Toward a macro-modelling of European Innovation Union: The contribution of NEMESIS model[1]

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Abstract

This paper presents the methodology adopted to represent innovation in NEMESIS, a Large Scale Multi-Sectoral model for EU-28 countries, widely used for the assessment of EU R&I policies. While the previous version of the model was based on R&D only, in this new version we extend the range of innovation inputs to investments in ICT and in a set of OI assets (Softwares and Training). It allows notably to better represent innovation in service sectors and the diversity of the innovation strategies adopted by the different countries and production sectors. The theoretical concepts were inspired by the semi-endogenous and fully endogenous growth theories (Ha & Howitt, 2007) that emerged in the second half of the 90', that we bridge with the concept of ICT as GPT proposed first by Bresnahan and Trajtenberg (1995). Surveying the recent empirical literature on innovation, we show notably that, as for R&D, there exist also for ICT and OI knowledge spillovers associated to the investments realized in these assets that we model explicitly. Our simulation experiments show that the model results are in phase with the key findings of the recent literature on innovation. They confirm notably the pulling effects that the three innovation assets have one on the others, as the concept of ICT as GPT suggests. This new version of NEMESIS enriches finally considerably the range of R&I policies that can be assessed with the model, that is currently mobilized to achieve in-depth assessment of the European Innovation Union in the context of the I3U research project.

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1. Introduction

This paper proposes a detailed analytical presentation of the innovation mechanisms introduced in NEMESIS that is a Large Scale Macro-Sectoral Simulation (LSMS) model widely used for EU R&I policy assessments (Brécard et al., 2006; Muldur et al., 2006, Fougeyrollas et al., 2013, European Commission, 2011). These innovation mechanisms were improved recently thanks to new developments in databases and they are the outcome of two recent EC research programmes (DEMETER and SIMPATIC) and one ongoing project I3U[3] that will proceed to an in-depth assessment of the European Innovation Union. Compared to the former version of the model (Brécard et al., 2006), the innovations in the different economic sectors (30 by including also the public sector) do not result only from (public and private) R&D investments, but also from investments in ICT technologies (mainly from EU-KLEMS database) and in two categories of intangible other than R&D: Training and Software (from INTAN-invest database).

The methodology used to represent innovation follows the concept of ICT as GPT introduced by Bresnahan and Trajtenberg (1995) and describes explicitly the externalities arising from different networks effects: from the interactions between (1) producers and users of ICT, (2) ICT users' co-inventions, and (3) ICT users' investments in complementary intangible assets. It is particularly well adapted to represent the growing importance taken by innovation in service sectors.

After the presentation of the key mechanisms of NEMESIS innovation module (section 2) this paper will present the general methodology used to calibrate the model (section 3), with also the results of numerical experiments that illustrate its functioning (section 4). We check notably to what extent the results of the model are in phase with the main conclusions of the theoretical and empirical literatures on innovation, for central elements for the policy assessment of R&D and innovation policies. The conclusion (section 5) sums-up the key results and presents the ongoing improvements of our work.

2. Endogenous growth in NEMESIS

This new version of the model starts from the same theoretical foundations than the previous one (Brécart *et al.*, 2006), first operational in 2002, where innovations were based on the R&D inputs only.

From the endogenous growth models *à la Romer* (1986) it retains both the *semi- endogenous* and the *fully endogenous growth II* (or *Schumpeterian*) approaches in the terminology of Ha and Howitt (2007). As explained by Ha and Howitt (2007), in the former developed by Jones (1995), Kortum (1997) and Segerstrom (1998), the long term rate of growth of GDP per capita rises proportionally to the growth of knowledge externalities and depends only on growth rate of population that governs the expansion of R&D activities. In the later, introduced by Aghion and Howitt (1998), Dinopoulos and Thompson (1998) and Peretto (1998) the long term growth rate of GDP relies this time on the rate of resources devotes to R&D activities (the R&D intensity). The implications of the two approaches for R&I policy are important. In the former, the long term growth rate of output that depends on exogenous factors cannot be influenced by policy, while it will be influenced in the later by the policies targeting an increase of the R&D intensity.

[3] http://www.i3u-innovationunion.eu/

While these two approaches that developed in parallel have *a priori* both solid empirical grounds, they cannot explain satisfactorily the difference in the level of productivity growth between OECD countries[4]. A dimension of the analysis to deeper for explaining the relative productivity performance of the different sectors and countries, concerns notably the role played by the sectoral composition of the economy, and the importance of key enabling technologies, such as ICT.

2.1- Multi-dimensional innovations

The theoretical and empirical representations of the innovation process based on the sole R&D inputs are too restrictive. A better approach is necessary and the recent empirical literature has shown[5] notably that besides R&D investments, efforts (1) in adopting certain enabling technologies, such as ICT, and (2) in improving the ability to adapt the production mode, through training and organizational investments, are of particular importance.

It is this broader approach that is used in the new version of NEMESIS where firms in the different countries base their innovation strategies on three different innovation components: R&D investments, investments in ICT technologies (Hardware) and Other Intangibles (Software and Training). The three innovation components, Aj_{cit} , $j = RD, ICT, OI$ are modelled symmetrically. They are specific to sectors (s) and countries (c) and are expressed at time *t*:

$$\mathrm{Aj_{cit}} = \mathrm{SCA_{jci}} \cdot \mathrm{KNOWj_{cit}}^{\lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}} \tag{1}$$

with $SCAjci$ a scale factor, λj a positive productivity parameter, $KNOWjcit$ the knowledge stock associated to asset *j*, and $\frac{j_{cit}}{Y_{cit}}$ the investment rate in innovation asset *j*.

The idea underlying this formulation is that, for a given innovation asset, the impact of the knowledge available to a sector in a country at time t on its innovation performance, is a positive function of its knowledge absorption capacity[6], which is proportional to its investment intensity in this asset.

2.2- Knowledge spillovers

The methodology developed allows to measure knowledge spillovers in the intra/intersectoral and international dimensions at the same time. The knowledge variables, $KNOWjcit$, are modelled as weighted sums of the stock of assets, *R&D*, *ICT* or *OI*[7], belonging to all sectors and countries.

For R&D, the knowledge variables of the sector i in country c , $KNOWj_{cit}$, is defined by the sum of

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[4] See for example Ha and Howitt (2007), Zachariadis (2003), Laincz and Peretto (2004), Ulku (2005), Barcenilla-Visús et al. (2010) and Madsen (2008) for empirical tests of the two approaches at national or sectoral levels.

[5] We will give elements on the main findings of the empirical literature in section 3 on calibration.

[6] The idea that external knowledge needs an absorptive capacity of the firm refers to the seminal works of Cohen and Levinthal (1990).

[7] The depreciation rates used are identical to Corrado et al. (2013): 15 % for R&D, 0.315 for ICT, 0.315 for Softwares and 0.4 for Training.

