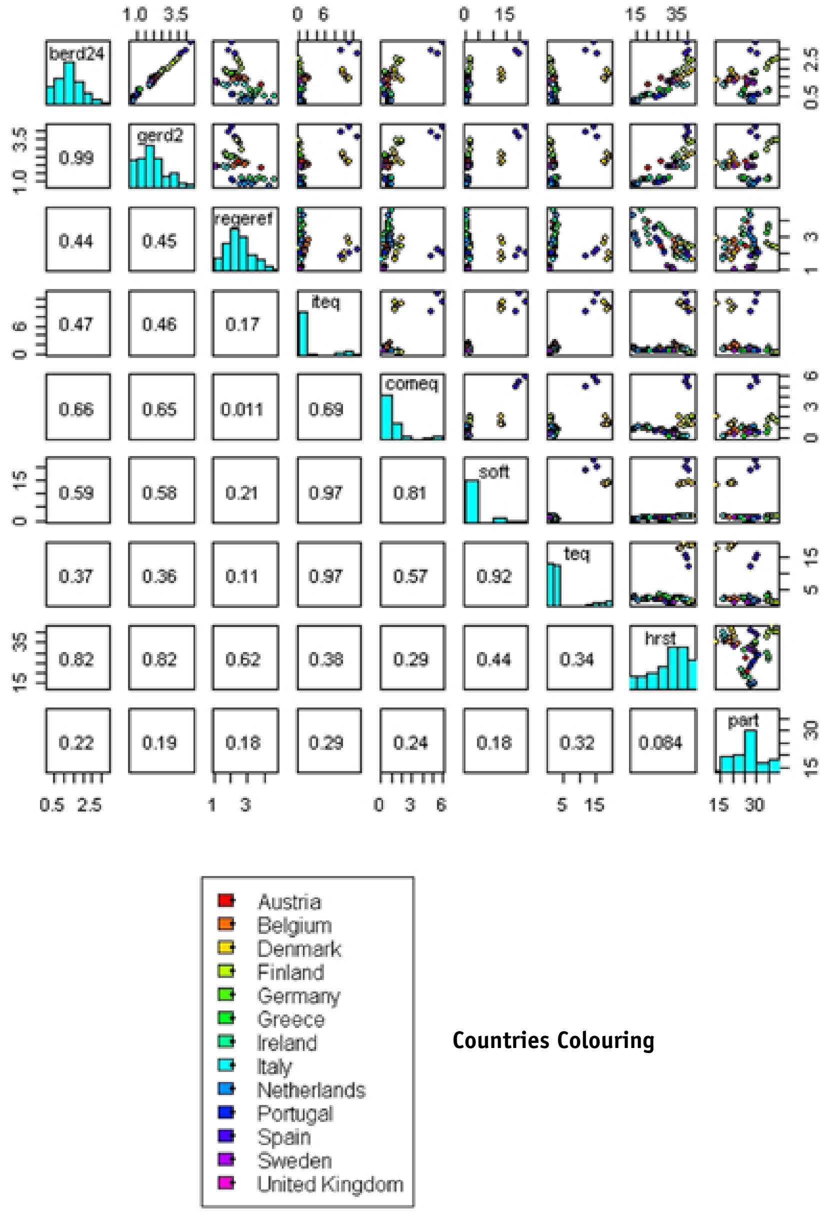
SOFT	Software expenditures (Source GGDC)
TEQ	elecommunication equipment's expenditures (Source GGDC)
ITEQ	IT equipment's expenditures (Source GGDC)
TEPART	Participation in tertiary education according to ISCED97, expressed as a percentage of total participation, in fields Science, mathematics and computing, engineering, manufacturing and construction for ISCED97 categories Tertiary education - levels 5-6 (Source EUROSTAT)
NCAT	Human Resources in Science and Technology, expressed as Percentage of total population (Source EUROSTAT)

ICT variables are normalized with respect to GDP.
The first step in this analysis has been to identify a core dataset where all missing values have been removed. As a consequence a drastic reduction in data amount is observed.
Figure 4, in the upper right panel reports the pairwise scatter plot of variables, and a colour coding of countries. Variables histograms are plotted on the diagonal, so as to analyse the symmetric, or skewed nature of each variable. In the lower plot panel correlations between data are reported.

Observe that all the dynamic aspects are lost in this dataset. For example, Austria has only two complete records of data one in 1998 and the other in 2003. This consideration leads to apply data analysis techniques in such a way that the time aspect won't be completely lost. For instance applying a Principal Component Analysis (PCA)[12], some time-information can be kept by organising the dataset as in Table 5, i.e. by "piling" countries in different years:

12 PCA is a multivariate technique that allows to explore the linear relationships existing between the rows of a data matrix. It involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called *principal components*. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. In other words it is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analysing data. The other main advantage of PCA is that once these patterns in the data have been found, data can be compressed (i.e. the number of dimensions can be reduced), without much loss of information

Figure 4: ***Descriptive Analysis of PCA Variables (ICT Variables on GDP)***



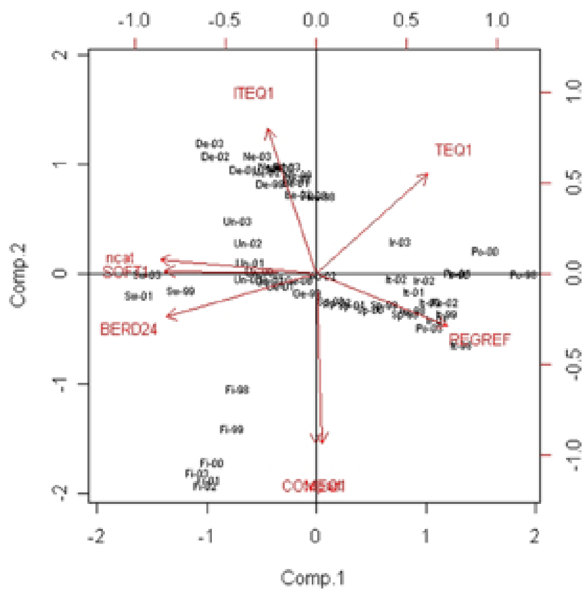
Countries Colouring

Table 5: ***MVA Dataset Sample***

Country	Year	BERD24	GERD2	ITEQ1	COMEQ1	SOFT1	TEQ1	REGREF	tepart	ncat
Austria	1998	1.12	1.77	0.59	0.68	0.63	2.08	3.88	26.32	20.76
Austria	2002	1.42	2.12	1.05	0.66	0.93	1.88	2.46	25.53	27.23
Belgium	2000	1.45	2.00	2.20	0.82	0.91	2.43	2.80	20.96	33.14
Belgium	2001	1.54	2.11	2.46	0.82	0.95	2.40	2.54	21.21	33.77
....	....	....	....	....	....	....	....	....	....	....
United Kingdom	2002	1.25	1.89	1.46	0.54	1.32	1.59	1.11	26.44	32.28
United Kingdom	2003	1.24	1.88	1.44	0.49	1.34	1.42	1.05	21.20	33.22

It then becomes possible to produce some graphical representation of the reduced dataset by means of a *biplot*[13] of the first two Principal Components.

Figure 5: ***Biplot from PCA (ICT Variables over GDP)***



13 Biplots at there most general are two-dimensional plots showing a set of data points and a set of axes. Biplots were originally named by K. R. Gabriel, who used them with principal components. The simplest biplot is to show the first two PCs together with the projections of the axes of the original variables. In this plots each variable is represented by a vector, and the direction and length of the vector indicates how each variable contributes to the two principal components in the plot. Each observation is represented in this plot by a labelled point, and their locations indicate the score of each observation for the two principal components in the plot.

By studying the vectors in the biplot it is possible to characterise the two represented axis according to the analysed variables. By observing the position of units it is possible to identify their pattern (ordering) with respect to the variable characterising the PC components (plot axis). Countries are labelled with a combination of their name and year in order to follow the evolution over time of such ordering in the few available years.

Figure 5 reports the results of PCA applied to the above selected variables.
The first two components account for only 25% of total variability and 5 out of 8 components are needed to explain more then 50% of total variation (6 components represent 75% of total variability). This result is not very satisfactory in terms of data reduction; however it is useful as it points out that data are highly heterogeneous. In other words, this means that each included elementary indicator contributes with a relevant amount of information. Only COMEQ1 and TEPART, seems to provide the same type of information. This can be seen in the biplots observing the length and position of red arrows labelled with indicators names.
The above graphs suggest also that:

- Product market regulatory index contributes to the first axis (horizontal) in a relevant way (size of the arrow) and with the same sign of Telecommunication (TEQ1) expenditures. However, it shows an opposite behaviour with respect to R&D and IT indicators, as if it has a restraining effect on their growth (and vice versa). This aspect needs further investigation at country level.
- Software expenditures (SOFT1) and the human capital indicator NCAT relevantly contribute to the definition of the first axis, but not to the second one. They have a very similar behaviour.
- Communication (COMEQ1) and the human capital indicator TEPART do not contribute to first axis but they are quite relevant in defining the second one (vertical axis).
- The first component is characterised by expenditures in R&D, Software, IT and presence of human resources in science and technology in the negative side; on the positive side regulation and telecommunication expenditures. The second axis is characterised by IT and Telecommunication expenditures on the positive side, and by Communication expenditure, market regulation and participation in tertiary education on the negative side.
- The above characterization allows observing countries behaviour over time. Notice that highly developed countries, such as Sweden (SE) and Finland (FI) appear always on the left side of the figure, moving further to the left as the years passes. Countries with highly regulated markets appear on the right side of the figure and they move left in more recent years as the degree of market regulation decreases.

Concluding Remarks on PCA

Even if some useful hints can be obtained from the present analysis, it is clear that PCA cannot be used to synthesize and/or reduce selected data. Too many components should be retained in order to maintain an acceptable level of information. Thus it cannot be used in the construction of a synthetic index. Nevertheless some major indications seem to emerge:

1 it seems more sensible to analyse IT (IT+Software) separately from Communication equipment's expenditures. The two indicators present a very different behaviour and they seem to report a completely different type of information.

2 it may be better to use NCAT instead of TEPART as a proxy for the human capital when IT expenditure is considered, because: (i) TEPART presents too many missing values, and when the analysis is focused on factors influencing technological development a general indicator of the degree of participation to tertiary education might be less appropriate than the degree of technological workers' skills; (ii) NCAT returns a more complete information (less missing data) and it can be considered more suitable to characterize workers' skills exploiting technology.

4.2 Cluster Analysis: Partitioning Around Medoids (pam)

Now it is necessary to investigate the classification "ability" of the available indicators. The focus, in this section, is on the search for a classification of countries in time according to ICT diffusion and related factors such as the degree of market regulation and the level of human capital. It is of interest to value if a standard, appropriate, clustering technique is able to find groups of countries with common behaviour with respect to the above mentioned factors. The cluster analysis has been performed for the following elementary indicators:

GERD	GERD/GDP (Source MSTI-OECD)
ITSOFT	(IT+SOFTWARE)/GDP (Source GGDC)
REGREF	REGULATION INDEX, (Source OECD)
NCAT	Human Resources in Science and Technology, expressed as Percentage of total population (Source EUROSTAT)

Given the high variability of the dataset, the analysis has been based on a partitioning technique instead of a hierarchical one. The chosen method is the PAM[14] (Partitioning Around Medoids, futher details on the method are given below) algorithm in which clusters centres are found by choosing elements in the dataset (say a country in a given year) instead of com-

14 For a full description of the PAM method see the methodological appendix (see www.coleurope.eu/research/modellingICT).

puting averages or other synthesis that can be strongly affected by data variability. The PAM algorithm has been applied to a dataset consisting of 110 records, as shown in Table 6 below, to identify homogeneous groups of countries with respect to the above mentioned indicators in the available years.

Table 6: ***Data Consistency for Cluster Analysis***

Country	Avalable years	Number of Records
Austria	1995 - 2003	9
Belgium	1994 - 2003	10
Denmark	1995 - 2003	8
Finland	1998 - 2003	6
France	1995 - 2003	9
Germany	1994 - 2003	9
Greece	1995 - 2003	5
Ireland	1994 - 2003	8
Italy	1994 - 2002	9
Netherlands	1996 - 2003	8
Portugal	1998 - 2003	6
Spain	1994 - 2003	10
Sweden	1997 - 2003	4
United Kingdom	1994 - 2003	9

Pam Results discussion

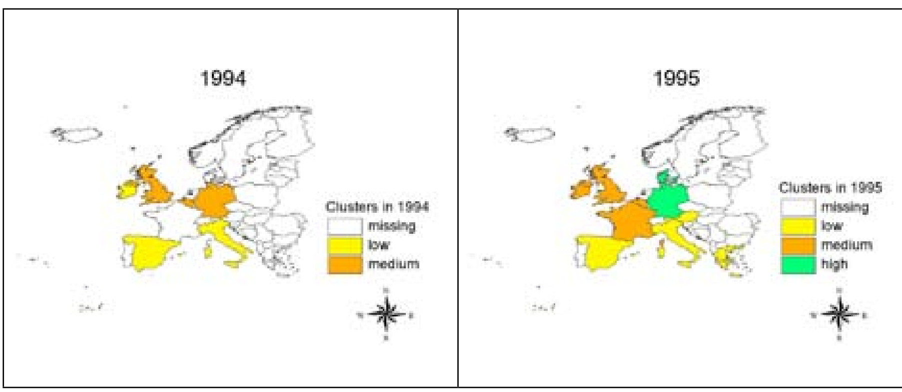
Four meaningful clusters are identified and can be labelled according to an idea of development in terms of high R&D expenditure (GERD), IT investment and Human capital (the higher, the better), and small degree of product market regulation. Detailed results are collected in the appendix to this report (available on www.coleurope.eu/research/modellingICT).

Table 7: ***Clusters centres (medoids)***

Country	Year	GERD1	IT-SOFT1	REGREF	Ncat	Label	Cluster's number	Cluster's average silhouette
Italy	1999	1.04	1.25	4.08	18.57	low	1	0.60
Ireland	2001	1.11	0.97	3.54	27.81	medium	2	0.47
Germany	2000	2.45	1.89	2.19	34.03	high	3	0.43
Finland	2003	3.48	2.13	2.36	40.25	very high	4	0.55

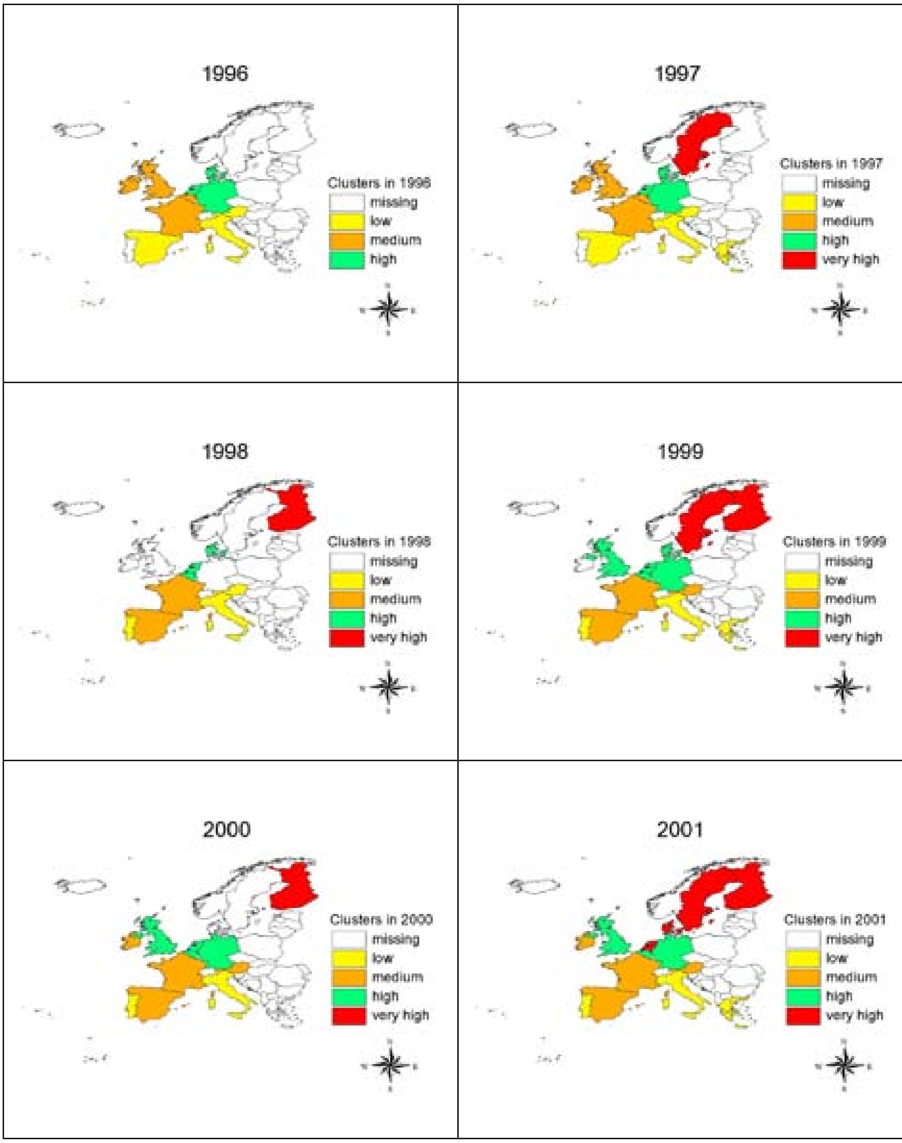
The overall average silhouette[15] is 0.5 which indicates that any strong structure could be found. However, even if with a smaller number of classes a higher silhouette is obtained, no meaningful pattern could be found in the larger clusters.
The time dynamic of countries development can be followed by mapping clusters changes of countries across the available years:

Figure 6: ***Clusters Maps***



15 The PAM function implemented in R software returns measures to assess the clustering quality, the so called *silhouette* (see Kaufman and Rousseeuw 1990 for details). Silhouettes' values are interpreted as:

s (*i*) = 1	object *i* has been assigned to an appropriate cluster.
s (*i*) = 0	it is not clear whether *i* should be assigned to one of two clusters *A* or *B*. It can be considered as an 'intermediate' case.
s (*i*) = -1	Object *i* is badly classified. When s is close to negative one, the object is poorly classified. Its dissimilarity with other objects in its cluster is much greater than its dissimilarity with objects in the nearest cluster. Why isn't it in the neighboring cluster?


1996
Clusters in 1996
missing
low
medium
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1997
Clusters in 1997
missing
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Clusters in 1998
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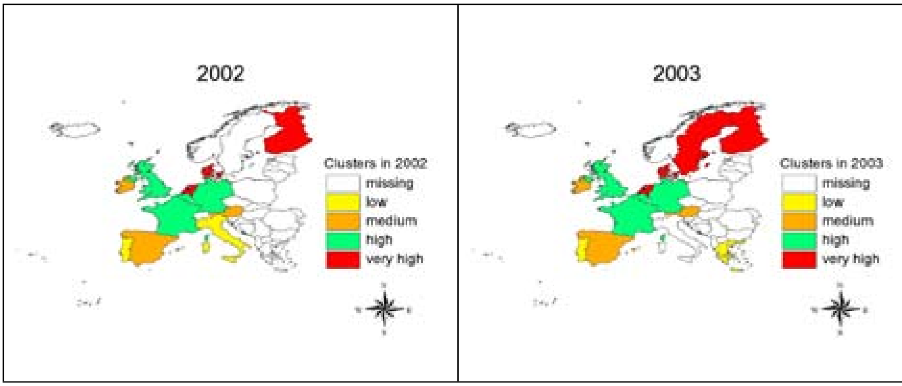


The above maps illustrate the evolution of countries such as the United Kingdom, France, Belgium, Spain and Denmark; going from low-medium groups to high and very high clusters over the entire period. On the other hand, Ireland and Portugal do not change cluster over time.

Concluding Remarks on the Cluster Analysis

The cluster procedure is able to capture very general patterns in the dataset. However, it cannot be sensitive to aspects such as policy objectives. For instance Italy has seen a constant growth in IT investment, a considerable decrease of market regulation and a growing availability of human capital. This progress cannot be perceived by means of clusters or other multivariate analysis techniques as it is very difficult to introduce there any reference to policy objectives or ranking strategies (as decreasing ordering for the regulation index).

5 The Issue of e-Inclusion in Europe

At the end of the nineties, when the European Council began to deliberate upon and formulate plans of action with regard to the role of ICTs within the European economy, the theme of e-Inclusion slowly began to attract the attention of policy-makers and researchers. Indeed, the implementation of the Lisbon strategy, intended to modernize the European economy and to build a knowledge-based economy and 'Information Society for All', could not have been pursued without a profound transformation in the use of ICTs by citizens.

The plan ***e*Europe 2002: An Information Society for All** (CEC, 2002), approved by the Council in Feira in 2000, constituted a first attempt to identify and organise the action necessary to attain the objectives previously set forth. The eEurope 2002 action plan redefined the regulation of networks and electronic communication services, as well as electronic commerce. At the same time, it facilitated the spread of mobile and new generation multimedia services. Besides providing rules and smoothing the way for new services, the eEurope 2002 plan engaged with issues such as the spread of computer and Internet use in schools, the public provision of online services to citizens and the need to improve Internet security[16]. Overall, these actions and indications had the common aim of extending connections in Europe, on the one hand, and enabling a significant growth of online services, on the other. Faced with such needs – preliminary and essential to the construction of an 'Information Society for All' – the issue of e-Inclusion inevitably remained in the background.

It attained greater centrality in the subsequent plan, *e*Europe 2005: An Information Society for All (CEC, 2002), presented at the European Council in Seville in June 2002. In the light of the progress made within the ambit of eEurope 2002[17], the new plan concentrated on two categories of action: "on the one hand, it was intended to stimulate services, applications and content both for public online services and e-business; on the other, it refers to the basic broadband infrastructure and issues linked to security" (p. 3).
The new attention given to the spread and availability of broadband and multi-platform access implies a different approach to the services offered and the role of the user. In fact, the eEurope 2005 plan clearly declares that it places "the user at the centre of attention", upon creating the conditions for improving social participation and offering new opportunities for all. To highlight the space granted to the user, it is stated that "all the lines of action of eEurope include measures dealing with the so-called e-participation or e-Inclusion" (p.3). The issue of e-Inclusion, rather than being considered in terms of its constitutive elements, is interpreted therein according to the category of access, characterised by a multi-platform logic. In short, it recognises the existence of various types of terminal, computer, television or mobile telephone – that may be used by citizens, and are therefore considered as part of the services available. However, it does not progress beyond this recognition and the issue of e-Inclusion does not figure as a specific objective to be attained. In brief, attention to the process of e-Inclusion of citizens is limited to the promotion of the development of alternative platforms of access for users with particular needs. Confirmation of an interpretation focused

16 Specifically, the actions were clustered around three main objectives: 1- A cheaper, faster, secure Internet; 2- Investing in people and skills; 3- Stimulating the use of the Internet.

17 In the identification of the eEurope 2005 objectives, the progress made in the ambit of eEurope 2002 may be noted. It may be summarised as follows:
- Internet penetration in homes has doubled
- Telecom framework is now in place
- Internet access prices have fallen
- Almost all companies and schools are connected
- Europe now has world's fastest research backbone network
- e-commerce legal framework is largely in place
- More government services are available online
- A smartcard infrastructure is emerging
- Web accessibility guidelines have been adopted and recommended in Member States

almost exclusively on access is given by a list of the principal objectives of the eEurope 2005 plan:

- Connection of public administrations, schools and health care to broadband
- Provision of interactive public services, accessible to all, and offered on multiple platforms
- Provision of online health services
- Removal of obstacles to the deployment of broadband networks
- Review of legislation affecting e-business
- Creation of a Cyber Security Task Force.

From a reading of the principal objectives defined in the eEurope 2005 plan, it may be deduced that the issue of e-Inclusion has not been granted any autonomous space other than as an indirect consequence of the implementation of the plan overall. In short, the question of e-Inclusion seems to be identified and resolved as one of access (multiplatform/convergence and broadband connection).

Two years after the formulation of the eEurope 2005 plan, the Commission set forth the ***e*Europe 2005 Action Plan: An Update** (CEC, 2004), which dedicated greater attention to the issue of e-Inclusion and the need "to understand in more detail the various facets of this complex issue" (p.3). To obtain this result, two forms of action were proposed: "first, a need was identified for better and more comprehensive data and analysis to assess the extent of regional and social imbalances in ICT diffusion and the reasons for low user adoption in certain groups, such as women. Second, specific practical actions should be reinforced and newly developed to address e-Inclusion" (p.16). The specific practical actions suggested included: 1- guidelines on multi-platform approaches to increase access to and widen use of e-services; 2- implementation targets for European e-accessibility and usability standards; 3- further development of public internet access points; 4- raising awareness and digital literacy in a gender sensitive manner, in particular among those groups at risk of exclusion and with specific needs, as well as provision of appropriate content and services.

Although predominantly focused upon access, the attention given to other aspects of e-Inclusion helps to make headway in determining alternative approaches, along with an awareness of the complexity of the phenomenon. This involves not only a timely survey of the opportunities and methods of access, but also deliberation and investigation of the issues surrounding e-accessibility and digital literacy among users.

The new strategic plan **i2010 – A European Information Society for Growth and Employment** (CEC, 2005), presented in 2005, follows this route even more clearly. The issue of the inclusion of citizens in the information society thus enters the Commission's priorities. The three priorities, or pillars as they are alternatively defined, are:

- the completion of a Single European Information Space which promotes an open and competitive internal market for the information society and media;
- strengthening Innovation and Investment in ICT research to promote growth, and more and better jobs;
- achieving an Inclusive European Information Society that promotes growth and jobs in a manner consistent with sustainable development and that prioritises better public services and quality of life.

The aim of an European society based upon the inclusion of its members is linked to the spread of broadband access and, more generally, to the achievement of digital convergence, the improvement of the services on offer in terms of both accessibility and costs, the spread of basic digital awareness and the improvement of citizens' health made possible by the new eHealth services. Attention is extremely clearly directed towards the social impact of ICTs and the need to guarantee the advantages of their use to an ever-greater number of citizens. Reference to various dimensions of access (both material and skill access), as well as the implementation of public services, indicates a distinctly richer and more structured interpretation of the themes of e-Inclusion, than in the past. If indeed one recognises that information and communication technologies have become key enablers in modern life, which may provide for an improvement in the quality of life, the result is an inevitable and automatic semantic shift from the domain of availability to that of empowerment.

This means that, within the new interpretative and operative framework, ICTs move beyond the enabling function assigned to them in the past to one of empowerment, while the same concept of e-Inclusion acquires new facets reflecting the complexity of the dimensions involved and confirming its multiform nature.

5.1 Defining e-Inclusion

In the early phase of study and reflection on the spread of ICTs, the prevalent approach was clearly based on the emphasis on the distinction between those with access and those without. This distinction became widely known as the 'digital divide', defined as "the gap between those who have access to the new technologies and those who do not" (NTIA, 1999, p.xiii). Steeped in a culture of technological determinism, the concept of the digital divide – even if connected to a range of economic, social, cultural and technological differences – maintains a predominantly dichotomic nature insofar as it utilizes the binary categories of *information* *haves* and *information have nots*. This rigid binary methodology of representation completely ignores the differences existing within the same groups as well as the existence of alternative options such as the so-called *information want-nots* (NTIA, 2000; Van Dijk, 2000), those who abandon Internet use (Katz, Aspden, 1998), and those who have sporadic access and decide not to make continuous use of it for various reasons (Gunkel, 2003).

The classic dichotomy between the *haves* and the *have not*, not only ignores other modes of use but also minimises to the point of ignoring the differences that exist within the two groups. In the literature on the subject, this result has been attributed to the difficulty of conceptualizing information and telecommunication poverty. To this effect, Wilhelm (2000), after having illustrated the principal conceptual difficulties due to the continuous mutation of ICTs, the difficulty of distinguishing between telecommunications tools as transportation or transmission media and as content carriers, and the extent to which antecedent resource and skill development are included in a definition of information poverty, proposes a "recategorization of information and telecommunications *have not*, into five mutually exclusive categories distinguished by the differential ability of participants in each of these divisions to achieve cooperative and participatory status in the social and economic life of the larger community" (p. 73). In the classification proposed by Wilhelm, the groups are differentiated in relation to proximity to/distance from the information society (center-periphery) established on the basis of a number of variables (socioeconomic status, technological capacity, possession of certain antecedent skills and talents, attitudes toward and perception of the information society). The recovery of the complexity of the dimensions at the basis of proximity to the centre of the information society enables the notion of a binary gap to be superseded (Warschauer, 2001) and the recognition of significant variability between the forms of information an individual may possess, and modes of access to and use of such information.

A similar perspective is adopted in the work of Van Dijk (2005), which defines the "digital divide as a social and political problem, not a technological one. Physical access is portrayed as only one kind of (material) access among at least four: motivational, material, skills and usage" (p. 3). This is not to deny the relevance of physical access, but rather to give value to the other dimensions normally left at the margins of analysis. Such a valorisation permits the recovery of factors of variability between ICT users – who have different motivations, levels of literacy and usage – as well as those who do not access ICTs for reasons such as lack of interest, lack of literacy connection difficulties and so on. It appears clear that the previous division of individuals into groups comprising those who have access and those who do not loses meaning in favour of a more complex form of classification constructed according to numerous variables determining relationships with ICTs.

According to Van Dijk (*ibidem*) the possible inequalities deriving from the the various modes of access are the consequence of old inequalities, to which new ones may be added. In brief, the link between old and new inequalities can be summarized in the following statements (p. 15):

1 Categorical inequalities in society produce an unequal distribution of resources.
2 An unequal distribution of resources causes unequal access to digital technologies.
3 Unequal access to digital technologies also depends on the characteristics of these technologies.
4 Unequal access to digital technologies brings about unequal participation in society.
5 Unequal participation in society reinforces categorical inequalities and unequal distribution of resources.

Central to this approach are questions of inequality in the distribution of resources – which are reflected, in the first place, in the various dimensions of the ICTs – and the participation of individuals in the information society. The resulting interpretative framework, constructed through a combination of technological and social factors, constitutes the characteristic element of more recent studies on the question of e-Inclusion.

According to some scholars, the discontinuity represented by the new interpretative tendency enables the past impasse to be overcome: "the focus on Information and Communication Technologies (ICT) access characterised by most current policy action on the information society fails to capture the real challenge: e-Inclusion is essentially about social inclusion in a knowledge society" (***e*Europe Advisory Group**, 2005). If e-Inclusion is to be identified with social inclusion, it follows that the dimension of access to ICTs represents an important pre-condition for the latter, which must inevitably, however, be accompanied by a further dimension taking account of 'people's empowerment', or rather the strengthening of individuals' ability to participate in different social spheres.

The recognition of the existence of two distinct dimensions, into which the concept of e-Inclusion may be divided, has by now become the starting point from which it may be defined. In the report formulation by the eEurope Advisory Group (*ibidem*), a definition is proposed according to the following terms: "beyond access to ICT tools and services, beyond even digital literacy, a definition of e-Inclusion should focus on people's empowerment and participation in the knowledge society and economy. Skills and competences (both ICT- related and regarding new ways of working using ICT), awareness and willingness, social capital and the means to grow it are also key factors of e-Inclusion" (p.7). This first definition is followed by another, more articulate and precise, used by the Commission in the formulation of the **i2010 –First Annual Report on the European Information society** (CEC, 2006):

- e-Inclusion refers to the effective participation of individuals and communities in all dimensions of the knowledge-based society and economy through their access to ICT, made possible by the removal of access and accessibility barriers, and effectively enabled by the willingness and ability to reap social benefits from such access.
- Further, e-Inclusion refers to the degree to which ICT contributes to equalizing and promoting participation in society at all levels (i.e. social relationships, work, culture, political participation, etc.).
- The digital divide measures the gap between those who are empowered to substantially participate in an information and knowledge-based society and economy, and those who are not.

The key words in this definition of e-Inclusion are access, participation and empowerment, presented in terms of both the individual and the community. Furthermore, particular attention should be given to the role played by awareness and the tendency to use ICTs in order to obtain social benefits, thus recognising the importance of the personal evaluations given by individuals. On the other hand, the fact that focusing on access and skills is not sufficient to promote or give an adequate account of e-Inclusion is confirmed also in a recent document formulated by the High Level Group of Member States' Experts on Employment and Social Dimensions of the Information Society (ESDIS, 2005), which highlights that "adequate policy measures should take into account how ICT is experienced in the context of people's everyday life. Along this line, focusing on the impact of ICT on social capital, individual well-being and quality of life can help make the connection between the adoption of technology and general social participation and cohesion" (p. 19).

The notion that the process of e-Inclusion has assumed these characteristics, and should be operationalised in these terms, is confirmed in the Ministerial Declaration approved unanimously on 11 June 2006 in Riga[18] by the Ministers of the European Union, which states: "e-Inclusion means both inclusive ICT and the use of ICT to achieve wider inclusion objectives. It focuses on participation of all individuals and communities in all aspects of the information society. e-Inclusion policy, therefore, aims at reducing gaps in ICT usage and promoting the use of ICT to overcome exclusion, and improve economic performance, employment opportunities, quality of life, social participation and cohesion".

Reference to the use of ICTs which people make in order to achieve their goals and enhance their position leads to the elaboration of a number of profiles by means of which the various

18 The Ministerial Conference "ICT for an inclusive society" was held on 11 June 2006 in Riga, Latvia, and unanimously approved a Ministerial Declaration available at: http://europa.eu.int/information_society/events/ict_riga_2006/doc/declaration-riga.pdf

forms of use and non-use may be differentiated. The continuum thus created between those who invest in ICTs and those who do not therefore constitutes a rich and complex interaction between different variables. During the conference held in Riga, for example, Cuellen (2006) presented a spectrum of e-Inclusion including positions such as “Technophobes”, “Uninformed”, “Disinclined”, “Minimalists”, “Pragmatists”, “Specialists”, and “Extremists”. The usefulness of this method of classification, and other similar systems, lies in the explicit or implicit reference to the social entrenchment of processes of use and domestication of technologies, giving substance to the interpretation of e-Inclusion as social inclusion in a knowledge society.

A final element to be considered in the analysis of the phenomenon relates to its mobile nature; that is, e-Inclusion is a moving target. This characteristic derives, on the one hand, from its social roots, and on the other, from the spread and evolution of such technologies. Or rather, it may be posited that the process of e-Inclusion is linked to the process of technological innovation; in fact, we can assume that “ICTs are both *agents* of change, shaping their contexts of use, and *objects* of change, which are shaped and redesigned by users in their familiar contexts” (Van Dijk, 2005, p. 184).

6 The Operationalisation of the Concept of e-Inclusion

The complexity of the various dimensions which constitute the concept of e-Inclusion as defined so far is inevitably reflected in the identification of the semantic areas into which it may be divided. Before proceeding in this respect, however, it is useful to consider some of the uncertainties set forth with regard to the core data set available for monitoring the process of e-Inclusion.

For example, the report **Benchmarking Social Inclusion in the Information Society in Europe and the US**, drawn up under the auspices of the SIBIS project (2003) states in no uncertain terms that “the general impression is that the body of research on digital inclusion in the EU, particularly that of a quantitative nature and at a cross national level is still not sufficient” (p. 13). A recent Commission document with the support of ESDIS (2005) points out that “ it is regrettable that the effectiveness of currently implemented e-Inclusion policies at national level cannot be really evaluated, as Member States are still far from relying on coherent sets of indicators for benchmarking it” (p.15). Finally, the eEurope Advisory Group (2005) complains that “the quantitative and qualitative understanding of ICT and e-services usage remains extremely poor and uncoordinated. For example, while voice, e-mail, instant messaging, SMS etc clearly drive usage, the attention is mostly focused on the use of e-content and e-services. Likewise, critical issues such as the building of social capital though ICT remain understudied. This bias is clearly reflected in the current indicators used in Europe for benchmarking ICT developments” (p.14).

Other opinions could be added to this brief list of uncertainties and criticisms without, however, significantly changing the tone and the nature of the disappointment expressed therein. In fact, while expressed in different forms, the most frequent criticism relates to the insufficient operationalisation of the concept of e-Inclusion, with the consequent production of indicators and data only partially able to account for the phenomenon or to evaluate the effectiveness of policy responses. In the light of the considerations that have emerged from the debate reconstructed so far, in order to facilitate the transition from the limited discourse of e-Adoption to the more complex concept of e-Inclusion, a multi-focal strategy needs to be proposed. More specifically, such as strategy should be multi-perspective, multi-methodological e multi-dimensional, and able to provide a data set more responsive to the need to monitor a complex concept in continual evolution, such as e-Inclusion.

The multi-perspective approach, first of all, could enable the gathering of data referring to both individuals and communities (local, cultural, ethnic, professional, interest-based, etc), bearing in mind that the same individual may belong to several communities and that community membership is an important component of the inclusion of individuals through processes of capital building. Similarly, these should provide indications relating both to the overall population and to target groups, such as women, low income groups, those with low levels of education, the unemployed, ethnic minorities and so on. Finally, the data should represent geographical differences, subdivided in terms of national and regional, urban and rural or remote and isolated areas with no access to broadband or advanced mobile networks. This structuring of the data should be identifiable in all the data sets produced and in all readings targeted at defining the state of the process of e-Inclusion.

