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

MODELLING ICT AS A GENERAL PURPOSE TECHNOLOGY

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The Final Report (200p) presents all findings in their technical details and provides an in-depth overview of the methodology, policy simulations, the underlying theoretical framework, and literature references. The Report as well as the Final Report Paper will be made available at the College of Europe website:

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Introduction

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 what is required is an assessment of how existing models can lead to improvements in policy design and analysis, both at national and EU levels. 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; 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 could satisfy the increasing requirements for evidence based impact assessment and evaluation of policies and programmes;
- To assess their availability and capabilities for quantitative evaluation of the impact of IST research and investment in terms of growth, competitiveness, jobs and social inclusion;
- To identify one or two models and tools which could best meet the requirements of DG Information Society;
- 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.

The paper is structured into two parts.

Part I offers a description of the methods and data available. Section 1.1 investigates the implications of treating ICT as a General Purpose Technology (GPT). It then presents a survey of the existing modelling approaches to ICT concentrating on computable general equilibrium models (CGE) (section 1.2). The reviewed models are classified according to a set of general criteria that allow identifying the preferred models used in this study for ICT policy simulation. Section 1.3 then offers a different approach to modelling the impact of ICT, which is to be seen as complementary to the CGE models, since it allows modelling some of the main features of ICT as a GPT. Finally section 1.4 provides an overview of the availability of official data and indicators, which are useful to analyse the impact of ICT on growth performance at macro and industry level as well as for social inclusion.

Part II reports on the preliminary assessment and the main findings of the impact of ICT on economic performances and policy simulations carried out in this project. Section II.1 offers a set of policy simulations on the impact of ICT on performance carried out with a CGE model (International Futures). Then we present estimation results of an endogenous determination of ICT (section II.2). In section II.3 simulations are carried out with the SETI model that incorporates an endogenous determination of ICT. Section II.4 offers a new technological development index (TDI) and section II.5 presents our approach and the indicators to assess e-Inclusion in the European Information Society. Finally, section II.6 summarises the results of the study and offers recommendations for further model and data improvements.

PART I. ICT AS A GENERAL PURPOSE TECHNOLOGY: METHODOLOGY AND DATA

I.1. 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 generalised productivity gains.

In today's economy 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 simply by considering it an additional factor of production. A fully satisfactory way of modelling an ICT-driven growth would require a totally new modelling approach. It would be a demanding long-term research project that deserves to be undertaken. A first set of recommendations for future research in this field are made in part II of this study.

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, we consider it a useful strategy to complement the analysis carried out with existing 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.

Following a comparative assessment of eight CGE models, we have carried out a preliminary assessment of the impact of policy actions to support ICT adoption. The results 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. Moreover, to better simulate the impact of ICT on the economy, 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.

I.2. Technology, ICT and performance: A comparative assessment of Computable General Equilibrium Models (CGE) -

This part considers a set of existing Computable General Equilibrium Models (CGE) with the purpose of identifying 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 the following sections of this study. On the other, hand we suggest possible ways of introducing ICT in several CGE models, taking into account the complexity of the transmission mechanisms available in the models.

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 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 as exhaustive, but as representative of the range of available quantitative tools. In particular, they have been chosen 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 endogeneity of technical change. In order to make a comparative assessment and comparison of these models, we look at three aspects: i) performance variable; ii) structural specification and detail; iii) methodological approach.

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

With respect to the structural specification and details, the models exhibit different characteristics. As the literature points out, ICT has different impacts on economic sectors. A sectoral dimension is therefore an important condition for a model to properly evaluate the impact of ICT. Models with a structural dimension are WorldScan, NEMESIS, IFs and GEM E-3.

On the basis of the methodological approach, the models can be classified between those that are calibrated and those that are estimated. Both calibrated and estimated models are potentially capable of analysing 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 rely on different properties resulting in different pros and cons.

With the exception of IF, none of the models considered includes 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.

For our 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.

To summarise, the models that offer the best possible balance between the different factors are the IF model 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.

Results are summarised in tables 1 and 2.