R&D capital stock $SRD_{p,s,t-\Delta}$ in all countries/sectors (p,s), weighted by a spread[8] parameter $\Phi RD_{p,s\to c,i}$ reflecting the relative propensity of the knowledge of a sector *s* in country[9] p to be useful for innovating in sector i in country c:

$$KNOWRD_{cit} = \sum_{p,s} \Phi RD_{p,s\to c,i} \times SRD_{p,s,t-\Delta} \tag{2}$$

We consider also that R&D investments start producing knowledge after a decay Δ that we fix to two years. Public investments in R&D (*PIRD*) are taken into account and allocated towards the different sectors according to a "grand fathering" distribution. They produce spillovers after a longer lag than private R&D (2 years later) so that $SRD_{pst} = (1-\delta_{RD}) \cdot SRD_{pst-1} + RD_{pst} + \propto_{ps} \cdot PIRD_{pt-2}$ where $\propto_{ps} = \frac{RD_{pst_0}}{RD_{pt_0}}$.

The same methodology is applied to *ICT* capital and to *OI* capital and we have respectively:

$$KNOWICT_{cit} = \sum_{p,s} \Theta \mathrm{ICT}_{p,s\to c,i} \times SICT_{p,s,t-\Delta} \tag{3}$$

and:

$$KNOWOI_{cit} = \sum_{p,s} \Theta \mathrm{OI}_{p,s\to c,i} \times SOI_{p,s,t-\Delta} \tag{4}$$

The spread parameters are calibrated using matrices based on patent citations between sectors and countries[10]. These matrices combine the citations between patents (that are allocated by technology class and country) with the OECD concordance table (Johnson, 2002) in order to allocate these citations between sectors. Two ways can be adopted for the sectorial allocation: (i) one considers the sectors that produce the technology related to the patents (Industry Of Manufacturing, IOM thereafter) and (ii) the other considers the sectors that use this technology (Sector Of Use, SOU thereafter). The assumptions underlying the choice of the method to build these matrices were the following:

- For R&D, patents citations are allocated between IOM sectors. These sectors regroup the firms (mainly from manufacturing) that pay the R&D and patent citations between IOMs are supposed to measure the knowledge spillovers between them.
- For ICT and OI, patents citations are allocated between SOU sectors. They regroup the firms (from all sectors) that adopt the technologies developed by IOMs to introduce organizational innovations that are not patentable. The idea is that the more two SOUs cite each other, the more they are using the same technologies and the more they receive spillovers from the organizational innovations (the development of a new online device for instance) that each other introduce by adapting ICT from their co-investments in OI.

[8] We prefer to call it "spread parameter" instead of "diffusion parameter" as it reflects the diffusion of the knowledge through space and not through time.
[9] For a given EU-28 country, international knowledge externalities come from every other EU-28 countries plus US and Japan. It will be extended to other world regions in the future.
[10] These matrices, built from PATSTAT database, were developed by Meijers and Verspagen (2010) in the framework of the DEMETER project. See also Belderbos and Mohnen (2013) for alternative methodologies for measuring knowledge spillovers.

2.3- Innovation services and complementarities

The three-dimensional vector of innovations components $(ARD_{cit}\ ,AICT_{cit}\ ,AOI_{cit}\ )$ characterizes the strategy follows at time t in country c, by the firms of sector i, to innovate. The strategies are much contrasted depending of the groups of sectors and countries. For example, High-Tech sectors and other R&D intensive industries, such as Equipment Goods and Pharmaceutical industries, base mainly their innovations on the R&D inputs. By contrast, service sectors invest only few in R&D but realize the bulk of ICTs investments that are a main driver of their innovations. Investments in OI reveal themselves to be an important factor of innovation in every sectors[11].

Innovation strategies reflect therefore strong national and sectoral patterns, that evolve slowly, and one may expect strong complementarities between the three innovations components[12] chosen by a sector i in a country c at time t. To represent these complementarities, we consider in NEMESIS that innovation components $(ARD_{cit}\ ,AICT_{cit}\ ,AOI_{cit}\ )$ are combined with a CES technology to provide a flow *of Innovation Services*, A_{cit}, we have:

$$\mathrm{A_{cit}} = SCA_{ci}\cdot\left(\delta ARD_{ci}^{1+\rho A_{ci}}\cdot ARD_{cit}^{-\rho A_{ci}} + \delta AICT_{ci}^{1+\rho A_{ci}}\cdot AICT_{cit}^{-\rho_{Aci}} + \delta OI_{ci}^{1+\rho A_{ci}}\cdot AOI_{cit}^{-\rho_{Aci}}\right)^{-\frac{1}{\rho A_{ci}}} \qquad (5)$$

with SCA_{ci} a scale parameter, δARD_{ci} , $\delta AICT_{ci}$ and δAOI_{ci}, the distribution parameters and $\sigma A_{ci} = \frac{1}{1+\rho A_{ci}}$, the substitution elasticity between ARD_{cit} , $AICT_{cit}$ and AOI_{cit}.

The empirics suggest (see Section 3) a low value for the substitution elasticity σA_{ci} and we show in section 4 the implications of setting alternative values for it.

2.4- Endogenous growth rate of sectoral output

The endogenous growth mechanisms are introduced at sectoral level in NEMESIS where the representative firm uses a constant returns to scale CES production technology that combines the innovations services, A_{cit} , with the compound production input, X_{cit}[13]:

$$\mathrm{Y_{cit}} = SCY_{ci}\cdot\left(\delta A_{ci}^{1+\rho Y_{ci}}\cdot A_{cit-1}^{-\rho Y_{ci}} + \delta X_{ci}^{1+\rho Y_{ci}}\cdot X_{cit}^{-\rho_{Yci}}\right)^{-\frac{1}{\rho Y_{ci}}} \qquad (6)$$

with $\mathrm{SCY_{ci}}$ a scale parameter, $\delta\ \mathrm{A_{ci}}$ and $\delta\ \mathrm{X_{ci}}$, the distribution parameters and $\sigma\ \mathrm{Y_{ci}} = \frac{1}{1+\rho\ \mathrm{Y_{ci}}}$, the substitution elasticity between $\mathrm{A_{cit-1}}$ and $\mathrm{X_{cit}}$.

The long term growth of sectoral output decomposes therefore in two components[14]:

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[11] See the data overview in appendix.

[12] It is the idea underlying in the concept of ICT as GPT (see e.g. Helpman and Trajtenberg, 1998) and we give illustration of these complementarities in the literature review of section 3 and in the simulation experiments of section 4.

[13] $\mathrm{X_{cit}}$ is itself a nesting of CES functions combining five production inputs (Capital, High skilled and Low skilled labour, Energy and Materials) that are not detailed here.