Secondly, the adoption of a multi-methodological approach should be characterized by the use of both quantitative and qualitative tools, enabling the creation of a data bank reflecting in a timely fashion the transformations of the concept under examination. The qualitative dimension should acquire greater space within the ambit of the official European statistics on e-Inclusion in relation to motivational and attitudinal aspects. Reference to such aspects would transform the existing data sets into an excellent tool – in the light of their characteristic breadth of coverage, quality and timeliness – for recording the changes underway promptly and accurately. Furthermore, particular attention should be paid to an analysis of the appropriation of ICTs in the everyday life of citizens, an aspect for some time indicated as important for "catching the relevant socio-technical phenomena at the current stage of ICT diffusion in the EU" (Commission Staff Working, 2005, p. 5). Qualitative research – as defined and carried out in European projects such EMTEL[19] – is focusing on the "domestication process", by means

19 EMTEL – European Media Technology and Everyday Network – is an European research network with an interest in studying user appropriation of technology in everyday life processes, http://www.emtel2.org/.

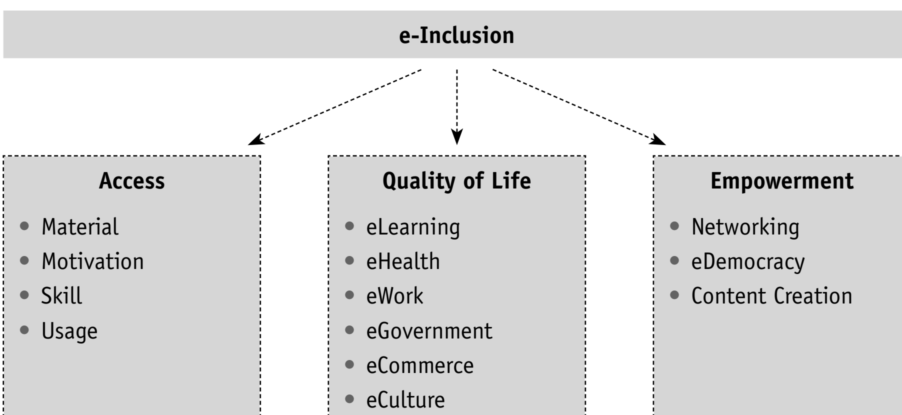
of semi-structured and depth interviews and ethnographic methods (Haddon, 2004; Hartmann, Hoflich, 2006; Silverstone, 2005). The combination of the two approaches – quantitative and qualitative – would provide useful data to policy makers enabling the accurate evaluation of the impact of ICTs on the development of an information society.

With regard to the multi-dimensional approach, this should be adopted in order to simplify the task of identifying indicators relating to the diverse and complex dimensions of the concept of e-Inclusion. A starting point is provided by the Ministerial Declaration approved in Riga last June, according to which "e-Inclusion focuses on participation of all individuals and communities in all aspects of the information society. e-Inclusion policy, therefore, aims at reducing gaps in ICT usage and promoting the use of ICT to overcome exclusion, and improve economic performance, employment opportunities, quality of life, social participation and cohesion".

The following dimensions may thus be considered:

- access
- quality of life
- empowerment.

Fig. 7: ***e-Inclusion as a multidimensional concept***



In the first dimension, "Access", we could include the **sub-dimensions** of **material access**, **motivation**, **skill**, and **usage**.

The sub-dimension of **material** access refers to prerequisites for the appropriation of ICTs, or rather the conditions of physical access and quality. The provision of points of access and forms of connection is the first step in the process of domestication of technology and its use in improving quality of life and participation in an information society. This is particularly relevant for broadband connection, which enables a dramatic change in the use of multimedia products and enables individuals to assume the role of content producers.

It is clear that the possibility of access to ICTs alone is inadequate to guarantee their use: it is a necessary condition but insufficient. Access needs to be accompanied by another condition associated with motivation: indeed, motivation is one of the preliminary conditions of full appropriation of ICT by potential users. In the sub-dimension of **motivational access**, one may also locate the complex area of personal investment and the system of expectations regarding ICTs. For many years at the margins of official surveys, the dimension of motivational access has attained greater relevance following the recent re-evaluation of the qualitative approach and the attention given to intermittent ICT use by categories such as "net evaders", "net dropouts" and "intermittent users" (Lenhart et al., 2003).

Unlike other communication technologies, which do not require particular skills for use, ICTs require that their users possess so-called **digital skills**. Known predominantly as 'digital literacy', the key question here relates to the type of literacy required in working with computers. Among the numerous attempts at defining the areas which constitute **digital literacy**, that of Warschauer (2003) is the clearest and most exhaustive: the list includes computer literacy (basic forms of computer operation), information literacy (managing huge amounts of information), multimedia literacy (ability to understand and produce multimedia content), computer-mediated communication (ability to manage online communication such as chat, videoconference, and so on). In recent years, the number of individuals who have acquired skills of computer literacy has grown significantly but there has been a simultaneous increase in the need to master other types of literacy in order to realistically make use of the opportunities offered by ICTs. Although possession of the European computer driving license (ECDL) represents a useful indicator in the spread of digital literacy, it does not provide a reliable account of the real dimensions of the phenomenon, given that many individuals are self taught in their acquisition of the necessary skills. Finally, the issue of eAccessibility should be considered as a further barrier to open access for all.[20]

The availability of a connection, the necessary skills for using it and awareness of the importance of the opportunities offered by ICTs do not automatically give rise to specific usage patterns. The different levels of **use** intensity/frequency among users are the result of numer-

20 The European Commission has issued numerous documents and policies regarding eAccessibility. Among the most recent is the CEC (2005) document, which incluces directions for the implementation of the recently launched "12010 – A European Information Society for growth and employment".

ous variables which intervene in and influence the real possibility of ICT appropriation in everyday life.

The real appropriation of ICTs in everyday life produces an improvement in citizens' quality of life, or rather significant repercussions in the domain of activities linked to eLearning, eHealth, eGovernment, eCommerce, eWork and eCulture.

The sub-dimension of **eLearning** comprises the numerous and various processes of net-based learning, including both those organized by traditional educational institutions and those initiated for the updating and professional training of adults and workers. According to the logic of lifelong learning characteristic of contemporary societies, the availability of opportunities, tools and educational material undeniably constitutes a step in the direction of continual development and potentially unlimited educational updating.

Other tangible advantages brought to the lives of individuals due to the spread of ICTs may be identified in the sub-dimension of **eHealth**. These range from the possibility of obtaining information about health through Internet navigation, to communication with health services and one's own doctor (to obtain diagnoses and prescriptions) via e-mail, from the possibility of booking appointments and diagnostic examinations to direct consultation with a doctor on-line (teleconsultation) or even to undergo real surgical operations (telemedicine). In all the cases mentioned, the use of ICTs enables appreciable savings to be made in terms of service provision, on the one hand, and a decisive transformation in the methods of treating and monitoring disease in everyday life.

The sub-dimension of **eWork** also includes applications which improve quality of life. Not only is the application of ICTs in the work context an ever-more important facet of many occupations, but it also enables certain activities to be carried out outside the company premises by maintaining continually open and active net connections. Furthermore, ICTs significantly broaden the spectrum of job seeking opportunities and of making contact with suitable applicants for given positions.

A notable simplification is evident in terms of relations with the public administration, government agencies and local authorities: or rather, in the domain of **eGovernment**. The quality of life of citizens improves significantly as a result of the provision of information regarding, for example, new legislation, and the facilitation of procedures for gaining access to services, concerning for instance the payment of taxes and the issue of certificates and declarations.

A further area in which ICTs can improve quality of life is that of **eCommerce**. Provided that security problems typical of the Internet are resolved, this grants a range of opportunities for individuals to acquire products that are otherwise difficult to obtain through conventional channels.

Through broadband connection, individuals are able to visit distant or difficult to reach museums, view films, consult libraries, read the daily and periodical publications, listen to the radio and make use of the podcast. Within the area of **eCulture** there has been a real transformation in the methods of ICT usage following a proliferation, in both spatial and temporal terms, of the modes of consumption of cultural products.

The final dimension of e-Inclusion does not connect to those dimensions immediately identifiable in the everyday life of citizens. The dimension of **empowerment** refers, rather, to the innovative potential of ICTs, yet to be fully developed. For this reason, the available indicators are still rare and in the process of being defined. Nevertheless, an examination of the concept of e-Inclusion cannot avoid engaging with the sub-dimensions of Networking, eDemocracy and Content Creation.

The sub-dimension of **networking** makes reference to the capacity of citizens in contemporary societies to create networks of relationships based on various forms of affinity (political, cultural, religious, etc.). Through these networks, individuals can confirm a process of identity construction, as well as activating forms of pressure to attain the satisfaction of specific needs, or to sensitise the public to specific problem areas.

The sub-dimension of **eDemocracy** comprises reference to the opportunities offered by ICTs to facilitate forms of engagement and influence on the part of individuals and groups at risk of social exclusion.

Finally, the sub-dimension of **Content Creation** is associated with the possibility of investing citizens in the information society with the role of prosumer (Producer and Consumer). Following the spread of broadband, the opportunity to produce widespread content by means of ICTs represents one of the most advanced aspects of ICT usage (for example, the spread of blogs).

7 Data Set for Benchmarking e-Inclusion

The greatest problem associated with the different dimensions used herein to define the concept of e-Inclusion is the unequal availability of some forms of data. In terms of access, for example, there is a good quantity of data useful for reconstructing certain tendencies, as illustrated previously in this Report; the same is valid for the domain of quality of life. However, the dimension of empowerment, which has only recently become an object of attention on the part of researchers and policy makers, is distinctly lacking. This asymmetry in terms of data availability inevitably limits the field in which indicators may be identified to the dimensions of access and quality of life, as follows, while reference to the dimension of empowerment remains at a purely theoretical level.

A document prepared by the Commission (CEC 2005) with the contribution of ESDIS, entitled *e-Inclusion revisited: The Local Dimension of the Information Society* clearly states in its conclusion that "the absence of a coherent set of indicators at national level for benchmarking the impact of e-Inclusion policies is regrettable and should be tackled as a major barrier, jeopardizing the possibility of monitoring progress and improving the effectiveness of public spending" (p. 19). If one considers that the theme of e-Inclusion has by now been present for several years on the agendas of policy makers as well as national and international research institutes engaged in monitoring the evolution of the information society in Europe, the unavailability of data enabling the benchmarking of e-Inclusion seems distinctly surprising.

The reasons for this anomaly may be found, first and foremost, in the reference to a reductive or indeed elementary concept of e-Inclusion, useful for giving an account of the initial stage of the spread of ICTs but thoroughly inadequate for describing the current phase. Secondly, attention to the issue is inconsistent, focusing at times on certain aspects, then on others. Finally, a significant quantity of the data available is not easily identifiable or usable (due to its method of construction, for example). Although confusion is created by the different definitions of the concept, the presence of indicators which are not always pertinent and on occasion only partially indicative, and the availability of data sets constructed by various individuals according to differing methodologies, we have attempted to outline a key for interpreting the process of e-Inclusion in Europe. This proposal is clearly exploratory in nature and may be further developed and structured in the presence of the necessary data.

Assuming as a point of reference the existing indicators used to take stock of the complexity of the concept of e-Inclusion – derived largely from the data sets constructed for the benchmarking of the plans e2005 (CEC, 2002) e i2010 (i2010 High Level Group, 2006) – a selective approach may be set forth in two broad areas, background indicators and advanced indicators. This subdivision has the advantage of providing extremely simple, concise data referring to the different dimensions and sub-dimensions, and of bringing to the fore evident differences in behaviour as well as possible tendencies for change.

Secondly, reference to the structure of the concept in different dimensions enables strengths and criticalities to be identified both in isolated contexts and at a comparative level.
Starting out from the existing data originating from various sources, adopting the subdivision of indicators into the categories ‘background’ and ‘advanced’, and using the structure of the dimensions of the concept of e-Inclusion, enables an interpretation structured according to the terms set forth in Table 8.

Tab. 8: ***Overvew of e-Inclusion Indicators***

Dimension	Sub-dimension	Description	Source
ACCESS	**Material**	**Background Indicators**	
		Percentage of population with computer at home	OECSE
		Percentage of households with access to the Internet at home	Eurostat
		Number of subscribers broken down by platform (DSL, cable, fibre, 3G, wireless connection)	Eurostat
		Percentage of households with broadband access at home	Eurostat
		Subscription numbers broken down by speed with the following thresholds 256, 512, 1024 (Kbps), 2 and 4 Mbps	I2010 (Survey of operators for electronic communications)
		Price to include installation costs and monthly charges. Prices for metered and un-metered offers separated	OCSE
		Percentage of households with access to the Internet broken down by device for accessing via PC, digital TV, mobile device (include all forms of mobile access; handheld computer, mobile phone, 3G)	I2010 (Community Household Survey on ICT usage)
		Various places in which the Internet was accessed in the last month (at home, at place of work, at place of education, at another person’s home, at Public Internet Access Point)	Eurostat
	Motivational	**Advanced Indicators**	
		Main reasons for not having Internet access at home	I2010 (Community Households Survey on ICT usage)
		Main reasons for not having broadband at home	I2010 (Households Community Survey on ICT usage)

Dimension	Sub-dimension	Description	Source
ACCESS	**Skill**	**Background Indicators**	
		Individuals' level of basic computer skills	Eurostat
		Individuals' recent training course on computer use	Eurostat
		Advanced Indicators	
		Individual's level of Internet skills (post messages to charrooms, make phone calls, file sharing, create a web page)	Eurostat
		Individuals'way of obtaining e-skills	Eurostat
	Usage	**Background Indicators**	
		Percentage of individuals regularly using the Internet	Eurostat
		Percentage of individuals who used a computer, on average, every day or almost every day in the last 3 months	Eurostat
		Percentage of individuals who used a computer, on average, at least once a week in the last 3 months	Eurostat
		Percentage of individuals who used a computer, on average, at least once a month in the last 3 months	Eurostat
		Advanced Indicators	
		Percentage of individuals carrying out specific online activities	I2010 (Community Household Survey on ICT usage)
QUALITY OF LIFE	**eLearning**	**Background Indicators**	
		Number of pupils per computer with Internet connection	Commission Study Eurostat
		Percentage of individuals who used Internet for formal educational activities (school, university)	Eurostat
		Advanced Indicators	
		Percentage of individuals who used Internet for other educational courses related specifically to employment opportunities	Eurostat
		Percentage of individuals who used Internet for post educational courses	Eurostat
		Percentage of enterprises using e-learning applications for training and education of employees	Eurostat

Dimension	Sub-dimension	Description	Source
QUALITY OF LIFE	**eHealth**	**Background Indicators**	
		Percentage of individuals who used Internet for seeking health information on injury, disease or nutrition	Eurostat
		Advanced Indicators	
		Percentage of individuals who used Internet for seeking medical advice online with a practitioner	Eurostat
		Percentage of individuals who used Internet for making an appointment online with a practitioner	Eurostat
		Percentage of individuals who used Internet for requesting a prescription online from a practitioner	Eurostat
	eWork	**Background Indicators**	
		Percentage of persons employed using computers connected to the Internet in their normal work routine	Eurostat
		Advanced Indicators	
		Percentage of individuals who used Internet for jobseeking or sending a job application	Eurostat
		Percentage of enterprises with persons employed working part of their time off site and accessing enterprise's IT system externally	Eurostat
	eCommerce	**Background Indicators**	
		Percentage of individuals who used Internet for financial services (Internet banking, share purchasing)	Eurostat
		Percentage of individuals who ordered goods or services over the Internet for private use in the last 3 months	Eurostat
		Percentage of individuals who, in the last 12 months, have not ordered goods or services over the Internet because of security concerns	Eurostat
		Percentage of individuals who, in the last 12 months, have not ordered goods or services over the Internet because of privacy concerns	Eurostat
		Percentage of individuals who used Internet, in the last 3 months, for selling goods and services	Eurostat
		Percentage of individuals having taken ICT security precautions within the last 3 months	

Dimension	Sub-dimension	Description	Source
QUALITY OF LIFE	eGovernment	**Background Indicators**	
		Number of basic public services fully available online	I2010 (web-based survey of e-Government services)
		Percentage of individuals who used Internet for obtaining information from public authorities' web sites	Eurostat
		Advanced Indicators	
		Percentage of individuals who used Internet for interaction with public authorities	Eurostat
		Percentage of individuals who used Internet for downloading official forms	Eurostat
		Percentage of individuals who used Internet for sending completed forms	Eurostat
	eCulture	**Background Indicators**	
		Percentage of individuals using Internet for reading/downloading online newspapers/ news magazines	Eurostat
		Percentage of individuals using Internet for playing/downloading games and music or movies	Eurostat
		Percentage of individuals using Internet for accessing/receiving online media subscription (such as newspapers, newsletters, etc.)	Eurostat
		Percentage of individuals using Internet for using digital broadcasting services (such as web tv or online radio),	Eurostat
		Percentage of individuals using Internet for downloading software	Eurostat
		Percentage of individuals using Internet for reading/downloading electronic books	Eurostat

As shown in the table, and as previously mentioned, the existing indicators do not enable a complete reconstruction of the three dimensions of the concept of e-Inclusion. This is true especially of the dimension of empowerment, which clearly lacks useful indicators for describing its presence or evolution. The unavailability of data on the subject is a direct consequence of an approach which attributes an enabling rather than an empowering character to ICTs. On the other hand, only in recent times, specifically beginning with the i2010 plan (CEC, 2005), has the dimension of empowerment gained relevance and attention in the identification of policies for creating an information society. Alongside this limitation one must consider also the unavailability of indicators for measuring the qualitative dimension, or subjective perception, which would provide the only guide to the state of development of the process of domestication of ICTs in the life of European citizens. Finally, the available data do not permit an interpretation at both individual and community levels.

Despite the limits indicated, which may be overcome only by means of the ad hoc collection of indicators, the data existing within the individual dimensions enable a description of the state of the process of e-Inclusion in Europe, providing a structured framework reflecting subtle differences between the various countries and the different areas affected by ICTs.

Furthermore, assuming as a reference point the experience of SIBIS (2003) in the social inclusion benchmarking which led to the construction of the DIDIX[21] Index (Digital Divide Index – version two), the construction[22] of concise indices regarding the various dimensions identified may be hypothesized.

Therefore, to construct the various indices we suggest initiating the identification of the single indicators fundamental for each sub-dimension within the dimensions of access and quality of life, to which a specific weight is attributed.

In the case of the access dimension, for example, the index related to background indicators is produced by calculating the average of the indicators selected as follows:

Sub-dimension Material Access		
Initial	**Indicator**	**Weight**
A1	Percentage of households with access to the Internet at home	0,30
A2	Percentage of households with broadband access at home	0,40
A3	Percentage of individuals regularly using the Internet	0,30

The summary value thus obtained may be considered a measure of inclusion with regard to the access dimension. As in the case of DIDIX, Index values close to 0 would indicate serious delays in the process of e-Inclusion, whereas values close to 100 would indicate completion of the process of e-Inclusion, at least with regard to the indicators concerned.

21 The DIDIX index constructed by SIBIS comprises three differently weighted indicators: percentage of computer users (50%), percentage of internet users (30%) and percentage of internet users at home (20%).

22 The same index has been used as a reference point by Hüsing (2006) to outline the features that should characterize an e-Inclusion Index (eIIx).

The same procedure can be applied to all the other dimensions, after having selected the indicators and attributing weight to each one. In the individual sub-dimensions, the indices will be constructed by attributing a different weight to background and advanced indicators, reflecting the complexity and structure of the same sub-dimension.

Again by way of example, the indicators useful for describing the sub-dimension of eLearning are as follows:

Sub-dimension eLearning indicators		
Initial	**Indicator**	**Weight**
L1	Percentage of individuals who used Internet for formalised educational activities (school, university)	50%
L2	Percentage of individuals who used Internet for other educational courses related specifically to employment opportunities	30%
L3	Percentage of individuals who used Internet for post educational courses	20%

The eHealth sub-dimension:

Sub-dimension eHealth indicators		
Initial	**Indicator**	**Weight**
H1	Percentage of individuals who used Internet for seeking medical advice online with a practitioner	50%
H2	Percentage of individuals who used Internet for making an appointment online with a practitioner	30%
H3	Percentage of individuals who used Internet for requesting a prescription online from a practitioner	20%

The eWork sub-dimension:

Sub-dimension eWORK indicators		
Initial	**Indicator**	**Weight**
W1	Percentage of persons employed using computers connected to the Internet in their normal work routine	40%
W2	Percentage of individuals who used Internet for jobseeking or sending a job application	30%
W3	Percentage of enterprises with persons employed working part of their time off-site and accessing enterprise's IT system externally	30%

The eCommerce sub-dimension:

Sub-dimension eCOMMERCE indicators		
Initial	**Indicator**	**Weight**
C1	Percentage of individuals who used Internet for financial services (Internet banking, share purchasing)	40%
C2	Percentage of individuals who ordered goods or services over the Internet for private use in the last 3 months	30%
C3	Percentage of individuals who used the Internet, in the last 3 months, for selling goods and services	30%

The eGovernment sub-dimension:

Sub-dimension eGOVERNMENT indicators		
Initial	**Indicator**	**Weight**
G1	Percentage of individuals who used Internet for obtaining information from public authorities' web sites	40%
G3	Percentage of individuals who used Internet for downloading official forms	30%
G4	Percentage of individuals who used Internet for sending completed forms	30%

The eCulture sub-dimension:

Sub-dimension eCULTURE indicators		
Initial	**Indicator**	**Weight**
CU1	Percentage of individuals using Internet for reading/downloading online newspapers/ news magazines	40%
CU2	Percentage of individuals using Internet for playing/downloading games and music or movies	30%
CU3	Percentage of individuals using Internet for using digital broadcasting services (such as web tv or online radio),	30%

At this stage it will be possible to create a general index of e-Inclusion based on the sum of the points given in the individual sub-dimensions. A general index thus constructed undoubtedly has the advantage of summarizing in a single figure the positions occupied by individual countries or groups at risk within a country. However, it is important to remember that that these summary measurements must always be considered alongside those relating to the individual sub-dimensions in order to identify strengths and weaknesses in the process of e-Inclusion.

8 Concluding Remarks

The above described analyses clarify which type of direction should be followed in further studies. The extreme variability and complexity of available data have to be taken into account in the mechanism of "information extraction". This can be done by building an aggregate measure, a composite index, capable of including ICT data as well as several types of related information such as policy objectives and other factors influencing technological development. With this in mind the next step of this analysis would be the identification of a synthetic index of technological diffusion to be adopted in modelling the ICT impact on growth.
Composite indicators have become very popular in several policy areas, including those related to information society, mainly because of their promise to capture and reduce complexity of multi-dimensional concepts. However, they have to be build with extreme care, very often they are computed by applying several transformations to data and simple indicators and using arbitrary weighting systems, so that the final reading of their values can be highly distorted.

As a concluding contribution to this section a proposal for the building of a composite technological development index is briefly outlined:

1 Policy objectives can be introduced by classifying indicators values accordingly.
2 The choice of a standardization strategy must be made. A proposal by Ott and Hunt (1976) written for air quality index evaluation can be adopted. This standardization function allows to keep intra-class differences in the process.
3 No arbitrary weighting system will be used. If the need for such system arises, weights' choice could be based on the opinion of a pool of experts quantified by applying an "objective" criteria, such as the *Multi Criteria Decision Making Model*. We will use a model called Analytic Hierarchy Process (AHP), introduced by Thomas Saaty in 1977 and well illustrated in Satty et al. 2001. The model is useful to translate qualitative opinions into a quantitative weighting, through a series of pairwise comparisons1. Comparisons should be made by one or more human decision makers, with expertise on the subject.
4 The composite indicator must allow the treatment of missing values and it must be able to discriminate between countries.

CHAPTER IV

TECHNOLOGY AND PERFORMANCE: A COMPARATIVE ASSESSMENT OF COMPUTABLE GENERAL EQUILIBRIUM MODELS (CGE)

1 Introduction

This chapter reviews a sample of existing Computable General Equilibrium Models (CGE) with the purpose of identifying their ability to model and simulate the impact of technology on economic performance. The list of selected models cannot be considered as exhaustive but as representative for the available quantitative tools. They have been chosen particularly because of their wide application and/or because of their endogenous treatment of innovation. The criteria we use to compare and evaluate these models include the complexity of transmission mechanisms, methodological aspects, the number of relevant endogenous variables, the level of sectoral disaggregation and the endogenous treatment of technical change.

The purpose of the Chapter is twofold. On the one hand, the evaluation will be used to choose the CGE model to be employed for simulation exercises of the impact of ICT on economic performance; on the other hand it will help identifying possible ways of introducing ICT in several CGE models, considering the complexity of the transmission mechanisms available in the models. We will come back to these issues in the next Chapters.

The chapter is organized as follows. It starts (section 2) with a review of the empirical studies that model and estimate the impact of ICT on growth and productivity in single equation models. This section highlights the most commonly used approaches to model the transmission mechanisms of ICT in the economy and discusses the uneven diffusion and impact of ICT across countries. However, most of the existing quantitative studies fail to capture the pervasive effects of ICT accumulation and diffusion on economic performance since they mainly treat ICT as an input in the production function.

Section 3 briefly describes the multi-equation models and carries out a comparative assessment based on the following criteria: i) performance variable; ii) structural specification and detail; iii) methodological approach.

Section 4 focuses on the main interest of the study, i.e. the transmission of the effects of technology improvements on economic growth. Technological progress may originate from an exogenous shock or from an endogenous process. The review presented in this section only considers CGE models in which technological change is endogenous and describe in some detail the modelling of technological innovation, mainly in terms of R&D investment, and the transmission mechanisms from innovation to performance variables.

Section 5 presents a review of policy simulation exercises (an increase in R&D expenditures) that have been carried out using CGE models with the aim of shedding more light on the transmission mechanisms of innovation in the economy.

2 The contribution of ICT to Growth Performance and Single Equation Models[1]

Growth theory and growth empirics have undergone a revival from the mid-1980s. The neoclassical growth model paradigm has been revised to overcome its major limitations (New "augmented" neo-classical models) and a new growth approach has been introduced, the so-called "Endogenous growth model" (see Barro and Sala-i-Martin, 1995; and Aghion and Howitt, 1998 for comprehensive reviews). As to growth empirics, the recent wave of research has at first concentrated on cross-country studies and on panel data econometrics and, more recently, on time series and distribution dynamics (Durlauf and Quah, 1998).

From the mid-1990s, almost a decade after the start of the new growth debate, many studies have attempted to assess the contribution of ICT to growth performance and empirical works have flourished in particular in the US. Such studies have mainly been inspired by the growth-accounting methodology and have provided initial answers to many key issues.

A first problem to be tackled has been the measurement issues involved in the *definition* of the ICT sector itself, and in the economic evaluation of its different components (the ICT goods). This problem is now largely solved as the OECD provides an official definition of ICT, and *ICT goods and services* are evaluated taking into account their "intrinsic" quality (in the US by calculating hedonic pricing: see OECD, 2001, for an assessment of methodological issues).

Another problem was the definition of *productivity* and productivity dynamics as considered in the new-economy literature. The distinction between the production and use of ICT is central in this respect. According to a simple two-sector neoclassical framework, if we measure the growth contribution of technical progress in the sectors *producing ICT*, we have to compute *total factor productivity* (TFP) in the ICT-producing industries, as in this case technical progress is associated with an outward shift of the production function. If, on the other hand, we have

1 This section is largely based on Section 4.2 of the "Review of the theoretical literature" prepared for the EU project "Sustainable growth, Employment creation and Technological Integration in the European knowledge-based economy" (SETI), see www.seti.coleurop.be.

to measure the impact of *ICT utilization* on the productivity of the whole economy, we have to calculate the variation in *average labour productivity (ALP)* associated with the economy-wide rise in ICT investment (see Stiroh, 2001). This is a fundamental distinction as the overall impact of ICT on per capita output crucially depends on which is the main channel of productivity improvement, and on the relative weight of the ICT sector in the economy. The contribution of technical progress is smaller, the lower the relative weight of the ICT-producing sector. On the other hand, time is required for the new ICT capital goods to fully generate a permanent effect on labour productivity.

An additional related issue is whether productivity spillovers are associated with ICT investment. In this case too, we can observe spillovers due to the diffusion of technical progress from the *ICT-producing* sectors, and productivity spillovers due to the *use of ICT* in the rest of the economy (network externalities; technical complementarities with other innovations being generated in other sectors, such as the aerospace industry). In both cases, one has to distinguish between a neoclassical constant-returns-to-scale (CRS) paradigm, and an increasing-returns-to-scale (IRS) paradigm: no spillovers are possible in the first case, whereas they are possible in the second one. In general, empirical analysis is needed to discriminate between models. In addition while the literature on the economic impact of ICT has made progress in taking into account sectoral differences, the majority of these models are based on single equations, thus their ability to take into account structural aspects and changes are indeed very limited.

During the years of the so-called "Computer productivity paradox" (broadly speaking, the 1980s and the first half of the 1990s) (Triplett, 1999), the contribution of ICT services to growth was sluggish (Jorgenson and Stiroh, 2000). The paradox faded away in the second half of the 1990s, when the contribution of ICT to aggregate growth was estimated as being substantially larger. Jorgenson and Stiroh (2000) report that the contribution of computer hardware alone rose from 0.19 percentage points per year in 1990-95 to 0.46 percentage points in 1995-98; adding computer software and communication equipment, the global contribution of ICT to growth amounted to 0.75 percentage point in the second period. Slightly different figures are given by Oliner and Sichel (2000), who estimate a contribution of computer hardware of 0.25 percentage points per year in 1990-95, and of 0.63 in 1995-99. Both studies recognize the important role of ICT capital accumulation in the resurgence of US productivity growth in the late 1990s.

The reason why ICT investment was so late in materialising in aggregate accounting data was the limited size of both the ICT producing sector and of the ICT capital good stock at the beginning of the 1990s. This means that, in spite of a sustained technical progress and

TFP growth *in the ICT sector*, only a sustained boom in ICT investments during the 1980s and 1990s produced a sufficient amount of information technology inputs to affect significantly economy-wide productivity growth. In turn, ICT investment may act either as a substitute or a complement to other capital expenditure. However, in both cases one is likely to expect a positive contribution to growth through the ALP channel; either because ICT investment replaces more traditional, and less productive capital goods or because of capital deepening.

In 1999, the Economics Department of the OECD launched an ambitious two-year research project on "Sustainable growth and the New Economy", which, over time, has provided a large number of comparative studies on the nature and dynamics of innovation- and information-based growth. Also thanks to this initiative comparative studies have flourished.

Comparative studies assess two key issues. Firstly, the apparent gap in the size and diffusion of the ICT sector in continental Europe with respect to the US by the midst of the 1990s (Daveri, 2000). Fagerberg, Guerrieri and Verspagen (1999) have argued that the problems that Europe faces in terms of low rates of growth and high rates of unemployment are partly linked to the unsatisfactory performance of European countries in science based industries and in ICT in particular. Second, the growth performances of continental Europe and Japan have been remarkably worse than those of the US in the 1990s, although the gap in ICT diffusion has been progressively closed over the decade (Schreyer, 2000). This evidence poses a number of intriguing research questions. In the first place, is there still a gap in ICT adoption in Europe, or is it currently being filled? Second, what was (or, is) approximately the time lag in ICT adoption between the US and other main industrial countries? What is the time lag in the contribution of ICT to growth? What are the key features of the US growth mechanism of the 1990s, and what are the essential "systemic" features in order for a "New Economy" to be established in industrial countries? Let us review some of the answers to these questions.

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). But according to the OECD (2001) the wedge between leaders and slow adopter countries has not been closed since the mid-1990s.

This brings us to another issue outlined above. The US experienced a record period of uninterrupted growth during the 1990s, while the pace of economic growth has been sensibly reduced in continental Europe. Of course, many factors have contributed to these outcomes, but according to Daveri (2000), the growth contribution of ICT was substantial in the UK and the Netherlands, and rapidly increasing over the 1990s in Finland, Ireland and Denmark. This interpretation is therefore consistent with the hypothesis of a lag in the European adoption of ICT (say, five to seven years). Following the US experience, one could expect a more relevant contribution of ICT to European growth in the near future, and possibly several years of rising per capita output.

Schreyer (2000) offers a different view and suggests that both a methodological bias (namely, different measurement techniques) and the lack of a strong ICT-*producing* sector in continental Europe could explain the different growth contribution of ICT in the US and in the other G7 countries. Further evidence seems to reinforce this scepticism on possible “automatic” prospects for productivity growth in Europe in the near future. In a study adopting a harmonised price index and a new method for the treatment of software (considered as capital expenditure and not as intermediate consumption), the authors come to the conclusion that, while the role of ICT is relevant and increasing in the US, Canada, Australia and Finland, there is no evidence of an increasing contribution of ICT to growth in other industrial economies (OECD, 2001). Furthermore Roeger (2001), by using a calibrated two-sector-two-skill growth model of the US and European economies, featuring both an ICT-producing and an ICT-using sector, and skilled and unskilled labour, shows that higher rates of *TFP growth or technical progress* are at the core of the productivity growth leap in the US. In turn, TFP growth is associated with the US comparative advantage in the production of high-tech ICT goods. Hence comparative (dis)advantages and not Eurosclerosis in general must be blamed for the lower growth performance in Europe.

The above highlights another relevant issue, the role of structural factors in the comparative performances of the OECD economies, as well as the impact of factor markets on the different outcomes on the two sides of the Atlantic (and the Pacific as well). For instance, if financing of innovation is one of the key issues, in line with the Schumpeterian perspective on the role of financial markets, the contribution of capital markets to the development of the New Economy is crucial. Furthermore modelling the impact of ICT on growth, productivity and employment performances must take into account not only the dimension of the ICT efforts, but the interaction between technological and organizational changes, on the one hand, and the crucial role played by institutions in favouring or hampering the diffusion of ICT across countries, on the other.

The literature on technological paradigms (Perez, 1983, 1985, 1988; Freeman and Soete, 1987; Freeman and Perez, 1988; Fagerberg, Mowery and Nelson, 2005) and the neoclassical literature on ICTs share the view that ICTs play a crucial role in their ability to impact on different sectors of the economy. They also share the view that major innovations such as ICT generate imbalances in the system and that it takes time to exploit their full potentials. Moreover such innovations also involve organizational and social changes, if a new techno-economic paradigm is to be established.

The literature on the economic impact of ICT has made progress in taking into account sectoral differences (e.g. distinguishing between ICT producing, ICT using and non-ICT industries as in Van Ark, Inklaar and McGuckin, 2003 or in considering manufacturing and service sectors, Guerrieri, Maggi, Meliciani, Padoan 2005). The majority of the models however, are based on single equations thus their ability to take into account structural aspects and changes is limited, to say the least.

The explicit consideration of the interaction between ICT, producer services and the structure of the economy (as in Guerrieri, Maggi, Meliciani and Padoan, 2005) may also help to better understand why a given ICT effort can determine very different outcomes across countries, depending on their specialization pattern, degree of regulation and European integration, and development stages of the producer services sector. Even more so, since it is generally recognized that employment in advanced economies is increasingly dependent on services. Evangelista and Savona (2001) argue that technological change is likely to play an important role also with respect to the overall dynamics of employment in services.

Nevertheless, the overall impact of technological change on employment in services is very difficult to assess empirically, because of the coexistence of positive and negative direct effects and the influence of a complex set of compensating mechanisms, operating both within the service sector, between the service and the manufacturing sectors, and, increasingly at an international scale. In addition, the lack of data and systematic analyses of the service sector has so far made the assessment of the relationship between technological change and employment in services very difficult. In absence of robust statistical evidence, the literature abounds with optimistic scenarios on the employment perspectives driven by the new technological paradigm.

Most of the contributions have emphasised the positive employment effects of ICTs, both at the firm level and the service sector as a whole. On the other hand others have focused on the possibly negative effect of technological change on employment due to the labour-saving impact of process innovations and on the extent to which the capability of the system to compensate the initial displacement is effective. As it has been pointed out (Vivarelli, 1995) whereas the labour-saving effects of process innovations are only partly compensated elsewhere in the system, the job creation effects of product innovations can be very substantial and have a powerful compensating impact to the extent that the profits from labour saving process innovation are subsequently channelled, directly or indirectly, into the development of new products and services. This has been particularly evident both in the US and in East Asia, but apparently Europe has not benefited much from this mechanism. Empirical models that aim at understanding the impact of ICT on employment should thus take into account such mechanisms and should include a disaggregated structure to capture the compensating mechanisms across sectors.

We have already discussed the specific nature of ICT and its ability to have pervasive effects throughout the economy in Chapter 2. To take single equation models into considerations is important in the context of this research, since it suggests how to model the impact of ICT on variables of interest such as GDP growth and employment. However, for policy analysis, multi-equation models have the advantage of taking into account a richer set of relationships and endogenous variables (such as consumption, exports, imports, prices, etc).

3 A Comparative Assessment of Computable General Equilibrium Models (CGE)

In this section we describe the main characteristics of a number of Computable General Equilibrium Models (CGE) models that can be used to evaluate the impact of ICT investment on the economy. We also consider some methodological aspects. The list of models examined cannot be considered as exhaustive but they are representative of the range of available quantitative tools.