Table 1. Technology in CGE models

	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	Increase in R&D in industrial countries

Table 2. Model Assessment and Comparison

Reference Parameters		WORLDSCAN	NEMESIS	QUEST	MULTIMOD	International Futures	NiGEM	Oxford Economic Forecasting	GEM-E3
<i>Performance Variable</i>	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 Sustainable Development	No	No	No	No	Yes	No	No	Yes
<i>Structural Specification and Detail</i>	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 technological change	Endogenous in the extension	Endogenous	Exogenous	Endogenous in the extension	Endogenous	Endogenous in the extension	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
<i>Methodological Approaches</i>	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

I.3. A Structural model with endogenous ICT

Computable General Equilibrium models can be modified and have been modified in this study to accommodate the introduction of ICT and produce simulations to understand its impact on the performance of the economy. Simulations results are reported in section II.1 below. However, such an approach, while providing useful results, can not fully take into account the impact of ICT. In this section we offer a complementary approach to modelling the impact of ICT, based on simulations carried out with a small structural model, called SETI.

In SETI output growth is a function of (exogenous) labour and capital accumulation, as 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. It follows that 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. These are some initial steps in disentangling the black box of the production function and to capture the interactions between ICT, the facilitating structure, public policy and performance.

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 exogenous 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. Hence 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 receiving countries to use imported technology. Human capital in the receiving country measures the capacity of absorption of technology by the recipient country, while human capital in the sending 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 demonstrated in this report, ICT determination can be made endogenous when the role of the facilitating structure in determining ICT introduction in the economy is taken into account. For the purpose of this study the original SETI model has been modified (or enlarged) accordingly.

I.4. Information Society Technology: data and indicators

ICT data and indicators are an important instrument for policy in a number of ways. Firstly, quantitative data are needed to map the status quo, and to compare the degree of technological diffusion across regions or countries. Secondly, data are compulsory to understand and assess the improvements of the information society and to monitor the progress achieved over time.

This section provides an overview of the availability of official data and indicators necessary to analyse the impact of ICT on growth performance and employment both at macro and industry level. Furthermore we present an evaluation of data consistency and quality by source, and identify a *core dataset* to be used - and we have used it - in modelling ICT and economic performance. We also 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 when policy indicators are concerned. However, time series are currently too short. They will become a reference, once they can be extended, except for Human Resources in Science and Technology (HRST) measures for which ICT data is derived from another source known as EITO.
2. GGDC is currently the best source for ICT variables and indicators, since data come from official national statistical institutes with the highest available guarantees of quality and country coverage. However, information on data's quality is not totally clear. Missing data are estimated there is no indication of which values exactly are missing.
3. OECD data are affected by many missing values and reveals several inconsistencies between databases that emerge only when deep analysis is carried out. (Details can be found in the full report.) These data can be safely used when they are taken from the same DB. (No inconsistent behaviour has been found when working with a single DB).

Once data consistency has been assessed, a core dataset is identified. It concerns basic variables for growth empirics, ICT measures and R&D expenditures. Time series of selected variables have a 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 however, OECD data sources are preferably used, since the data are gathered directly from National Accounts without further elaboration. From a sectoral point of view however, the GGDC data provide a better coverage than the OECD. ICT variables are available only from GGDC according to our selection criteria. Finally, when it comes to cross-country non-dynamic analysis, one can only refer to EUROSTAT data.

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. 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 EUKLEMS database will be published by March 2007. As far as ICT data are concerned, this report analyses part of the elementary aggregate information that will be included in the EUKLEMS DB. As a consequence, it is most likely that several countries that are not included in the analysis will be available from EUKLEMS, allowing a deeper understanding of EU technological development. Indeed countries as Czech Republic or Cyprus could not be included because ICT data are not available at present, whereas other indicators, such as those related to human capital and R&D are accessible. Nevertheless an effort is still needed to include these countries, as far as market regulatory indices are concerned.

In the mean time, analysis can only be carried out on countries that report complete information about ICT and related technological variables.