[14] We suppose thereafter that there exists a long term equilibrium growth path where all variables grow at a constant rate and where all elasticity variables are constant in time. In reality these elasticities may in the reference scenario of the model vary slightly in time, as the price elasticity of demand, ε_{cit}^{D}, that is specific to

1. An endogenous one:

$$\frac{dln(Y_{cit}^{A})}{dt} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \frac{\mathrm{dln(A_{cit})}}{\mathrm{dt}} \quad (7)$$

with:

$$\varepsilon_{A_{cit}}^{Y_{cit}} = \frac{\partial \mathrm{ln(Y_{cit})}}{\partial \mathrm{ln(A_{cit})}} = SCY_{ci}^{\;-\rho Y_{ci}} \cdot \delta A_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{\mathrm{Y_{cit}}}{\mathrm{A_{cit}}}\right)^{\rho Y_{ci}} \quad (8)$$

driven by the growth of innovation services,

2. And an exogenous one, driven by the growth of traditional production factors:

$$\frac{dln(Y_{cit}^{E})}{dt} = \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{\mathrm{dln(X_{cit})}}{\mathrm{dt}} \quad (9)$$

with:

$$\varepsilon_{X}^{Y_{cit}} = \frac{\partial \mathrm{ln(Y_{cit})}}{\partial \mathrm{ln(X_{cit})}} = SCY_{ci}^{\;-\rho Y_{ci}} \cdot \delta X_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{\mathrm{Y_{cit}}}{\mathrm{X_{cit}}}\right)^{\rho Y_{ci}} \quad (10)$$

such as we have in definitive:

$$\frac{\mathrm{dln(Y_{cit})}}{\mathrm{dt}} = \frac{\mathrm{dln\left(Y_{cit}^{A}\right)}}{\mathrm{dt}} + \frac{\mathrm{dln\left(Y_{cit}^{E}\right)}}{\mathrm{dt}} \quad (11)$$

The endogenous growth rate given by equation (7) cans be further decomposed to represent the distinct contributions of the three innovation components on the long term endogenous growth rate. To do, we start by differentiating equation (5) that gives the mathematical expression of innovation services, with respect to time:

$$\frac{\mathrm{dln(A_{cit})}}{\mathrm{dt}} = \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \frac{\mathrm{dln(Aj_{cit})}}{\mathrm{dt}}, \mathrm{j = RD, ICI, OI} \quad (12)$$

with:

$$\varepsilon_{Aj_{cit}}^{A} = SCA_{ci}^{\;-\rho A_{ci}} \cdot \delta Aj_{ci}^{1+\rho A_{ci}} \cdot \left(\frac{A_{cit}}{Aj_{cit}}\right)^{\rho A_{ci}} \quad (13)$$

By assuming that the investment rates of innovation assets (in % of production) are constant in the long term, the growth rates of innovation components can themselves be further decomposed from equation (1) as:

$$\frac{\mathrm{dln(Aj_{cit})}}{\mathrm{dt}} = \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}} \quad (14)$$

We then get by substituting (14) in (12):

$$\frac{\mathrm{dln(A_{cit})}}{\mathrm{dt}} = \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}, \mathrm{j = RD, ICI, OI} \quad (15)$$

and by substituting (15) in (7):

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sectors and countries and is an average over demands from many origins: Export markets, households' and government's final consumption, investment and intermediate consumptions.

$$\frac{\mathrm{dln}\left(\mathrm{Y_{cit}^{A}}\right)}{\mathrm{dt}} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \sum_{j} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln}(\mathrm{KNOWj_{cit}})}{\mathrm{dt}}, \mathrm{j} = \mathrm{RD}, \mathrm{ICI}, \mathrm{OI} \quad (16)$$

The reduced form equation (16) summarizes the endogenous growth properties introduced in NEMESIS at sectoral level with three main points:

- Firstly, there is no endogenous growth at sectoral or macro levels in NEMESIS without growth in knowledge externalities. From a theoretical perspective, this property re-links the modelling of innovations in NEMESIS to the semi-endogenous growth literature where the ultimate source of growth is the size of the R&D sector (here at world level) and knowledge externalities that expend with the growth of population, as explained in introduction of this section. This property of the semi-endogenous growth models was simply extended in NEMESIS to other sources of externalities than R&D.
- Secondly, the approach used is NEMESIS conforms also to the *Shumpeterian* or *Fully endogenous II* approach initiated by Aghion and Howitt (1998), Dinopoulos and Thompson (1998) and Peretto (1998): the long term endogenous growth rate is an increasing function of investments rates in innovation assets, that can be influenced by policy instruments.
- Thirdly, from the two first points, the way the policies aiming to rise the innovation inputs intensities, such as subsidies, will act on the long term endogenous growth rate, decompose in two effects: (1) the rise of the ability of firms to exploit existing knowledge (*intensity effect*) and the creation of new knowledge (*knowledge spillovers effect*) that increases the intrinsic productivity of innovation inputs.

2.5- Process and product innovations

A last important feature of the innovation mechanisms of NEMESIS in the distinction between product and process innovations. While the two type of innovations lead to identical reduced forms and endogenous growth properties in the theoretical models, they prove on the contrary from empirical works to have very distinct impacts on employment and growth at both sectoral and macro levels.

Hall (2011) shows for example that the impact of product innovations on firms revenue and employment is always positive, while the impact of process innovations is always small[15], or negative if the price elasticity of demand is inferior to 1 in absolute value. The reason is that the rise in demand provoked by the fall on the unit production price, will be in this case generally insufficient to compensate the fall in employment and in the use of other production factors provoked by process innovations, with negative net impacts on employment (technological unemployment) and even on output at a macro-sectoral level. Hall (2011) finds notably by applying the CDM model (Crépon et al., 1998) to a set of 15 EU manufacturing firms using the CIS 3 survey, both weak or negative estimated impacts of process innovations on real revenue and employment, and conversely, strong positive impacts of product innovations. If the studies on this topic are still scarce, Hall's results were notably confirmed, for manufacturing as well as for service industries, by Peters et al. (2014), Damijan and Star (2014), Harrison et al. (2008) and Bogliacino and Pianta, 2010).

Most empirical studies assimilate the endogenous growth rate to a "pure" TFP effect (from

[15] It is not to say that product innovations have higher rates of return than process innovations as (1) product innovation are often costly to implement and (2) that the main return of process innovations come from their reduction of unit production cost.

equations 7 and 11 above):

$$\frac{\mathrm{dln(TFP_{cit})}}{\mathrm{dt}} = \frac{\mathrm{dln(Y_{cit})}}{\mathrm{dt}} - \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{\mathrm{dln(X_{cit})}}{\mathrm{dt}} \tag{17}$$

that-is-to-say as the slack between the growth of output and the growth of traditional production factors, that they explain by investments in innovation inputs such R&D and the related knowledge externalities.

In reality, the TFP indexes than can be computed from economic data summarize many different effects. In our modelling (as already in Brécard et al., 2006) , and similarly to Hall (2011), it is the result of three combined effects:

1. A "TFP effect" that we define as *minus* the elasticity of the demand of traditional production inputs with respect to innovations services, that expresses from equation (6) by keeping $\mathrm{Y_{cit}}$ constant:

$$\alpha_{cit} = -\frac{\partial \mathrm{ln(X_{cit})}}{\partial \mathrm{ln(A_{cit})}} = \frac{\varepsilon_A^{Y_{cit}}}{\varepsilon_X^{Y_{cit}}} \tag{18}$$

   This TFP effect is different from the definition given by equation (17) and must be interpreted this time as a measure of the deformation of the set of production possibilities provoked by the growth of innovation services in time, for a fix level of output.