The models we have reviewed are the followings:

1. **NEMESIS**, developed by the Research Group System's Analysis and MacroEconomics Modelling (ERASME) of the École Centrale Paris, the Belgium Federal Planning bureau, the Chambre de Commerce et d'Industrie de Paris, and the Institute of Computers and Communication Systems;
2. **MULTIMOD** developed by the IMF (International Monetary Fund);
3. **WORLDSCAN** developed by the CPB (Netherlands Bureau for Economic Policy Analysis);
4. **QUEST** developed by the European Commission;
5. **NiGEM** developed by the National Institute of Economic and Social Research (NIESR);
6. **International Futures (IFs)** developed by Prof. Barry B. Hughes of the Graduate School of International Studies, University of Denver;
7. **Oxford World Macroeconomic Model** and the BAK Oxford New IIS (NIIS) Model of the Oxford Economic Forecasting;
8. **GEM E-3** Model developed by the National Technical University of Athens.

3.1 NEMESIS

NEMESIS is a Macro-Sector Econometric model designed to asses the effect of structural policies, to study short- and medium-run consequences of economic policies and to provide short/medium-term forecasts for producing base line scenarios. The model covers EU-15 countries plus Norway, and each of the country models includes 30 sectors and 27 consumption categories. All the behavioural equations are based on the assumption that there exists a long-run equilibrium, but that there are rigidities that prevent the adjustment process to be instantaneous. All equations are estimated through an Error Correction Model (ECM), using Engle and Granger methodology. NEMESIS also includes an Energy/Environment module that describes the power/steam generation sector.

All model equations are behavioural equations. One main feature of the model is to cover a large number of sectors, each of which is described by a simple structure. Equations in each sector describe production and demand with intra and extra Euro area trade, domestic and foreign prices, factors demands with corresponding prices. Prices include production prices and retail prices with a mark-up. Once prices are determined, consumption is allocated for various categories of consumer goods. Countries are linked via trade and sectors interactions are considered by means of five conversion matrices referring to final consumption, intermediate consumption, investment, technology (R&D) and energy.

As the model is fully estimated and the ECM procedure enables to consider short and long run aspects, the question arises how to combine non-stationary data, from which the ECM is obtained, with the optimization scheme.

3.2 MULTIMOD

MULTIMOD is a dynamic multi-country macro-econometric model. Its focus is the transmission of shocks across countries and short- and medium-run consequences of fiscal/monetary policy action. MULTIMOD is not intended to be a forecasting tool: the baselines for the simulations are derived from the medium-term IMF's World Economic Outlook projections, which are then extended into a model-consistent balanced-growth path. The model includes two separate sets of equations for each country and for the economy as a whole: 1) a set of dynamic equations (DYNMOD), and 2) a system of steady state analogue equations (SSMOD). The dynamic model explains the evolution of macroeconomic variables towards the steady-state equilibrium, which is described by the system of analogue equations.

In the steady state, each of the industrial country models grows at an exogenous growth rate (population and Total Factor Productivity growth) and it is characterized by the behaviour of four units: households, firms, non-residents, and fiscal authorities: i) Households choose between consumption and saving and thus determine the level of wealth; ii) Firms determine the stock of physical capital through investments; iii) Governments determine the level of public debt, and iv) Non residents, through international trade and by financial borrowing and lending with domestic residents (i.e. determining the net foreign asset position), make these positions consistent. Moreover, in the steady state real exchange rates are fixed at the level that generates the trade and the current account flows which are associated with the steady-state stocks of net foreign assets, the interest rates level is such, that global saving matches global investments.

MULTIMOD includes a specific model for each of the seven largest industrial countries (Canada, France, Germany, Italy, Japan, the U.K. & the U.S.), a single model for an aggregate group of the fourteen smaller industrial countries, and two other models for the rest of the world (developing countries and transition economies). The model is not able to capture the consequences of shocks on the different sectors of the economy. In fact, in the model each country produces a single good (main-composite good). The model also includes the oil sector, the non-oil primary commodities sector, and, for the developing country block, a non-tradable good sector. The model treats oil and non-oil primary commodities as homogeneous goods with a single world market price: the price of oil is exogenous, whereas the price of non-oil primary commodities is endogenously determined. Hence, international trade consists of trade in the main composite good, in oil and in non-oil primary commodities.

3.3 WORLDSCAN

Worldscan is a dynamic Computable General Equilibrium (CGE) model with a long term focus. It does not describe plausible short-run dynamics. The model is not designed to evaluate the reaction of the economy to specific shocks with comparative static/dynamic exercises. Its focus is to analyze structural changes. Worldscan is composed of up to 87 country/regions and 57 sectors. Each sector has a different factor requirement which is however the same in each region. The developing countries include a low productivity sector.

Worldscan is a calibrated model with the exception of a number of estimated equations. The model is large, due to the fine sectoral coverage and large number of countries, Worldscan is also manageable, thanks to well specified hypotheses. The steady state hypothesis is rather compelling in that it constraints the model to be used in a strictly specified long term context. One example of such constraints is the form of the production function that resembles the Leontief formulation, given the small elasticities assigned to the productive factors. This choice is acceptable in a short term context; however it reveals a possible contradiction with the philosophy of the model. Moreover to obtain convergence of the paths of the variables to their steady state, some coefficients are derived ad hoc.

Worldscan can provide more insights than Multimod for the purpose of the present book as it specifies spillovers in a larger context. Spillovers are gauged on specific sectoral TFP and can originate from other sectors. One critical aspect is the side-effect, deriving from the rest of the model in determining total TFP.

3.4 QUEST

QUEST is a Business Cycle and Growth Model that focuses on and the transmission of economic shocks on the Member States of the European Union. The model is not a forecasting tool, as it has been designed to carry out simulations. QUEST includes a structural country model for each of the EU-15 Member States, a model for the US, a model for Japan, and a trade feedback model for each of ten other regions (Canada, Australia, Norway, Switzerland, Rest of OECD countries, OPEC, Central and Easter European countries, the Asian NICs, other NIC, and the Rest of the World).

QUEST does not offer the possibility to analyse the effects of shocks in the different sectors of the economy. In the model each country/region produces a single good, conceived as an imperfect substitute of the other countries' goods. For short run analysis the model is characterized by Keynesian features; with prices and wages that are imperfectly flexible, and investment and labour adjustment costs. The behaviour of the model in long term analysis is similar to a standard neo-classical growth model: with the steady state growth rate being determined by the rate of (exogenous) technical progress and the growth rate of population.
As for Worldscan, a steady state is fundamental for the solution of the model and constitutes the terminal condition for each simulation. Changes in technology are very traditional of the type "Labour or Capital oriented".

3.5 NiGEM

NiGEM is a one-sector estimated model, designed to produce short-run forecasts as well as long-run simulations. The model incorporates a single country-model for each of the OECD countries, as well as for China, Russia, Hong Kong, Taiwan, Brazil, Estonia, Latvia, Lithuania and Slovenia. In addition, there are six regional blockmodels: Latin America, Africa, East Asia, Developing Europe, OPEC and a miscellaneous group. However, models of the G7, EU-15, Poland, Hungary and the Czech Republic are more detailed than the other country and regional models.

NiGEM exhibits 'New-Keynesian' characteristics: because of rigidities that prevent instantaneous convergence to the equilibrium, nominal shocks have a real impact on the economy in the short/medium – run, but these effects die out in the long run.

Technical progress is exogenous and it determines the long run equilibrium, together with labour and interest rates. The estimation technique is ECM. All the equations are not treated as interdependent but as single equations.

NiGEM is a multi-country model. Like Quest, the model has the drawback that technology is exogenous, conditioning directly the steady state solution and contributing in that way to the simulations. The model doesn't provide insights on the transmission effects of research efforts to the economy, or to the level of technology.

3.6 International Futures (IFs)

International Futures (IFs) is a large-scale integrated global modelling system that focuses on the analysis of short-and long-term issues. IFs covers 164 countries for each of which there are seven models: population, economic, agricultural, energy, socio-political sub-model, international political sub-model, environmental, implicit technology model.

For each country/region the economic model includes six sectors (agriculture, energy, primary materials, manufactures, services, and ICT) and two household types (high-skilled and low-skilled). Each country is modelled through a dynamic general equilibrium seeking-model: meaning that the system is not in equilibrium at each point in time, it rather converges toward equilibrium over time. In this framework, changes in inventory stocks and prices work as signals for agents (both firms and households). The agricultural and energy sectors are not part of this system, in the sense that they are modelled bottom-up, with a partial equilibrium model. Finally, the economic module has been introduced into a social accounting matrix (SAM) so that economic production and consumption are connected to intra-actor financial flows.

IFs models are calibrated sectoral multi-country models. In addition to calibration, the model makes use of SAM to determine coefficients and simulation outputs. Such an instrument, being the analogous of the input-output table for immaterial goods, is of accounting relevance, and can be used only for short term purposes and not for simulation or forecasting. The technology module is set out in an accounting additive basis. Technology is related to exogenous variables (such as deregulation and others), a feature of interest for the present study. IFs also include a specific module for ICT (see the section related to the treatment of technology).

The model includes a detailed explanation of technology, also as a function of ICT. Furthermore, the model is a sectoral one. Provided that the calibration is frequently updated, its implementation might give relevant insights thanks to the combined effects of sectoral detail and technology-ICT.

3.7 Oxford Economic Forecasting

The Oxford Economic Forecasting (OEF) model is composed of two sub-models: the Oxford World Macroeconomic Model, is a macro-econometric model, whereas the BAK Oxford New IIS (NIIS) Model is a sectoral model. The two models can operate separately or together. The macro-econometric model has been constructed to perform forecasts and to simulate country/world impact of economic shocks. The NIIS model is used to perform forecasts at a sectoral level. The BAK model derives the sectoral forecasts from a set of macroeconomic projections.

The macroeconomic model consists of forty-four countries and six regional blocks. The countries are treated with different levels of details (ranging from 25 to more than 250 variables) with US, Japan, Germany, France, Italy, UK, Canada, and China being the countries with the higher level of detail. The BAK model covers ten countries (US, Japan, Germany, France, Italy, UK, Spain, the Netherlands, Sweden and Belgium), and provides also aggregates for Western Europe and the Triad (Western Europe, US, and Japan).

The appealing characteristics of these models are the high level of sectorialisation and the mix of the two techniques. The model offers the possibility to produce an output suitable for statistical testing other than with frequent updating. The model's poor specification of technology is a disadvantage.

3.8 GEM-E3

The GEM-E3 model is an applied general equilibrium model in which the world is divided into 18 zones that are linked together with endogenous trade. Each of the zones has the same model structure, but parameters and variables are zone specific. The economy is divided into 18 sectors. Four of the sectors are involved in the supply and distribution of energy and the remaining sectors are broad aggregates of the rest of the economy.

The production in each sector is modelled by using a nested constant-elasticity-of-substitution (CES) production function. The use of inputs and primary factors in each sector follows from a procedure involving several steps; at each step, inputs and primary factors are optimally combined according to a constant returns-to-scale CES production function and the producer behaviour is modelled on the basis of standard assumptions about profit maximisation in a perfectly competitive environment.

The two primary factors of production are capital and labour. The labour market is assumed to be perfectly competitive and total labour supply is determined by households that maximise their utility functions. For each period, the model endogenously allocates the available labour force over sectors. Capital is a quasi-fixed variable, and is defined in a way that allows firms to change next year's capital stock by investing in the current year. It is further assumed that the stock of capital is immobile between sectors and countries.

The households are modelled as one representative household, which can supply labour, save, invest and consume thirteen consumer goods. The representative household allocates its resources in an intertemporal environment. The household's consumption behaviour is derived from utility maximisation. The demand for products by the household, the producers and the public sector constitutes the total demand. It is allocated between domestic products and imports, following the Armington specification. The major advantage of this model for our purposes is the detailed sectoral disaggregation.

3.9 A Comparative Assessment

A comparative assessment of these models for the purpose of the current study requires looking at three aspects:

i performance variable;

ii structural specification and detail;

iii methodological approach.

Table 1 summarizes this assessment.

With respect to the *Performance Variable* the models are very similar. None of the models includes Total Factor Productivity as a performance variable, whereas in all models GDP (either computed in levels or in growth rates) is a performance variable. With respect to the *structural specification and detail*, the models exhibit different characteristics. The main feature we are interested in is the sectoral dimension. As the literature points out, ICT has different impacts on economic sectors; hence a sectoral dimension is an important condition for a model to properly evaluate the impact of ICT. Models with a structural dimension are Worldscan, NEMESIS, IFs and GEM-E3.

On the basis of the *Methodological Approach*, the models can be classified between those that are calibrated and those that are estimated. Both are potentially capable to analyse the effects of ICT investment on the economy. In general, it is not possible to say whether a calibrated model is better than an estimated model or vice versa, as they are different types of models that rely on different properties and hence have different pros and cons.

Such models often carry a large dimension (i.e. a large number of equations necessary to adequately represent the economy). The detailed level of sectoral specification of some of the models accounts for the huge number of equations (in some cases an order of thousands of equations). In this context it is straightforward to impose the restriction of the steady state

Table 1: ***Model Assessment and Comparison***

Reference Parameters		**WorldScan**	**NEMESIS**	**QUEST**	**MULTIMOD**	**International Futures**	**NiGEM**	**Oxford Economic Forecasting**	**GEM-E3**
Performance Variable	Economic Growth or Total Factor Productivity	Economic growth	GDP	GDP	GDP	GDP	GDP	GDP	GDP
	Employment Effects	No	Yes	Yes	Yes	No	Yes	Yes	Yes
	Social Inclusion and/or Sustain-able Development	No	No	No	No	Yes	No	No	Yes
Structural Specification and Detail	Multi-Equation vs. Single Equation	Multi-equation	Multi-equation	Multi-equation	Multi-equation	Multi-equation	Multi-equation	Multi-equation	Multi-equation
	Exogenous vs. Endogenous innovation process and techno-logical change	Endogenous in the extension	Endogenous	Exogenous	Endogenous in the extension	Endogenous	Exogenous	Exogenous	Exogenous
	Aggregate or Sectoral Dimension	Sectoral	Sectoral	Aggregate	Aggregate	Sectoral	Aggregate	Sectoral	Sectoral
	Input-Output Linkages and/or Technological Spillovers	Technological spillovers in the extension	Yes	No	Technological spillovers in the extension	No	No	No	No
	Microeconomic Foundations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Flexibility in Simulations of Policy Impact	Yes	No	No	No	Yes	No	Yes	Yes
Methodological Approaches	Non Structural Approach	No	No	No	No	No	No	No	No
	Structural Approach	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous Time Approach	No	No	No	No	No	No	No	No
	Estimation Vs. Calibration	Calibration	Estimation	Calibration	Estimation	Calibration	Estimation	Both	Calibration

hypothesis and to concentrate the analysis to the long run (Worldscan, Multimod, Quest). Consequently it is necessary to neglect the short run or transition equations and obtain simpler relations, possibly expressed in levels. However, given the need either to save degrees of freedom in the estimation phase or to quantify coefficients -and then to calibrate them- and the fact that short run relations actually matters, the long run hypothesis is often contaminated with short run assumptions. These often derive from input/output tables that underlay each sectoral model. As examples, we mention the low elasticities of substitution, characterizing the production function in Worldscan, which reflect rigid isoquants as in the Leontief case; or the sectoral spillover effects of R&D, based on the combination of an estimated long run relationship with the input/output coefficients, or with the import/output ratio for the external spillover effects (also Multimod). In such a model, in fact, very often the concept of long term is confused with that of long run. The difference is substantial, as in the first case we refer to a limit approachable condition; while in the second case we refer only to desirable condition. Consequently the results of such models have to be interpreted very carefully especially with regards to the timing effect of the policy implications. A strategy to overcome this problem is a frequently updated calibration of the coefficients – whereby the implementation of such a method is based on the historical ex-post variables considered (IFs) – rather than the estimation and the use of accounting methods.

Other relevant methodological aspects include: (1) the coherence of the hypotheses underlying the models and (2) the choice of the methodology employed to identify the relevant coefficients or simulation outputs. The first aspect is not only relevant from a conceptual or theoretical point of view, but also from an empirical one, and when applying the model. Some of the hypotheses, in fact, might be incorrect, when coupled with an empirical strategy that implicitly relies on a different vision of the world. The second methodological aspect is related to the empirical tool used and the extent to which it is appropriate, having as a term reference the data set and variables used, and the specification of the system of equations.

As regards the coherence between the method and the data and variables, the questions that arise are related to (a) the functional forms and (b) the econometric method. The first observation pertains exclusively to Nemesis as it is the only model that includes, though only in special cases, estimates based on economic theory, whereas the other models are calibrated. As usual in these cases, the functional form chosen might help in the estimation, because it can justify omitted endogenous variables. For example theory might be forced on the model as in the case where perfect competition in factor markets is to be proved at aggregate or sectoral level. Moreover, when dealing with an approximated nonlinear function, it is fundamental to adopt a functional form that approximates the true functional from an econometric point of view.

Other models suffer from the opposite problem. In NiGEM, and the modulus estimated of Worldscan and Multimod, the functional form is linear according to the correct statistical method used. A combination of the two methodological approaches – i.e. using calibration or estimation – can be found in the Oxford models, where calibration allows for a more frequent revision of the parameters.

To summarise, the pros and cons are the result of the commendable attempt to use large models to study a wide range of policy implications, and the difficulties that arise when implementing and managing such dimensions. The models that better balance these two extremes are the IFs and Oxford models; the former for the results it provides at sectoral levels, linked with ICT (which is not considered in other models), the latter also for the highly detailed sectorialisation, together with an appropriate (ECM) statistical tool.

4 The Treatment of Technological Change in CGE

One key aspect in this review is the transmission mechanism of the effects of technology improvements on economic growth. Therefore, in this section we consider only models with endogenous innovation. NEMESIS and INTERNATIONAL FUTURES (IFs) include a treatment of endogenous technical change (albeit with very different assumptions). MULTIMOD and WORLDSCAN do not include endogenous technological change in their original version, but have been updated in later versions. We focus our attention on these four models.

4.1 Technological Change in NEMESIS

Nemesis is one of the few macro-econometric models that consider endogenous technological change with the advantage of having a detailed sectoral disaggregation (thirty sectors including both manufacturing and service industries). The sectoral disaggregation is important since R&D expenditure displays different intensities and impacts in the different sectors of the economy. Moreover it is well known that one of the main effects of technological progress is structural change, and this phenomenon can be taken properly into account only through a disaggregate analysis.

In NEMESIS the endogeneity of technological change is modelled in three stages:

1 from R&D to knowledge;

2 from knowledge to innovation;

3 from innovation to economic performance.

From R&D to the stock of knowledge. The R&D stock for each sector is determined by R&D expenses taking a constant rate of depreciation into account. For each sector the stock of knowledge depends on the own sector's R&D stock, and also on the R&D stock of other domestic sectors, on the R&D stock of foreign sectors and on the government's R&D stock. Externalities deriving from R&D carried out in other domestic sectors are modelled, using the input/output coefficients of a matrix of technological linkages across sectors as weights. This matrix is built following the methodology of Johnson (2002), using information on patents registered at the European Patent Office, considering the sector of production and use of the patent.

From the stock of knowledge to innovation. Innovation is determined by the variation of the stock of knowledge and is separated between process and product innovation. Process innovation increases sectoral TFP, while product innovation, given the number of sectors in the NEMESIS model, increases quality. The two types of innovation have different impacts on economic performance.

From innovation to economic performance. Process innovation increases TFP through two effects: i) an increase in the supply of goods; ii) a decrease in prices. The decrease in prices has an impact on demand that depends upon the sectoral price elasticities of demand. If the value of the elasticity is equal or larger than unity, the increase in demand meets the increase in supply with no change in employment. However, since econometric estimations on time series reveal elasticity values smaller than one, process innovation generally decreases employment because of excess supply. Product innovation increases the volume unit efficiency, reduces unit prices, increases demand in efficiency units and the volume of demand. In general, product innovation leads to an increase in employment that is higher than the decrease in employment due to process innovation, so that R&D leads to an increase in both GDP and employment.

4.2 Technological Change in WORLDSCAN

The endogenisation of technological change in WORLDSCAN is due to Lejour and Nahuis (2005), aiming at assessing the impact of trade liberalization on growth in the presence of trade-related R&D spillovers. The model is estimated (and simulated) at a disaggregate level, as in NEMESIS. TFP depends on the own sector's R&D stock, on the R&D stock of other domestic sectors and on the R&D stocks of other foreign sectors. It is therefore possible to take into account the role of domestic and foreign knowledge spillovers. Domestic spillovers are included using an input–output weighted summation of the own-R&D stocks of the delivering industries, whereas foreign spillovers are taken into account considering the other regions' industries' stocks, weighted with import relations.

4.3 Technological Change in MULTIMOD

The endogenisation of technological change in the MULTIMOD model is due to Bayoumi, Coe and Helpman (1996) and to Bayoumi, Coe and Laxton (1998). In the standard version of MULTIMOD total factor productivity and the labour force are exogenous. Although in each country investment need not equal savings (because the gap can be financed by international capital flows), the inter-temporal budget constraints imply that the long run growth of the capital stock is determined by the growth of labour and of total factor productivity. In the long run, growth of output is determined by the same factors, and the capital output ratio is constant. An implication of these relationships is that the long-run growth rate of per capita output is entirely determined by the growth rate of total factor productivity that, in the original version of the model, grows at a constant exogenous rate.

Bayoumi, Coe and Helpman (1996) and Bayoumi, Coe and Laxton (1998) endogenise TFP as a function of the domestic and foreign R&D stocks whereby the foreign R&D stock is interacted with the country share of imports of manufactures on GDP (a proxy for the degree of openness of the country whereby trade is assumed to be a vehicle for R&D spillovers). The modelling of the TFP equation is different for the various groupings of countries. In fact in small developing countries the impact of domestic R&D is assumed to be smaller (or zero), while trade directly enters the TFP equation and not only as interaction with foreign R&D spillovers. TFP impacts GDP growth not only directly, but also indirectly by affecting capital accumulation. Differently from NEMESIS and WORLSCAN, MULTIMOD does not allow the consideration of intersectoral R&D spillovers.

4.4 Technological Change in International Futures (IFs)

IFs is a multi-sector model that is less disaggregated than NEMESIS and WORLDSCAN but includes a specific ICT sector. Technology is modelled in the “Economics” part of the model in the section “production of goods and services”. Similarly to NEMESIS, WORLDSCAN and MULTIMOD, IFs uses a Cobb-Douglas production function with disembodied technology/human capital that is considered as multifactor productivity. Together with capital and labour (that are also endogenous) total factor productivity contributes to GDP production. Like capital and labour, multifactor productivity is treated as a stock, augmented or decreased by an endogenously computed annual change.

Growth of multifactor productivity is the key relationship in the long-term dynamics of the model. IFs groups the many drivers of multifactor productivity into five categories, recognizing that the categories overlap somewhat. The base category is based on convergence theory, with less developed countries gradually catching up with more developed ones. The four other categories incorporate factors that can either slow or accelerate convergence, transforming the overall formulation into one of conditional convergence.

The convergence base. The base rate of multifactor productivity growth is the sum of the growth rate for technological advance or knowledge creation of a technological leader in the global system and a convergence premium that is specific to each country/region. The basic concept is that it can be easier for less developed countries to adopt existing technology than for leading countries to develop it (assuming some threshold of development has been crossed). The base rate for the leader remains an unexplained residual in the otherwise endogenous representation of TFP.

Knowledge creation and diffusion. Changes in the R&D spending, computed from government spending on R&D as a portion of total government spending, contribute to knowledge creation, notably in the more developed countries. Many factors contribute to knowledge diffusion. For instance, growth in electronic and other related networking should contribute to diffusion, in spite of the fact that the empirical basis for estimating that contribution is skimpy.

Human capital quality. This term has two components, one deriving from changes in educational spending and the other from changes in health expenditure, both relative to GDP.

Social capital quality. An addition to growth can come from changes in the level of economic freedom. The parameter was estimated in a cross-sectional relationship of change in GDP level from 1985 to 1995 to the level of economic freedom.

Physical capital quality. There is a close relationship between energy supply availability and economic growth. For instance, a rapid increase in world energy prices makes much of the capital stock less valuable. IFs uses the world energy price relative to world energy prices in the previous year to compute an energy price term.

All the adjustment terms (for R&D expenditures, human capital quality, etc.) are computed on an additive basis, as adjustments to underlying patterns, and can be added to compute the overall productivity growth rate. They are all applied to the potential value added in each sector.

Finally, IFs contains an implicit technology module that is distributed throughout the overall model and allows changes in assumptions about the rates of technological advance in agriculture, energy, and the broader economy. The IFs model explicitly includes the extent of electronic networking of individuals in societies and is tied to the governmental spending model with respect to R&D spending.

4.5 Overall evaluation and suggestions

For the assessment of the various models we focus on the following criteria:

i Richness of transmission mechanisms.

ii Complexity of the factors affecting technology;

iii Degree of sectoral disaggregation;

iv Presence of domestic and foreign spillovers;

v Presence of diffusion effects

Richness of transmission mechanisms. As far as transmission mechanisms are concerned, NEMESIS is the more articulated. R&D impacts on both GDP and employment by affecting at the same time supply and demand. Moreover, process and product innovations are treated separately and the possible counteracting effects on employment are explicitly modelled. In all other models technology only affects supply by positively affecting TFP.

Complexity of the factors affecting technology. In NEMESIS, MULTIMOD and WORLDSCAN technology depends only on R&D (domestic and foreign). The richest representation of factors affecting technological accumulation can be found in IFs. Together with R&D expenditures, the model considers educational and health expenditure (both relative to GDP), an institutional factor (economic freedom), energy supply and a convergence premium for developing countries, due to the possibility of innovation diffusion from countries that are technological leaders. IFs, however, does not consider technological spillovers.

Degree of sectoral disaggregation. NEMESIS has the higher degree of sectoral disaggregation (30 sectors including services), followed by WORLDSCAN and International Futures. However IFs has the advantage of having a separate ICT sector. MULTIMOD is an aggregate model.

Presence of domestic and foreign spillovers. Domestic and foreign spillovers are present in NEMESIS, WORLDSCAN and MULTIMOD. In NEMESIS the modelling of domestic spillovers presents the advantage of weighting other sectors' R&D expenditures by a technological matrix (rather than the more traditional I/O matrix) and to take public R&D expenditures into account. Nevertheless, the treatment of foreign spillovers appears rather simplistic (there is no attempt to weight them with the degree of openness). WORLDSCAN and MULTIMOD are more accurate in the treatment of foreign spillovers. In particular WORLDSCAN has the advantage of weighting foreign spillovers with imports at the sectoral level. MULTIMOD also uses imports, but only as an interacting variable and at an aggregate level.

Presence of diffusion effects. Some of the models take technology diffusion via foreign spillovers indirectly into account (NEMESIS, WORLDSCAN and MULTIMOD), whereas in IFs, technology diffusion is modelled as a convergence premium for less advanced countries. Nevertheless, the mechanisms leading to diffusion are not modelled.

An overall evaluation of multi-equation models suggests the following considerations:

i Richness of transmission mechanisms;

The transmission mechanisms in the models do not allow a full view into the impact of technological change on growth, international competitiveness, employment and social inclusion. In all models (except NEMESIS), technological change only affects TFP and, therefore, economic growth (in NEMESIS also employment). This is a weakness of the models, which on the other hand, are rich enough to possibly incorporate the impact of technology on other variables of interest. This is particularly true for the impact on international competitiveness, where product quality (as a function of technology) could be added into the import and export equations with no major problems of overall consistency. The impact on employment might be more problematic, since the majority of these models have a neo-classical inspiration, therefore aggregate demand does not affect employment. However, MULTIMOD presents some Keynesians features in the short run (inflation-unemployment nexus) and technology could be assumed to affect the long run natural rate of unemployment. In WORLDSCAN, labour supply and the unemployment rate are exogenous for both high-skilled and low-skilled workers (except for non OECD countries, where employment for low skilled workers is modelled following Lewis, 1954). The role of technology (and, in particular ICT) could be added in affecting employment and wages for low and high skilled workers (with the impact on wages and on unemployment depending on the degree of flexibility of the labour market). Finally as far as indicators of sustainable development are concerned, the IFs model appears to be better suited, in comparison to the other models, to study the impact of technological change since IFs includes sub-models (such as an energy model, an environmental model and a socio-political model).

ii Complexity of factors affecting technology.

In order to make innovation endogenous, it is important to consider various factors affecting technology accumulation and diffusion, other than R&D expenditures. Among these factors, human capital is an important variable (which is partially taken into account in IFs as education spending). Moreover, the role of some categories of services for innovation could be taken into account. Finally, a better understanding of technology accumulation and diffusion should involve an explicit effort to model some institutional and compositional features, which for a given level of R&D (or ICT) effort, can result in very different outcomes.

iii Degree of sectoral disaggregation.

Although the degree of sectoral disaggregation in some of these models (NEMESIS, WORLDSCAN) is rather accurate, it is not the most appropriate factor for modelling the impact of technology. In this respect, different sectoral aggregations, considering for example innovation taxonomies (which also take the role of services into account), or input/output relations, could better capture the different role of technology in various groups of sectors.

iv Presence of domestic and foreign spillovers.

The modelling of spillovers (both domestic and foreign) in WORLDSCAN is, (considering appropriate weighting matrices) in our view, the most appropriate. Nevertheless, a further improvement could be obtained by considering a technological variable with a bilateral dimension.

v Presence of diffusion effects.

Some sort of "catching up" effect (as in the IFs model) can be a way of modelling diffusion (but should be improved by allowing the convergence premium to depend on a set of variables that can hamper or favour the diffusion process). Another, possibly complementary, way of treating diffusion is by modelling foreign spillovers, taking into account some measures of "proximity" among economies (which can be related to the extent of bilateral trade, but also to technological transactions).

5 Simulations of the Impact of R&D in CGE models

As a further source of information in this section we discuss the results of some simulation exercises in a subset of the models (the ones for which such exercises are available). We focus on simulation exercises that include an increase in R&D expenditures, since this is a technology policy that shares some common features with an increase in ICT expenditures. Both in NEMESIS and in WORLDSCAN the exercise consists in meeting the Lisbon target of 3% share of R&D in GDP in 2010, while in MULTIMOD two R&D policy actions are simulated: an increase in R&D expenditures in one of the G7 countries and a simultaneous increase in R&D expenditures in all industrial countries. While the first two simulations can be compared rather easily, the study of the simulation results in all models sheds light on transmission mechanisms and on the variables that are affected by a technology policy in all three models.

5.1 Simulations with NEMESIS

Hypotheses. In NEMESIS the simulation scenario for an increase in R&D expenditure is the following:

i the elasticity of economic growth to the stock of knowledge increases from 0.075 in 2002 to 0.124 in 2030;

ii one third of TFP gains goes to workers while the remaining two thirds go to firms;

iii almost all the increase in R&D expenditure is due to the private sector, only 0.16% of the supplementary effort is due to the government (in 2010 R&D expenditures increase by 1.14% of GDP with 0.16% due to the government and 0.98% to the private sector);

iv 70% of the increase in R&D is carried out in the private sector and 30% in the public sector;

v there are no increases due to public procurement.

Results for Europe as a whole. In NEMESIS the impact of R&D on growth and employment can be divided into two phases, the first affecting the income multiplier (Keynesian mechanism) and the second affecting TFP (supply-side impact). In the first phase (*growth due to the multiplier effect*) lasting until about 2010, the increase in R&D acts as a multiplier. Though, the increase in total factor productivity is slow[2] (0.8%) since there are important lags in the impact of R&D on productivity. In this phase the increase in GDP is 1.7% for an increase in R&D of 1.1% of GDP (a multiplier of 1.6). The increase in GDP leads to an increase in employment via the Phillips curve. Employment increases by 1.4% in 2010. Until 2008 the increase in employment is higher than the increase in GDP due to the fact that the increase in R&D spending requires a rise in employment in the R&D sector. All components of domestic final demand increase; in particular total consumption by 2.4%, due to the increase in employment and disposable income, and total investment by 1.8%. During the first phase there is an increase in prices due to the increase in domestic demand and to the fact that most of the increase in R&D is financed by firms through higher prices (until 2008 when the increase in productivity compensates the R&D effort). Due to the increase in prices and in consumption there is an increase in imports (1.7%) and a decrease in exports (0.2%), with an overall increase in the trade deficit. After 2008 the external deficit decreases due to the deceleration of inflation.
In the second phase (*growth due to innovation*) innovation produces its effects on total factor productivity that increases by 0.8% until 2010 (1.92% in 2015, 3.11% in 2020, 5% in 2030) and on product quality (by 2,1 % in 2010, 4,9 % in 2015, 7,5 % in 2020, 11,1 % in 2030). Demand increases due to the decrease in costs and prices and to the increase in product quality. In this context exports increase and imports decrease despite the increase in final consumption, with a positive impact on the trade balance. Private investment, on the other hand, increases more slowly due to the increase in total factor productivity (by 2.1% in 2015, 3% in 2020, 5.9% in 2030). Employment increases by 4.9% in 2030 much less than the increase in GDP (12.1%). Labour productivity increases by 8.1% in 2030 and a large part of the increase in employment is due to increase in the R&D sector (the increase in the employment net of the R&D sector is only 3.4% in 2030). Overall GDP increases by 12.1% (which is a surplus

2 All increases are computed with respect to the baseline.

of 0.5% per year in real terms) without taking into account the increase in product quality, total consumption increases by 15.5%, exports by 13.7% and imports decrease by 3.2%. The fact that most of R&D expenditure is financed by the private sector avoids an increase in the government deficit.

Country and sectoral aspects. The fact that European countries have very different starting points in terms of R&D intensity (with a minimum of R&D/GDP share of 0.67 in Greece to a maximum of 4.27% in Sweden in 2000) leads to different impacts across countries. In particular, while the mechanisms are the same, the size of the gap and therefore the increase in the R&D effort varies across countries with the consequence that in the first phase laggard countries lose competitiveness with respect to R&D intensive countries, but, at the end of the period, the impact of R&D on total factor productivity is larger in laggard countries with a for that reason higher GDP growth.
At the sectoral level four types of sectors are identified: 1) R&D intensive sectors; 2) Intermediate goods sectors; 3) R&D intensive intermediate good sectors; 4) Consumption goods and service sectors. Overall the sectoral trends are similar to the macroeconomic trends but intermediate goods sectors tend to shrink relative to the other sectors since there is a decrease in demand for intermediate non R&D intensive goods due to the increase in total factor productivity.

Alternative scenarios:

i *Different elasticities of growth to the stock of knowledge.* There are two alternative hypotheses. In the first one the elasticity increases to 0.141 in 2030 (rather than 0.124) and the change is higher in R&D intensive sectors. In this scenario GDP and employment grow more (GDP growth is 16.3% versus 12.1% in the base scenario). In the second hypothesis the elasticity grows to 0.10 and there are neither sectoral nor country differences. In this case growth in GDP is 10.9% and employment grows much less than in previous scenarios.

ii *Different distribution of productivity gains between employers and employees.* In the base scenario employees receive 1/3 of the increase in productivity. Two other scenarios are simulated. One in which all the increase in productivity goes to employees and one in which all goes to employers. There are some differences in growth performance in the latter two scenarios although not very pronounced (the main difference is that in the first case consumption increases more while in the second case exports increase more due to the decrease in prices). Major differences are observed for employment growth that is much higher in the case of wage moderation (third scenario).

iii *Different R&D policies.* In this scenario the increase in R&D is fully financed by governments. The consequence is higher GDP growth (15.2%) and employment growth both in the first phase (when the multiplier effect operates) and in the second phase (when growth is due to increases in supply). This is because the increase in public expenditure avoids the price increases associated with private investment in R&D. The overall effects might be exaggerated by the fact that the model does not consider the possible increase in interest rates due to the increase in government deficit. However, at the end of the process the public deficit does not increase. This evidence suggests that there can be important gains in increasing government R&D with only in the short run increases in deficits.

iv *Public procurement.* The last exercise assumes that part of the increase in R&D is due to an increase in government demand to R&D intensive sectors. It is assumed that increases in government demand in 2010 are 2.5% of GDP. This leads to a growth of 8.9% for chemical goods, 12.1% for office and computing machinery, 18% for electrical goods, 9.4% for transport goods. This increase is however not sufficient to reach the Lisbon goals and must, therefore, be complemented by an increase in private R&D spending (2/3 of the total supplementary increase in R&D). The consequences of this scenario are more favourable in terms of both GDP growth and employment compared with the base scenario. Although, in the first phase there is a larger loss in competitiveness due to an increase in prices as a consequence of increasing demand. Overall productivity increases less in labour intensive sectors with a positive impact on overall employment growth.

5.2 Simulations with WORLDSCAN

In the extended version of WORLSCAN with endogenous technical change there is a simulation of the impact of raising the R&D share of GDP to the 3% level as indicated in the Lisbon Agenda.

Hypotheses. The parameters to model the impact of R&D on TFP are taken from the estimation of a TFP equation with own sector's R&D, domestic spillovers and international spillovers. The results of the estimation report are a sector's elasticity of 4.9%, a domestic spillovers' elasticity of 7.4% (both lower than in other studies) and a foreign spillovers' elasticity of 5.6% (similar to that found by Coe and Helpman, 1995) for a total impact of R&D on productivity of 18.0%. With this elasticity the return to R&D is much higher: for a Euro spent on R&D, growth increases by 0.9 euros, that is a rate of return of 90%. This is an upper bound of the results of other studies. Since these estimates refer to a marginal increase in R&D expenditures (while the increases necessary for achieving the Lisbon Agenda goals are substantial) a lower rate of return (30%) is assumed. This assumption depends on the fact that more profitable projects are undertaken first and, therefore, only when there are substantial increases in R&D expenditures also less profitable projects will be financed, with a lower impact of R&D on TFP and GDP growth.