PART II. MODELLING ICT AS A GENERAL PURPOSE TECHNOLOGY

II.1. ICT as a General Purpose Technology (GPT): modelling its impact on performance using IFs

To illustrate the capability of the most appropriate models, we carried out a series of simulation exercises on the impact of ICT on economic performance, using the International Futures (IFs), CGE model. Among the multi-equation models that we have reviewed, 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 simulations of the impact of ICT on economic growth are carried out by presenting a scenario analysis that considers the consequences of changing some key parameters, which govern the ICT sector performances over time. In particular, the transmission mechanisms that we take into account in the simulation exercises are:

- a) the capital productivity of the ICT sector (elasticity);
- b) the time of convergence of services sector productivity to the one of the ICT sector;
- c) the number of networked persons in the system (as a proxy of the effective implementation of ICT in the economies);
- d) the elasticity of TFP to investments in electronic networks;
- e) the elasticity of TFP to investment in telecommunication infrastructures;
- f) the multifactor productivity of the ICT sector of the system leader (endogenously determined).

These simulation exercises do not aim to fully capture the transmission mechanisms of ICT to the performance variables; they are rather examples of a larger set of possible exercises to be conducted with IFs and possibly other CGE models. When presenting the results, we particularly 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 by using the IFs model, it is possible to study the effects of ICT in a more complex way than by studying its impact on GDP as an input of the production function. We come back to this issue again in section II.2, when we endogenise ICT investment.

Moreover, in assessing the impact of ICT on performance, one must take into consideration different ways in which ICT can influence economic growth. The literature distinguishes three such ways.

- 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 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.

Our own estimates of the impact of ICT on growth, presented in the full report, confirm a positive and significant impact of ICT, but also show that the spillover (indirect) effects are larger than the direct effects. More interestingly, the indirect effects are linked to some variables capturing the general environment, such as regulation, the share of dynamic producer services and the sectoral composition of the economy. These results lend support to the idea that ICT is a general purpose technology that emphasises the role of facilitating factors in explaining differences across countries in the development, diffusion, and impact of ICT on the economy.

We consider the following scenarios:

Scenario A - This scenario explores the effect of a more productive capital factor in the ICT sector. More specifically 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 - In this scenario 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.

In summary, the IFs platform contains useful features to simulate the effects of key parameter changes on the economic system related to the introduction and diffusion of ICT. Nevertheless, it is important to remark that the magnitude of the effects on performance is dependent on the highly complex set of inter-connections among the building blocks of Ifs. In other words, it is necessary to significantly increase the parameter values to obtain significant impacts on the performance variables, given that several constraints exist in the blocks that limit the range of variation of variables.

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

- a more productive capital factor in the ICT sector, which increases GDP, but only in the very long run;
- a more rapid rate of adoption and diffusion of ICT in the service sector, which 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, which in turn 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, which leads to higher aggregate investments that, in turn, affect GDP;
- a higher elasticity of ICT MFP to communication infrastructure leads to higher GDP, only 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

From a quantitative point of view, our simulations produce results with relatively small effects for the relevant macroeconomic variables. The reason for such limited effects should not be interpreted as the limited effect of the transmission channels of ICT sector in the economic system, but rather as the result of a highly non linear econometric model embedded in the framework of a “super” model composed by seven blocks (socio-political, demographic, economic, technological, environmental, agricultural, energy). The economic block is the central one and, consequently, the outcome of economic functioning is influenced directly and indirectly by all the other blocks. (See figure 1.)

In addition, it remains to be clarified to what extent the scenarios considered can offer a realistic representation of the consequence of policy measures.

With all these limitations in mind however, the use of the IFs model can offer some first useful insights on the transmission mechanisms of several ICT related policies. The simulation exercises in particular, allow us 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, 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 also offer some insights on the diffusion of the

impact of ICT on performance across countries. As we have seen, an increase in ICT productivity in the USA (the leading country) affects GDP not only in the USA, but also in European countries, albeit to a lesser extent.