2. A "Quality effect" linked to the increase of the demand addressed to the firms provoked by the gradual improvement of the characteristics of their products that we define as:

$$\frac{\mathrm{dln(Q_{cit})}}{\mathrm{dt}} = \mathrm{\alpha'_{cit}} \cdot \frac{\mathrm{dln(A_{cit})}}{\mathrm{dt}} \tag{19}$$

   We suppose that in each sector the quality of output evolves in time proportionally (with a coefficient m_{ci}) to the "TFP effect" such as we have:

$$\mathrm{\alpha'_{cit}} = m_{ci} \cdot \mathrm{\alpha_{cit}} \tag{20}$$

3. A demand effect through the price elasticity of demand $\varepsilon_{cit}^D < 0$ that is finally the channel through which these TFP and Quality effects will impact on sectoral output:
   - Process innovations (TFP effect) reduce the unit cost of the firms with an elasticity α_{cit} and then increase demand with the elasticity: $-\varepsilon_{cit}^D \cdot \alpha_{cit}$.
   - Product innovations (Quality effect) increase demand with the elasticity: $-\varepsilon_{cit}^D \cdot \mathrm{\alpha'_{cit}}$,

   At equilibrium the level of output equates the level of demand and the growth rate of output provoked by the growth of innovations, that-is-to-say the endogenous growth rate of output (equation 16) can be re-expressed finally (from equations 7 and 16):

$$\frac{\mathrm{dln(Y_{cit}^A)}}{\mathrm{dt}} = -\varepsilon_{\mathrm{cit}}^{\mathrm{D}} \cdot (1+\mathrm{m_{ci}}) \cdot \alpha_{\mathrm{cit}} \cdot \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}, \mathrm{j = RD, ICI, OI} \tag{21}$$

   where the elasticity $\varepsilon_{\mathrm{A_{cit}}}^{\mathrm{Y_{cit}}}$ in equations 7 and 16 was replaced by the expression $-\varepsilon_{\mathrm{cit}}^{\mathrm{D}} \cdot (1+\mathrm{m_{ci}}) \cdot \alpha_{\mathrm{cit}}$ that sum-up the three combined effects just described.

2.6- Sum-up of the key mechanisms

The operational equations finally implemented in NEMESIS are listed in table 1.

Variable description	Equation	Nb
Optimal demands for innovation inputs	$j_{cit}^{*} = \left[\frac{ln(C_{ci}) - \sigma A_{ci} \cdot ln\left(\frac{PAj_{cit}}{PA_{cit}}\right) + ln(A_{cit}^{*})}{ln(KNOWj_{cit})}\right] \cdot \frac{Y_{cit}}{\lambda j_{ci}}$, with C_{ci} a positive constant	(E1-E3)
Optimal demand for innovation components	$Aj_{cit}^{*} = SCA_{ci}^{\sigma A_{ci}-1} \cdot \delta Aj_{ci} \cdot \left(\frac{PAj_{cit}}{PA_{cit}}\right)^{-\sigma A_{ci}} \cdot A_{cit}^{*}$	(E4-E6)
Optimal demand for innovation services	$A_{cit}^{*} = SCY_{ci}^{\sigma Y_{ci}-1} \cdot \delta A_{ci} \cdot \left(\frac{\widetilde{\omega} A_{cit}}{PY_{cit}}\right)^{-\sigma Y_{ci}} \cdot Y_{cit}$, with $\widetilde{\omega} A_{cit}$ the user cost of innovation services	(E7)
Actual levels of innovation components	$\mathrm{Aj_{cit}} = \mathrm{SCA_{jci}} \cdot \mathrm{KNOWj_{cit}}^{\lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}}}$	(E8-E10)
Actual level of innovation services	$\mathrm{A_{cit}} = SCA_{ci} \cdot \left(\delta ARD_{ci}^{1+\rho A_{ci}} \cdot ARD_{cit}^{-\rho A_{ci}} + \delta AICT_{ci}^{1+\rho A_{ci}} \cdot AICT_{cit}^{-\rho A_{ci}} + \delta OI_{ci}^{1+\rho A_{ci}} \cdot AOI_{cit}^{-\rho A_{ci}}\right)^{-\frac{1}{\rho A_{ci}}}$	(E11)
Actual stocks of innovation assets	For R&D stocks: $SRD_{pst} = (1 - \delta_{RD}) \cdot SRD_{pst-1} + RD_{pst} + \propto_{ps} \cdot PIRD_{pt-2}$ For ICT and OI stocks: $Sj_{pst} = (1 - \delta_j) \cdot Sj_{pst-1} + j_{pst}$	(E12) (E13-14)
Actual stocks of knowledge	For R&D: $KNOWRD_{cit} = \sum_{p,s} \Phi RD_{p,s \to c,i} \times SRD_{p,s,t-\Delta}$ For ICT: $KNOWICT_{cit} = \sum_{p,s} \Theta ICT_{p,s \to c,i} \times SICT_{p,s,t-\Delta}$ For OI: $KNOWOI_{cit} = \sum_{p,s} \Theta OI_{p,s \to c,i} \times SOI_{p,s,t-\Delta}$	(E15) (E16) (E17)
Price of innovation components	$PAj_{cit} = \frac{Pj_{cit}}{Aj_{cit}} \cdot \frac{Y_{cit}}{\lambda_{ci}}$, with Pj_{cit} the prices of innovation inputs	(E18-E20)
Price of innovation services	$PA_{cit} = \left[\delta ARD_{ci} \cdot PARD_{cit}^{1-\sigma A_{ci}} + \delta AICT_{ci} \cdot PAICT_{cit}^{1-\sigma A_{ci}} + \delta AOI_{ci} \cdot PAOI_{cit}^{1-\sigma A_{ci}}\right]^{\frac{1}{1-\sigma A_{ci}}}$	(E21)
Demand of production inputs	$X_{cit} = Y_{cit} \cdot A_{cit}^{\alpha_{cit}}$	(E22)
Product innovations	$Q_{cit} = A_{cit}^{\alpha'_{cit}}$,	(E23)

Table 1: Analytical expression of the equations at the "core" of the innovation module of NEMESIS

For simplicity we give only the optimal expression for the decision variables[16], corresponding to the variables with a star in table 1. The index j is by default at each time respectively for $j = RD, ICT, OI$. Time lags where also removed as well as expectations operators. The table includes 23 equations[17]

16 The final expression for decision variables includes the impact of adjustments costs and various delays.

17 These are the equations at the core of the innovation module but there exist others as Research employment detailed in three categories (Researchers/engineers, Technicians, Other), etc.

that decompose in four categories of equations or variables:

1. Behavioural equations[18] (7) or decisions variables that result from the maximisation of intertemporal profit by firms and that can be directly impacted by the implementation of policy measures in the model;
2. Update equations of state variables that result from past decisions and past evolutions such as the accumulation of the knowledge variables that influence the productivity of the different innovation inputs;
3. Equations that calculate the "price" of innovation components and innovation services, that result from the resolution of the system of equations;
4. The "transmission" equations that link the innovations decisions (1) to the production decisions of the firms from the impacts of TFP effects on the demand of production inputs X and (2) to the demand of goods and services by firms' customers that are influenced by the relative improvements of products characteristics (product innovations).

If we addition over countries and sectors, we get finally a set of 23X28X29 = 18676 equations at sectoral level to which one must add an epilogue for the calculus of key indicators e.g. national innovation inputs intensities, etc.

3. Calibration and empirical validation

The calibration task is not that straightforward as most of the effects we want to measure with the model and compare with the findings of economic literature on innovation, are indirect, and pass through all a chain of mechanisms and interdependencies that the Figure 1 below sums-up.