The simulations assume that the Lisbon goal of R&D to GDP reaching 3% are achieved in 2010 and the policy tool is a R&D subsidy. This is an aggregate subsidy so that there are no differences across sectors and is financed by lamp-sum taxes on consumers (the exercise, therefore, does not take into account possible negative effects of proportional taxes, i.e. the distortions they create).
It is also assumed that the gap between current R&D spending and an artificial target is covered by increasing R&D expenditure between 2005 and 2010. The artificial target is set at 4.5%. For each country the gap between current spending and the limit of 4.5% is proportionally decreased, in such a way that the 3% level for the EU is reached in 2010. Countries with initially less spending on R&D have to increase their R&D effort substantially, while countries with initially high R&D spending face less ambitious targets. Their R&D spending will exceed the target of 3%.
Finally some assumptions on the elasticity of substitution between the R&D stock and the capital-labour in production are to be made. Empirical estimates of the elasticity of substitution are lacking and in most theoretical models an elasticity of 1 is assumed. Since most economists think that R&D and physical capital are complementary, which implies a low elasticity, in sensitivity analysis the parameter is set to 0.5 while in the base simulation a 0.9 level is assumed.
In the simulation exercise R&D spending in the EU increases by more than 50% between 2005 and 2010. However, R&D stocks do not increase proportionally because 3% spending only takes place in 2010 and the depreciation rate of R&D is considered to be 11%. The model assumes that the governments stick to the 3% target between 2011 and 2020. After that, even with a constant subsidy rate, R&D investment (and thus spending) will return to a level of replacement investment that belongs to the R&D stock which will be less than 3% of GDP. The reason for is lies in the baseline WORLDSCAN model, in which the R&D to GDP ratio is bound to decrease due to a shift of the economy towards less R&D intensive sectors (services) and because simulations suggest that less R&D intensive countries will grow on average more than R&D intensive countries with a negative composition effect for Europe as a whole.

Results for Europe. Results of simulations are reported till year 2025. Over the period the R&D stock in the EU is increased by about 66%, causing a GDP gain of about 3.2% (higher than the baseline). This corresponds, by and large, to a R&D elasticity of 5%. The increase in productivity leads to lower producer and export prices. This causes a negative terms-of-trade effect. Consumption will increase about 2% and exports by about 6%. Finally real wages increase by about 3%. For Europe as a whole the R&D subsidy is of the order of 1% of GDP. The government subsidy leads also to an increase in private spending in R&D which is in the short run limited (15% of the extra public expenditure) while in the long run the leverage effect disappears and all the increase in private spending is financed by the subsidy.

Country and sectoral aspects. The country results depend more or less on the country's distance from the target. Stronger impacts are observed for laggard countries (Italy, Spain, Ireland and Portugal have growth rates of about 4% and Greece and new entrants higher than 4%, while Sweden shows a gain of only 0.7% due to international spillovers). In 2020 in Germany, France, and the UK the subsidy rate is in the same order of magnitude of Europe as a whole (1% of GDP). For Italy and Spain it is much higher and for countries like Greece, Poland, Hungary and Slovakia the R&D subsidy is even 2% of GDP.

There are sectoral differences in the impact of the R&D subsidy since sectors make different uses of R&D inputs. First of all, the stimulus of R&D benefits the R&D sector. Demand for its output rises substantially while labour productivity hardly increases, because it is assumed that the R&D sector itself does not use R&D as input. On the other hand employment in R&D increases by 75%.

The most R&D intensive sectors (medium-high technology and high technology manufacturing) benefit most from lower input prices for R&D. Labour productivity increases most in these sectors while in the other sectors this effect is smaller. As a consequence of the R&D subsidy the EU countries will also export relatively more high technology goods.

The other sectors benefit less from the boost in R&D because they are less R&D intensive and because the demand for labour in the R&D sectors attract employees from the other sectors. In particular in the services industries Europe loses competitiveness.

Alternative scenarios. The alternative scenario uses the estimated elasticities of R&D (that are much higher than those assumed in the baseline scenario) with a rate of return of R&D of 90%. In this case the increase in R&D for Europe is on average slightly larger (75% instead of 66%). Also the GDP effects are much higher (about 10% in 2025) with consumption increasing by 7%, exports by 16% and real wages by 9.5%. Country trends are similar but the variation is more pronounced.

A second exercise assumes a different value for the parameter of the substitution between R&D and capital and labour (0.5 rather than 0.9, both in the simulation and in the baseline). With this value the macro effects will be about half a percentage point lower. For the EU as a whole, GDP and consumption increase 0.3% and 0.6% respectively, while export increases by 0.4% more. The reason is that the level of R&D expenditures is on average higher in the baseline scenario. Over time sectoral R&D expenditures decrease in the baseline because R&D becomes more expensive than labour. Firms want to substitute R&D for labour. Due to the low elasticity of substitution firms have less substitution possibilities. Thus the R&D stock as well as the expenditures are higher in the new baseline. For all countries the subsidy and the increase in the R&D stock will be lower.

Finally the same sensitivity analysis has been conducted with the assumption of larger returns to R&D. The results show that this does not make much difference so that it can be concluded that, also in the absence of valid estimates of the substitution between R&D and capital and labour, the results are robust to the value of this parameter.

5.3 Simulations with MULTIMOD

General assumptions. In the extended version of MULTIMOD with endogenous technological change, two simulations exercises concerning R&D have been undertaken (Bayoumi, Coe and Helpman, 1986). The first is an increase in R&D expenditure in individual G7 countries, and the second is a simultaneous increase in R&D expenditures in all industrial countries. In both cases the model focuses on the long run and the baseline is taken from the October 1995 World Economic Outlook projections to the year 2000, so that each country adjusts slowly to a steady state by the year 2075. In each simulation, tax rates adjust endogenously to achieve a pre-specified path for real government debt, and real government spending is assumed to remain constant relative to potential GDP. In addition, the money supply is kept proportional to potential GDP, which leaves the price level broadly unchanged.

In the simulations, the increases in R&D expenditures are assumed to raise business consumption, a new element of aggregate demand is introduced into the MULTIMOD model for these simulations. The Cobb-Douglas factor shares in the production function determine the allocation of the increase in GDP between profits and wages. The simulated increases in R&D expenditures, which are sustained throughout the simulation period, are assumed to be financed out of future business profits. The reduction in the discounted value of future profits lowers the market value of the physical capital stock and hence physical investment. In effect, enterprises must forego fixed investment in order to increase R&D expenditures.

The impact of an increase in U.S. R&D expenditures. The simulation consists of a sustained increase in R&D expenditures that is equivalent to 0.5% of GDP, which represents an increase in the level of real U.S. R&D expenditures of about 25 percent relative to baseline. The bulk of the rise in the R&D capital stock takes place early in the simulation period as a progressively larger proportion of the higher R&D expenditures are needed to replace a growing amount of obsolete R&D capital. After 15 years, the R&D capital stock has increased by about half its long-run value and by 2075 it has risen by almost the full amount of its steady-state increase of about 40%.

The higher R&D capital stock implies an increase in the future level of total factor productivity, potential output, and profits. This increase in future profits, however, has to be weighed against the extra costs of firms to finance the higher level of R&D spending. In the first few years, the increased cost of R&D expenditures dominates, and both the market value of the capital stock and business fixed investment decrease. The boost to aggregate demand from higher R&D spending and consumption also increases real interest rates, which further reduces investment in the short run. From 2003 onward, however, the discounted benefits from future

profits cause both the market value of the capital stock and investment to start to rise sharply. Physical investment increases relatively fast for the next 15-20 years and then begins to taper off as the actual capital stock slowly adjusts to the higher level of its market value.
In contrast to investment, real consumption rises steadily throughout the simulation as consumers react to the expected increase in future wealth.
Compared with the baseline, the level of potential output in the United States is about 4% percent higher in 2010 and 9 percent higher in 2075, with the time pattern reflecting the simulated paths of the increases in the R&D and physical capital stocks. During the first 15 years, almost all of the increase in potential output is due to higher total factor productivity, but by 2075 the rise in the physical capital stock accounts for about one quarter of the total increase in output. The annual growth of real output is more than 0.3 percentage point higher during the first 10 years of the simulation compared with the baseline. Growth remains stronger than in the baseline, although by progressively smaller amounts, throughout the 80 years of the simulation. In the last 25 years, potential output growth is only 0.025 percentage points higher than in the baseline. In the long run, the rate of growth returns to the same level as in the baseline.
The rise in output in the United States relative to the rest of the world would require a real devaluation of the U.S. dollar to create the needed demand for higher U.S. exports. This represents one channel through which other countries are affected by the higher output in the United States. In MULTIMOD, R&D spillovers represent an additional channel of influence through which other countries benefit from the increase in U.S. R&D expenditures. The foreign R&D capital stocks of U.S. industrial and developing country trading partners increase 24% and 20% respectively by 2075 compared with the baseline. The increases in the foreign R&D capital stock in specific countries and regions depend on the relative weight of U.S. imports compared with imports from other industrial countries. Manufacturing imports are the vehicle for the R&D spillovers. The higher imports of U.S. trade partners from industrialised countries stemming from the depreciation of the dollar magnify the impact on growth from the rise in their foreign R&D capital stocks. In the United States, on the other hand, manufacturing imports as a share of GDP decline somewhat with the depreciation of the dollar, which also reduces the spillover from foreign R&D capital arising from R&D investment by U.S. trade partners.
The rise in foreign R&D capital interacting with the import share boosts total factor productivity, investment, and potential output in trade partners of the U.S. in much the same way as the rise in domestic R&D did in the United States. Potentially output increases gradually, again slowing down after 15-20 years. By 2075, potential output in other industrial countries is 3% percent above its baseline level while potential output in the developing countries is 4% higher. On average, the developing countries benefit more than the industrial countries, reflecting the greater scope for catching up through R&D spillovers implied by the larger elasticities.

In order to assess the impact on welfare it is important to focus on the dynamics of private consumption. In the United States, private consumption is 7% above baseline by 2075. This is to some extent a smaller rise than the 9 percent increase in output. The opposite occurs for the other countries and regions. By 2075, the average percentage increase of consumption in other industrial countries is one and a quarter times that of output.
Similar exercises conducted for the other G7 countries give similar results. The main difference is that domestic effects tend to be larger and international effects smaller. Moreover the geographical distribution of the effects changes depending on the structure of trade.

The impact of a simultaneous increase in R&D expenditures in all industrial countries
A simultaneous, exogenous increase in R&D expenditures in all industrial countries equivalent to 0.5% of GDP (with both domestic and foreign R&D capital stocks increasing about 50% in all countries by 2075) has an impact on potential output, TFP, and private consumption. Potential output is 18.75% above the baseline in 2075 and TFP increases account for about ¾ of the increase in output. Private consumption increases 17.25% above the baseline on average in industrial countries, with larger increases in Europe compared to the U.S.

5.4 Simulations with INTERNATIONAL FUTURES

International futures is a model with endogenous innovation. Moreover, it has a specific ICT sector and it is therefore a good candidate for simulating the impact of ICT on economic performance. We are not aware of any existing simulation exercise of this kind with the IFs model. This is a potentially fruitful line of research that we will pursue in Chapter 5.

5.5 Overall Evaluation of the Modelling of Technology and Simulation Exercises

Table 2 reports a summary of the characteristics of multi-equation models that can be used in order to evaluate their relative performance with respect to the ability of modelling and simulating the impact of technology policies (see also section 4.5).

Table 2: ***A summary of the characteristics of multi-equation models that can be used in order to evaluate their relative performance with respect to the ability of modelling and simulating the impact of technology policies***

	WORLDSCAN	**NEMESIS**	**INTERNATIONAL FUTURES**	**MULTIMOD**
Variables affecting technology	R&D	R&D	R&D, education, health, energy prices, freedom, distance from the leader	R&D
Transmission mechanisms	R&D affects TFP	R&D affects both supply and demand	R&D affects output	R&D affects TFP
Variables directly affected by technology	TFP	TFP and employment	TFP, OUTPUT	TFP
Sectoral disaggregation	YES	YES	YES	aggregate
Presence of domestic spillovers	YES	YES	NO	NO
Presence of foreign spillovers	YES	YES	NO	YES
Diffusion effects	Through imports	NO	Through the convergence premium	Through imports
Technology simulation exercise	Target of 3% of R&D on GDP	Target of 3% of R&D on GDP	No (See Chapter 5 for various new simulation exercises on ICT)	Increase in R&D in industrial countries

A look at the table shows that, among the models with endogenous technological change, NEMESIS has the advantage of modelling the impact of technology not only on Total Factor Productivity, but also on employment, distinguishing between product and process innovation. As a consequence, also in the simulation exercise, we can distinguish between short run impacts of technology policy (technology affects demand) and long run impacts (technology affects TFP), with different behaviours of some variables (for example prices increase only in the short run and in the short run the trade balance deteriorates while the opposite occurs in the long run). WORLDSCAN and MULTIMOD present a more convincing treatment of foreign spill-overs (in the MULTIMOD simulation of an increase in R&D expenditures in the US the impact via spillovers on other countries is easily shown). WORLDSCAN has the advantage of presenting a sectoral disaggregation that allows studying the important structural effects of technology policy. Finally, IFs does a good job in presenting a richer treatment of technology (not only R&D expenditures) but is less articulated than NEMESIS in modelling the transmission mechanisms and, differently from WORLDSCAN, does not model domestic and foreign spillovers.

6 Final Remarks

In this chapter we have reviewed some CGE models with the purpose of identifying their ability to model and simulate the impact of technology on economic performance. The models have been assessed considering their general structure, methodological approach and treatment of technological change. We have also reviewed single equation studies of the impact of ICT on performance. Complex CGE models offer the possibility to study the impact of innovation on many different variables but have not provided a completely satisfactory treatment of innovation. Moreover, with the exception of IFs, they have not explicitly considered ICT. On the other hand the assessment of single equation studies is important to identify the role of ICT for performance and to highlight transmission mechanisms but the single equation studies cannot capture the pervasive impact of ICT on the economy. In the next chapters we suggest different ways of modelling the impact of ICT on economic performance with various degrees of complexity, and taking into account the trade-off between complexity in transmission mechanisms and the necessity of simplification that is intrinsic in quantitative exercises.

CHAPTER V

ICT AS A GENERAL PURPOSE TECHNOLOGY (GPT): MODELLING ITS IMPACT ON PERFORMANCE USING IFS

1 Introduction

The existing CGE models with endogenous technical change cannot fully capture the complex mechanisms through which ICT influences economic performance. However some transmission mechanisms can be identified in the various models. At a first degree of approximation ICT can be introduced in these models as a variable directly affecting TFP and/or GDP (the traditional way in which R&D simulation exercises have been conducted). However this approach neglects indirect effects and can be improved at least in three, relatively simple, ways. First, the list of endogenous variables that are affected by ICT could be extended by including employment and international competitiveness. Second, the interaction between ICT and other variables affecting the overall business environment (such as regulation, sectoral composition, and human capital) could be taken into account. Third, the uneven impact of ICT across sectors could be considered as well.

As far as the issue of extension of endogenous variables is concerned, MULTIMOD and WORLDSCAN suffer from the limitation of assuming full employment and from assuming that technology affects endogenous variables only via the supply side. NEMESIS does better in this respect since it distinguishes between process and product innovation with different impacts on growth and employment. Process innovation acts as to increase sectoral total factor productivities, while product innovation, given the fixed number of sectors in the NEMESIS model, acts as to increase quality. This approach can be useful to model the impact of ICT since ICT involve both process and product innovation. IFs platform is rigid with respect to the modification of the underlying economic model and it allows only scenario exercises on a limited set of structural parameters affecting different nexus between endogenous variables.

In NEMESIS process innovation increases total factor productivity with two effects: i) an increase in the supply of goods; ii) a decrease in prices. The decrease in prices has an impact on demand that depends upon the sectoral price elasticities of demand. If the value of the elasticity is equal or larger than unity the increase in demand meets the increase in supply with no change in employment. However, since econometric estimations of time series reveals an elasticity smaller than unity, process innovation generally decreases employment because of excess supply.

Product innovation increases the volume unit efficiency, reduces unit prices, increases demand in efficiency units and the volume of demand. We can therefore expect that product innovation leads to an increase in employment. Therefore, the overall impact of ICTs on employment will depend on the relative magnitudes of the positive impact of product innovation and the negative impact of process innovation. We can expect that there will be important sectoral differences in the size of the two effects so that ICTs will lead to a process of structural change in which some sectors will grow in terms of employment while other sectors will experience job losses. Following this approach the overall effects of ICTs on employment will also differ across countries, depending on the sectoral composition of the economy.

In order to capture the impact of ICTs on employment in the models considered (WORLDSCAN, IFs and MULTIMOD) some modifications would be required. In the case of MULTIMOD, despite the assumption of the Long-Run Natural Rate, some indirect effects of ICT on employment could be captured via the Okun's law equation that translates movements in the output gap to movements in the unemployment gap. However more interesting effects could be captured by introducing rigidities in the labour market and by allowing demand to affect employment at least in the short run. In this respect it is important to keep in mind that the aggregate nature of MULTIMOD would not allow capturing the impact of ICT on structural change. Therefore, considering the main changes that are required in the model in order to study the impact of ICT on employment and the impossibility of capturing sectoral differences, we conclude that MULTIMOD is not appropriate for our purposes.

In WORLSCAN, for OECD countries the unemployment rate of both high-skilled and low-skilled workers are exogenous, while for non-OECD countries the unemployment rate for high-skilled workers is exogenous and the unemployment rate for low-skilled workers is modelled following the concept of Lewis. As it is, the model is, hence, unable to capture the impact of ICT on employment, however, its disaggregate nature and its distinction between high and low skilled workers make it a better candidate (in comparison to MULTIMOD) to be modified in a direction that allows specifying transmission mechanisms from ICT to employment. Introducing some rigidities in the labour market would make employment depend on demand and since ICT would affect demand differently in the various sectors employment would increase in some sectors and decrease in other sectors. Moreover employment shares between high and low skilled workers could also change as a result of the introduction of the new technologies. Similar considerations can be made for IFs with the advantage of having a separate ICT sector and the disadvantage of not distinguishing between high and low skilled workers.

The existing CGE models offer some opportunities for modelling the impact of ICT on international competitiveness. WORLDSCAN models two way trade using an Armington specification where market share depends on product prices and previous market shares. In MULTIMOD imports and exports depend on relative prices and respectively on domestic and foreign activity. In IFs exports respond to production and relative prices while imports respond to income and prices. Finally NEMESIS is the only model where R&D stocks have been added as explanatory variables in trade equations to capture the role of innovation. In this respect the existing models could easily be improved by adding technology as an explanatory variable in import and export equations along the lines suggested by the technology-gap theories of trade (e.g. Soete, 1981; Fagerberg, 1988; Amendola *et al.*, 1993; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995; Verspagen and Wakelin, 1997; Fagerberg, 1997; Anderton, 1999; Laursen and Meliciani, 2000; Carlin *et al.*, 2001; Laursen and Meliciani, 2002; Montobbio, 2003). Since most of the studies on the role of technology in affecting market shares have found that the relative importance of cost and technology variables varies across sectors models with a sectoral disaggregation should be preferred for conducting simulation exercises. Since ICT have important effects on product and process innovation, they could have both a direct impact on trade via the increase in demand and an indirect impact via a change in relative prices.

The qualitative literature on the determinants and effects of ICT has emphasized the crucial role played by the “business environment” in facilitating or hampering the adoption and diffusion of the new technologies. A report by Indepen (2005) on the role of ICT for achieving the Lisbon Agenda has underlined that simply increasing total investment in ICT will not, in itself, deliver improvements in productivity and economic growth. To be productive, this investment also requires complementary changes in the way organisations are structured and function, as well as changes in human capital.

Among the main reasons behind Europe’s lag in ICT investment is the lower profitability and effectiveness of ICT investment in Europe. Indepen (2005) identifies several factors that are responsible for lower profitability and, therefore, lower levels of ICT investment is Europe. These are: (a) difficulties in making investments in organisational change, (b) employment protection, (c) inappropriate educational and skill levels, (d) product market regulation, (e) low levels of service market integration across Europe.

While several qualitative studies have stressed the importance of these factors, no attempt to model their impacts on ICT investment and on ICT profitability has been undertaken. It is, therefore, important, when trying to model the impact of ICT on economic performance, to take into account the interaction with organizational and structural variables. This can be done in multi-equation models by introducing ICT investment into output or TFP equations allowing for different elasticities according to countries’ levels of regulation, structural composition of the

economy, levels of human capital, etc. Moreover, it is important to recognize that national and international policy makers cannot directly affect the total amount of ICT investment. Therefore, they must be able to identify the determinants of private investment in ICT if their policies ought to be effective. Also in this respect the complementarities between ICT and institutional and structural variables should be taken into account in simulation exercises (see Chapter 6 for a more extensive discussion on this issue and an attempt to endogenise ICT).
Finally, we recall that one of the stylised facts of ICT diffusion is that it has been uneven across sectors, spreading from ICT-intensive industries (computers, electronic components, telecommunications) to the whole economy with different impacts across sectors on growth, productivity and employment creation/destruction (for a detailed discussion of this evidence see Chapter 2). The higher the degree of sectoral disaggregation of CGE models the better will, therefore, be their ability to capture this feature of ICT. In terms of policy issues one can ask whether a higher aggregate impact on the economy can be achieved by concentrating ICT expenditures in the leading sectors or rather enhancing the rate of diffusion to the user sectors (e.g. some service sectors such as business, communication, finance). The answer to this question can possibly also depend on the pattern of specialisation of the various countries. Simulation exercises of different policy options (i.e. involving the same total level of ICT expenditure) in terms of sectoral distribution could be carried out, for example, using the NEMESIS or WORLDSCAN model.

Given the above discussion, in this chapter we carry out a series of simulation exercises to study the impact of ICT on economic performance using the IFs CGE model. As we have already argued in Chapter 1, IFs has the advantage of modelling a separate ICT sector and this makes it possible to study the impact of ICT on performance going beyond the simple introduction of ICT expenditures in the aggregate production function.

The literature shows how the effects of ICT on economic performance can be pervasive. More specifically, it is possible to pin down some important factors that on one hand facilitate the development of ICT and on the other hand, favour the spread out of ICT adoptions throughout the economic system, namely by changing the structure of supply side (i.e. the production technology regimes), the institutional framework, organisational practices, and public policies. These issues are thoroughly discussed within the framework of techno-economic paradigms and General Purpose Technologies (GPT). However, the complex and rich causation mechanisms highlighted in these frameworks cannot easily be translated into quantitative models.

The simulation analysis presented in this chapter tries to fill this gap by setting up a framework in which we can *quantitatively* assess the impact of innovation on the economy in general, and ICT in particular. Nevertheless, it is worthwhile to remember that the simulation exercises presented below are just a first step towards a more comprehensive treatment of ICT in theoretical and empirical analysis. In particular, the simulations are grounded on some of the elements that appreciative theorising proposes on the issue.

Starting from the idea of ICT as a GPT, we show how, in the context of an aggregate production function, the indirect effects of ICT on GDP are larger than the direct effects (the effect of ICT on GDP as a simple input). In this vein, we show how diffusion processes (both geographical and sectoral), adoption choices and system factors have to play a central role in explaining the transmission mechanisms of ICT on GDP[1].
Using the IFs model we carry out a set of simulations highlighting the impact of ICT on economic growth. We use scenario analysis to study the consequences of changing some key parameters governing the ICT sector performances over time. These simulation exercises do not aim at fully capturing the transmission mechanisms of ICT to performance variables. They are, rather, examples of a larger set of possible exercises to be conducted with IFs and, possibly, other CGE models. In particular, in presenting the results, we show the impact in terms of GDP but results can be replicated also in terms of employment and other endogenous performance variables. The purpose of the simulations is to understand to what extent it is possible to study the effects of ICT on the economy through a more complex way than studying its impact on GDP simply as an input of the production function. We come back to this issue in Chapter 6, when endogenising ICT investment.

Simulations are organized in order to take into account firstly those parameters that directly affect TFP. A second group of simulations analyse the effects of diffusion processes of ICT, both across sectors and across countries. The role of the institutional setup is studied with particular emphasis on the role of electronic and communication networks. Finally, we study the effect of past ICT choices on the number of networked person in the economy directly.
The above analyses are conducted using scenario analysis facilities of the IFs platform with the following parameters: (a) capital productivity of the ICT sector (elasticity of multifactor productivity to ICT sector physical capital); (b) the period of convergence of the ICT sector productivity to the one of service sector; (c) the MFP of ICT sector of the system leader (endogenously determined); (d) the number of networked persons in the system (as a proxy of the effective implementation and diffusion of ICT); (e) the elasticity of multifactor productivity (MFP) to investments in electronic networks; (f) the elasticity of MFP to investment in telecommunication infrastructures.

1 The analysis of the whole set of factors facilitating the spread out of ICT in the economic system – which can be classified under the terms of “facilitating structure” and “policy structure” in the GPT literature – will be introduced in Chapter 7, where out a set of simulations with the SETI model are carried out.

2 ICT and Economic Performance: the Simulation Analysis using the IFs Model

The present section aims at disentangling the role of the ICT sector both at cross-country and at within-country level using the IFs simulation platform. In order to explore the issue we use scenario analysis by using historical values for parameters and variables from the simulated time series provided by IFs up to the year 2000. Through a preliminary analysis we have identified the key parameters governing the ICT sector performances over time. From this set of parameters we chose the most important, both from a theoretical point of view and in terms of their possible impact on the time series of GDP.

Obviously, the choice of the parameters also reflects the way in which ICT is modelled in the economic block of IFs and the linkages with its general model. In what follows we present a scenario analysis that considers the impact of changing these key parameters. In particular, we focus on the following issues:

a the magnitude of direct effects on GDP by a change in the supply side of the economy. Put it differently, we would measure the effects of a change in the ICT sector production function. Ifs offers the possibility of changing the parameter $salpha_{ict}$ representing the capital productivity of the ICT sector (elasticity of multifactor productivity to ICT sector physical capital);

b the across-sectors diffusion process. We change the parameter $mfpconv2_{ict}$ that gives the period of convergence of ICT sector productivity to the one of service sector;

c the across-country diffusion process of technology, working on the parameter $mfpleader_{ict}$, namely multifactor productivity of ICT sector of the system leader (endogenously determined);

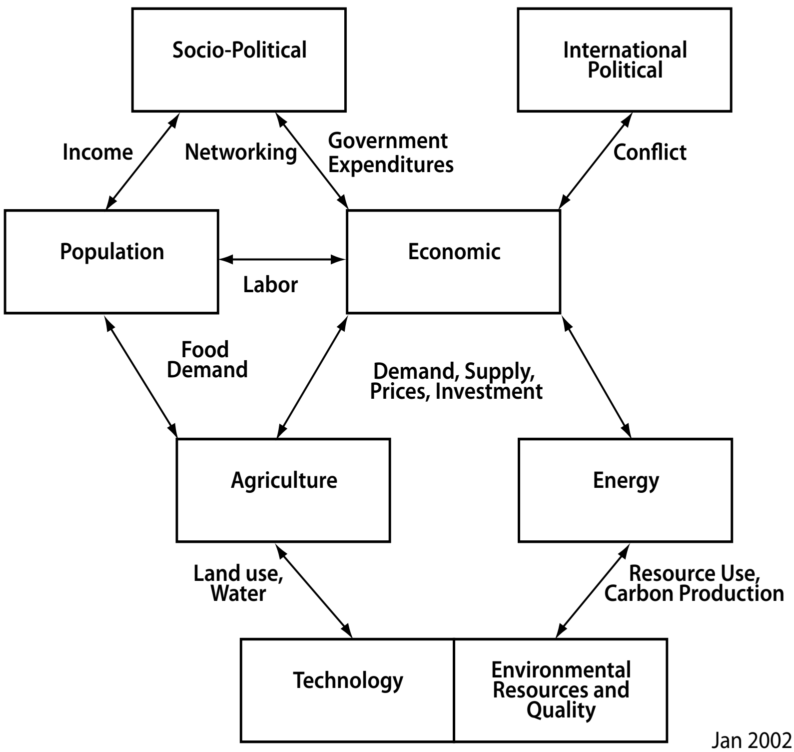
d the effect of past adoption of ICT. We use the number of networked persons in the system -*numplim* (as a proxy of the effective implementation of ICT);

e the role of the institutional setup I: in which we change the elasticity of multifactor productivity (MFP) to investments in electronic networks -*mfpinfrrate*;

f the role of the institutional setup II: in which we work on the elasticity of MFP to investment in telecommunication infrastructures -*mfpcommrate*.

To appreciate the results of our scenario exercises some preliminary remarks must be kept in mind. The first important aspect is related to the magnitude of the effects obtained in the model modifying a single parameter value in the context of a highly non linear and complex model as IFs. Our simulations produce results with relatively small effects for the relevant variables under observation, namely GDP, consumption, exports, etc.. The reason for those limited effects should not be interpreted as only small effects of the ICT sector on the economic system but rather as the result of a highly non linear econometric model set in the framework of a "super" model composed by seven blocks (socio-political, demographic, economic, technological, environmental, agricultural, energy). Figure 1 shows the IFs blocks and highlights the main linkages among them. The economic block appears to be the central one and, consequently, the outcomes of economic functioning are influenced directly and indirectly by all the other blocks.

Figure 1: ***The structure of IFs: the "seven blocks". Source: IFs (2006).***



A closer look at the economic block reveals some interesting features that should be taken into account to correctly analyze the results of the scenario analysis. The supply side of the economic model is based on a Cobb–Douglas (CD) specification of the production function at the sectoral level. This function gives the potential value-added of each sector. Potential sectors value-added takes also into account the degree of capital utilization. The following equations summarize the analytic form of the production function discussed above:

$$VDAPP_{r,s} = CDA_{r,s} \times TEF_{r,s} \times CAPUT_{r,s} \times KS_{r,s}^{CDALFS_{rs}} \times LABS_{r,s}^{(1-CDALFS)_{rs}} \qquad [1]$$

$$CDA_{r,s} = \frac{VADDP_{r,s}^{t=1}}{\left(KS_{r,s}^{t=1}\right)^{CDALFS_{r,s}} \times \left(LABS_{r,s}^{t=1}\right)^{(1-CDALFS)_{r,s}}} \qquad [2]$$

Here, VADDP is the potential value-added, TEF is the productivity growth factor, KS and LABS the sector inputs, respectively for capital and labor, CAPUT is the capital utilization, CDALF is the exponent of CD production function. In particular, two key assumptions emerge:

a the CD involves sector-specific capital and labour inputs to generate the potential value added of each sector. The function assumes constant returns to scale so that in each sector the sum of the values of the exponents of inputs is constrained to one. In this respect, the productivity of capital input is modelled through a parameter, that can be set in the scenario development phase and gives the sectoral exponent of the CD ($cdalf_s$);

b technological growth is disembodied and consequently is not related to specific vintages of capital and to cohorts of labor (TEF). The productivity growth factor is assumed to be endogenous and is calculated as the accumulation of the annual growth in multifactor productivity over time.

The drivers of the productivity growth of IFs can be divided into five categories:

1 a convergence factor across countries, i.e. the model assumes a positive spin-off for the technology adopted by the technological leaders;

2 the knowledge creation and diffusion;

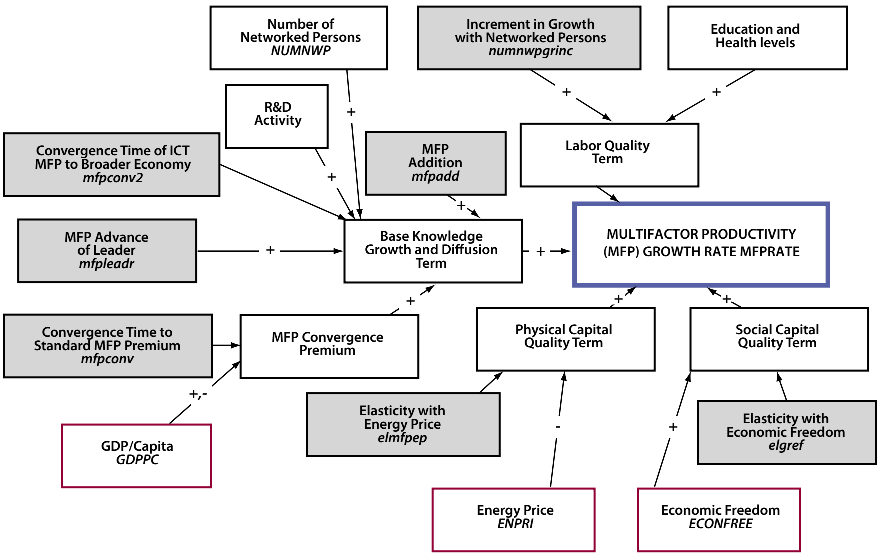
3 the human capital quality;

4 the social capital quality;

5 the physical capital quality.

In Figure 5.2 we show the determinants of MFP growth rate.

Figure 2: ***main relationships of the determinants of multifactor productivity growth rate. Source: our elaboration on IFs (2006).***



The different scenarios results are analyzed at group-of-country level. In particular, we study the GDP growth process induced by different setups for Europe focusing on four grouping schemes: EU25, EU15, EU continental (Italy, France, Germany, Spain) and EU small (Netherlands, Denmark, Finland, Austria, Sweden). The effects of different scenarios are studied looking mainly at deflated GDP time series[2]. Where necessary we deepen the analysis by looking at investments, capital of ICT sector and multifactor productivity. This strategy aims first at evaluating the impact of ICT different scenarios on GDP and secondly at tracing back the different effects through the causal nexus existing in the model. The time horizon of the simulation scenarios is the longest possible using Ifs, i.e. from year 2001 to 2100.

Each scenario is described in terms of different values of the parameter of interest. Moreover, the logic underlying this change is fully discussed. For each scenario, we show a set of replications ranked by the magnitude of parameter changes within each single replication and describe the main findings of the experiment.

2 In the following, the GDP time series are evaluated on the basis of 1995 US $ in PPP.

Scenario analysis

Scenario A: The role of capital accumulation in the ICT sector

In this group of simulations we consider a variation of the sectoral exponent of the production function for capital in ICT sector (**$salpha_{ict}$**). This scenario aims at understanding the effect of a more productive capital factor in the ICT sector. The idea is to investigate whether a more productive ICT sector in the model leads to widespread effects into the economic system or not. We present three different simulations in addition to the base scenario provided by IFs originally (Table 1). In the sce2 and sce2_2 simulations we apply, respectively, a variation of 0.1 and 0.3 points to the basic value of the parameter, starting from the first IFs forecast year (2001). In the simulation sce2_1 we tried a linear increase of the parameter in order to test whether a milder parameter change is able to spread some effects across the model.

Table 1: ***The setup of scenario A***

Scenario A: ***The role of capital accumulation in the ICT sector*** *Parameter of interest:* **$salpha_{ict}$** (capital share in ICT sector).	
Simulations	***Parameter settings***
Base scenario (IFs original settings)	**$salpha_{ict}$**(t)**=0.6**; t=2001,…,2100
Sce2	**$salpha_{ict}$**(t)**=0.7**; t=2001,…,2100
Sce2_1	**$salpha_{ict}$**(2001)**=0.6**, …, **$salpha_{ict}$**(2100)**=0.9** (linear increase)
Sce2_2	**$salpha_{ict}$**(t)**=0.9**; t=2001,…,2100

The simulation reveals that the model takes a very long time to let different results emerge for GDP. More specifically the time series of GDP for the regimes take more than 50 years to generate different outcomes that in any case seem to be small in magnitude (figure 3). If we look at the disaggregated time series for VA of ICT sector we observe a negative effect of the increase of **$salpha_{ict}$** (figures 4 and 5). The bigger the variations of **$salpha_{ict}$**, the lower are the corresponding values of VA in the time series for the ICT sector. In table 2 can be seen that small European countries are more affected than other groups of countries by the change in the elasticity of ICT capital endowment in the economy in terms of GDP growth rate. Such regularity suggests the existence of some kind of saturation for the growth process.

These results suggest that the impulse given by the change in the parameter for the ICT sector modifies only one (not the most important in terms of its magnitude) of the key drivers of GDP. In particular, there exist three critical steps where part of the effect is washed away:

1 the simultaneous impact of the parameter on CDAict and on the production function for the ICT sector -Fict(Kict,Lict);

2 the jump from potential to actual value added in the ICT sector;

3 the aggregation of the six sectors obtained through a normalization.