Figure 1. The structure of IFs: the “seven blocks”

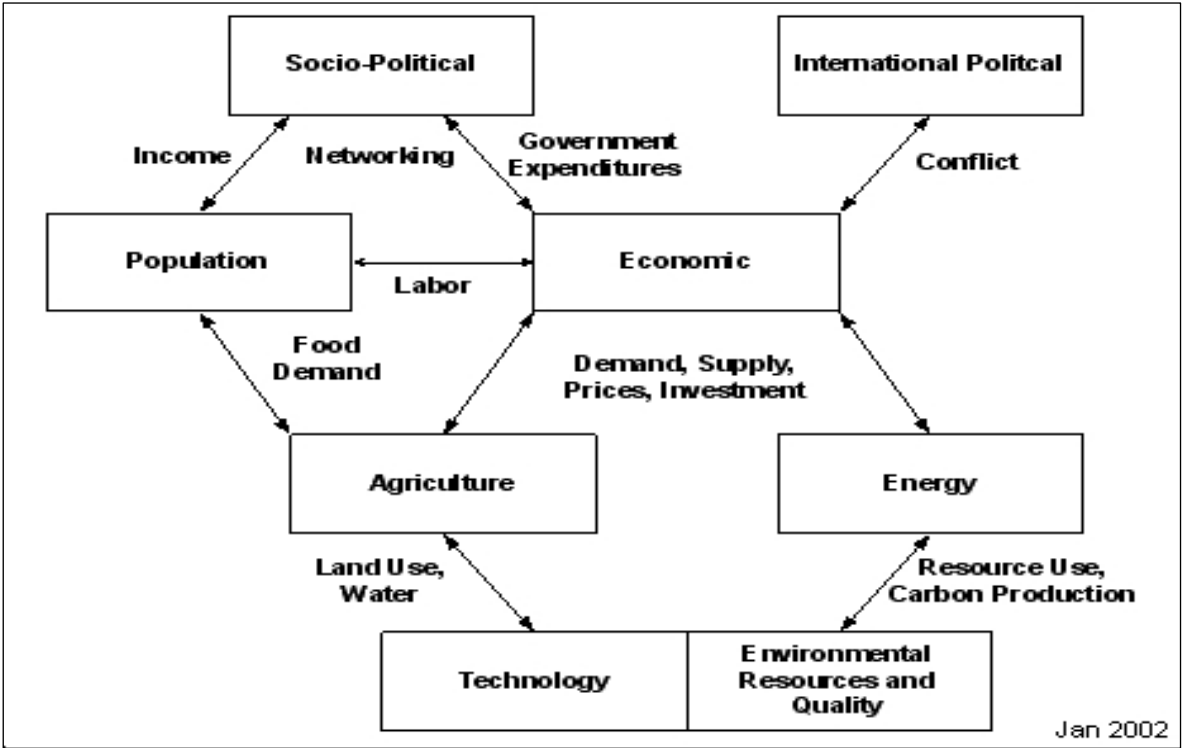
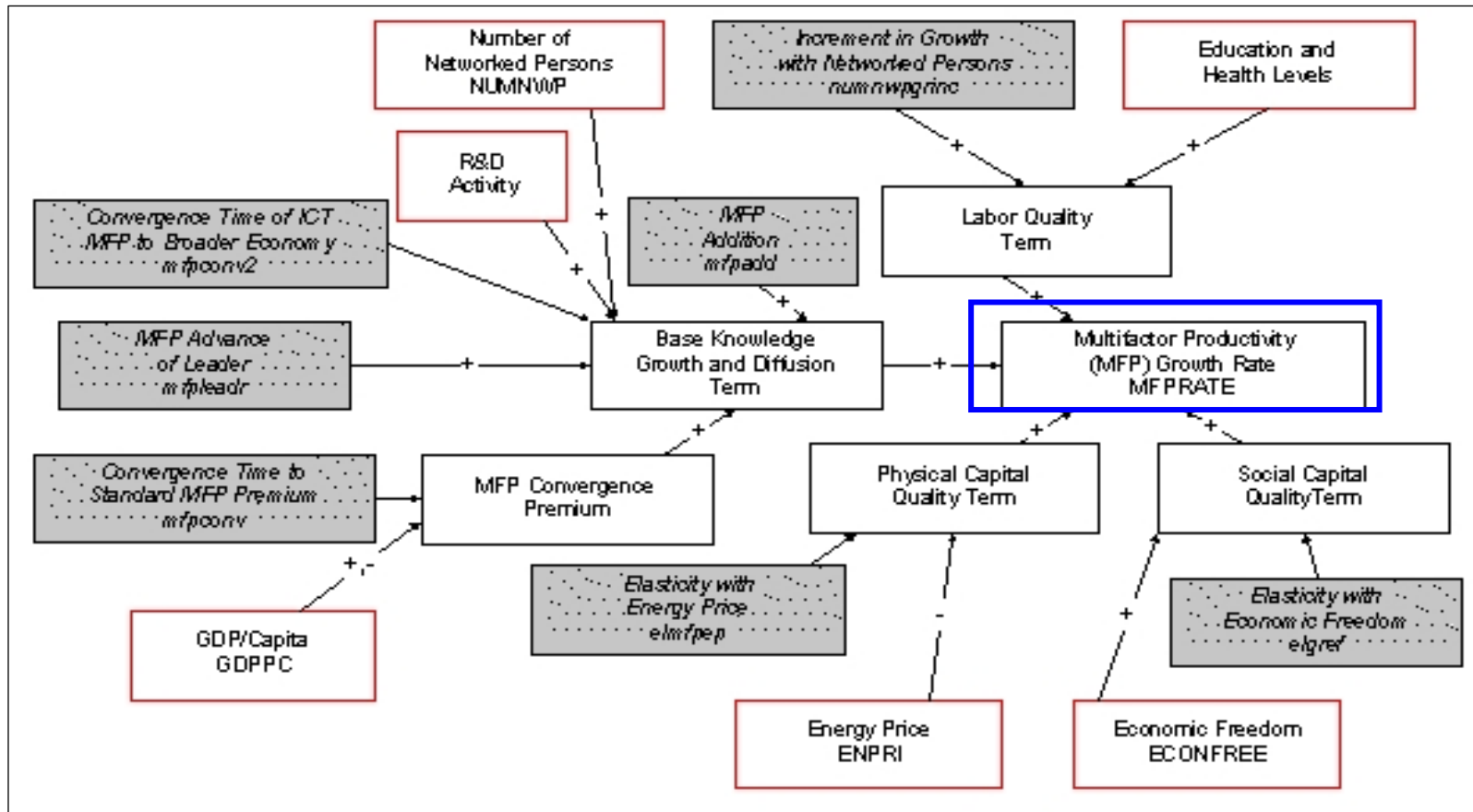