Starting from the top of the figure and rotating clockwise, the four first rectangular boxes and the three first categories of functions in the circles synthesize the innovations mechanisms introduced at sectoral level and summed-up in Table 1. All the variables, parameters, elasticities and functions in these boxes and circles involve calibrations that must be done for every countries and every sectors of NEMESIS. One the contrary, the last circle and the last box of the left side, describe the interactions and feedbacks that occur, when solving the model[19], between the innovation mechanisms introduced at sectoral level and the macroeconomic forces coming for example from the impact of innovations on households' disposable income and consumption choices, on external competitiveness and firms' export performance, or on labour demand by skill and wages evolution that will retract on innovation inputs productivity and private and social rates of return.

To clearly distinguish the effects that are calibrated at a sectoral level, before the interactions and macroeconomic feedbacks coming from the solving of the model, and the effects that are measured after the simulation of the model, we are used to call these former the *ex-ante* effects, and these later, the *ex-post* effects. The results of empirical studies are also by definition *ex-post* and it is therefore ultimately the simulation results of the model that must be compared with the main findings of the economic literature.

[18] In fact for the representative firm in the sector, the "true control variables" are only the vector of demands for innovation inputs (RD^*, ICT^*, OI^*).

[19] The solver classes and computes the equations in order of increasing degree of interdependencies, or we could say "endogeneity", and initiates loops until a stable solution is found.

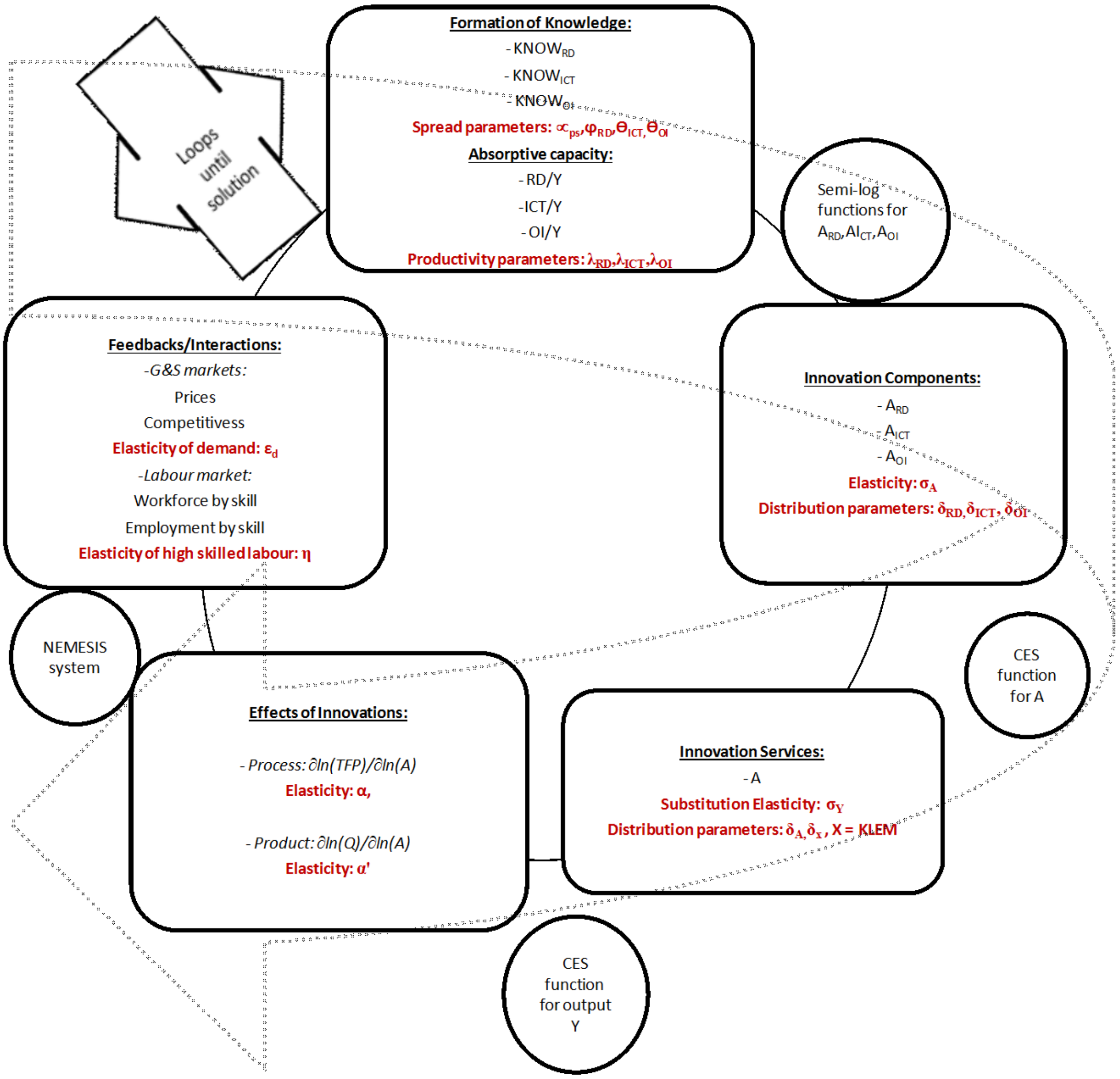


Figure 1: The chain of effects to calibrate from sectoral level to interactions with the whole NEMESIS system

3.1- What confirmations ask to the economic literature?

The modelling of innovation in NEMESIS was based on the most recent advancements of the theoretical literature on innovation. Empirical validation is anyway necessary on at least three crucial issues:

1. From the reduced form equation (21), the long term growth rate of sectoral output and TFP is influenced positively by the investment effort in innovation inputs realized by firms. The greatest the investment rate is, the greatest is the endogenous growth rate of TFP and output. Is this property in accordance with the empirics?
2. Knowledge externalities play a central role in the endogenous growth process and in our setting, there is no endogenous growth at all without knowledge externalities. Can this

feature be confirmed by empirical studies? Notably, does it exist knowledge externalities associated to ICT and OI investments, as it is largely recognized by the empirical literature for R&D investments?

3. Our general setting uses the concept of *General Purpose Technologies* (GPT) initiated by Bresnahan and Trajtenberg (1995) and the *Fully Endogenous growth approach* initiated by Aghion and Howitt (1998), Dinopoulos and Thompson (1998) and Peretto (1998). It supposes that there exist strong complementarities between innovation inputs, and notably that investments in ICT need complementary OI investments to become a vector of endogenous growth. Are these features confirmed by the empirical studies? And does it exist also complementarities between the R&D input and ICT and OI inputs?

3.2- The contribution of the empirical literature on R&D

To examine these questions, it is useful to start from the empirical literature on R&D and productivity that developed from the early 60's and remains the richest in terms of methodologies and results. Following the extensive survey by Hall, Mohnen and Mairesse (2011), this literature focused on two main issues: (1) the estimation of the output elasticity of R&D and (2) the estimation of the marginal rate of returns of R&D investments. For that, two alternative estimation strategies are found in the literature: The first option is to consider that the R&D elasticity of output is identical in every firms, industries or countries, the second considers on the contrary that it is not the elasticity of output to R&D that is constant over firms, industries or countries, but the rate of return of R&D.