Table 2: ***Scenario A: total growth rate of GDP (% PPP base year 1995)*** **.**

	IFs base	**Sce2**	**Sce2_1**	**Sce2_2**
EU small	457.29	458.79	458.79	520.19
EU continental	367.17	368.54	368.54	366.51
EU 15	431.19	432.77	432.77	430.33
Japan + US	636.72	647.14	647.48	643.32

In fact, we can sketch the chain that transmits the impulse given by a change in the parameter **salpha**$_{\mathbf{ict}}$ through the model as follows:

$$\Delta \mathbf{salpha}_{ict} \Rightarrow \Delta \mathbf{CDA}_{ict} \text{ and } \Delta \mathbf{F}_{ict}(\mathbf{K}_{ict}, \mathbf{L}_{ict}) \Rightarrow \Delta \mathbf{VADDP}_{ict} \Rightarrow \Delta \mathbf{VADD}_{ict} \Rightarrow \Delta \mathbf{VADD} = \Delta \mathbf{GDP},$$

where the symbols have the same meaning as in equations 5.1 and 5.2. The last implication highlights the causal nexus from potential to actual value added and is explained by the following relationship:

$$VADD_{r,s} = VADDP_{r,s} \times (1 - ShoMF_r) \times \left(\frac{MKAV_{s=manuf}}{MKAV^{t=1}_{s=manuf}} \right)^{PRODME}$$

which quantifies the impact of parameters and variables on VADD, that in turn mediates the direct impact of the potential value added of the ICT sector. In particular, a key role is assigned to:

- possible energy shortage measured by a physical shortage multiplier factor (SHOMF);
- the availability of intermediate goods proxied by the level of import of manufactured goods (MKAV);
- a scale parameter (PRODME).

The aggregation of sectors is obtained using an exogenous input-output matrix (*A*) which leads to the production levels for each sector. Moreover, given that the ICT sector accounts only for less than 6% of total GDP along all the time series, the magnitude of the effects spreading from this sector is small in absolute value (figure 6).

Figure 3: ***Simulated GDP time series for EU continental.***

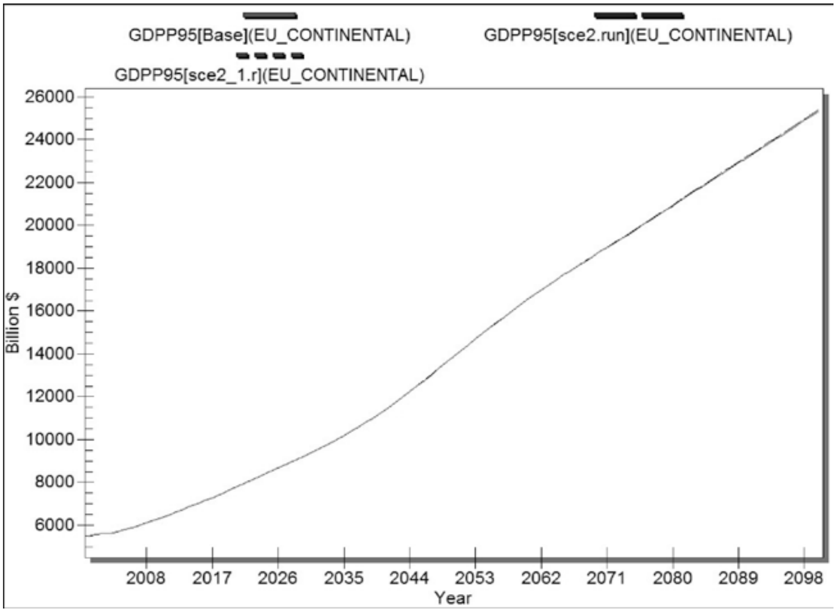


Figure 4: ***Simulated ICT sector capital time series for EU continental.***

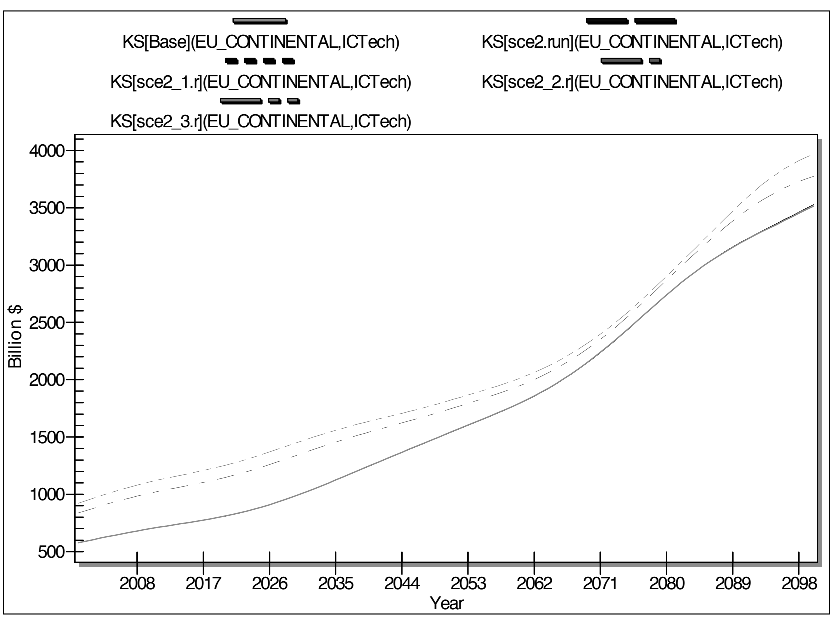


Figure 5: ***Simulated ICT sector VA time series for EU continental.***

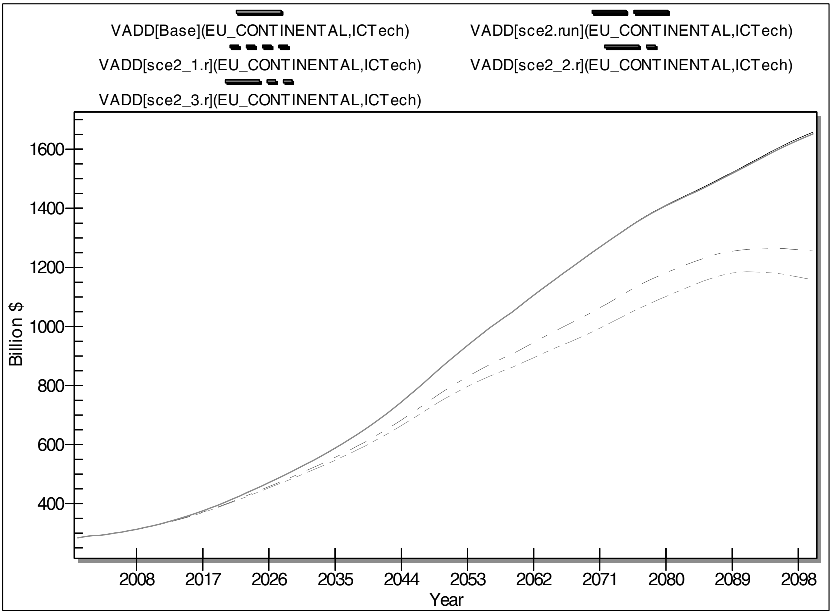
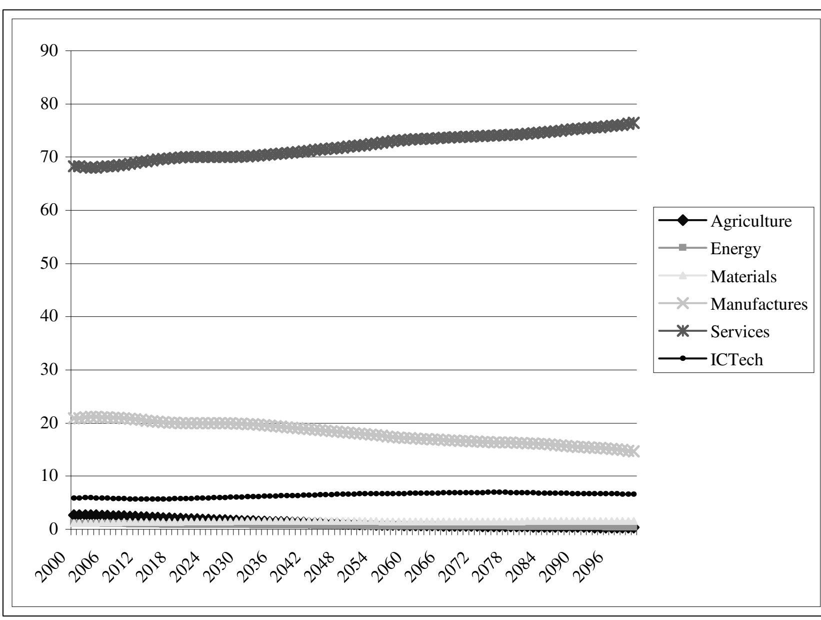


Figure 6: ***The relative percentage contribution of ICT sector to GDP.***



Scenario B: The diffusion process of ICT best practices across sectors

This scenario considers a change in the time lag needed for the convergence of the services sector (all services) MFP to the MFP of the ICT sector (figure 5.7). The scenario tries to evaluate the impact of a more rapid rate of adoption and diffusion of ICT through the service sector, which is typically a large user of ICT. The data show an ICT sector with higher productivity compared to all services (quite intuitively). For instance, this pattern emerges looking at the time series of MFP for EU continental for the services and ICT sectors (figure 5.8). The parameter *mfpconv2* allows users to guide the process of catching up of services MFP to ICT MFP.

We present two simulations where we first reduce the convergence time and then set it to a longer time horizon (table 3). The aim is to find out the impacts of a parameter change in the two opposite conditions.

Table 3: ***The setup of scenario B***

<table>
<tr><td colspan="2">Scenario B: The diffusion process across sectors of ICT best practices
Parameter of interest: mfpconv2 (convergence time of MFP of ICT sector (in years) to that of services sector)</td></tr>
<tr><td>Simulations</td><td>Parameter settings</td></tr>
<tr><td>Base scenario (IFs original settings)</td><td>Mfpconv2(t)=60; t=2001,…, 2100</td></tr>
<tr><td>Sce3</td><td>Mfpconv2(t)=30; t=2001,
…,
2100</td></tr>
<tr><td>Sce3_1</td><td>Mfpconv2(t)=80; t=2001,…, 2100</td></tr>
</table>

The main effect of a longer (shorter) catching up period is an anticipation (posticipation) of swings in the MFP aggregate growth rate. However, the modification of the parameter is not able to change the time pattern of MFP dramatically. This effect is driven by the variation in the capital availability of the ICT sector (figure 11). Table 4 confirms the small effect of the parameter change in this scenario: only for Japan and US it is possible to note a mild increase in the GDP growth rate in the long run.

To understand the result, we must realise that the effects on GDP are explained by the impact of *mfprate* of the ICT sector on sectors VA. The magnitude of the effect can be explained considering that the parameter *mfpconv2* acts on the sectoral value added and on the aggregate GDP of a country through *mfprate* (multifactor productivity of sectors) directly. However, this variable shapes *mfpratet* (aggregate MFP rate) after a normalization that could reduce the magnitude of the changes. Moreover, the limit imposed to MFP by the return ratio on land investments (measured by the parameter *retrat*) does not allow drastic changes in aggregated MFP. To put it differently, the normalization that the model has to introduce to use the sectoral MFP partially sterilizes the parameter changes.

Table 4: ***Scenario B: total growth rate of GDP (% base year 1995)***

	Ifs base	Sce3	Sce3_1
EU small	457.29	493.43	458.32
EU continental	367.17	361.08	368.56
EU 15	431.19	425.97	432.38
Japan + US	636.72	639.32	647.14

Figure 7: ***Drivers of sectoral value added: the role of the mfpconv2 parameter***

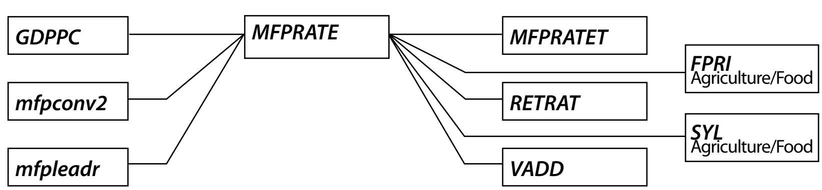


Figure 8: ***Historical time series of sectoral MFP annual rate of growth: services vs. ICT in EU continental.***

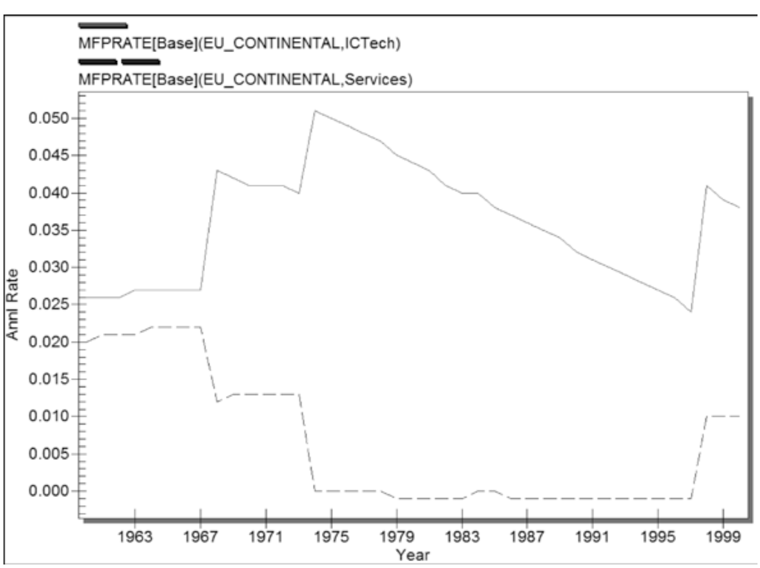


Figure 9: ***GDP $1995 PPP time series for Japan and US (JAP_USA).***

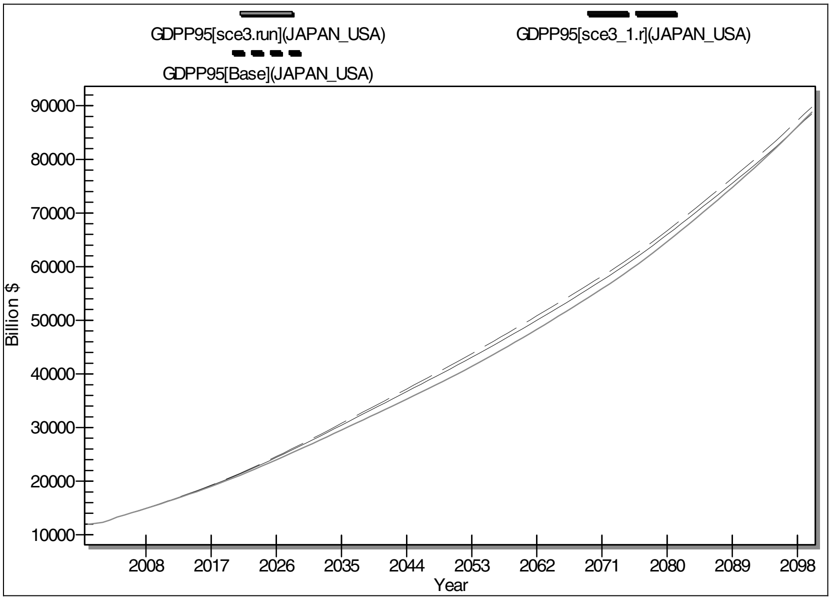


Figure 10: ***Percentage changes of GDP $1995 PPP time series for Japan and US (JAPAN_USA)***

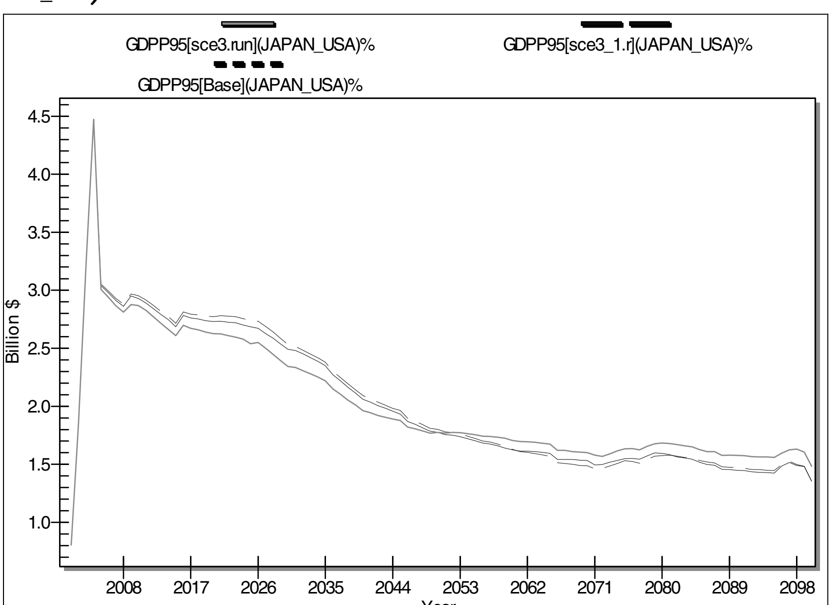
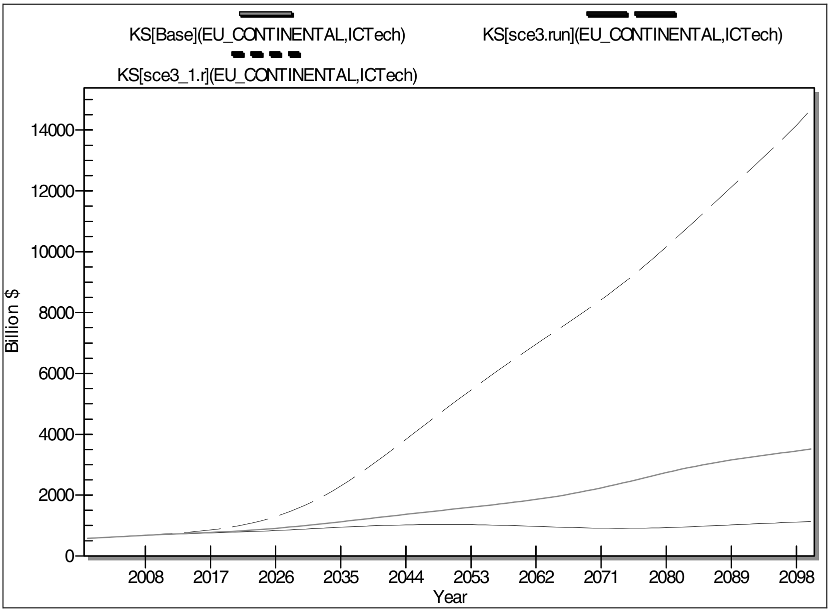


Figure 11: ***ICT sector physical capital***



Scenario C: The diffusion of ICT across countries

In this scenario we assume different regimes for the MFP of the ICT sector for technological leaders, in order to evaluate the diffusion of different technological frontiers reached by a country which is assumed to be a system leader. IFs allows to change directly a determinant of MFP for the ICT sector. Table 5 shows the simulations we performed. Sce7 proposes a linear increase from year 2001 of the *mfpleadr* parameter; sce7_1 implements an increase of 0.01 of the MFP premium for a system leader (figure 12).

Table 5: ***The setup of scenario C***

Scenario D: ***The diffusion process across countries of ICT*** *Parameter of interest:* $\mathbf{mfpleadr}_{ICT}$ (MFP of technological country leader for ICT sector)	
Simulations	***Parameter settings***
Base scenario (IFs original settings)	$\mathbf{mfpleadr}_{ICT}$(t)=0.06; t=2001,…, 2100
Sce7	$\mathbf{mfpleadr}_{ICT}$(2001)=0.06, …, $\mathbf{mfpleadr}_{ICT}$(2100)=0.08; (linear increase)
Sce7_1	$\mathbf{mfpleadr}_{ICT}$(t)=0.07; t=2001,…, 2100

The increase in the MFP of the ICT sector for a system leader has a positive effect on GDP. In particular, the time series of US GDP (figure 13) reveals that both simulations lead to an increase in GDP in each year starting from around 20 years after the parameter change. The impact seems to be driven by the higher investments (figure 14), and the effect is bigger as the parameter's positive change gets larger. Looking at the EU continental GDP time series, we note a similar result (figure 15), with two specifications: (a) the effects seem to be smaller than for US; (b) in sce7 the effect is quite small (hardly observable). Similarly to the previous scenarios, the effect on the long run GDP growth rate is small for every group of countries –see table 6. If we try to deepen the analysis, we can consider the physical capital of the ICT sector (figures 16 and 17). We see that a positive variation of the parameter under analysis causes an increase in the stock of capital.

Table 6: ***Scenario C: Total growth rate of GDP (% PPP base year 1995)***

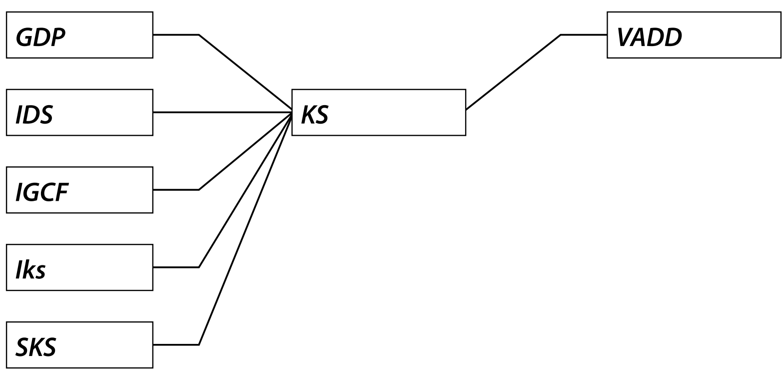
	Ifs base	**Sce7**	**Sce7_1**
EU small	457.29	502.32	458.82
EU continental	367.17	368.56	368.58
EU 15	431.19	432.38	432.86
Japan + US	636.72	647.14	659.46

The analysis of IFs' geographical diffusion of shocks on the supply side is of some help in understanding the results. A positive impact of a change in the parameter of interest enters directly in the determination of MFP growth rate, as can be seen from the following equation:

$$MFPRATE_{r,s} = mfpleadr_s + MFPPrem_r + MFPCor_{r,s},$$

where the parameter *MFPcor* represents a convergence rate of countries over time. In this setup the MFP component of the system leader is only one –and perhaps not the most important- of the determinants of MFPRATE for the ICT sector. The impulse of a more active system leader, then, is reduced in its effectiveness.

Figure 12: ***The driver of stock of sectors capital and their impact on sectors VA.***



The larger impact of the parameter change in the case of US and Japan is explained by the historical evidence that describes US as a technological leader. A premium in the ICT MFP for this country has direct effects on its GDP, while the impact on other countries is mediated by the process of diffusion that takes some time to reduce the magnitude of the impact itself.

Figure 13: ***US GDP time series.***

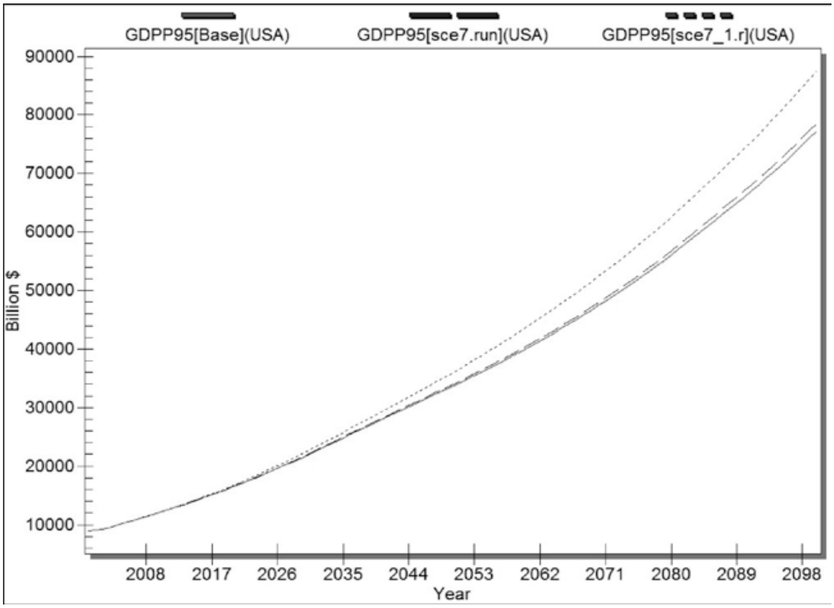


Figure 14: ***Time series of investments in US***

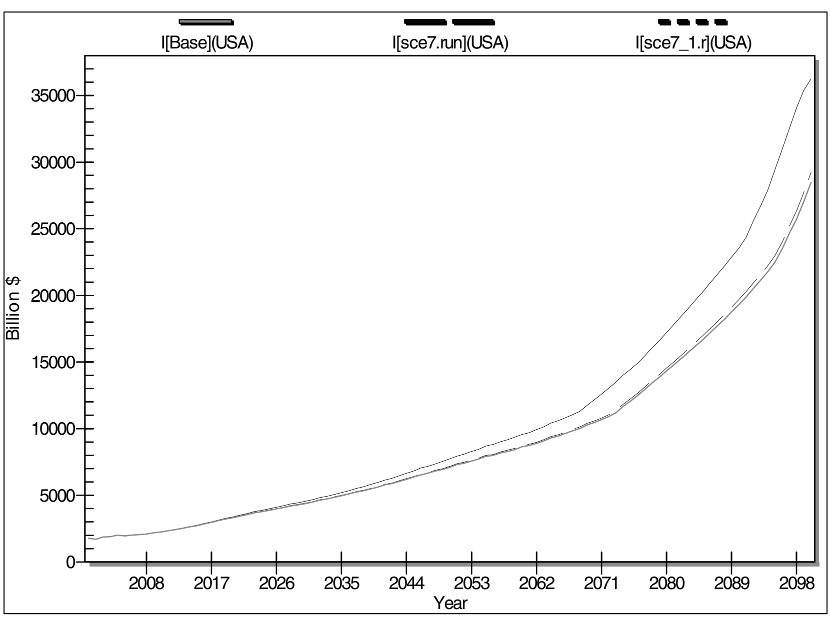


Figure 15: ***EU continental GDP time series.***

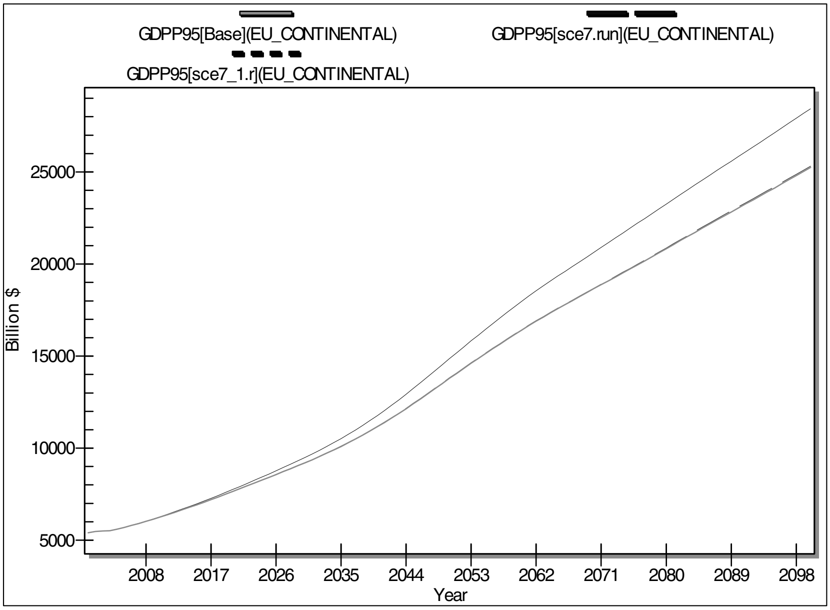


Figure 16: ***Time series of physical capital in ICT sector in US.***

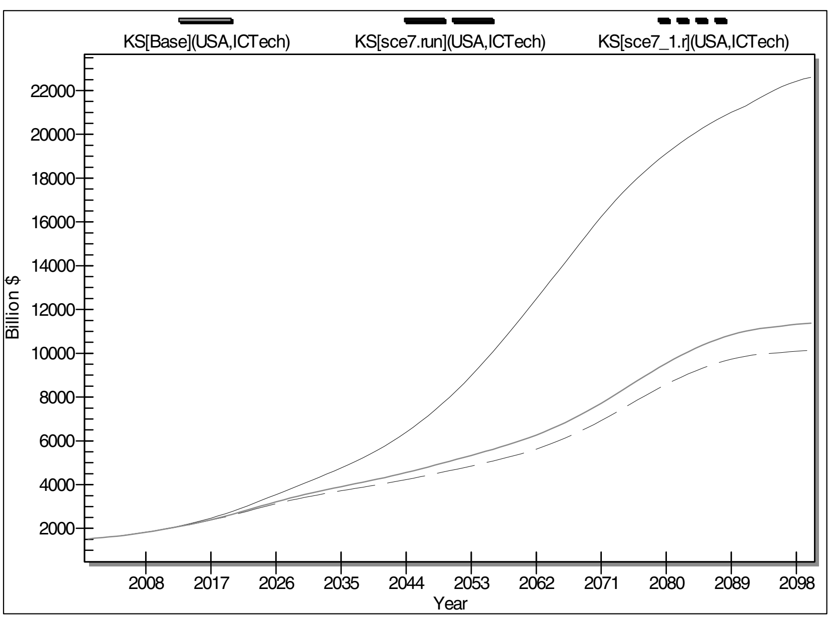
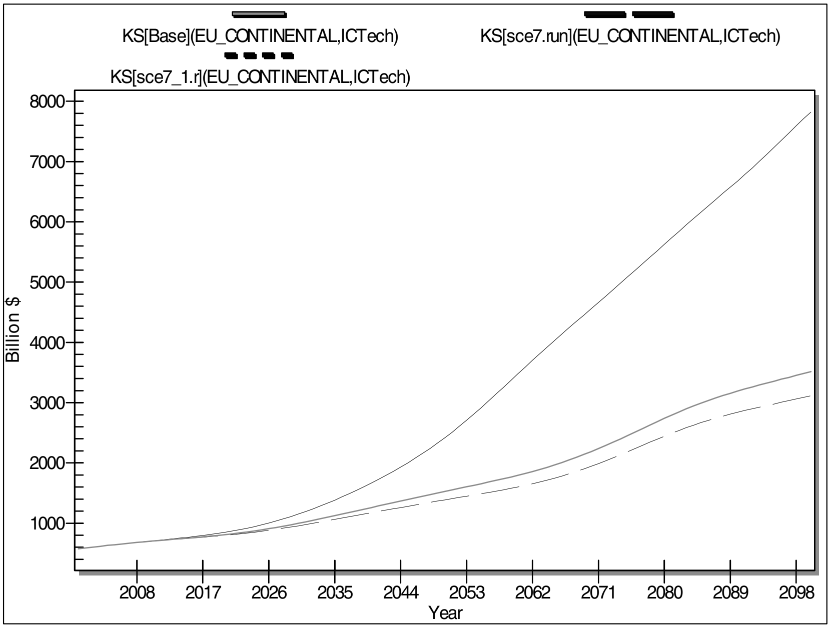


Figure 17: ***Time series of physical capital in ICT sector in EU continental.***



Scenario D: The effects of past adoptions of ICT

In this scenario we simulate different regimes regarding the adoption of ICT technologies in the economic system. We use the percentage of networked persons in the economic system as a proxy for the ICT adoption rate. A preliminary analysis shows that the variable NUMNWP converges quickly to the maximum threshold given by the parameter *numplim*. Hence, we decided not to use the parameter *numnwpgr* but rather to concentrate directly on the threshold, identified by the parameter *numplim*. Actually, this behaviour is explained by the assumption in IFs of a saturating function for the number of networked persons with a limit imposed by a parameter. In particular, IFs implements the number of networked persons using the following equation:

$$NUMNWP_s^t = NUMNWP_s^{t-1} \cdot (1 + NumNmGR_r^t),$$

where NumNmGR represents the growth rate of the number of networked persons and is given by

$$NumNwGR_s^t = NumNwGr_s^1 \cdot \left(\frac{numnwp\ \mathrm{lim} \cdot POP_s - NUMNWP_s^1}{numnwp\ \mathrm{lim} \cdot POP_s - NUMNWP_s^{t-1}} \right)^2,$$

where *numwplim* is a parameter that measures the maximum percentage of networked persons allowed in the system and POP is the population. In figure 18 we see the main drivers of the number of networked persons.

In sce4 we modify the parameter *numplim* (maximum number of networked persons in decimal terms) changing its values from 0.85 to 0.90, where a value of 0.85 means that 85% of the population can become networked -i.e. 85% of the population can be ultimately saturated with networking along time.

Table 7: ***The setup of scenario D***

Scenario D: ***the role of institutional setting*** *Parameter of interest:* **Numplim**: maximum number of networked persons (in decimal terms)	
Simulations	***Parameter settings***
Base scenario (IFs original settings)	**Numplim**(t)**=0.85**; t=2001,…,2100
Sce4	**Numplim**(t)**=0.9**; t=2001,…,2100

The change of 0.05 in the parameter allows a change in the number of networked persons over time (figure 19). In turn, this influences the MFP and sectors VA, that finally lead to a positive impact on the GDP time series, caused by a larger number of networked persons over time (figures 20 and 21). Looking at cross-country evidence, we notice that EU small shows the larger effect on the GDP growth rate. Once again it is clear that countries in which the technological frontier is farther are characterized by bigger growth opportunities.

Table 8: ***Scenario D: Total growth rate of GDP (% PPP base year 1995)***

	Ifs base	Sce4
EU small	457.29	501.41
EU continental	367.17	368.54
EU 15	431.19	432.77
Japan + US	636.72	647.48

The results can be understood by considering that IFs models the total number of networked persons as a s-skewed curve: the number of networked persons over time increases (with a decreasing speed) and approaches its maximum value set parametrically by numplim. In IFs one of the sources of advances in MFP is given by the knowledge creation and diffusion. In turn, the model assumes as a key factor the number of networked persons that is considered as a proxy of the output coming from the activity of knowledge diffusion:

$$MFPGRO_{r,s} = MFPRATE_{r,s} + KnowledgeTerm_{r,s} + HumanCapitalTerm_{r,s} + SocialCapitalTerm_{r,s} + PhysicalCapitalTerm_{r,s} + mfpadd_{r}.$$

Figure 18: ***The drivers of the growth rate of number of networked persons***

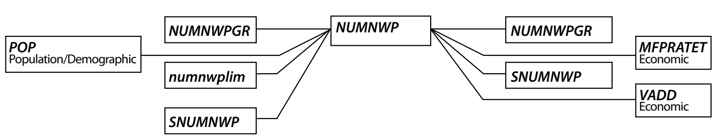


Figure 19: ***Time series of total number of networked persons in US.***

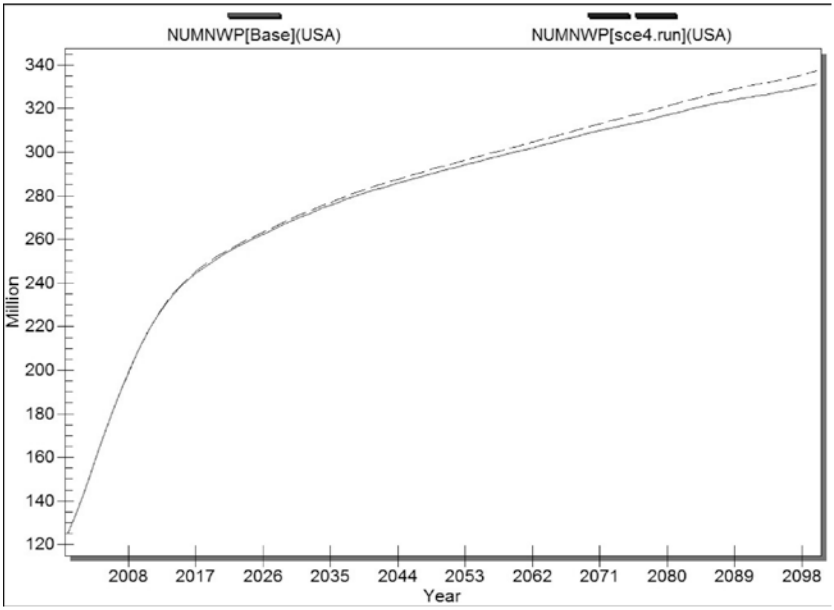


Figure 20: ***Time series of GDP for US.***

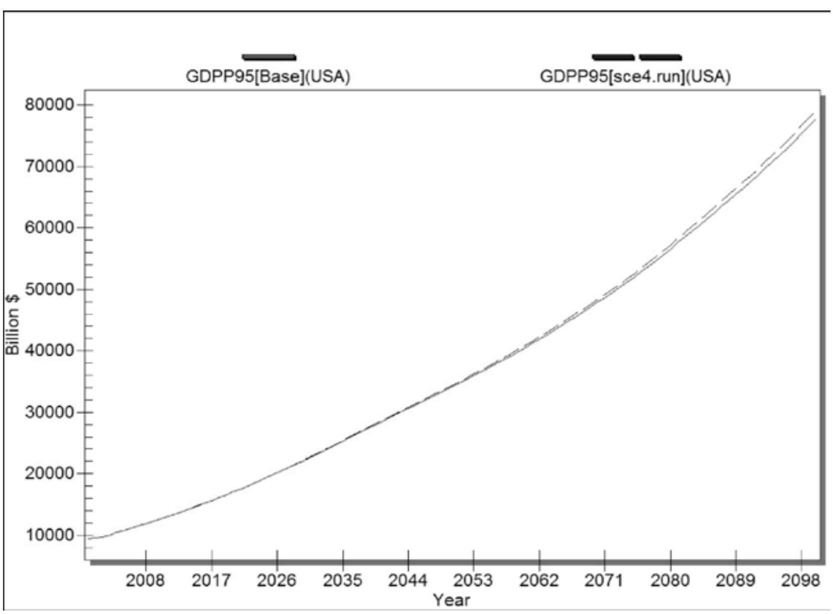
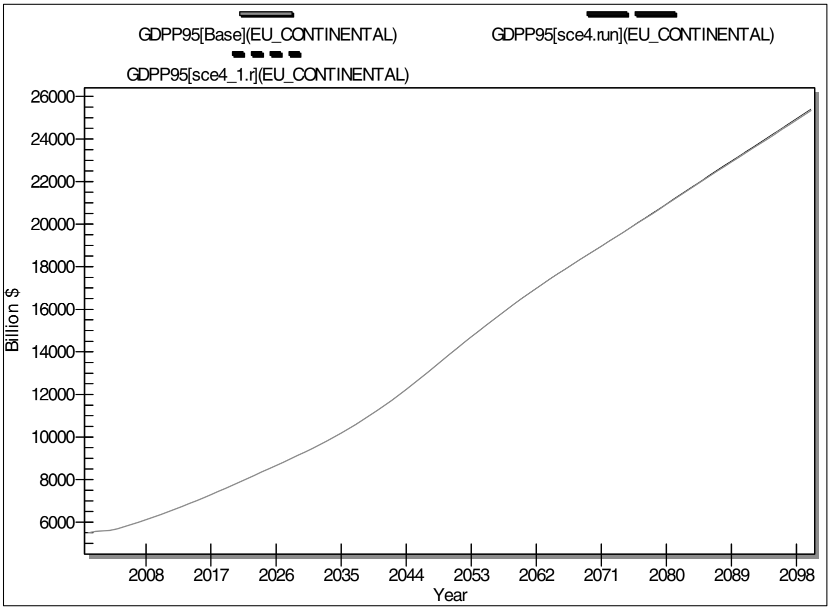


Figure 21: ***Time series for GDP of EU continental.***



Scenario E: The role of institutional setup I

This scenario explores the possible effects of a change in the elasticity of the multifactor productivity of the ICT sector to the level of network infrastructure in the economic system (set in the IFs model by the parameter mfpinfrnt).
We implement two scenarios: sce5 implements a smooth increase of the parameter mfpinfrnt that measures the aforementioned elasticity; sce5_1 assumes a bigger change from the year 2001 (table 9).