Figure 2. The main relationships of the determinants of the multifactor productivity growth rate



II.2. The Determinants of Adoption and Diffusion of Information and Communication Technologies

We present estimates of ICT equations with the aim of understanding the factors that promote (or prevent) the investments in information and communication technologies at a macro level.

The results are in line with the literature on the *digital divide*, which refers to the striking difference in the adoption of information technologies between developed and developing countries. 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 increase ICT investments, while burdensome regulation tends to lower them. The structure of the economy also turns out to be a relevant factor when 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*. The 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 explain these results with the consideration that a fraction of less than 1% of population (who are graduates) is probably not relevant, when it comes to having a substantial influence on a large component such as the investments in ICT, which represent more than 2% of GDP. 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 performance of the variable *spending in human resources* is also not surprising. The source of this variable, Eurostat, defines it as “total public expenditure on education.” 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. What remains to be clarified is, whether priority should be given to Science and Technology education, or to general education in order to enhance investment in ICT.

Finally, we consider the effect of **R&D expenditure** on investment in ICT. This variable is positively correlated with ICT investment and enters with a positive sign in most of our equations. We included 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 who invest more in ICT. Not surprisingly R&D expenditure is strongly correlated with the amount of human capital. This makes sense, as 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 dynamic services sector on the economy influence either negatively or positively investment in ICT, both directly and indirectly. These results are in line with the idea that ICT is a general-purpose technology. We also investigate the effects of variations in hardware and software prices on ICT. Our results suggest that prices affect ICT investments only after a period of persistent decline/increase that allows markets to establish expectations about these values.

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) on the role of ICT in achieving the Lisbon Agenda, 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.

Among such determinants 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 across Europe.

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 one attempts to model the impact of ICT on

economic performance, to take into account the interaction with organisational 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 national levels of regulation, structural composition of the economy, levels of human capital, etc.