The results of the empirical studies based on the first assumption, "the output elasticities are constant", show on the contrary that the output elasticities tend to increase with the average R&D intensity of firms, industries, or countries that are analyzed and it gives reasons to the second assumption that the marginal rates of return tend to equalize between them. A recent study by (Kancs and Siliverstovs, 2016) at firm level using a methodology that allows a non-linear relationship between the R&D intensity of the different firms and their TFP growth rates, confirms and generalizes these previous finding of the literature. They find notably, for a large set of OECD firms[20] that:

1. "R&D investment increases firm productivity with an average elasticity of 0.15";
2. "The impact of R&D investment on firm productivity is different at different levels of R&D intensity - the productivity elasticity ranges from −0.02 for low levels of R&D intensity to 0.33 for high levels of R&D intensity implying that the relationship between R&D expenditures and productivity growth is highly non-linear, and only after a certain critical mass of knowledge is accumulated, is productivity growth significantly positive ";
3. "There are important inter-sectoral differences with respect to R&D investment and firm productivity - firms in high-tech sectors not only invest more in R&D, but also achieve more in terms of productivity gains related to research activities".

All these results are in line with those of the empirical literature analyzed by Hall, Mohnen and Mairesse (2011) that show in summary:

1. That elasticities and rates of returns to R&D do not vary much whether the studies are based on firm or industry data, with "research elasticity ranging from 0.01 to 0.25 but

[20] They use as principal data source the EU industrial R&D investment scoreboard that covers 750 EU and non EU firms.

centred on 0.08 or so". They are high, and if we consider an average R&D intensity in % of value-added in the range[21] of 2% to 4%, they exceed about two to four times their factor share;

2. These "excess" returns to private R&D investments may contribute to TFP growth of about 0.1 point to 0.2 point per year, and about 1.5 time more if we account also the contribution of public R&D;
3. The rates of return of private R&D are higher than those found usually for physical capital, their magnitude is about 20 to 30%;
4. When including knowledge externalities in the analysis, the studies conclude to social rates of return at least two times larger than private ones. The elasticities of output to external R&D (externalities) are found around 0.05 - 0.09 for spillovers calculated at industry or national level and strong elasticities are found also for international spillovers (in the range 0.01 – 0.13). The absorptive capacity of the spillovers receiver (if terms of R&D effort) is also found important to benefit from external knowledge. As external and internal R&D are positively correlated, the inclusion of externalities in the analysis tends to reduce the size the output elasticities of R&D that come closer to their factor share.
5. The output elasticities of R&D are positively correlated to the R&D investment rates, as it is assumed in NEMESIS;
6. The marginal rate of returns to R&D tends to equalize between countries and sectors, which is a consequence of the fifth point above.

3.3- Are there, as for R&D, excess returns associated to ICT?

For ICT the literature is more recent and less abundant. Regarding first if there exists excess returns associated to ICT capital, Biagi (2013), Lopez and Mairesse (2011) and the meta-analysis from Stiroh (2002), covering 20 studies for different periods and different groups of countries and industries, give first interesting results. Stiroh (2002) estimates from its meta-analysis the mean elasticity of output to ICT capital to about 0.05, but with a quite high standard deviation (0.05). In particular, he finds that (1) studies using the more recent data tend to provide higher elasticities, partly because ICT diffusion have increased in time, and (2) that elasticities are increasing with the level of aggregation of the data, suggesting the presence of externalities effects or of omitted variables, not taken into account in the analysis. In addition, Stiroh (2002) confirms this finding by conducting various econometric estimations on US data with different level of aggregation and different estimations techniques. He shows notably, by breaking ICT between IT and non-IT capital stocks, that, while non-IT elasticities are inferior to their share or not significant, IT elasticities are superior to their value-share.

These first econometric results tend thus to confirm "excess" returns of ICT capital, that is to attribute to the it's IT share. The increasing size of elasticities with the level of aggregation gives also strong indications of the presence of externalities associated with the use of ICT technologies.

Lopez and Mairesse (2011) investigate also the output elasticity to ICT capital at macroeconomic level, using a panel of 20 OECD countries on the period 1985-2004. The originality of this study is that it jointly estimates the output elasticity of ICT and R&D capitals, and it shows that the elasticity relative to ICT is importantly modified when we omit the R&D variable in the production function,

[21] This average R&D intensity of course varies depending the scope of the study.

supporting the idea that these two types of investments may be complementary. The result is re-enforced by the quite large range of elasticities they estimate depending of the country, with generally higher ICT elasticities in countries where the R&D capital stock is higher, and *vice-versa*.

The output elasticities with respect to ICT range from 0.1 and 0.18, and those with respect to R&D between 0.07 and 0.16. Moreover they find that elasticities increase with the level of aggregation, suggesting again the existence of externalities. At macro level their results are very close to Ketteni et al. (2007), which use macro data of 15 OECD countries from 1985 to 2004, and find elasticities of value-added to ICT capital ranging between 0.18 and 0.26. Van Reenen et al. (2010) find, at the firm level for a panel of 13 EU countries for the period 1998-2008, elasticities of output to ICT capital ranging from 0.023 and 0.09, which is in line with the previous results of Brynjolfsson and Hitt (2003) estimated for the U.S. in the period 1987-1994.

3.4- Are there ICT and OI externalities and complementarities between ICT, OI and R&D?

ICT externalities are generally introduced in the analysis by introducing cross effects between the aggregate ICT capital stock and the productivity of ICT capital at sectoral level, or by a cross effects between the ICT stock of the firm or the sector and other inputs of the production or TFP function. Unfortunately, the studies investigating the impact of complementary assets on productivity and output growth are very few because of the scarcity of databases on intangible.

An important contribution to the analysis is provided by Corrado et al. (2014) who developed the INTAN-INVEST database which breaks down intangible investments into 10 business sectors. The authors cross the INTAN-INVEST and EU-KLEMS databases for the period 1998-2007 and 10 EU countries, and bring first important results at macro level on the role played by intangible assets, complementary to ICT for productivity growth. They find first that the productivity impact of ICT is increased when complemented with intangibles, and that non-R&D intangibles have, as we just reported for R&D and ICT capitals, higher estimated output elasticity than their input shares, implying that they produce also positive spillovers. The authors explain that these results are in line with the "cross country source of growth literature" revealing a strong correlation between intangible capital deepening and productivity, as in Corrado et al. (2012) or in Roth and Thum (2010).

In another study using the labour force survey data on training and the EU-KLEMS database, O'Mahony and Peng (2010) find, for EU countries at sectoral level, significant positive impact of training on productivity. They find in particular that a part of this impact comes from interactions with ICT and is heterogeneous between industry and services. For the authors, "This is consistent with a recent literature that emphasizes the role of organisational changes and associated retraining of the labour force in diffusing new technologies".

Crass and Peters (2014), using firm level data for Germany for the period 2006-2010, find also important productivity impacts of training, with more important effects than R&D and marketing in the short term, whereas in the long term, they find an important impact of innovative capital goods in conjunction with human capital on productivity growth.

Similarly, Bresnahan et al. (2002) find for US important complementarities between ICT, human capital, decentralized work practices, and product and process innovations. They underline the important role played by IT investments in provoking organizational change, and in rising firms' investment in human capital (skill biases).