Table 9: ***The setup of scenario E.***

Scenario E: ***the role of ICT infrastructures*** *Parameter of interest:* **Mfpinfrnt** (elasticity of MFP of ICT sector to network infrastructures)	
Simulations	***Parameter settings***
Base scenario (IFs original settings)	$\mathbf{mfpinfrnt_{ict}}$(t)**=0.025**; t=2001,…,2100
Sce5	$\mathbf{mfpinfrnt_{ict}}$(2001)**=0.025**,…, $\mathbf{mfpinfrnt_{ict}}$(2100)**=0.05**; linear increase
Sce5_1	$\mathbf{mfpinfrnt_{ict}}$(t)**=0.06**; t=2001,…,2100

Non linear effects on GDP emerge(figure 22). A smooth increase of *mfpinfrnt* (sce5) leads to a positive effect on GDP, while a bigger change (sce5_1) induces a smaller negative effect. Looking at table 10, a non linear effect is even clearer for almost every group of countries. In fact, in sce5 all groups of countries show a higher rate of growth of GDP than in any other scenario. Interestingly enough, in this scenario too EU small seems to be the group that responds more to changes in the institutional setup in terms of GDP time series modification.
The transmission mechanism that goes from infrastructures to MFP can be briefly explained as follows. The positive effect of larger values of mfpinfrnt leads to larger aggregate investments that, in turn, affect GDP directly (figure 23). If we assume a larger change in the elasticity, then the positive impact on MFP is stronger and leads to a counter-effect: the higher productivity of the stock of capital discourages further investments (it is possible to obtain the same amount of production using less capital).

Table 10: ***Scenario E: total growth rate of GDP (% PPP base year 1995).***

	IFs base	**Sce5**	**Sce5_1**
EU small	457.29	501.41	487.79
EU continental	367.17	368.54	358.40
EU 15	431.19	432.77	421.42
Japan + US	636.72	647.48	632.62

Figure 22: ***Time series for GDP of EU continental.***

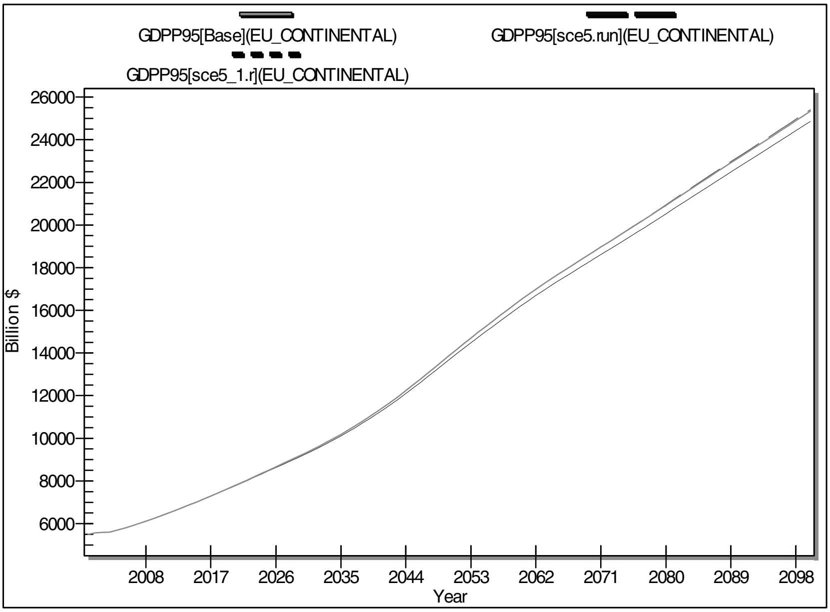
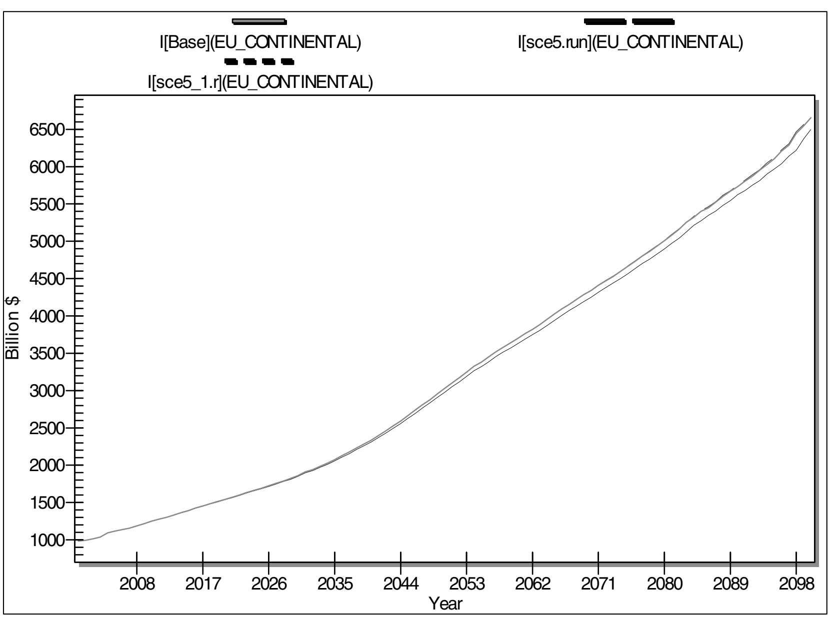


Figure 23: ***Time series of investments for EU continental.***



Scenario F: The role of institutional setup II

In these simulations we change the value of the elasticity of MFP of the ICT sector to the infrastructures in communication technology. We propose three simulations where the value of the parameter *mfpinfrate* is increased gradually until it reaches one, its maximum possible value (table 11).

Table 11: ***The setup of scenario F***

Scenario A: ***the role of ICT infrastructures II*** *Parameter of interest:* **Mfpinfrate**: elasticity of mfp of ICT sector to communication infrastructures	
Scenarios	***Parameter settings***
Base scenario (IFs original settings)	$\mathbf{mfpinfrate_{ict}}(t)\mathbf{=0.6}$; t=2001,…,2100
Sce6	$\mathbf{mfpinfrate_{ict}}(t)\mathbf{=0.7}$; t=2001,…,2100
Sce6_1	$\mathbf{mfpinfrate_{ict}}(t)\mathbf{=0.8}$; t=2001,…,2100
Sce6_2	$\mathbf{mfpinfrate_{ict}}(t)\mathbf{=1}$; t=2001,…,2100

A larger elasticity of ICT MFP to communication infrastructures leads to a larger GDP only if the change is “big enough” (figure 25). In our setting, the effect emerges in scenario sce6_1 (scenario 6_2 sets the parameter to its maximum value). A significant effect is present for EU small in sce6_2 – table 12. A small effect emerges for US and Japan also as a consequence of a small change in the value of the parameter under analysis. Some impact can also be detected for investments, but only for large changes in the parameter values (in particular, **if** we set its value to one, the largest possible) both in the ICT sector and at aggregate level (figure 26) .

A necessary remark is on the role of the *mfpinrate* parameter in IFs given the available documentation (see figure 27). We think that there exist a mismatch between the actual role of the parameter and the lack in documentation. We can describe a impact-response chain as represented in figure 24.

Figure 24: ***The causal nexus from mfpinfrate to GDP.***

$$\Delta \mathbf{mfpinrate_{ict}} > 0 \Leftrightarrow \Delta \mathbf{infrastructure_{ict}} > 0 \Rightarrow \Delta \mathbf{mfp_{ict}} \Rightarrow \Delta \mathbf{VADDP_{ict}}$$

$$\Rightarrow \Delta \mathbf{VADD} = \Delta \mathbf{GDP} > 0 \Rightarrow \Delta \mathbf{GDP\ per\ capita} > 0 \Rightarrow \Delta \mathbf{I} > 0$$

The functioning can be summarized by saying that a higher elasticity to communication network leads to (given the same variation of network infrastructures) a larger MFP of the ICT sector that, in turn, enhances the potential and the actual value added of the ICT sector. As a result, both a larger GDP and a larger GDP per capita (which is one of the determinants of sectors' investments) are obtained. Finally, we have to take into account the retroaction of an increase in investments on the sectors' value added and on GDP; this induces an acceleration in the growth process.

Table 12: ***Scenario F: total growth rate of GDP (% PPP base year 1995)***

	IFs base	Sce6	Sce6_1	Sce6_2
EU small	457.29	458.79	458.79	501.41
EU continental	367.17	368.54	368.54	368.54
EU 15	431.19	432.77	432.77	432.77
Japan + US	636.72	647.48	647.48	647.48

Figure 25: ***Time series for GDP of EU continental***

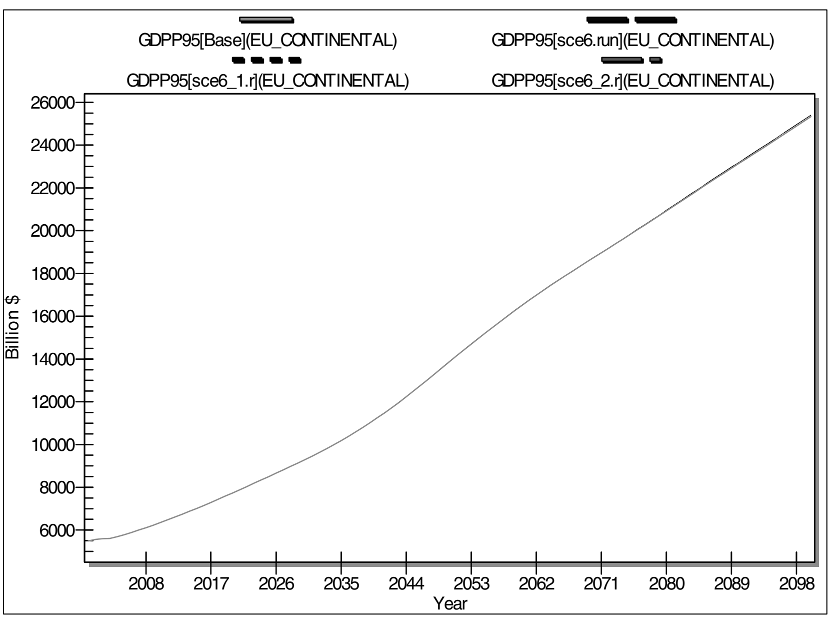


Figure 26: ***Time series for aggregate investments of US.***

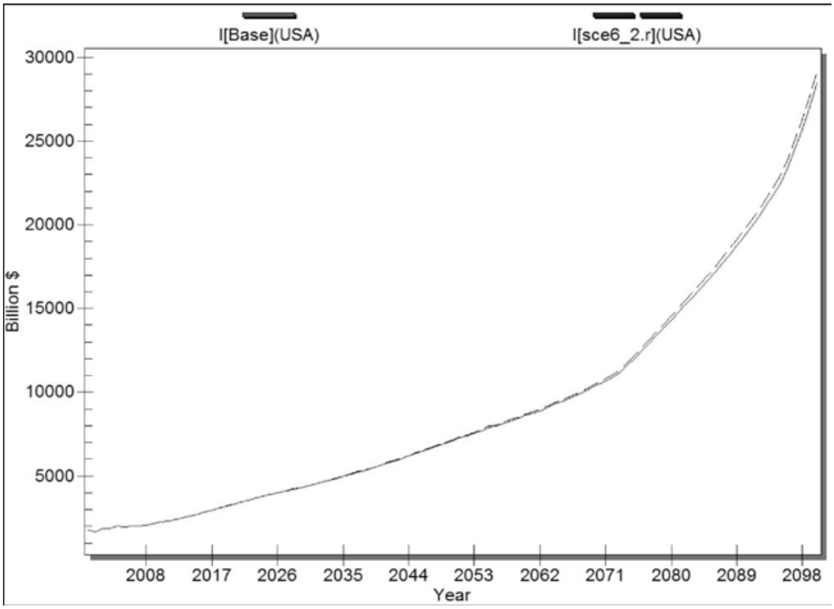
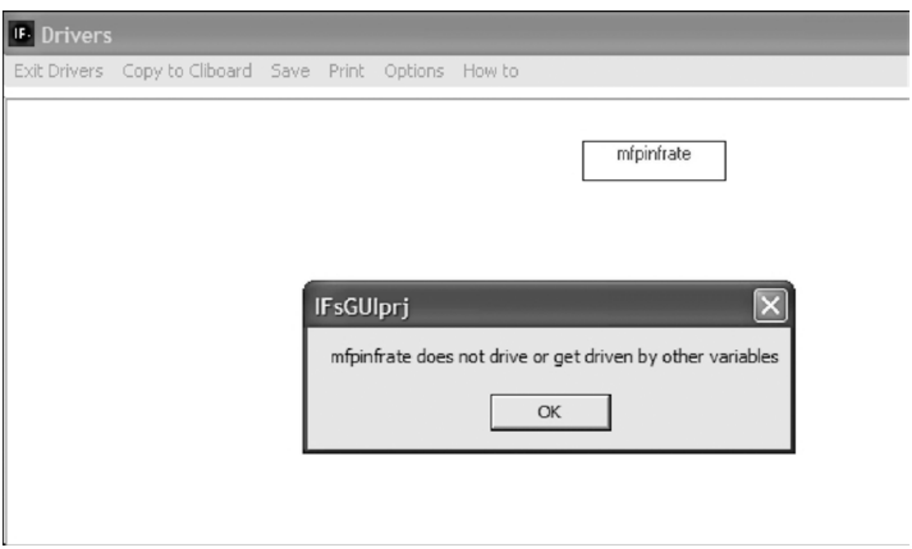


Figure 27: ***A puzzle in IFs: non existence of effects of mfpntrate.***



3 Policy Implications and Concluding Remarks

The IFs platform allows for the implementation of interesting experiments related to different aspects of the economic system. Nevertheless, it is important to point out that the magnitude of the effects obtained using the scenario analysis implied by the parameters belonging to an economic block is bounded from above. The reason is mainly related to the highly complex set of inter-connections among the six building blocks of IFs. In other words, even if we set the parameter values to their maximum (as allowed in the model), we will only in some cases obtain significant impacts on variables. There are indeed several constraints incorporated in the six blocks that limit the maximum range of variation of variables over time. For instance, the physical shortage of intermediate goods plays a key role in the determination of the sectors' value added. A second important example is the maximum limit imposed to growth by an assumption made in the energy block: a parameter setting which imposes strict limits to the energy needed to produce goods and services creates constraints that are difficult to identify.

Another important source of bias in the results comes from the default parameter settings in IFs (the base scenario provided when the user runs the program). As economists, we analyse -and possibly modify- the parameters belonging to an economic block, but we strongly rely on parameter settings of other blocks set by default. Moreover, at some extent, we do not have a valid tool to evaluate such parameter settings. On the basis of the scenario analysis performed here, our intuition is that the five-blocks model is characterized by several constraints in addition to the economic ones. Some parameter values have to be carefully evaluated and possibly changed to avoid nonsense results. Hence, scenario analysis has to be conducted after a complete evaluation of the parameters that can alter results. The risk is a mis-interpretation of the effects of each single parameter variation due to the high non-linear structure of the IFs model. Putting it differently, if we compare the results of two simulations, we can interpret a smaller (in magnitude) effect on a variable X as a consequence of the reduced influence of one of the parameters. However, these results could be due to some nonlinear interaction among other parameter values and variables in the models. Such interactions can impose additional constraints on the X time path, distorting the causal nexus of the parameter changes.

Nevertheless, we think that IFs can offer some basic useful insights on the transmission mechanisms of various ICT-related policies, even if one has to take all the above remarks into account. In particular, the simulation exercises allow to study the impact of those policies aimed at facilitating ICT adoption (increasing the percentage of networked persons) or affecting the responsiveness of ICT productivity to the general environment (network infrastructure, infrastructure in communication technology). Moreover, it allows to study the interaction between ICT and services. These are all elements of the "facilitating structure" emphasized in the GPT literature. Finally, the model also offers some insights on the diffusion of the impact of ICT on performance across countries. In fact, as we have seen, an increase in ICT productivity in the US (the leader country) affects GDP not only in the US but also, although to a lesser extent, in European countries.

CHAPTER VI

ENDOGENIZING ICT: QUANTITATIVE RESULTS

1 The Determinants of Adoption and Diffusion of Information and Communication Technologies

As we have seen in the previous chapters, the existing multiequation models can be modified to accommodate the introduction of ICT and produce simulations to understand its impact on the performance of the economy. Such an approach however, while providing some useful insight, cannot fully take into account the impact of ICT. As is discussed at length in Lipsey, Carlaw, and Bekar (2006) ICT is a "general purpose technology" (GPT) and, as such, it cannot be modelled simply by considering it an additional factor of production. As Lipsey et al. (2005), as well as Jan Fagerberg et al. (2004) argue, a fully satisfactory way of modelling GPT (and ICT) driven growth would require a dramatically different modelling approach including an endogenous determination of ICT. This is certainly a demanding research project which deserves to be undertaken. In the meantime some initial steps can be taken if progress is to be made in the area of quantitative results and policy simulations.

To implement the strategy above we proceed in steps. In this chapter we first examine the literature on the determinants of ICT adoption and diffusion and then produce estimation results of equations explaining ICT. In chapter 7 we present a structural model (SETI) where the role of ICT in supporting growth interacts with other variables, including the role of producer services and variables referring to the "business environment".

The topic of ICT diffusion has received increasing attention in the literature but in a slightly different direction with respect to our own analysis. Most of the literature deals with the so-called *digital divide*, *i.e.* the striking difference in the adoption of information technologies between developed and developing countries. Thus the analysis focuses mainly on the difference between developed and developing countries. This topic is of course of great interest: as it is well known from growth theories, technological progress is one of the main sources of growth. One of the factors that is able to influence technological progress is the production and use of ICT. As a consequence, one could say that with different rates of adoption of ICT between developed and developing countries, the already large difference in income per capita and in the standard of living could further increase. While our main goal is to understand the differences in ICT adoption within developed countries, we believe it is important to look at the *digital divide* literature as it can provide some useful hints for our purposes as well.

2 Review of the Literature

First, it is important to point out that in all the *digital divide* literature the endogenous variable (*i.e.* ICT) is never measured as ICT investment, rather it is measured as either the number of internet host per capita, or computer per capita, or internet connection per capita, or internet users, or mobile phones per capita and other similar formulations. In addition, what matters for a country's growth is especially the adoption of ICT by firms rather than by consumers, even if these two patterns of adoption are somehow linked. It is hard to imagine an economy where firms use PCs and the internet, whereas consumers (who after all are the labour force that uses this technology on the job) would not. In the review of the literature that follows, we do not make a distinction on the endogenous variable used; we generally call it ICT. Even though from a formal point of view this is incorrect, it facilitates the readability.

In the literature there is a widespread agreement that the *digital divide* is mostly due to the difference in economic wealth of countries. Caselli & Coleman (2001), Baliamoune-Lutz (2003), Chinn & Fairlie (2004), and Pohjola (2003), by analysing a sample including both developing and developed countries, provide empirical evidence that income per capita is positively and significantly related to ICT adoption. Dasgupta, Lall & Wheeler (2001) on the other hand, find income per capita non significant in determining ICT. Moreover, Hargittai (1999) argues that income per capita *per se* is not sufficient to describe economic wealth, and that a distribution component, such as a *gini* index, should be considered as well. Estimating an equation for ICT with both income per capita and a *gini* index as explanatory variables on a sample of OECD countries, Hargittai further supports the idea that economic wealth matters.

Another factor that is widely considered in the literature 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 reorganisation of the firm, a firm with a high percentage of skilled workers can implement information technologies more easily. In the empirical analysis Human Capital has been taken into account through different variables: years of schooling, literacy rate, percentage of population with at least a secondary school degree, and other indices. Caselli & Coleman and Chinn & Fairlie provide empirical evidence for human capital to be a major explanatory variable of the difference of investment levels in ICT between developed and developing countries, whereas Baliamoune-Lutz find it to be non significant. Furthermore, Gust & Marquez (2002) and Hargittai provide evidence for human capital being significant, even when excluding developing countries from the analysis. Some of these authors have also tested and concluded that in addition to an education variable, English proficiency is a further explanatory variable for ICT adoption, given that the language of most web sites is English. However, other empirical results do not support this hypothesis (Hargittai and Caselli & Coleman).

The impact of regulation on the adoption of ICT has received much attention in the literature. In general, it is well known that all kinds of restrictions, regulation or constraint that somehow limit the set of decisions of an economic agent, drive the economy to a sub-optimal equilibrium. The question is, if they also negatively influence the adoption of ICT. Gust & Marquez demonstrate that regulation in the labour market slows down the process of adoption, Dasgupta, Lall & Wheeler state that competition policy matters, while Hargittai focuses on the influences of the structure of the telecom market (monopoly *vs*. competition). Some authors analysing the *digital divide* have also included indices of property rights and/or of civil liberties that resulted to be important variables as well (Baliamoune-Lutz, Chinn & Fairlie, and Caselli & Coleman).

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. For example Chinn & Fairlie argue that if the developing countries had the same population age composition of the US, the divergence in adoption of ICT would have been even larger. However, in their study they find a negative coefficient for urban population and they 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). In contrast Dasgupta, Lall & Wheeler find the elasticities for urban population positive.

Another variable that has been extensively investigated in the literature is the degree of openness of an economy. While on the theoretical ground the inclusion of this variable is reasonable, empirical evidence does not fully support it. The justification for the inclusion of this variable is that technological spillovers due to ties with foreign countries could be an important factor in supporting the adoption of ICT. On the empirical ground Baliamoune-Lutz, by measuring the degree of openness with Foreign Direct Investment, find it positively significant, and the same result is obtained by Caselli & Coleman, who measure openness by the share of imports on GDP.[1] In contrast however, both Pohjola and Chinn & Fairlie do not find the share of import plus export on GDP to be significant.

1 C&C also investigate if the source of imports matters and conclude that it actually does: in fact, they find that imports from OECD countries are significant while imports from non-OECD are not.

Starting from the consideration that some economic sectors use more ICT than others, the possibility that the different sectoral composition of the economies determines different rates of investment in ICT has also been investigated. Gust & Marquez find that a high share of the service sector on GDP is associated with a high rate of ICT adoption, while Pohjola finds that a large share of agriculture on GDP is associated with low rates. Caselli & Coleman investigate the issue more thoroughly and conclude that: *i*) a high share of manufacturing on GDP is positively related with ICT adoption; *ii*) a high share of agriculture is negatively related; and *iii*) that the share of government spending on GDP is negatively related with the ICT adoption.[2]

Finally, there is no agreement yet 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 includes a price index in his regression and finds it to be significant. On the other hand, Caselli & Coleman do not include a price index in their regression because of lack of data. While Chinn & Fairlie argue that given that prices exhibit a downward trend, they should not be included in the analysis.

3 Empirical Analysis

In this section we estimate equations for ICT investment. Our goal is double: to better understand the determinants of ICT and to define one equation to be included in the SETI model. Estimating the SETI model with the ICT equation included will be better for future research.

As we have seen above, there are many factors that influence ICT investment such as Economic Wealth, Regulation/Policy, Sectoral Composition, Openness to Trade and 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 choice of variables however, has also been limited by data availability. We have included the Sectoral Composition, Human Capital and Regulation. The sample of countries we have considered includes nine West European countries, plus the US and Japan.[3]

The endogenous variable is the ratio of IT expenditure on GDP (henceforth *IT*). We could have also taken the expenditure on communication equipment into account, but we constrained our choice so as to insure consistency, since the ICT variable in SETI is the ratio of IT expenditures on GDP. To proxy the sectoral composition we have considered the share of the service

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2 The rationale for this result is that the public sector often lacks the incentive to obtain a high productivity standard, thus to innovate, and so to adopt ICT.

3 The country set is also consistent with the one used in SETI.

sector in the economy (*service*), while human capital is measured as the share of researchers in total population. The level of regulation is measured by three different indices: an index of Regulatory Conditions in Seven Non-Manufacturing Sectors[4] (*Regulation*, time series and cross-sectional data), an Index of Administrative Burdens on Start-ups (*absu*, cross-sectional data), and an index of the flexibility of the labour market (*labour*, cross-sectional data).[5] Moreover, 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.[6]

The analysis is carried out on a panel of eleven countries (Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, Sweden, the United Kingdom, the United States, and Japan) with yearly observation from 1991 to 2001.[7] The equation has been estimated with simple OLS and the results are shown in table 1*a* (in the Figures & Tables section below.)[8] We present three different specifications: the first including the absu index, the second including the *regulation* index, and the third including the *labour* index. In two equations (column 1&2), all variables have the expected sign and are significant at 10%, whereas in the third specification the variable *GERD* is not significant at 10%. Furthermore, the first two equations fit the IT data relatively well (respectively with an R^2 of 85% and 75%) that is encouraging for performing simulations.

However, looking at figure 1 we can easily see that the residuals are autocorrelated. Moreover, if we look at the graph of the *IT* data versus the fitted values (figure 2), we can see that some country-component is probably missing. Therefore we estimate a random effect model with GLS for the three equations (table 1*b*).[9] In two of the three equations, parameters are significant and have the expected sign. Moreover, as a robustness check, we can notice that OLS estimates fall within a 95% confidence band except for *services* in column 1, and for *human capital* in column 2. It is also noteworthy that in all three equations the variable *GERD* has almost the same parameter estimate: a 1% increase of the ratio GERD/GDP lead respectively

4 Airlines, telecoms, electricity, gas, post, rail, and road freight

5 For all Regulation indices a higher value of the index means a tighter level of regulation.

6 Formal definitions of the data are presented in the appendix.

7 The countries included in the analysis are the same as in the SETI model, however the time period is slightly different as the sample in SETI covers 1988 through 1998.

8 Given that in the SETI model one of the endogenous variables is a service sector variable, the variable *service* enters in the equation with a one period lag in order to avoid a problem of endogeneity. All variables are log transformed.

9 The choice of a random effects *v.s.* a fixed effect was obliged. In fact, both the variable *absu* and *labour* have only a cross-sectional dimension. Thus, we cannot estimate a fixed effect model because by doing so we would run into a problem of perfect multicollinearity.

to a 0.22-0.25% increase of the IT/GDP ratio; whereas the estimate for *service* (0.87 vs. 0.61) and human capital (0.24 vs. 0.16) are quite different.[10]

Overall, the first equation is the one that performs better. Given that three variables are the same in the three equations, this result can be attributed to the different regulation indices included in the regressions. This leads us to the conclusion that what matters the most are barriers to entry in the market (*absu*). The literature on the effects of regulation on the economy has reached the same conclusion: the 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).[11]

The results are in line with the literature. What our estimation adds is the consideration of *GERD*. The variable enters positively and significantly in two of three equations. This result was expected: the idea is that countries which invest more in research and development not only have a high propensity to innovation, but also require updated IT equipment and software in order to make R&D profitable. However, *GERD* is strongly correlated with human capital (table 2), hence it is possible that its impact on *IT* is smaller than our results suggest. We will discuss this issue more thoroughly in the concluding section.

4 Some Further Investigation

The estimation presented above was carried out with constraints regarding the country sample that had to coincide with that of SETI, and the choice of the dependent variable. In this section we carry out some empirical investigation disregarding these constraints also with the purpose to suggest possible future research avenues.

We first modify the country sample. In the previous section we have used a relatively small sample. In this section we further restrict the sample in order to concentrate on the determinants of ICT adoption and diffusion among the EU countries. The analysis is carried out on a panel of fourteen EU countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom) on yearly data from 1998 to 2003. The choice of the time period is due both to data limitation and

10 It is necessary to point out that for human capital: *i*) the value of the estimate of the second equations falls within the 95% confidence band of the first equation (shown in parenthesis in table 1bis), and *ii*) vice versa. However, while the first statement is true for service, the second statement is not. Moreover, if we compare our results with those of G&M, which use our same endogenous variable and the same *service* variable, we find that our estimate of human capital is close to what they have obtained (a value between 0.29 and 0.25 using the variable *years of schooling*), while the one for services is considerably different. (They estimate a value between 0.09 and 0.1).

11 For a review of the literature see Schiantarelli (2005).

because 1998 is the starting year for EMU, which can be seen as a major structural change in Europe.

The second issue deals with the ICT variable. The one used in SETI and on the previous section (IT/GDP) is available from Eurostat up to 2001. In fact, that variable was 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. In other words the ICT series we have used cannot be updated. Hence we decided to switch to the data published by the Groningen Growth & Development Centre. The first thing to notice is that GGDC does not provide the IT/GDP and Communication/GDP expenditure ratio, rather it provides data for the Gross Fixed Capital Formation of: IT Equipment, Communication Equipment, Non IT Equipment, Non Residential Structure, Telecommunication Equipment, and Software. Our strategy has been to analyse the data on IT equipment (henceforth (*iteq*) and Software (*soft*) separately.

We also reconsider the human capital variable. Both in SETI and in the previous section, the variable used is the ratio between Total Researchers and Total Population. We try three more variables here, namely Number of Graduates on Science and Technology (henceforth *graduates*), the Percentage of Population with at Least an Upper Secondary Degree (*education*), and the Spending on Human Resources (*shr*). All variables are provided by Eurostat. The first variable is more closely connected to the one used in the previous specification, while the second and the third capture a broader measure of human capital.

The fourth (and last) issue deals with the Regulation/Policy variable. We have tested the influence of some of the regulation variables provided by the OECD. The new indices are: Barriers to Entrepreneurship (*be*), Scope of Public Enterprise Sector (*scope*), and Size of Public Enterprise Sector (*size*), all of them having only a cross-sectional dimension. As in the previous paragraph, we have also included an index of Regulatory Conditions in Seven Non-Manufacturing Sectors (*Regulation*, time series and cross-sectional data), an Index of Administrative Burdens on Start-ups (*absu*, cross-sectional data), and an index measuring the flexibility of the labour market (*labour*, cross-sectional data).[12]

Table 3 (in the Figures & Tables section below) shows a preliminary descriptive analysis of the data.[13] Pairwise correlations point out that *iteq* and *soft* have different relationship with the variables under analysis. Both variables are similarly correlated with *services*[14] and *regula-*

12 For all Regulation indices a higher value of the index means a tighter level of regulation.

13 Formal definition of the data will be presented in the appendix.

14 Share of the service sector on the economy.

tion,[15] while *soft* exhibits a much stronger correlation with the human capital variables and the GERD variable.[16] Due to somewhat unexpected results (i.e. negative or negligible correlations), the variable *graduates* needs a separate discussion. The variable definition is "Science and technology graduates: Tertiary graduates in science and technology per 1000 of population aged 20-29 years."

Table 4 shows mean values for the human capital variables. Our interpretation is that the number of graduates in science and technology is such a small portion of total population that it is not able to influence the investment in IT Equipment or Software. The EU average value over the sample is 1.2% of population aged 20-29, that, compared with total population, is an even smaller percentage. Is a fraction of population less than 1% able to influence a country's IT equipment and software investment? What the data tell us is that this variable is negatively correlated with *iteq* and almost uncorrelated with *soft*. However, the value of both these variables is large and not likely to be influenced by small values such as those of *graduates*; hence the negative correlation for *iteq*, and the zero correlation for *soft* could have no relevant economic meaning. This interpretation is supported by the performance of *education* and *shr* that are positively correlated with both variables. Table 4 shows that mean values of these variables are much more important for an economy (average EU: *education* = 60.9, *shr* = 5.5). In fact, it is more likely that for a country, having 50% or 70% of the working age population with a secondary degree makes a larger difference in terms of IT investment, than having 1% or 2% of people aged 20-29 with a degree in Science and Technology.

Column 1 of table 5 (in the Figures & Tables section below) shows OLS parameter estimates of the basic regression for the *iteq* equation, while columns 2 and 3 show results of the basic regression augmented in each case with a different regulation index.[17] All variables included in the regression are significant and exhibit the expected sign. As in previous estimations, a human capital variable and a sectoral composition variable, as well as a regulation index enter the equation significantly. However, as shown by a low value of the R^2, the explanatory ability of this model is poor. This was to be expected given the low correlations of *iteq* with the other variables under analysis. Another problem refers to the residual that exhibits autocorrelation (figure 3). We have thus performed GLS random effects estimates for all three equations but, *i*) in all cases the only variable to be significant is *services*, and *ii*) the R^2 is really low. This

15 Index of Regulatory Conditions in Seven Non-Manufacturing Sectors.

16 In this analysis we have also included the variable "GERD financed by the business sector" (b-GERD).

17 All variables are log transformed.

drives us to the conclusion that this simple model is not able to explain the IT equipment capital formation.[18]

Table 7*a* reports various estimates for the *soft* equation. In the regression we have considered two human capital variables (namely *shr* and *education*), one Regulation/Policy variable (regulation), and for the Sectoral Composition the variable *services*. All four regressions except the one in column 2 seem to perform well, with the one in column 3 that better fits the data. This result was somehow expected given that *education* and *regulation* are the variables more strongly correlated with *soft*. Some other results are worth commenting upon.

First, we have tried to include the variables *services* and *regulation* at the same time, however by doing so the parameter of the variable *service* became negative and not significant; this is due to the high correlation between these two variables.

Second, we tried to include both the variable *GERD* and *b-GERD*, but we found that the inclusion of one of those variables makes other variables not significant. Again, we believe that this is due to the high correlation of *b-GERD* with the other regressors. In fact, it is plausible that countries rich in human capital invest more in research and hence require updated software. To further support our interpretation we estimate the model of column 3 by substituting the variable *b-GERD* to the education variable, and by doing so we obtain a slightly similar result (column 5).

Third, and most important, as it can be seen from figure 4 the residuals are autocorrelated. To overcome this problem we estimate the same four equations by feasible GLS using a country-specific AR(1) structure for the variance-covariance matrix. Results are shown in table 7*b* and are similar to those obtained with OLS.[19] In particular:

- i as in the previous estimate, the model of column 2 presents some problems; and
- ii the regressions of column 1 and 4 yield parameter estimates close to those obtained by OLS;
- iii the model in column 3 is still the one that performs better, but it has parameter values that are a little bit different from those previously obtained. The value obtained by OLS however falls within a 95% confidence band and is therefore not significantly different from a statistical point of view;
- iv Finally, we have investigated the impact of other regulation indices, but they either enter with a positive sign or make one of the exogenous variables non significant, prob-

18 Regarding the other regulation variables, they either enter with a positive sign or make *shr* or *services* non significant. This result can be justified by the fact that these three variables are highly correlated with *iteq* and at the same time very weakly correlated with the other exogenous variables (tables 5 and 6).

19 We couldn't estimate the model of table 7, column 5 because of too few observation of the variable *b-GERD* for Austria and Sweden in order to compute an AR(1) process for the respective residual

ably because they are not strongly correlated with *soft* and are *highly* correlated with the other exogenous variables (table 6).[20]

To conclude this section, we investigate the effects that variations of Hardware and Software prices have on *iteq* and *soft*. Table 8 shows correlation between these two variables and the corresponding inflation rate at different time horizons. The variable more correlated with both *iteq* and *soft* is the 5 years inflation rate (π_i).[21] Nevertheless the correlation with iteq is much smaller for all the lags considered. This result suggests that prices affect ICT investments only after a period of persistent decline/increase. This conclusion is supported by the results shown in table 9. Column 1 to 3 shows results of the OLS regression for *soft* augmented with a Software inflation rate at different time horizons:[22] five, four, and three years one inflation have an impact on *soft*, albeit of small amount. However, while the coefficients of the five and four year inflation rate are significant at 10%, the three years is not. Moreover, even in this regression, the residuals show autocorrelations. We thus estimate the equations by feasible GLS using a country-specific AR(1) structure for the variance-covariance matrix, but by doing so we could not obtain the π parameter significant.