In our estimation of such an IT equation, we proved that IT spending is positively influenced by: the share of advanced services in the economy, the amount of human capital, government spending in R&D, and negatively affected by business start up costs, product market regulation, and labour market protection

II.3. ICT as a General Purpose Technology in a structural model (SETI): Policy Simulations

As explained above, computable general equilibrium (CGE) models can be modified to accommodate the introduction of ICT and produce simulations to understand its impact on the performance of the economy. However, while providing useful results, such an approach can not fully take into account the impact of ICT as a GPT. We therefore offer a different approach to modelling the impact of ICT, which is to be treated as complementary to the CGE models. This is based on simulations carried out with a small structural model (SETI) that allows some of the main features of ICT as a GPT to be taken into account. To carry out policy simulations with SETI we introduce a new equation, which allows for an endogenous determination of ICT. .

The following scenario exercises were carried out including:

- a) elimination of the impact of regulation on services;
- b) deeper EU 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)

In addition to these scenarios, which had been carried out in the original SETI model and have been reproduced in the extended version of SETI, new ones have been carried out to explore the impact of the endogenous determination of ICT.

In the extended SETI version, for obvious reasons, scenario c) has not been reproduced, scenario f) collapses to case e), and scenario g) includes cases a) and d) only.

We have considered the following additional scenarios to take into account the endogenous determination of ICT:

- i) doubling the impact of R&D spending on ICT;
- l) elimination of the impact of the administrative burdens on start ups;
- h) a combination of h) and i).

Not all the policy scenarios we have performed take into account the impact of ICT on performance, but all have relevant policy implications for the process of European integration.

Our 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 (scenario e). The stock of technology is higher with respect to baseline, when the stock of human capital (both in 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. Hence, it is fair to say that this is a long term process. 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.

In SETI (2005), ICT spending increases growth indirectly by boosting services. In the enlarged SETI, which includes an endogenous determination of ICT spending, the impact of ICT on growth is in turn dependent on the impact of variables affecting ICT on the production of the latter. Here we have considered scenarios in which, contrary to the case of SETI (2005), policy can impact ICT only indirectly in a number of ways.

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 be considered a key public policy strategy, boosts human capital accumulation, and therefore ICT, and consequently producer services 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 has attracted in several policy simulations analyses. Scenario l) seems to be the least effective among the three cases.

In summary, 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 through 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, or more investment in R&D) provide potent additional stimuli to growth.

It could also be shown that a combination 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 which make up the enlarged SETI version, we have used for our scenario analysis.

II.4. The Technological Development Index (TDI)

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. These indicators are needed as output data and/or as indicator of policy effectiveness. 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.

The need for a composite index became clear with the multivariate statistical analysis carried out in our study that has been proven not to be sensitive enough to differences in countries over time.

In the full report we present an innovative method to develop technological composite indicators and to provide an example of their application to analyse technology diffusion across time and space. More precisely the proposed Technological Development Index (TDI) is a synthetic index, able to capture the joint changes of technological expenditures (as

proxied by IT and R&D expenditures), workers' skills and product market regulation. It is a very flexible tool for policy makers to monitor technological development and diffusion together with related favourable and unfavourable influencing factors, represented respectively by workers' technological expertise and the degree of regulatory environment. It also allows to benchmark across countries.

Another relevant aspect of the methodology is that the chosen methodology can be easily generalised to include other policy variables. The TDI has several advantages with respect to usual composite indicators. Firstly, it is not affected by the choice of an arbitrary weight system; policy objectives are simply included in its definition. Furthermore, it is not influenced by extreme behaviours, and countries comparability is obtained, so that they can be easily classified according to the degree of their technological development. The index is consistent with statistical protocols already suggested for the construction of compound indicators.

11.5. Datasets and indicators for benchmarking e-Inclusion

The issue of e-Inclusion has gained new relevance and centrality within the scope of the strategic plan, i2010 – A European Information Society for growth and employment. An Inclusive European Information Society, promoting growth and jobs in a manner consistent with sustainable development has been formulated as a priority, together with better public services and promoting quality of life. Indeed, the implementation of the Lisbon strategy could not have been pursued without a profound transformation in the use of ICTs by citizens. 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 in this Report 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 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 individuals may belong to several communities and that community membership is an important component of the inclusion of individuals through processes of capital building.