Finally Crespi et al. (2007) show for UK using the CIS 3 (1998-200) significant returns to IT capital (30%) when we do not "control" for organizational capital, IT and organizational capital having jointly a strong impact on productivity, but no impact separately. And Polder et al. (2010) find similar results for Netherlands, using CIS 3 to 5, with strong productivity effects of organizational innovations, and from combination from process, product and organizational innovations, ICT investment being also an important driver of innovation in both manufacturing and services.

3.5- Summary of literature key findings

The empirical literature provides finally the following elements of confirmation of the methodology adopted to represent innovation in NEMESIS:

1. There exists for ICT and OI investments, as for R&D, "excess" returns and specific spillovers effects that may be source of endogenous growth;
2. For ICT, the existing studies tend to estimate output and TFP elasticities close to those generally admitted for R&D, that are centred around 0.08. For OI, the number of empirical studies stays very low. The studies conclude that there exists also "excess' returns to OI, notably with training. The strong contribution of software to productivity growth was already recognized by the recent growth accounting literature[22] and by the econometric studies including software, besides hardware, in their definition of ICT capital.
3. For R&D, the econometric literature finds that output and TFP elasticities increase with the factor share of R&D. The recent study by Kancs and Siliverstovs (2016) shows furthermore that this positive relationship is not linear and is a concave function.
4. Most studies conclude to strong complementarities between ICT and different kinds of intangible. There exists complementarities between, on the one hand, ICT and OI and, on the other hand, R&D, but these later are more transversal.

3.6- The parameterization of the innovation chain

We present our calibration methodology by crossing the different terms of equation (21) from right to left and by following Figure 1 from top to down moving clockwise.

The first terms, the growth of knowledge variables, $\frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}$, are computed following the equations E15 to E17 in Table 1. Their growth is conditioned by the growth of innovation assets stocks at inter-sectoral and international levels, that are weighted by the "spread" parameters $\Phi RD_{p,s\to c,i}$, $\Phi ICT_{p,s\to c,i}$ and $\Phi OI_{p,s\to c,i}$ for respectively R&D, ICT and OI knowledge externalities. For R&D there are additional spread parameters, $\propto_{ps}=\frac{RD_{pst_0}}{RD_{pt_0}}$, that measure the knowledge transfers from public research towards private firms.

The second term is $\lambda_{\mathrm{jci}}\cdot\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}\cdot\frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}$, that, from equation 15, measures the growth of innovation components, , $\frac{dAj_{cit}}{dt}$, in the reference scenario of NEMESIS. These innovation

i[22] But the growth accounting literature focuses on the contribution of capital deepening to labour productivity growth but doesn't "explain" the growth of TFP *per se*.

components are "work" variables that cannot be measured and we make the assumption that they grow at the same rate than the knowledge externalities they are related to:

$$\frac{\mathrm{dln(Aj_{cit})}}{\mathrm{dt}} = \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}, \mathrm{j} = \mathrm{RD, ICI, OI.} \tag{22}$$

For that, in equation (15), the "productivity" parameters, λ_{jci} are all set to 1 and the innovation inputs intensities, $\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}$, are normalized by their value in the reference scenario of the model, $\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}$, such as the ratio $\frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}}$ is equal to one. With these assumptions, the equation 21 becomes therefore:

$$\frac{\mathrm{dln}\left(\mathrm{Y_{cit}^{A}}\right)}{\mathrm{dt}} = -\varepsilon_{cit}^{D} \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}, \lambda_{\mathrm{jci}} = 1, \mathrm{j} = \mathrm{RD, ICI, OI,} \tag{21b}$$

The third term, $\varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}$ (from equation 21b) measures the contribution of the growth of knowledge to the one of innovation services, $\frac{dA_{cit}}{dt}$. We see that in the reference scenario of the model, by normalizing to 1 the investment rates of innovation assets in equation (21) and by setting the values of parameters λ_{jci} to 1, that these contributions are measured by the elasticities $\varepsilon_{Aj_{cit}}^{A}$ defined by equation (13). In the Cobb-Douglas case, when the substitution possibilities between the three innovation components are perfect ($\sigma A_{ci} = \frac{1}{1+\rho A_{ci}} = 1$ and $\rho A_{ci} = 0$), these elasticities are equal to the value of the distribution parameters of innovation components in the production function of innovation services (equation E11):

$$\varepsilon_{Aj_{cit}}^{A} = \delta Aj_{ci}, \qquad \mathrm{j} = \mathrm{RD, ICI, OI,} \tag{23}$$

In our calibration we use as default value for the substitution elasticity between innovation components 0.25 (σA_{ci}), which is far from the Cobb-Douglas case. Anyway one can show that the elasticity $\varepsilon_{Aj_{cit}}^{A}$ stays strongly related to the values of the distribution parameters of innovation components, whatever the value of σA_{ci}.

These distributions parameters are calibrated such as they reflect, in each sector, the share of the innovation input *j*, relatively to the total investment in innovation inputs. We impose also that they sum to 1, such as: $\sum_j \delta Aj_{ci} = 1$. The precise calibration methodology is as follows. We have:

$$\delta Aj_{ci} = \frac{\bar{\delta} Aj_{ci}}{\sum_{\mathrm{j}} \bar{\delta} Aj_{ci}}, \mathrm{j} = \mathrm{RD, ICI, OI} \tag{24}$$

with:

$$\bar{\delta} Aj_{ci} = 0.5 \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{cit}} + 0.075 \cdot \left(1 - \frac{j_{cit}}{Y_{cit}}\right)}, \mathrm{j} = \mathrm{RD, ICI, OI} \tag{25}$$

which implies well that $\sum_j \delta Aj_{ci} = 1$.

We see from equation 25 that the links between the values of the distribution parameters and the sectoral intensities of innovation inputs are not strictly linear and are concave (homographic) functions of the inputs intensities. This solution allows to avoid "outliers" problems that may occur for sectors very intensive in certain innovation inputs. It was already used in the previous version of the model with R&D only (Brécart et al., 2006) and it is confirmed for R&D by the empirical studies. In this new version of NEMESIS we assume that it is true also for ICT and OI.

The fourth term $\cdot \alpha_{cit} \cdot \sum_j \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j^{Ref}_{cit}}{Y^{Ref}_{cit}}} \cdot \frac{d\ln(KNOWj_{cit})}{dt}$ measures this time the contribution of the growth of the different knowledge externalities – and innovation components – to the "TFP" effect, from the elasticity α_{cit}. This elasticity is defined by the equation 18 as the ration $\alpha_{cit} = \frac{\varepsilon^{Y_{cit}}_{A}}{\varepsilon^{Y_{cit}}_{X}}$. If the CES function that combines the innovation services, A_{cit}, with the bundle of traditional production factors, X_{cit}, is a Cobb-Douglas ($\sigma Y_{ci} = \frac{1}{1+\rho Y_{ci}} = 1$ and $\rho Y_{ci} = 0$), this elasticity is equal to the ratio between the distribution parameters of innovation services and of the bundle of traditional production factors in equation 6:

$$\alpha_{cit} = \frac{\delta A_{ci}}{\delta X_{ci}} \tag{26}$$

We already made this assumption in Brécart et al. (2006) as there exist no good conceptual reasons to suppose that process innovations are not perfect substitutes to traditional production inputs in the long term.