5 Conclusions

Our empirical results are in line with the literature on the *digital divide*. In addition we highlight the role of facilitating factors that are considered relevant determinants for the spread of general purpose technologies such as ICT. Human capital, and investments in R&D are factors that increase ICT investments, while burdensome regulation tends to depress them. Furthermore, 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 usually display higher ICT investment. A number of facilitating factors, including the degree of labour market flexibility and the obstacles to start up firms have proven to be important determinants of ICT, to the extent that they influence the business environment.

Of particular interest are the results on Human Capital. The analysis has been carried out by using four different measure of human capital:

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20 The fact that regulation variables enter the iteq equation and not the soft equation has a rationale behind. The idea is that once a firm invests in IT equipment in order to make the investment profitable it has to buy software. Hence, regulation can prevent or discourage investment in IT equipment, but it is less likely to do the same for software investment.

21 $\pi_i = \frac{p_t - p_{t-i}}{p_{t-i}} \times 100$

22 Given the low level of correlation between iteq and π we haven't performed a similar exercise for iteq. All variables are log transformed except prices.

i total researcher over population;

ii science and technology graduates over population aged 20-29;

iii percentage of population aged 25-64 with at least an upper secondary degree; and

iv spending in human resources.

All of them perform well, except for the *science and technology graduates*. We explain these results with the consideration that a fraction of less than 1% of population is probably not relevant to substantially influence a large component such as the investments in ICT (representing more than 2% of GDP).[23] We are aware that this result is not in line with what was expected. Given that increasing the number of graduates in mathematics, science, technology and engineering is one of the EU goals, this result requires further analysis.[24] On the other hand, and in line with the EU goal of reaching a rate of 80% of *population aged 25-64 with at least a completed upper secondary degree*, this variable performed well. A 1% increase in the fraction of population with a upper secondary degree leads to a 0.86% increase in investment in software. The performance of the variable *Spending in Human Resources* is also not surprising. Eurostat defines this variable as "total public expenditure on education." Given that in the EU education is in large part provided by the public sector, this result further supports the idea that general education matters a lot for ICT investment. What remains to be clarified is the question whether, in order to enhance investment on ICT, the attention should be directed to science and technology education or to general education.

Finally, it is worth considering the effect of R&D expenditure on investment in ICT. This variable is positively correlated with ICT investment and enters with positive sign in two of the three equations. It is necessary however to interpret this result carefully. We included this variable in order to capture the propensity to innovation of a country. We expected that countries with a propensity to spend more on R&D would be those who invest more in ICT. Not surprisingly, R&D expenditure is strongly correlated with the amount of human capital. This makes sense, since the availability of researchers (*i.e.* educated people) is a necessary condition for R&D activities. Hence, countries with a large amount of human capital are those that spend more in R&D and invest more in ICT. In conclusion, the amount of human capital, the expenditure on R&D, the intensity of regulation measured in a number of ways, and the share of the service sector on the economy are factors that influence the investment in ICT both directly and indirectly; confirming the role of ICT as a general purpose technology.

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23 Average over the whole sample.

24 For example it would be interesting to extend the sample either in the time or in the country dimension.

Data Definitions and Sources Section

ict = Information Technlogy Expenditure as a percentage of GDP. Source: Eurostat.

*iteq** = IT equipment, Gross fixed capital formation (in constant 2000 prices, millions of Euros), as a percentage of GDP (in constant 2000 prices, millions of Euros). Source: Timmer *et al.* (2005).

*soft** = Software, Gross fixed capital formation (in constant 2000 prices, millions of Euros), as a percentage of GDP (in constant 2000 prices, millions of Euros). Source: Timmer *et al.* (2005).

* Both variables have been considered as a percentage of GDP. Data for *iteq* and *soft* are provided in millions of euros with the exception of those for Denmark and Sweden that are provided in national currency. We have converted the data by using a fixed (average) exchange rate over the whole period. We are aware that this means assuming that the Danish krone-euro and the Swedish krona-euro exchange rate were fixed. The Danish krone-euro has remained stable over the whole period (Average = 7.44, standard deviation = 0.01), while the Swedish krona-euro exchange rate have been stable at least from the beginning of 2002 (over the whole period, average = 8.99, standard deviation = 0.31; from 2002, average 9.14, standard deviation 0.09). Data on Danish krone-euro and Swedish krona-euro exchange rate are daily observation from 1/4/1999 to 12/31/2004 (total observations = 137); source: European Central Bank.

services = Ratio of the number of person engaged in: *i*) Communications (ISIC rev 3 = *64*); *ii*) Financial intermediation, except insurance and pension funding (*65*); *iii*) Computer and related activities (*72*); *iv*) Research and development (*73*); *v*) Other business activities, nec (*749*); and *vi*) Legal, technical and advertising (*741-3*); on the number of person engaged in all industries (*01-99*). Source: 60-Industry Database, Groningen Growth &Development Centre.

GERD = Gross Domestic Expenditure on R&D (million current PPP $) over Gross Domestic Product at Market Prices (million of euros). Sources: MSTI database, OECD; and Eurostat.

hc = Ratio of Total Researchers (Full Time Equivalent) to total Population. Sources: MSTI Database, OECD; and Eurostat.

shr = Spending on Human Resources Total public expenditure on education as a percentage of GDP. Source: Eurostat.

graduates = Science and technology graduates – total: Tertiary graduates in science and technology per 1000 of population aged 20-29 years. Source: Eurostat.

education = Total population having completed at least upper secondary education Population aged 25 to 64 (%). Source: Eurostat.

regulation = Index of Regulatory Conditions in Seven Non-Manufacturing Sectors: airlines, telecoms, electricity, gas, post, rail, and road freight. Source: Conway & Nicoletti (2006).

labour = Average of the index on *i*) Difficulty of Hiring a New Worker, *ii*) Restriction on Expanding or Contracting Working Hours, and *iii*) Difficulty and Expense of Dismissing a Redundant Worker. Source: Doing Business Database, World Bank.

absu = Index of Administrative Burdens on Start-ups. Sources: Conway et al. (2005).

sc = Index of State Control. Sources: Conway *et al.* (2005).

be = Index of Barriers to Entrepreneurship. Sources: Conway *et al.* (2005).

bti = Index of Barriers to Trade and Investment. Sources: Conway *et al.* (2005).

scope = Index of Scope of Public Enterprise Sector. Sources: Conway *et al.* (2005).

size = Index of Size of Public Enterprise Sector. Sources: Conway *et al.* (2005).

control = Index of Direct Control Over Business Enterprise. Sources: Conway *et al.* (2005).

use = Index of Use of Command & Control Regulation. Sources: Conway *et al.* (2005).

pc = Index of Price Controls. Sources: Conway *et al.* (2005).

π = either Hardware or Software Inflation Rate. Source: Groningen Growth & Development Centre (Austria, Belgium, Denmark, Finland, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Sweden, and the United Kingdom), Bundesamt (Germany), INSEE (France), and University of Valencia (Spain).

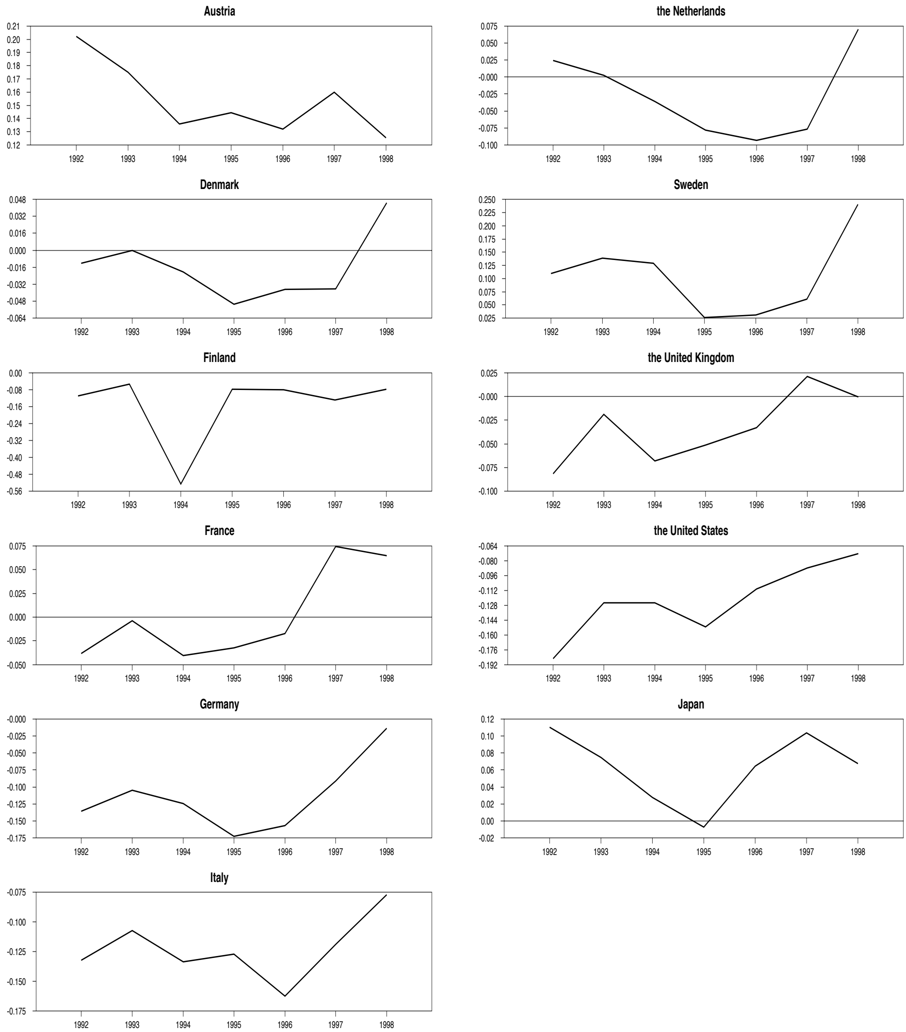
Figures & Tables Section

Table 1*a*: *OLS Parameter Estimate for* IT *equation#*

	1	2	3
services$_{t-1}$	0.5325968 0.0722121	0.5471741 0.0760811	0.6543693 0.0775794
human capital	0.1639408 0.0511169	0.2979716 0.0710997	0.3393918 0.0693722
GERD	0.3512921 0.0780174	0.174244* 0.1159104	0.217335** 0.1160136
absu	-0.204603 0.0159521		
regulation		-0.2188342 0.034755	
labour			-0.0460884 0.0172153
constant	4.682138 0.1096373	5.085732 0.1448187	4.754532 0.148468
R-squared	0.8492	0.7479	0.7274

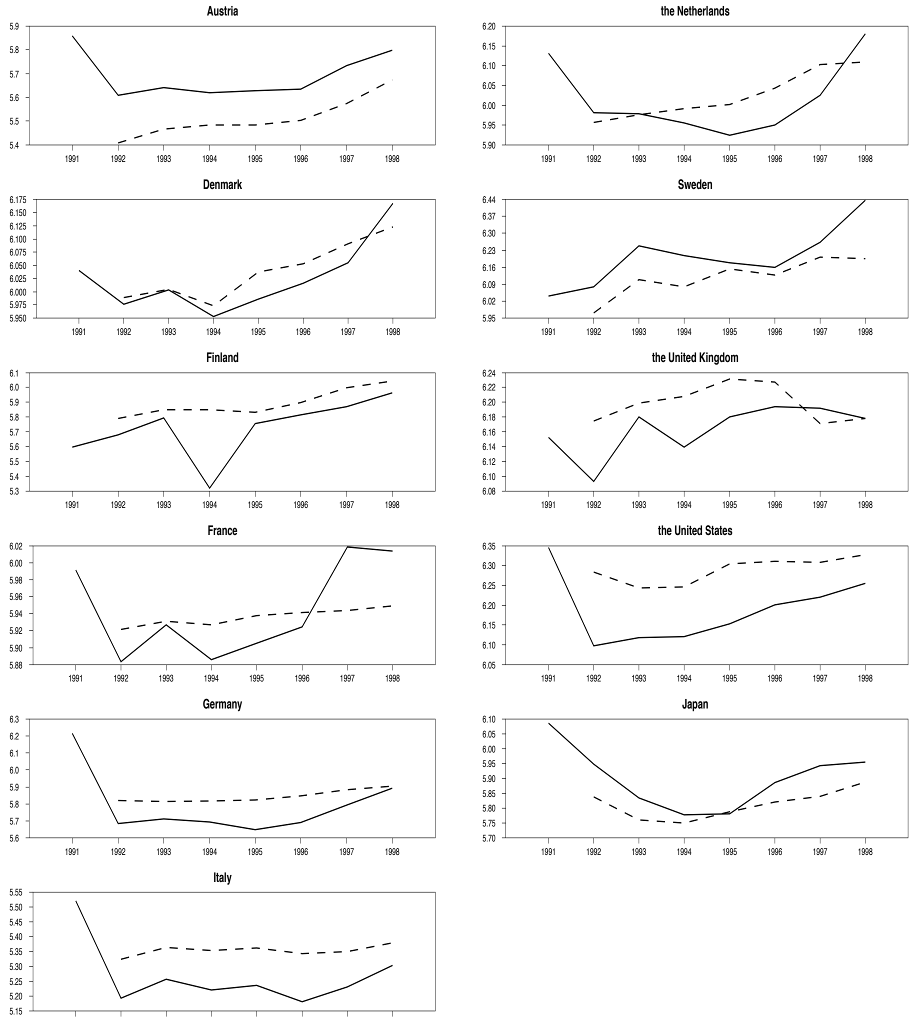
For each variable top line is point estimate and bottom line is White (1980) robust standard-error.
* Denotes not significant
** Denotes significant at 10%; all other variables are significant at 5%

Figure 1: *Residual Plot*



Residuals come from equation of column 1 table 1

Figure 2: ***ICT/GDP vs. Fitted Values***



In each graph straight line is the natural logarithm of ICT/GDP and dotted line is fitted values. Fitted values come from equation of column 1 table 1

Table 1*b*: *GLS Random Effect Parameter Estimate for* IT *equation*[#]

		1	2	3
services$_{t-1}$		0.8690807 0.0870774 (0.698412 ; 1.039749)	0.612524 0.1472045 (0.324008 ; 0.90104)	0.9438328 0.0961194 (0.755442 ; 1.132223)
human capital		0.2418122 0.0546941 (0.134614 ; 0.349011)	0.162643 0.0605284 (0.04401 ; 0.281276)	0.2257715 0.0577285 (0.112626 ; 0.338917)
GERD		0.2213983 0.0814052 (0.061847 ; 0.38095)	0.2517862 0.080501 (0.094007 ; 0.409565)	0.2228712 0.0827885 (0.060609 ; 0.385134)
absu		-0.1755172 0.0577769 (-0.28876 ; -0.06228)		
regulation			-0.1850584 0.0652414 (-0.31293 ; -0.05719)	
labour				-0.05401* 0.0645158 (-0.18046 ; 0.072437)
constant		4.042532 0.2514561 (3.549687 ; 4.535377)	4.656781 0.4165523 (3.840354 ; 5.473209)	3.926797 0.3509505 (3.238946 ; 4.614647)
R-squared:	within between overall	0.752 0.8335 0.8133	0.7683 0.7153 0.719	0.7551 0.6486 0.6595
Fraction of Variance Due to Random Effect		0.718	0.867	0.873

[#] For each variable top line is point estimate, middle line is standard error, and bottom line is 95% confidence band.
* Denotes not significant

Table 2: ***Correlations for* IT *equation***

	IT	*regulation*	*Services$_{t-1}$*	*GERD*	*human capital*	*absu*	*labor*
IT	1						
regulation	-0.70	1					
services$_{t-1}$	0.47	-0.35	1				
GERD	0.70	-0.54	0.19	1			
human capital	0.64	-0.52	-0.10	0.76	1		
absu	-0.67	0.56	-0.11	-0.28	-0.46	1	
labour	-0.39	0.61	-0.06	-0.27	-0.36	0.63	1

Table 3: ***Pairwaise Correlations (N° of Observations)***

	iteq	*soft*	*services*	*graduates*	*education*	*GERD*	*b-GERD*	*shr*	*regulation*
Iteq	1 84								
Soft	0.12 84	1 84							
services	0.32 84	0.42 84	1 84						
graduates	-0.24 75	0.01 75	0.19 75	1 75					
education	0.11 81	0.7 81	0.53 81	0.32 72	1 81				
GERD	0.03 79	0.78 79	0.52 79	0.26 73	0.8 76	1 79			
b-GERD	0.01 77	0.75 77	0.61 77	0.4 69	0.81 74	0.97 75	1 77		
Shr	0.26 80	0.59 80	0.21 80	0.06 73	0.35 78	0.63 75	0.59 73	1 80	
regulation	-0.37 84	-0.52 84	-0.52 84	-0.13 75	-0.39 81	-0.45 79	-0.51 77	-0.28 80	1 84

Table 4: ***Mean Value (Standard Deviation – N° of Observations)***

	graduates	*education*	*shr*	*iteq*	*Soft*
Austria	7.57 0.50 6	76.47 1.74 6	5.68 0.12 6	1.01 0.27 6	0.87 0.16 6
Belgium	10.33 0.56 4	58.88 1.77 6	6.06 0.06 3	2.17 0.64 6	1.00 0.06 6
Denmark	10.73 2.02 6	79.88 0.78 6	8.31 0.13 6	1.73 0.53 6	2.07 0.09 6
Finland	16.95 0.80 6	73.08 2.00 6	6.27 0.15 6	0.38 0.10 6	1.98 0.17 6
France	19.86 1.36 5	62.50 1.86 6	5.87 0.08 6	0.58 0.15 6	0.98 0.10 6
Germany	8.35 0.31 6	82.04 1.45 5	4.57 0.12 5	1.06 0.28 6	0.96 0.07 6
Greece	. . 0	51.83 2.83 6	3.75 0.18 6	0.98 0.34 6	0.48 0.08 6
Ireland	23.08 1.40 6	58.58 2.64 5	4.43 0.21 6	0.87 0.28 6	0.32 0.05 6
Italy	6.47 1.47 6	44.05 1.87 6	4.67 0.13 6	0.79 0.29 6	0.84 0.06 6
Netherlands	6.27 0.59 6	66.48 1.81 6	4.86 0.11 6	1.28 0.29 6	1.62 0.08 6
Portugal	6.63 1.05 6	19.98 1.53 6	5.49 0.11 6	1.15 0.19 6	0.26 0.05 6
Spain	10.52 1.70 6	38.97 3.20 6	4.31 0.07 6	0.71 0.15 6	1.01 0.11 6
Sweden	11.47 2.28 6	78.93 2.70 6	7.45 0.17 6	1.62 0.30 6	2.55 0.22 6
UK	18.23 2.46 6	64.66 1.45 5	4.88 0.34 6	0.96 0.17 6	0.99 0.09 6
EU14	11.98 5.63 75	60.90 17.48 81	5.46 1.25 80	1.09 0.55 84	1.14 0.66 84

Table 5: ***OLS Parameter Estimate for* iteq *equation*#**

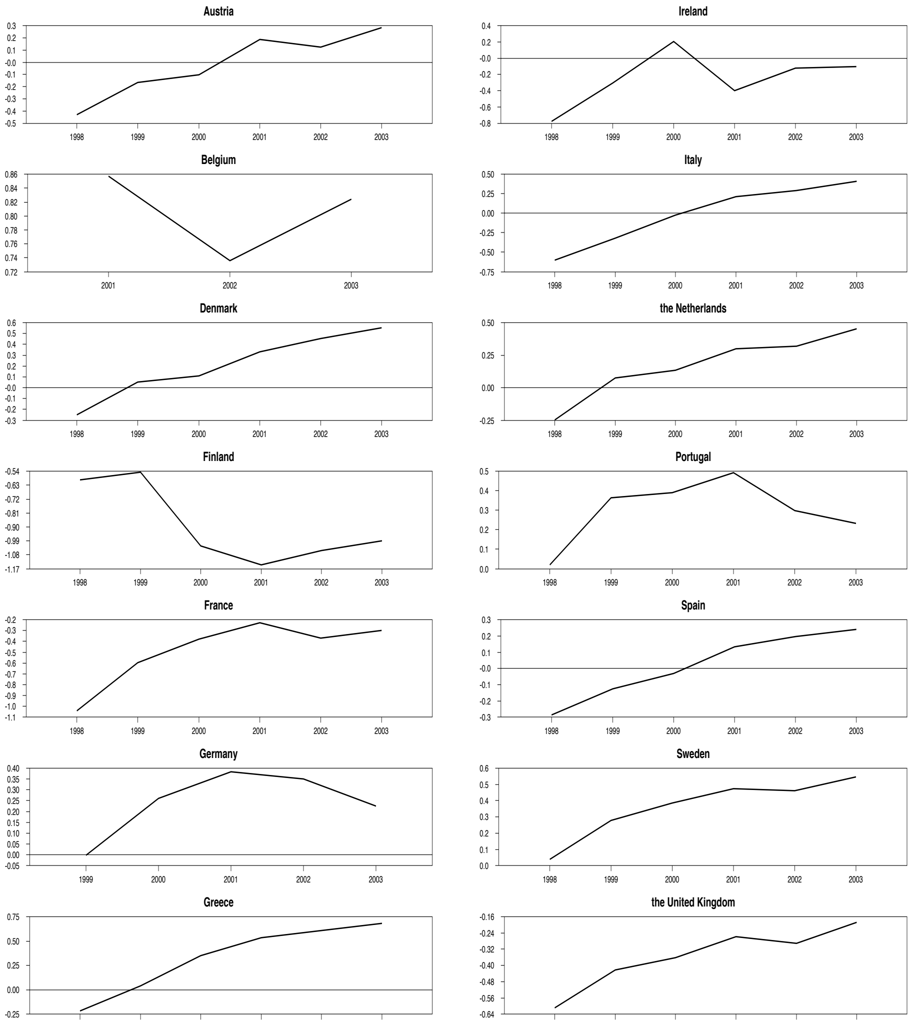
	1	2	3
shr	0.497478 0.2297397	0.4098885* 0.2310603	0.4471842 0.2269453
services	0.482611 0.2045271	0.4102753 0.2011656	0.4120235 0.2061723
size		-1.174968 0.4583407	
be			-1.148293 0.4391733
constant	-2.096478 0.5846197	-1.167789* 0.6859957	-1.525917 0.640611
R-squared	0.1233	0.1985	0.1903

For each variable top line is point estimate and bottom line is White (1980) robust standard-error.
* Denotes significant at 10%; all other variables are significant at 5%

Table 6: ***Correlation of* iteq *and* soft *with regulatory variables***

	iteq	*soft*	*services*	*shr*
services	0.28	0.43	1	
shr	0.26	0.59	0.21	1
be	-0.31	0.13	-0.15	-0.11
scope	-0.20	-0.05	-0.41	0.05
size	-0.34	-0.03	-0.16	-0.16
labour	-0.36	-0.24	-0.43	-0.41
absu	-0.45	-0.25	-0.26	-0.54

Figure 3: *Residual Plot*



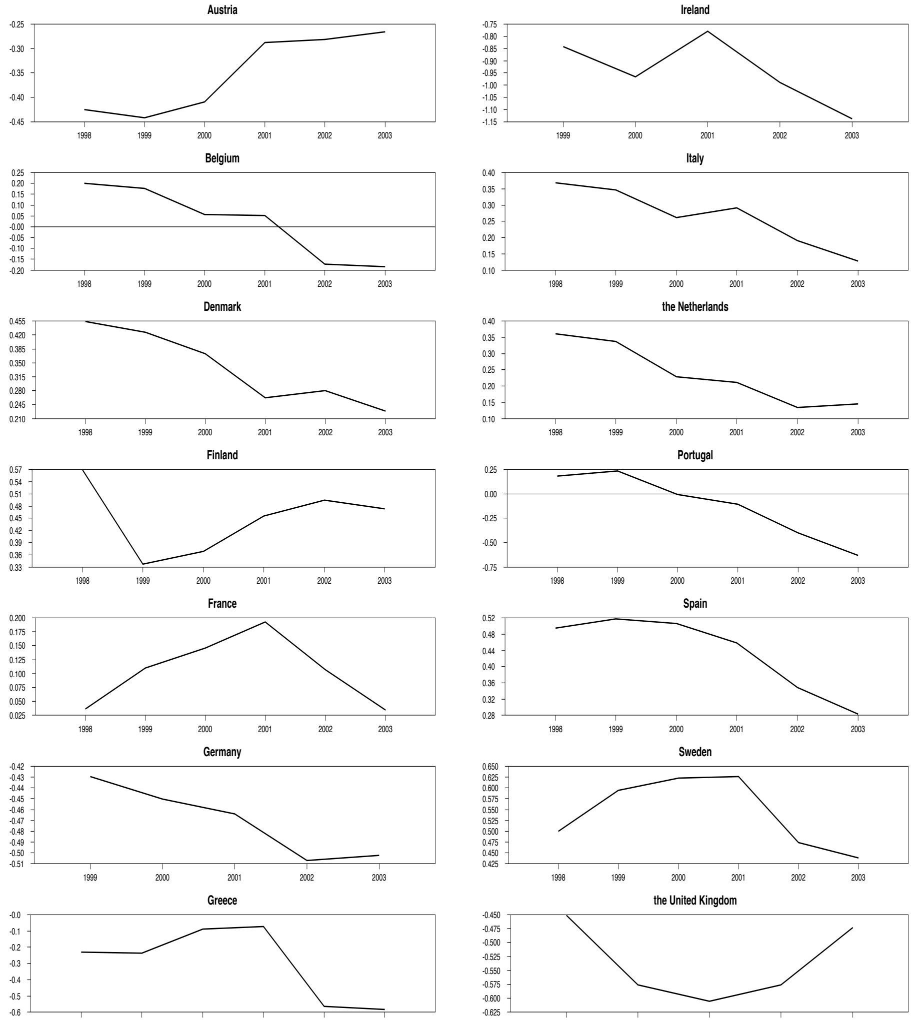
Residuals come from equation of column 2 table 5

Table 7*a*: *OLS Parameter Estimate for* soft *equation*[#]

	1	2	3	4	5
shr	1.611907 0.2104387			1.483886 0.1769522	
services	0.8647492 0.2679359	0.1712644** 0.1948175			
education		1.151626 0.1296319	1.022882 0.1247575		
regulation			-1.162943 0.3558741	-1.613553 0.3133437	-0.66762 0.364481
B-GERD					0.552046 0.068506
constant	-4.93616 0.6979308	-5.144728 0.4572714	-3.698593 0.5872145	-1.869077 0.3553747	0.251582 0.150335
R-squared	0.4452	0.4876	0.5515	0.4874	0.5753

[#] For each variable top line is point estimate and bottom line is White (1980) robust standard-error.
** Denotes not significant

Figure 4: *Residual Plot*



Residuals comes from equation of column 3 table 7

Table 7*b*: *FGLS Panel-Specific AR(1) Parameter Estimate for* soft *equation*#

	1	2	3	4
shr	1.441546 0.1877246 (1.073612 ; 1.809479)			1.174923 0.206035 (0.771102 ; 1.578744)
services	0.7658147 0.2314517 (0.312178 ; 1.219452)	0.3858964** 0.2431056 (-0.08152 ; 0.910152)		
education		0.4143139** 0.2529831 (-0.09058 ; 0.862375)	0.8603575 0.1367054 (0.59242 ; 1.128295)	
regulation			-0.6079806 0.291041 (-1.17841 ; -0.03755)	-1.340254 0.2671012 (-1.86376 ; -0.81674)
constant	-4.418455 0.5599436 (-5.51592 ; -3.32099)	-2.792266 1.105865 (-4.95972 ; -0.62481)	-3.119148 0.6255086 (-4.34512 ; -1.89317)	-1.38772 0.3981833 (-2.16815 ; -0.6073)
Log Likelihood	56.83846	74.54425	70.73591	55.34227

For each variable top line is point estimate, middle line is standard error, and bottom line is 95% confidence band.
** Denotes not significant

Table 8: *Correlation of* soft *and* iteq *with their prices*#

	iteq	*soft*	*education*	*b-GERD*	*shr*	*regulation*
π_1	0.21*	-0.17	-0.21	-0.17	-0.21	0.23
π_2	0.17*	-0.23	-0.24	-0.22	-0.25	0.21
π_3	0.10*	-0.32	-0.27	-0.27	-0.30	0.18
π_4	0.01*	-0.42	-0.32	-0.36	-0.34	0.17
π_5	-0.08*	-0.46	-0.35	-0.40	-0.36	0.14

#All correlation refers to Software prices but for * that refers to Hardware prices

Table 9: *OLS Parameter Estimate for* soft *equation with* π#

	1	2	3
education	0.9256814 0.1384162#	0.9562636 0.1391161	0.993394 0.1382712
regulation	-1.12987 0.3338407	-1.128761 0.3402431	-1.1196 0.3440353
π_3			-0.0114** 0.0105891
π_4		-0.0151712* 0.0086671	
π_5	-0.0157709 0.0071398		
constant	-3.389476 0.6164633	-3.488543 0.6257717	-3.62078 0.6255202
R-squared	0.5832	0.5723	0.56

[#] For each variable top line is point estimate and bottom line is White (1980) robust standard-error.
* Denotes significant at 10%; all other variables are significant at 5%
** Not-Significant

CHAPTER VII

GENERAL PURPOSE TECHNOLOGY IN A STRUCTURAL MODEL

1 Introduction

This final chapter presents a structural model where the role of ICT in supporting growth interacts with other variables, including the role of producer services and variables referring to the "business environment". Whereas the model, called SETI, in its original version treated ICT as exogenous the structural model was modified to incorporate an endogenous determination of ICT, using one of the ICT determination equations estimated in chapter VI. The enlarged model has been used to perform a number of policy simulations, whereby attention is given to how ICT production can be enhanced and how this translates into higher performance.

2 General Issues

To introduce an endogenous determination of ICT in a structural model a number of specific issues should be taken into consideration.

The standard production function, TFP approach to technology is inadequate to deal with ICT. By its very nature this approach is based on a "black box" idea, which must be progressively disentangled. This is a complex process, which must be pursued in steps, especially if each theoretical step is to be accompanied by a quantitative step, so as to provide useful policy recommendations. In disentangling TFP a number of different elements must be taken into account. At this stage we concentrate on three elements: *i)* the relationship between GPT (ICT in our case) and specific technology accumulation, *ii)* the relationship between ICT and the structure of the economy, *iii)* the relationship between ICT and the "facilitating structure".

a ***The relationship between ICT and specific technology accumulation.*** As we have seen in chapter VI, one central feature of a GPT such as ICT is that its indirect impact on productivity and hence performance is more important that the direct impact. More specifically, ICT increases the productivity of direct knowledge accumulation (e.g. investment in R&D) which would otherwise exhibit decreasing returns.

b ***The relationship between ICT and the structure of the economy*** is crucial to understand the channels through which such an indirect effect takes place, as well as how strong such an impact would be. As the use of ICT takes different intensities according to the sectors in which it is applied, a given increase in ICT investment will generate different impacts according to the presence in the economy of sectors in which ICT can be better combined with other factors and/or in which organisational improvements can be more easily introduced. For example business services are intensive ICT users, therefore a widespread presence of such services in the economy enhances the impact of ICT on performance.

c ***The relationship between ICT and the facilitating structure*** is crucial to understand to what extent the economic system is prepared to receive and use a GPT such as ICT. Precisely for its nature ICT introduction requires not only a specific investment in ICT equipment but, even more importantly, a number of facilitating factors that generate the appropriate environment for ICT adoption.

Elements a,b,c interact in generating a virtuous circle of ICT, sustained growth and the impact of positive spillovers. ICT enhances the productivity impact of technology accumulation, which facilitates structural and organisational change towards more ICT intensive activities. This, in turn, facilitates the introduction of ICT.

3 A Structural Model: SETI

The issues discussed above can be better understood in the framework of a structural multi equation model of endogenous growth. SETI (Guerrieri et al. 2005) is a continuous time model of endogenous growth, business services and technology diffusion. The model allows to identify important structural links that help to better understand the role of ICT as a GPT. The model is estimated through simultaneous estimation on several European countries, Japan, and the US. Policy simulations illustrate the benefits for EU growth of the deepening of the Single Market, the reduction of regulatory barriers, and the accumulation of technology and human capital, as well as more ICT investment; the benefits of which are enhanced by the diffusion of business services, both domestic and imported. In SETI, economic growth in Europe (partly a consequence of more ICT investment) is enhanced to the extent that:

- trade in services increases;
- technology accumulation and diffusion increase and become less expensive over time (economic distance decreases also as a consequence of integration);
- regulation becomes both less intensive and more uniform across countries; and
- human capital accumulation increases in all countries (a possible result of integrating national education systems).

The SETI model is based on a different approach with respect to the GEM models discussed in chapter 3. Differences relate to the methodology, the theoretical approach and the construction of the economic relationship. The relatively limited size of the model offers drawbacks as well as advantages. On the one hand, the limited number of equations does not allow too much detail in the analysis and it lacks a fully micro-founded structure. On the other hand, the limited size allows for a rigorous formal analysis of the characteristics of the model, as well as a simultaneous estimation of the parameters. Continuous time specification and estimation allow for a detailed analysis of the dynamic properties of the model, while the panel approach allows to take into account geographical diversity. Finally, SETI introduces the novel feature of the role of services, both domestic and imported, in explaining the process of knowledge accumulation and diffusion. Simulations of the impact of ICT on performance highlight the benefit of taking such interdependencies into consideration.

In addition to the formal properties, SETI allows for a better modelling of the facilitating factors which, as seen in chapter VI, 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). Estimation results and policy simulations confirm the validity of the approach.

Whereas the interaction, as described above, could not be taken into account in the original version of SETI which treated ICT as an exogenous variable; the model has been modified to endogenise ICT determination, in accordance to the approach described in chapter 6.

3.1 Model Equations

The structure of the original model is as follows. Output growth is a function of (exogenous) labor and capital accumulation, as well as of endogenous accumulation of technology and business services. Communication, financial services and insurance are included, both domestically produced and imported. They grow in relation to output and technology levels, reflecting the idea that the share of "advanced" services in the economy increases with technology accumulation.

The model also takes into account the role of the composition of the manufacturing sector for producing and importing business services. This can be interpreted both as the direct stimulus, coming from a higher level of intermediate demand and as the result of knowledge flows associated with forward linkages or "spillovers". Moreover, technological change leads to a "splintering" process, by which services (in particular, business services) spring from the increased technical and social division of labour within production, engendering a strong interdependence between manufacturing and service activities. National regulation intensity depresses the production of services whereas uniform (and low) levels of regulation across countries favour production and import of services. SETI uses a measure of product market regulation to investigate the impact of regulation on production and imports of business services.

In its original version, the model includes four differential disequilibrium equations. The dependent variable in each equation is the rate of growth of the variable, so that each variable x grows at a rate Dlogx according to the difference between the actual (x) and the partial equilibrium value (xd). Endogenous variables include output (Y), business services, both domestic and imported (Sh, Sm) and technology (T). The model is a panel, hence each equation refers to a number of countries. Output growth is a function of (exogenous) labour (L) and capital (K) accumulation, as a well as of endogenous accumulation of technology (T) and services, both domestic and imported (Sh, Sm). Services are treated as a production factor in the same way as intermediate goods. The introduction of services in the production function can be interpreted as a contributing factor to TFP due to the presence of spillovers, generated by the interaction among sectors in the economy. The model (1)-(4) can be seen as a way to endogenize the components of TFP and to take into account the feed back effects of output growth on the TFP components themselves.

Services, both domestic and imported, (eqs. 2-3) grow with output and with technology, reflecting the idea that they represent an important intermediate input and that the share of "advanced" services in the economy increases with technology accumulation. Therefore, services do not include traditional services. Services are also expressed as a function of the expenditure in information technology (ICT) and of the structure of the economy (STR), according to how the manufacturing sector is oriented towards the use of services in production. Finally, higher levels of regulation (REG) have a negative impact on the production of services, both domestic and imported.

Output

(1)

$$\begin{cases} D \log Y = \alpha (\log Y^{d} - \log Y) \\ \log Y^{d} = \alpha_0 + \alpha_1 \log T + \alpha_{sh2} \log S_h + \alpha_{mh2} \log S_m + \alpha_3 \log K + \alpha_4 \log L \end{cases}$$

Services domestic

(2)

$$\begin{cases} D \log S_h = \gamma_{sh} (\log S_h^{d} - \log S_h) \\ \log S_h^{d} = \gamma_{sh0} + \gamma_{sh1} \log Y + \gamma_{sh2} \log T + \gamma_{sh3} \log STR + \gamma_{sh4} \log ICT + \gamma_{sh5} \log REG \end{cases}$$

Services imported

(3)

$$\begin{cases} D \log S_m = \gamma_{sm} (\log S_m^{d} - \log S_m) \\ \log S_m^{d} = \gamma_{sm0} + \gamma_{sm1} \log Y + \gamma_{sm2} \log T + \gamma_{sm3} \log STR + \gamma_{sm4} \log ICT + \gamma_{sm5} \log REG \end{cases}$$

Technology

(4)

$$\begin{cases} D \log T = g(\log T^{d} - \log T) \\ \log T^{d} = f(\delta_{j}, HK, HKR, S_{h}, S_{m}, Y, dist) \end{cases}$$

3.2 Technology in SETI

Technology (eq.4), grows with output, services and, through diffusion, with foreign technology, also given the contribution of human capital. Technology accumulation in each country depends both on domestic factors and on the diffusion of technology between countries. This, in turn, depends on the intensity of technology accumulation in other countries, on the impact of “distance” between countries, as well as on the ability of receiving countries to use imported technology. Human capital in the receiving country (HKR) measures the capacity of absorption of technology by the recipient country, whereas human capital in the sending country HK measures the capacity of the latter to produce technology. Services operate as an attractor of technology in that the more developed the service sector in the recipient country is, the larger the demand for technology will be. Technology in country j grows as a negative function of geographical distance (dist) from country i, from which technology is acquired. The impact of distance decreases over time, reflecting lower cost of transferring technology and information across space, as technological progress increases productivity. The technology variable is patents citations. Flows of patents (Pat) measure the accumulation of the stock of technology. Bilateral flows of patents (Patij) capture the diffusion of technology between two countries. The technology flow relations among countries give rise to a matrix of which value changes over time. In a three country case where patent flows take place between different pairs of countries the matrix would look as follows.