Secondly, the adoption of a multi-methodological approach should be characterised by the use of both quantitative and qualitative tools, enabling the creation of a data bank reflecting the transformations over time of the concept under examination. The qualitative dimension should acquire greater space within the framework of the official European statistics on e-Inclusion in relation to motivational and attitudinal aspects.

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 2006, 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, which should lead to better economic performance and employment opportunities, as well as improved quality of life, social participation and cohesion".

The following dimensions may thus be considered:

- access to ICT;
- quality of life;
- empowerment.

The greatest problem associated with the different dimensions of defining 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 and empowerment, since reference to the latter remains at a purely theoretical level.

Assuming, as a point of reference, that 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 and e2010 (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, as well as bringing to the fore evident differences in behaviour and 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.

Finally, with reference to the DIDIX (Digital Divide Index), formulated within the ambit of a social inclusion-benchmarking project, we propose to construct indices regarding the dimensions of *access* and *quality of life*. For these dimensions the construction of the Indices results from the selection of indicators to which a specific weight is attributed. The value thus obtained may be considered a measurement of inclusion with regard to the dimension under consideration.

The adoption of the Indices thus constructed enables possible differences within the single dimensions to be identified, but at the same time, accounts for the general evolution of e-Inclusion in Europe, proceeding from the total sum of the specific indices. It is therefore a versatile and practical tool suited to the cognitive and interventional needs of policy-makers by allowing country comparisons and the monitoring of effectiveness of policy measures.

II.6. Conclusions and recommendations

The present report assesses models and tools that can provide a quantitative evaluation of the impact of ICT research and investment in terms of growth, competitiveness, and social inclusion. It also suggests further developments and improvements in these models and tools, so as to better satisfy innovation policy and design. Finally the study assesses quality and availability of ICT data by identifying appropriate indicators and suggesting improvements where necessary.

The research has confirmed that ICT is rightly considered a general purpose technology (GPT) and that its modelling involves a high degree of complexity. Factors determining ICT investment and diffusion are numerous; the regulatory and business environment (the so called "facilitating factors") are of crucial importance. It is very difficult however, to include them into a framework for quantitative analysis.

II.6.1. Main Findings

Looking at the initial objectives of this study, its main findings can be summarised as follows:

1) Models and data that could satisfy the increasing requirements for evidence based impact assessment and evaluation of ICT policies and programmes.....

- The comparison and evaluation of a set of existing Computable General Equilibrium models, with the purpose of identifying their ability to model and simulate the impact of technology in general, and ICT in particular, has shown that the International Futures (IFs) model is particularly adequate to perform simulation exercises. The IFs model ranked top of the list because 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. Consequently, part of the research involved modifying the Ifs model in order to accommodate the introduction of ICT and produce simulations to understand its impact on the performance of the economy

- A complementary approach to modelling the impact of ICT is offered, based on simulations carried out with SETI, a small multi-country structural model that allows some of the main features of ICT as a GPT to be taken into account. To carry out policy simulations with SETI a new equation has been introduced, which allows for an endogenous determination of ICT. It also permits the modelling of interaction between ICT, the structure of the economy, and a number of facilitating factors.
- Several results, including from a number of policy simulations, confirm that these two classes of models (CGE and small structural models) should be seen and could be used as complementary tools in evaluating the impact of ICT.
- Concerning data and indicators, the study considered three databases and identified a core data set. 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. Our Core Dataset has been obtained as a combination of two data sources (GGDC and STAN OECD) with some overlap. In this case, the 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, the GGDC data provide a better coverage than the OECD. ICT variables are only available from GGDC according to our selection criteria. Finally, when it comes to cross-country non-dynamic analysis, one can only refer to EUROSTAT data.

2) Assessing model availability and capabilities for quantitative evaluation of the impact of ICT research and investment in terms of growth, competitiveness, and social inclusion...

- Modelling the ICT impact on performance, using the IFs and SETI models, aiming at the endogenous determination of ICT and a closer examination of the transmission mechanism of ICT has emphasised the importance of indirect spillover effects of ICT as a GPT, which resulted to be more pronounced than direct effects. A series of policy simulations has been carried out and concentrated on three elements: i) the relationship between ICT 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 therefore performance is largely “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 countries production structures (i.e. 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).
- The relationship between ICT and the facilitating structure is very important 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 (i.e. business environment) that generate the appropriate environment for ICT adoption.
- As to the issue of e-and social-Inclusion, a multi-focus approach is suggested in this study 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). With regard to the multi-dimensional approach the uneven availability of some data limited the field in which indicators may be identified to the dimensions of access to ICT and quality of life in our Report (background indicators and advanced indicators) while reference to the dimension of empowerment remained at a purely theoretical level.
- With regard to the dimensions of access and quality of life, the construction of the Indices results from the selection of indicators to which a specific weight is attributed. The value thus obtained may be considered a measurement of inclusion with regard to the dimension under consideration. The adoption of the Indices thus constructed, enables possible differences within the single dimensions to be identified, but at the same time, accounts for the general evolution of e-Inclusion in Europe, proceeding from the total sum of the specific indices. It is therefore, a versatile and practical tool suited to the cognitive and interventional needs of policy-makers.

3) Further developments and improvements of these models and data indicators, with a view to assess innovation policy ...

- There is a need for further refinement of IFs and/or other CGE models when it comes to modelling the impact of ICT on economic performance so as to introduce an explicit treatment of the role of ICT. Simulating the impact of ICT on performance, along lines that have been used to simulate the impact of R&D on performance is not satisfactory, considering that ICT is a General Purpose Technology. To move forward it is necessary to capture the interactions between ICT and the complex transmission mechanism; in

other words the interaction between ICT, organisational and structural variables and performance. 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. Therefore any attempt to simulate the impact of ICT on the economy must take the endogenous nature of ICT into account, as well as the elements that make it more profitable for countries to invest in the development and diffusion of these technologies.

- CGE models can and should 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 useful results, can not fully take the impact of ICT into account. As discussed in the report, a more satisfactory way of modelling GPT (and ICT) driven growth would require a more articulated set of tools. By taking into consideration CGE limitations, a useful strategy is to complement analysis carried out with existing large multi-equation models with analysis carried out with other models, which are small and flexible enough to provide additional information on the transmission mechanism of ICT (i.e. the relationship between ICT and the structure of the economy). A first appreciation of such effects would require a model in which ICT is made endogenous through a simultaneous estimation of the equations. We propose an enlarged SETI version for carrying out such policy simulations in order to confirm some of the characteristics of ICT as a GPT. Nevertheless other structural models could be proposed to fully appreciate the impact of ICT. The research results confirm that these two classes of models (CGE and small structural models) should be seen as complementary tools in evaluating the impact of ICT.
- The study assesses to what extent data issues and appropriate systems of indicators put limitations to the modelling of ICT and economic performance and on this point it formulates directions for improvement. Part of the discussion is based on the claim that ICTs produce benefits that go beyond those pertaining to investors and owners. In fact, as we have seen, 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. To assess these effects new proxy variables are required, in particular with relation to the e-inclusion area and its multidimensional nature (access to ICT; quality of life; empowerment). In this area new proxies and indicators are needed and they should be inserted and verified in the quantitative models mentioned above.

11.6.2. 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. Even if it has clear limitations, the IFs model can offer some useful insights on the transmission mechanisms of several ICT related policies.

The simulation exercises notably allow us to study the impact of those 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 therefore on growth. Moreover, they also allow studying 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 on the diffusion of the impact of ICT on performance across countries. As we have seen, an increase in ICT productivity in the USA (the leading country) affects GDP not only in the USA, but also in European countries, albeit to a lesser extent.

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 also because it allows exploiting 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; as well as
- 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 therefore ICT and consequently producer services and growth.

In summary, results with SETI 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.

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

- because of its pervasiveness, ICT investment can only indirectly be increased, 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 make themselves felt only with a (possibly long) lag;
- as a consequence, in order to fully appreciate the impact of ICT (a comprehensive analysis of its policy impact), ICT investment should be evaluated in conjunction with other policy measures.