Origin\ Destination	**1**	**2**	**3**	**Total**
1	Pat^{11}	Pat^{12}	Pat^{13}	$Pat^{1\cdot}$
2	Pat^{21}	Pat^{22}	Pat^{23}	$Pat^{2\cdot}$
3	Pat^{31}	Pat^{32}	Pat^{33}	$Pat^{3\cdot}$
Total	$Pat^{\cdot 1}$	$Pat^{\cdot 2}$	$Pat^{\cdot 3}$	$Pat^{\cdot\cdot}$

The stock of technology in each country evolves over time from t-1 to t, given the initial condition of the stock of knowledge T in the three countries:

(5)

$$T_t^1 = T_{t-1}^1 + Pat_{11} + Pat_{21} + Pat_{31}$$
$$T_t^2 = T_{t-1}^2 + Pat_{12} + Pat_{22} + Pat_{32}$$
$$T_t^3 = T_{t-1}^3 + Pat_{13} + Pat_{23} + Pat_{33}$$

Where the first subscript of *Pat* indicates the sender country and the second subscript the recipient country. In (5) the process starts at *t*-1 while Pat_{ii} indicates the domestic accumulation of patents and Pat_{ij} indicates the amount of technology produced in country i that is actually received by country j.

Technology accumulation in each country can be disaggregated in two elements: technology accumulated domestically and the amount of technology accumulated in each of the two other countries, which is transferred to the recipient country through diffusion. In addition, SETI considers a transfer of technology generated in the "rest of the world", e.g. in the US. The impact of technology diffusion depends on distance, as well as on the sending and receiving countries' human capital. While distance affects diffusion negatively, the impact of distance decreases over time (t) if technological progress and/or integration decrease the costs of transferring technology. However, over time the value of technology decreases with obsolescence. So over time the impact of diffusion increases, if the first effect prevails.

3.3 Estimation Results

The model is estimated as a dynamic continuous time panel through the ESCONAPANEL program developed by Cliff Wymer (2002). SETI includes nine European countries, the US and Japan and a panel data for the period 1988-1998. Due to limitations in data availability on services, SETI covers the following countries in Europe: Austria, Germany, Denmark, Finland, France, UK, Italy, Holland, Sweden. US and Japan are included as representative of the "rest of the world". FIML estimation results of the continuous time parameters (see Table 1) are all significant at least at the 95% level and carry the expected sign. Both domestic and imported services are positively correlated with output and with technology accumulation. Technology accumulation affects imported services more than domestic service production. This result highlights the importance of trade services integration in European technology accumulation and hence on growth. The impact of EU integration is confirmed by the estimation results. Higher service production and trade may be associated with the positive impact of low regulatory barriers, as well as of regulatory harmonisation in the EU, but they can also be attributed to a relatively low level of other unobservable impediments to production and trade of services, possibly even associated with a deeper level of integration. Higher levels of regulation have a negative impact on production and trade of services. The structure of manufacturing and service sector specialisation exerts a significant impact on both domestic and imported services. ICT investment has a positive and significant impact on both service variables. Therefore ICT enhances growth also indirectly by increasing the availability of producer services and technology accumulation.

Technology accumulation in each country depends both on domestic accumulation factors and on the diffusion of technology between countries. This, in turn, depends on the intensity of technology accumulation in other countries, on the impact of "distance" between countries, as well as on the ability of receiving countries to use imported technology. Technology accumulation is positively correlated with output and with domestic services, although the estimated value of the elasticity of the latter is relatively low. The elasticity of technology with respect to imported services, on the contrary, is quite high. Human capital also exerts an important effect on technology accumulation, both in sender countries and in receiving countries. One implication of this result is that human capital accumulation in any country affects technology accumulation for two reasons; firstly because it increases the domestic ability to use imported technology and secondly, because it increases the domestic stock of technology that can be exported to other countries.

Table 1: ***SETI (2005) Estimation Results***

Equation	Explanatory variables	Point estimation	asymptotic s.e.	t
1 (output)	T	0.78009	0.01729	45.1
	Sh	0.10397	0.00203	51.3
	Sm	0.09405	0.00637	14.7
	K	0.70025	0.01562	44.8
	L	0.52626	0.00796	66.9
	adj. speed	0.00322	0.00128	2.50
2 (domestic services)	Y	0.50726	0.00463	60.1
	T	0.35290	0.00463	76.1
	beu	4.9995	0.00045	10917.8
	Regulation	-0.30311	0.00478	63.3
	Structure	0.48295	0.00885	54.5
	ICT	0.18024	0.00776	23.2
	adj. speed	0.00309	0.00037	8.2

Equation	Explanatory variables	Point estimation	asymptotic s.e.	t
3 (imported services)	Y	0.50915	0.00752	67.7
	T	0.52334	0.00985	53.1
	Ceu	2.08367	0.04997	41.7
	Regulation	-0.30546	0.00403	75.8
	Structure	0.48160	0.01120	42.9
	ICT	0.17389	0.01159	14.9
	adj. speed	0.00312	0.00058	5.31
4 (technology)	Sh	0.10423	0.00268	38.8
	Sm	0.49110	0.00632	77.7
	Y	0.36370	0.00822	44.2
	HK sender c.	0.472371	0.01375	34.3
	HK receiving c.	0.52622	0.01325	39.7
	Overall impact	0.01530	0.00070	21.6
	Distance	-0.01953	0.00028	67.4
	Time	1.03504	0.02242	46.2
	adj. speed	0.00725	0.00134	5.39

Log-likelihood value = 0.1586610E+04
R2 = 0.701413
F=296.2435

The overall positive impact of diffusion is negatively affected by distance and positively affected by time, confirming the idea that distance should be considered an economic factor of which the impact decreases over time, due to a decrease in the cost of transferring technology and information across space.

3.4 Endogenizing ICT in SETI

To carry out policy simulations with SETI we introduce a new equation, estimated with OLS, which allows for an endogenous determination of ICT. The equation has been estimated in chapter VI.

The equation we have selected to be introduced in SETI is the following:[1]

Number of obs =103	R-squared = 0.8492		RootMSE = 0.11854	
F(4,98) = 129.77			Prob>F = 0.000	
IT	**Coef.**	**Std. Err.**	**t**	**P>|t|**
$services_{t-1}$	0.532597	0.072212	7.38	0.000
human capital	0.163941	0.051117	3.21	0.002
GERD	0.351292	0.078017	4.5	0.000
absu	-0.2046	0.015952	-12.83	0.000
constant	4.682138	0.109637	42.71	0.000

Where the variables are all log transformed and their definition is:

IT = Information Technology Expenditure as a percentage of GDP.

services = (lagged) Ratio of the number of persons engaged in (total employment): *i*) Communications; *ii*) Financial intermediation, except insurance and pension funding; *iii*) Computer and related activities; *iv*) Research and development; *v*) Other business activities; and *vi*) Legal, technical and advertising (741-3); on the number of persons engaged in all industries.

human capital = Ratio of Total Researchers (Full Time Equivalent) to Population.

GERD = Gross Domestic Expenditure on R&D over GDP.

absu = Index of Administrative Burdens on Start-ups.

To make the estimated equation consistent with the continuous time dynamic adjustment structure in SETI, we have modified the ICT equation (6) as follows (whereby all variables are in logs).

(6)

$$ICT^{d} = 4.68 + 0.533\ Services + 0.16\ Human\ Capital + 0.35\ R\&D - 0.2\ Burden\ Sturt\ up$$

$$\mathrm{D}ICT = 0.03^{*}(ICT^{d} - ICT)$$

The adjustment speed has been calibrated to the value of 0.03.

1 We are perfectly aware that in order to get more consistent parameters other estimation methods are needed. For this reason we carried out a GLS estimation to cope with autocorrelated residuals. However, the GLS parameters are not significantly different from the OLS ones. A fully satisfactory approach requires FIML estimation of the full model. Something we leave for future research.

It should be noted that the variable *Services* in eq. 6 is not equivalent to either domestic or imported services in eqs 1-4 above. On the contrary the variable *human capital* is consistent with the ones included in eqs 1-4 above.

4 Policy Simulations

In SETI (2005) several scenario exercises were carried out including:

a elimination of the impact of regulation on services;

b deeper integration in the market for services;

c doubling of ICT spending;

d halving of diffusion costs as represented by distance;

e increase of 5% in the level of human capital in both receiving and sending countries;

f a combination of c) and e);

g a combination of a), c), and d)

These scenarios have been reproduced in the extended version of SETI and some new ones have been carried out to exploit the impact of the endogenous determination of ICT. For obvious reasons scenario c) has not been reproduced, scenario f) collapses to case e), scenario g) includes cases a) and d). We have also considered additional scenarios to take into account the endogenous determination of ICT in equation 5. Scenarios:

i doubling the impact of R&D spending on ICT;

l elimination of the impact of Absu (index of administrative burdens on start ups);

h a combination of i) and l).

Before discussing the scenarios in more detail let us recall briefly the results of a scenario that assumes the doubling of (exogenous) ICT spending rolled out with SETI (in its original version). The impact of a doubling of ICT investment on Gdp growth is positive, but much lower than other scenarios considered in SETI and slightly decreasing over time. These results should however be considered carefully, as they rest on some specific assumptions. First of all, to assume a one step increase in ICT is not consistent with the idea that ICT spending is largely a market determined variable. A one step increase implies assuming that ICT is a fully (or largely) policy controlled variable. Secondly, this scenario assumes that the full impact of ICT is felt in the system without any delay. These limiting assumptions are overcome in the next scenarios.

4.1 Scenario Results

Not all the policy scenarios involve the impact of ICT on performance, but all have relevant policy implications for the process of European integration. We discuss the results comparing the evolution of the five endogenous variables with respect to the EU9 aggregate[2]. We also discuss the details of the transmission mechanism with special emphasis on those related to ICT. Results are reported in figures 1-5 below, which show the percentage difference between scenario and baseline values over fifteen periods.

Our results confirm that services are a powerful driver of growth and that deeper integration in the European market for services does significantly contribute to growth. Scenario b) shows the highest relative performance in output and services, both domestic and imported. Services and hence growth are also boosted by a reduction of diffusion costs (scenario d), elimination of the impact of regulation (scenario a), as well as a combination of the two measures. Technology accumulation is enhanced especially by human capital accumulation (scenario e). The stock of technology is higher with respect to baseline when the stock of human capital, in both sending and receiving countries is increased. This last effect sheds some additional light on the interaction between technology accumulation and growth. The ultimate driver of growth is technology accumulation and the latter is strongly supported by human capital accumulation. However, for such a mechanism to produce significant effects a rather lengthy transmission mechanism is needed, so that it is fair to say that this is a long term process.

4.2 Transmission Mechanism of ICT on Performance

In SETI (2005), ICT spending increases growth indirectly by boosting services. In the enlarged SETI model, the impact of ICT on growth is, in turn, dependent on the impact of variables affecting ICT on the production of services, both domestic and imported. Here we have considered scenarios in which, contrary to the case of SETI (2005), policy can impact ICT only indirectly, although in a number of ways.

We can start by looking at the impact of the different scenarios on ICT. Scenario e) shows that more human capital is the single, most effective measure in boosting ICT, followed by i) doubling the impact of R&D on ICT, and l) elimination of administrative burdens on start ups. The combination of i) and l) –scenario h) – yields the highest relative impact in this group of scenarios.

Scenario e) assumes that higher investment in education, which can of course be considered a key public policy strategy, boosts human capital accumulation, hence ICT, and hence services

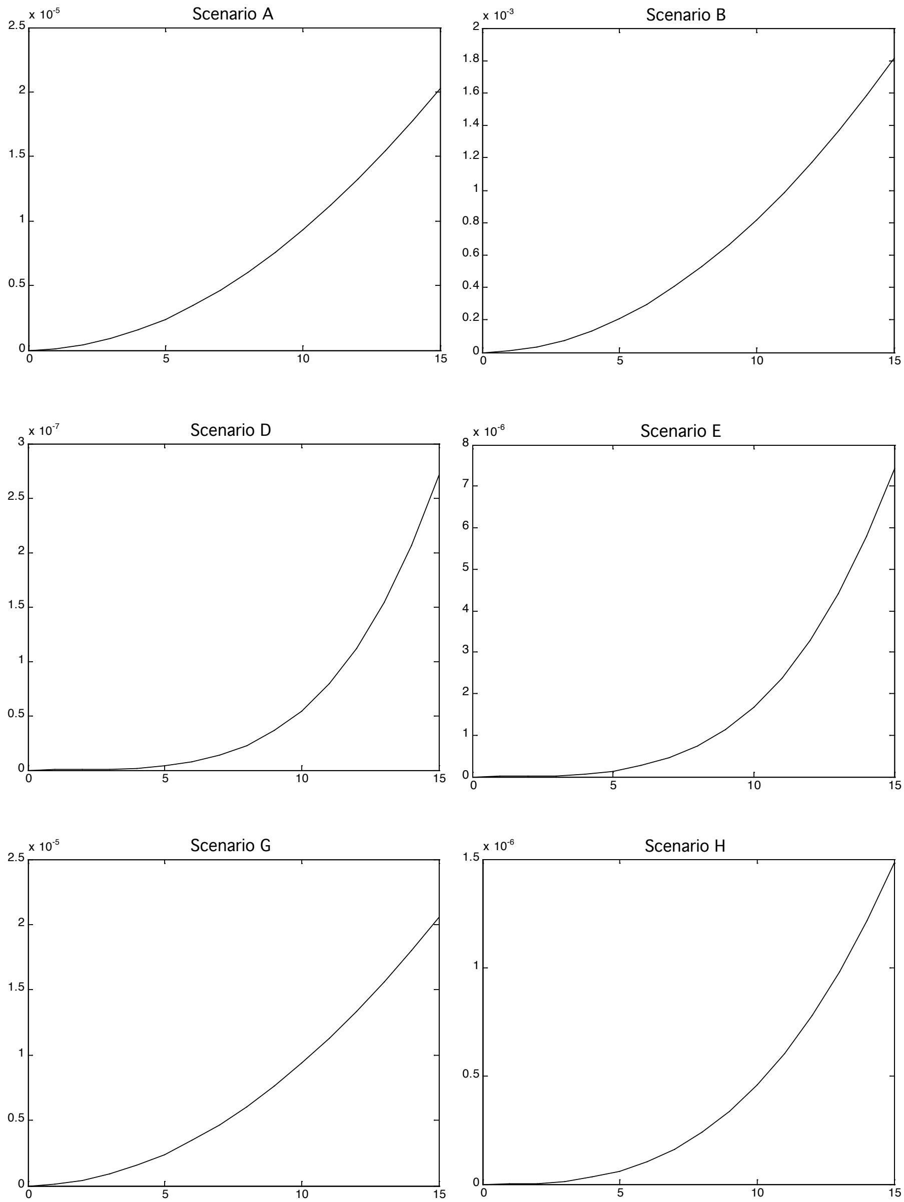
2 The results related to US and Japan are presented in the appendix (See www.coleurope.eu/research/modellingICT.)

and growth. Human capital supports growth also, and more directly, through technology accumulation. This scenario is the one, among those involving ICT, in which output performance improves more significantly. Scenario i) can also be thought of as policy scenario given the relevance of R&D spending in the European growth strategy and the attention that it has attracted in several policy simulations analyses as the ones we have discussed in chapter 4 Scenario l) seems to be the least effective among the three cases.

5 Conclusions

In conclusion, our results show that (EU9) output growth can be significantly increased, if the availability of business services and the accumulation of knowledge are enhanced. These results can be obtained through an improved regulatory environment, through deeper integration in service markets and a stronger impact of technology diffusion. Higher ICT investment, which can be boosted by a number of policy strategies such as more investment in human capital, lower start up costs for business and more investment in R&D, provide potent additional stimuli to growth. We have not presented additional scenarios but it could be shown that a combined strategy of deeper integration and deregulation would boost growth through the positive interaction and complementarity among business services, knowledge accumulation, and ICT. However a full appreciation of such effects would require a model in which ICT is made endogenous through a simultaneous estimation of the equations that make up the enlarged SETI version we have used for our scenario analysis.

Figure 1: ***Output. Percentage Change with Respect to Baseline.***



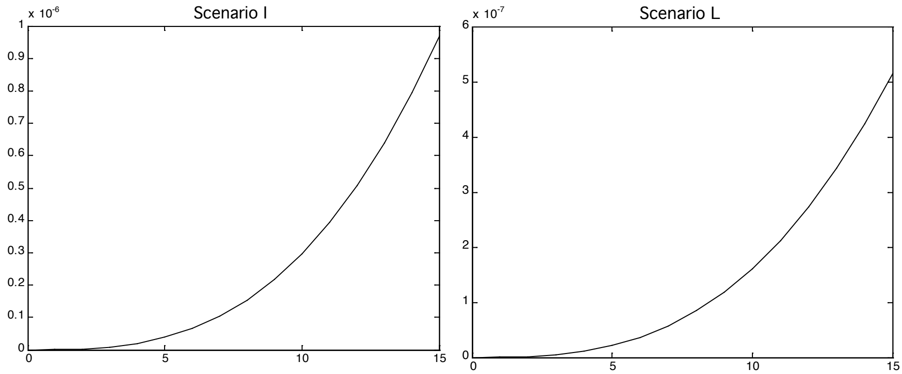
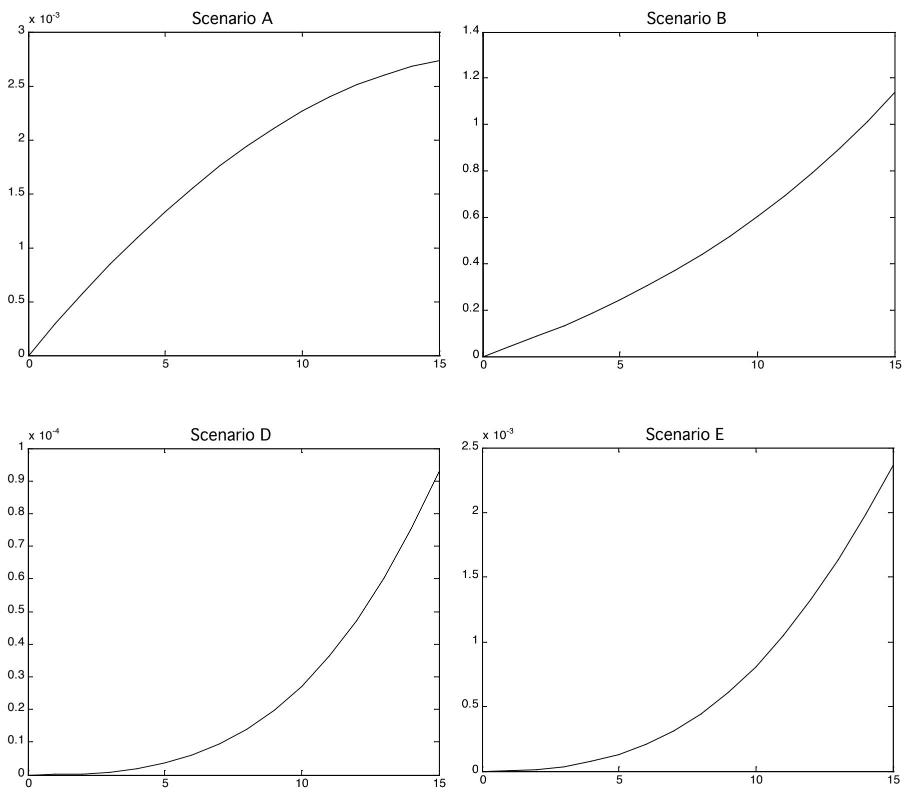


Figure 2: ***Domestic Services. Percentage Change with Respect to Baseline***



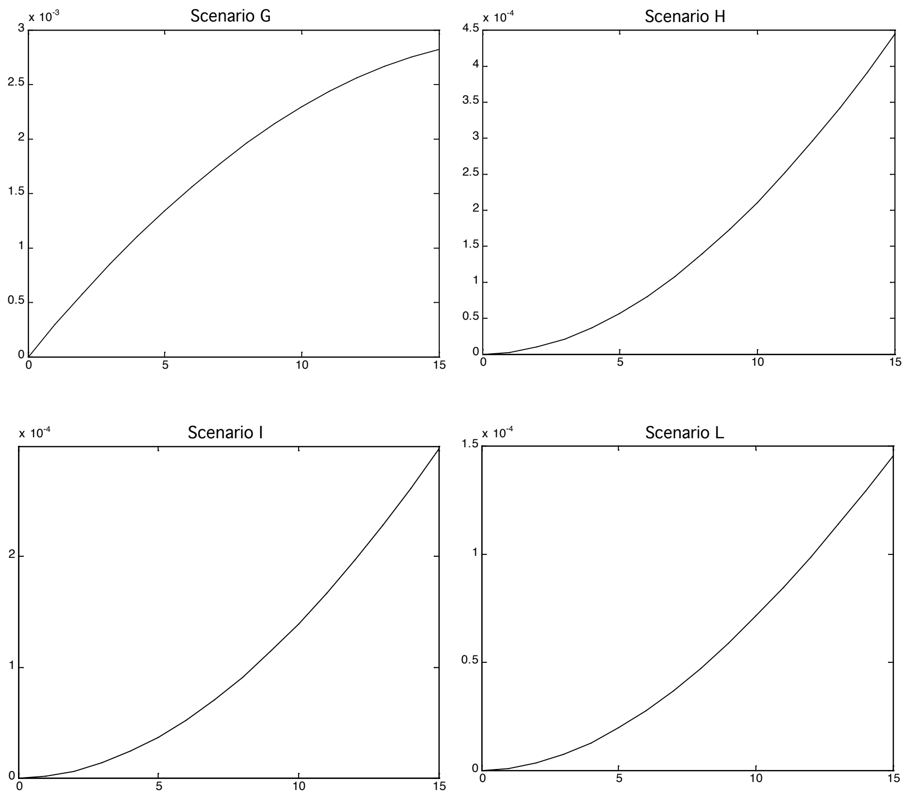
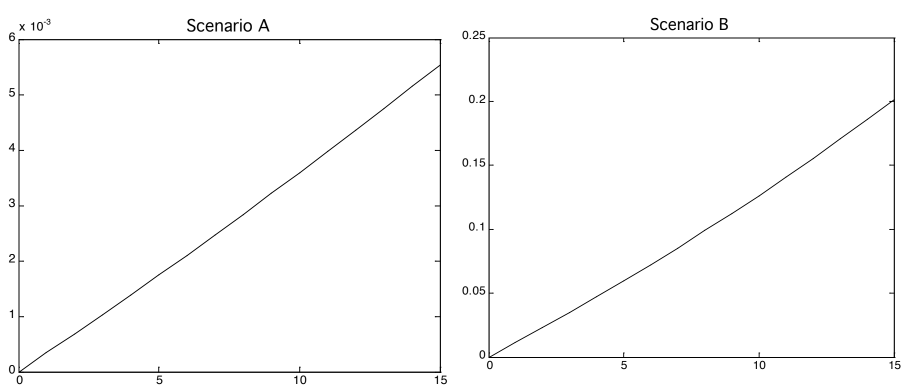


Figure 3: ***Imported Services. Percentage Change with Respect to Baseline.***



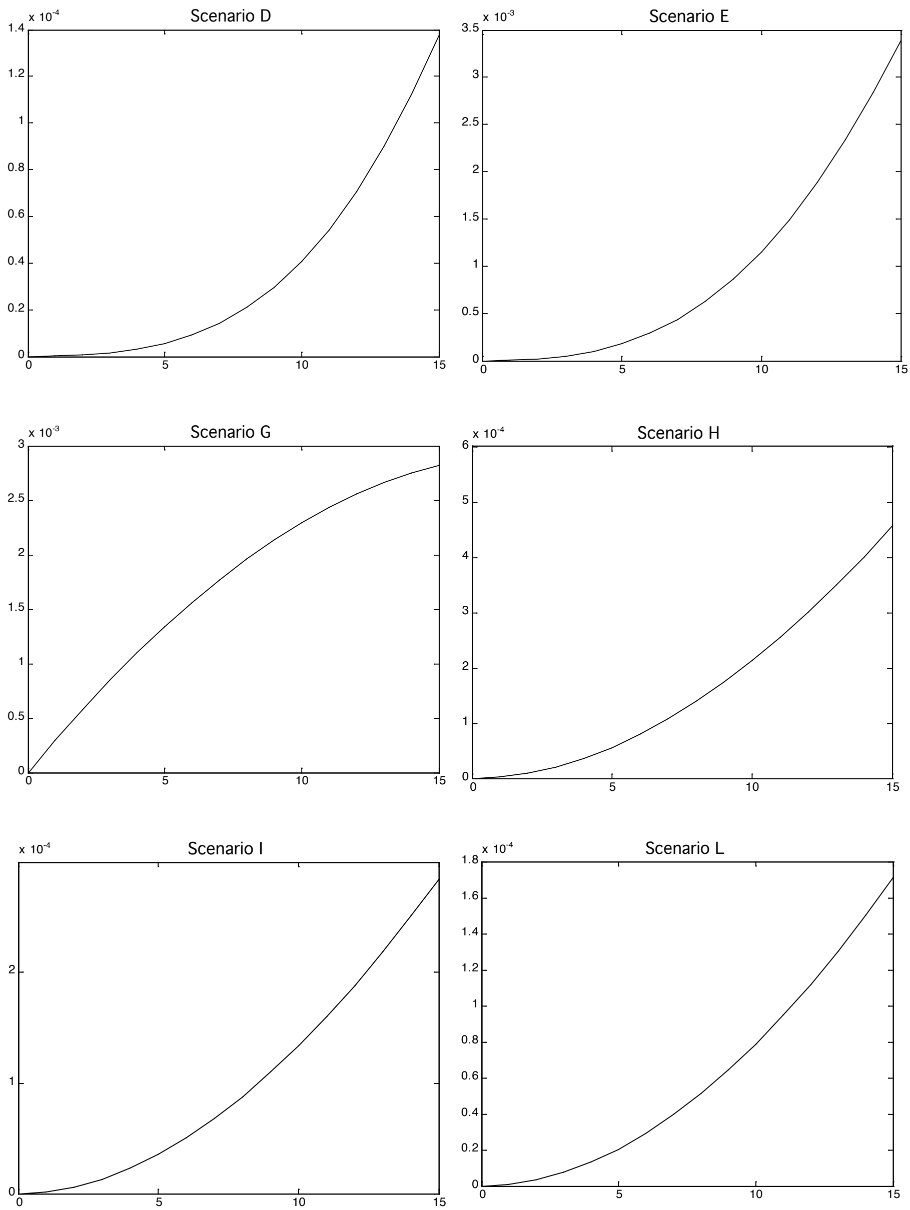
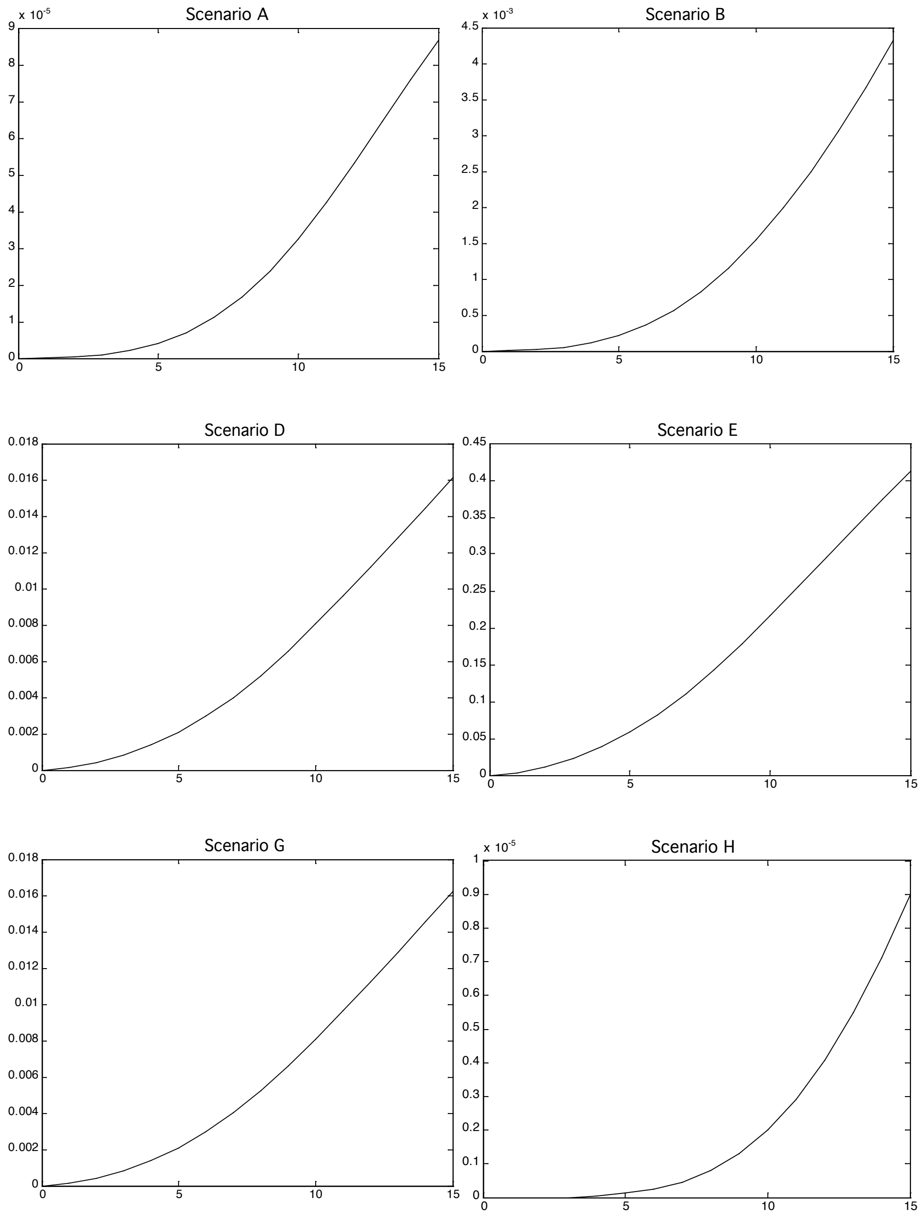

Scenario D
x 10^-4
Scenario E
x 10^-3
Scenario G
x 10^-3
Scenario H
x 10^-4
Scenario I
x 10^-4
Scenario L
x 10^-4

Figure 4: ***Technology. Percentage Change with Respect to Baseline.***



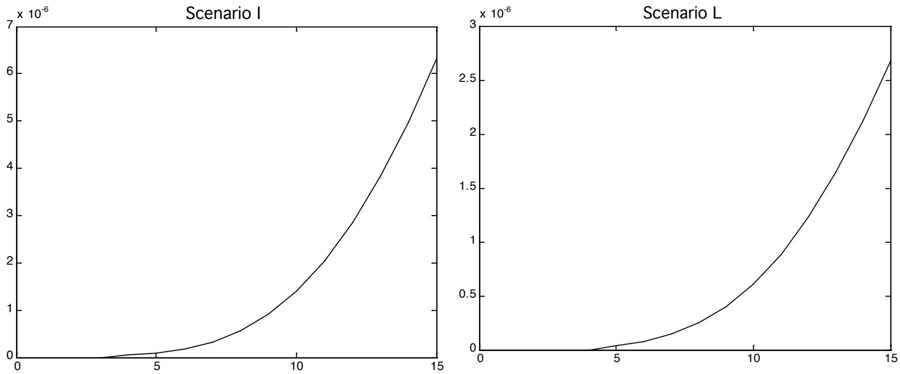
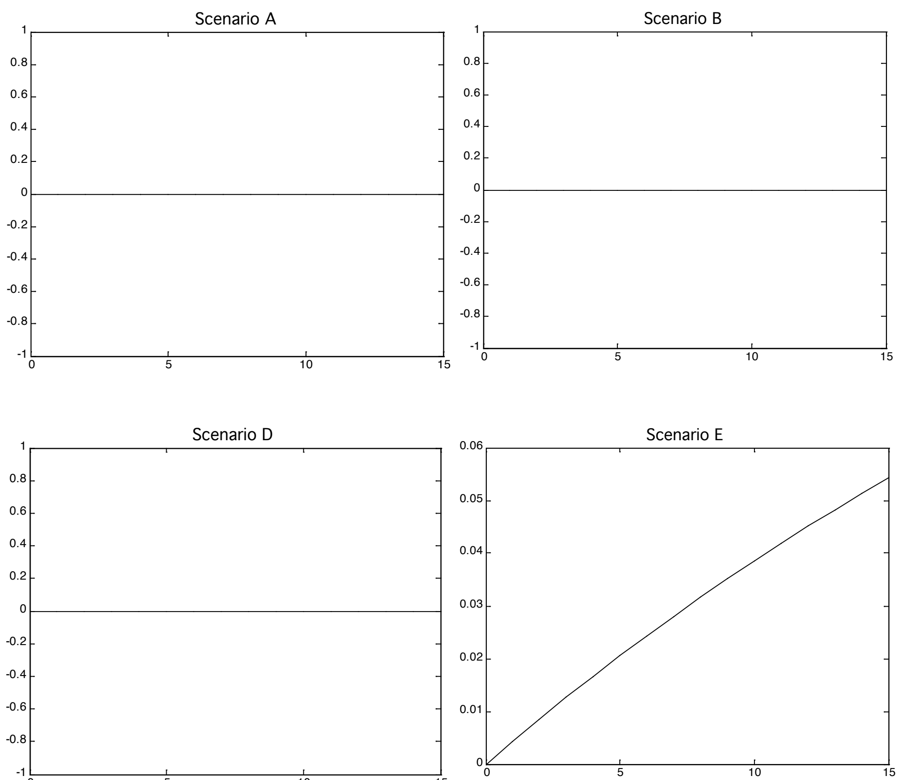
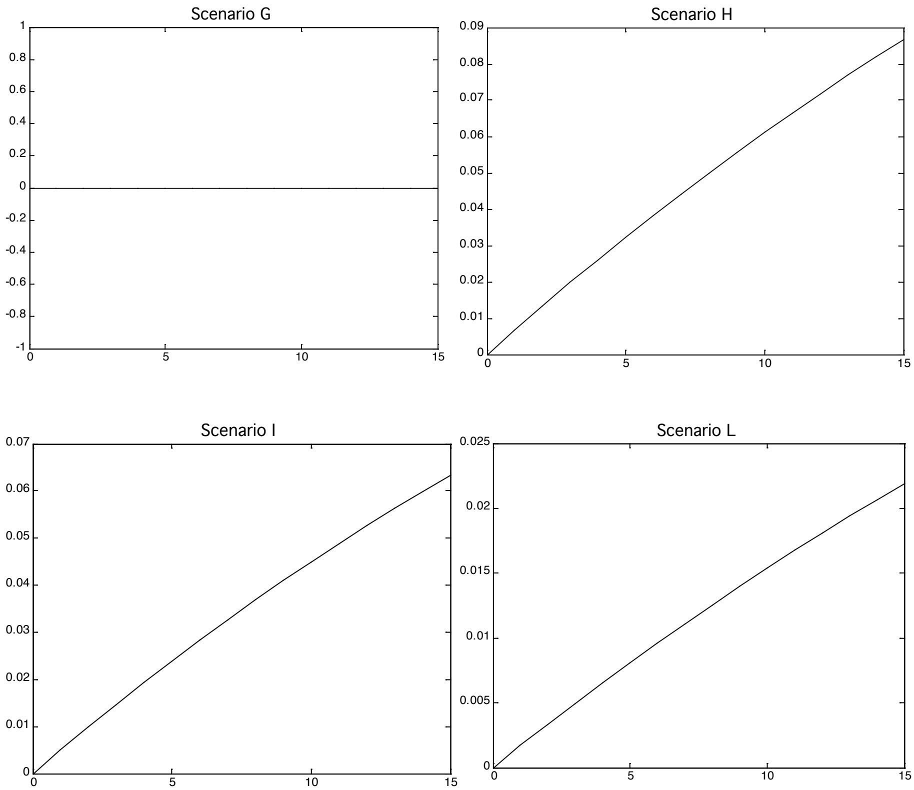


Figure 5: ***ICT. Percentage Change with Respect to Baseline.***




Scenario G
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
5
10
15
Scenario H
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
Scenario I
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
Scenario L
0.025
0.02
0.015
0.01
0.005
0
0
5
10
15

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