The parameters δA_{ci} are calibrated in NEMESIS such as:

$$\delta A_{ci} = \sum_j \bar{\delta} Aj_{ci}\, , j = RD, ICI, OI. \tag{27}$$

They "reflect" the cost of innovation inputs in the total cost of producing the final output, Y_{cit}. We impose equally that the two distribution parameters sum to 1, such as:

$$\delta X_{ci} = 1 - \delta A_{ci} \tag{28}$$

As the cost on innovation inputs in % of production cost is about 4.3% in EU-28 average[23] the δX_{ci} parameters are close to one in average and the α_{cit} elasticities close to the value taken by δA_{ci}.

The impact on sectoral TFP of the growth of knowledge externalities, $\frac{d\ln(KNOWj_{cit})}{dt}$, is therefore close to proportional to the product of the two preceding elasticities: $\alpha_{cit} \cdot \varepsilon^{A}_{Aj_{cit}}$, with $j = RD, ICI, OI$. Finally, if the production functions for final output and innovation services are both Cobb-Douglas, the impact on TFP is close to:

[23] It is, in our data, the EU-28 GDP "global" intensity for R&D (1.3%), ICT (0.95%) and OI (2.5%) investments realized by the private firms. If we include in the calculation the investments by the public sector, we get a global intensity of 5.4% with 2% for R&D, 1,1% for ICT and 2.3% for OI.

$$\bar{\delta}Aj_{ci} = \delta A_{ci} \cdot \delta Aj_{ci} = 0.5 \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{cit}} + 0.075 \cdot \left(1 - \frac{j_{cit}}{Y_{cit}}\right)}, \mathrm{j} = \mathrm{RD, ICI, OI} \quad (29)$$

and is a positive, concave (homographic function) of the investment rate in the innovation input *j*.

The next term, $(1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}$, introduces the role played by product innovations with the parameter m_{ci}. It was introduced in equation 20 that fixes the relative strength of the productivity and quality effects of innovation services.

We will show in the section 4 that the share of product innovations, relatively to process innovations, that is equal to $sp_{ci} = \frac{m_{ci}}{(1+m_{ci})}$, is a crucial determinant of the output and employment impacts of innovations. The higher it is, the higher the impact of innovations on sectoral output growth and employment. The share of product innovations is set to 33% in average in NEMESIS from the CIS 3 data from which we first established this figure. It was calculated at EU level and differentiated by sector. It varies between 26% in the "Auxiliary Transports Services – Storage" and 40% in the "Bank, Finance and Insurance" sector. As many product innovations imply large reorganization of production processes, and conversely many changes in production processes are realized to favour at the same time the arrival of product innovations, these later should actually predominate.

The last term, $-\varepsilon^{D}_{cit} \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}} \cdot \frac{\mathrm{dln(KNOWj_{cit})}}{\mathrm{dt}}$, includes finally the role played by the price elasticity of demand, ε^{D}_{cit}. We see that the endogenous growth rate of output provoked by innovations at sectoral level is proportional to the absolute value of this elasticity.

Our calibration strategy must of course be challenged and enhanced and we give in that direction in section 4 some illustrations of the impacts of changing key parameters values.

4. Some illustrations on the functioning of NEMESIS innovation module

This last section complements the presentation of the innovation mechanisms of NEMESIS with some illustrations of its functioning.

Four sets of tests where implemented:

1. In the first set we compare the distinct short term to long term impacts on GDP and employment of targeting the rise of innovation inputs either on R&D, on ICT or on OI. We compare notably the "pulling" effects that have the different innovation inputs on the others.
2. In the second we do sensitivity analysis on the value of the substitution elasticity between the three innovation components, from the perfect complementarity case ($\sigma\ \mathrm{A_{ci}} = 0$) to the perfect substituability case ($\sigma\ \mathrm{A_{ci}} = 1$). We examine the impacts on the pulling effects and on the long term growth rate of GDP.
3. In the third we remove the pulling effects and we focus on the "proper" impact of the inputs on the long term growth rate of GDP. We analyse also the impacts of the different

knowledge externalities by removing alternatively intra-sectoral externalities (national and international), inter-sectoral externalities (national and international) or all externalities at the same time.

4. The last set examines the role played by product innovations relatively to process innovations by decreasing or increasing product innovations in proportion of process innovations.

All these tests have in common exogenous shocks of 0.5 GDP point alternatively on private R&D, ICT or OI investments. They are high enough to check the robustness of the model to accept big shocks as those that will imply for example a scenario based on the H2020 3% target for R&D. They are nevertheless not realistic and have only an analytical objective. They are implemented in 2015 where in every EU-28 countries the intensity of the targeted innovation input is increased 0.5 GDP point in 2015, compared to its value in the reference scenario of the model, and the 0.5 GDP point increase is maintained constant up to 2050. It may represent a very important shock for certain countries, notably for private R&D for which the intensities in the different countries are very contrasted: From 0.1 GDP point in Cyprus to 2.3 GDP point in Finland for the year 2012.

The shocks are introduced at sectoral level following the grandfathering principle, that-is-to -say that the % increase of the innovation input is, *ex-ante*, before the simulation of the model, identical in every sectors, but that the change in intensity, compared to the reference scenario, is more important in the sectors initially intensive in this input. Finally, while the shocks are introduced "exogenously" and are not provoked by financial incentives, they are financed by the firms that report integrally these additional costs in their market prices. This is again a non-realistic assumption as the firms may prefer for example, to reduce their margins to preserve their price competitiveness in the short to medium term, before the arrival of innovations produce their full impacts in terms of TFP and quality effects.

4.1- Intensity and knowledge spillovers effects

The way the rise of the intensity of an innovation input acts in the model is first to modify the "*ex-ante*" endogenous growth rate of the sectors given by equation 21b:

$$\frac{\mathrm{dln}\left(\mathrm{Y}_{\mathrm{cit}}^{\mathrm{A}}\right)}{\mathrm{dt}} = -\varepsilon_{cit}^{D} \cdot (1+m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}} \cdot \frac{\mathrm{dln}\left(\mathrm{KNOWj_{cit}}\right)}{\mathrm{dt}}, \lambda_{\mathrm{jci}} = 1, \mathrm{j} = \mathrm{RD, ICI, OI},$$

This equation can be re-expressed for convenience in growth rates, such as we have:

$$\widehat{\mathrm{Y}_{\mathrm{cit}}^{\mathrm{A}}} = -\varepsilon_{cit}^{D} \cdot (1+m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon_{Aj_{cit}}^{A} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}} \cdot \widehat{\mathrm{KNOWj}}_{\mathrm{cit}}, \qquad \lambda_{\mathrm{jci}} = 1, \mathrm{j} = \mathrm{RD, ICI, OI}, \tag{30}$$

From equation 30, the change of the long term output growth of $(\Delta\widehat{\mathrm{Y}_{\mathrm{cit}}^{\mathrm{A}}})$ from increasing permanently the intensity of innovation input j compared to its level in the reference scenario of the model, $\frac{\Delta\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j_{cit}^{Ref}}}{\mathrm{Y_{cit}^{Ref}}}}$, is equal to :

$$\widehat{\Delta \mathrm{Y}^{\mathrm{A}}_{\mathrm{cit}}} = -\varepsilon^{D}_{cit} \cdot (1+m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{\mathrm{jci}} \cdot \frac{\Delta \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j^{Ref}_{cit}}}{\mathrm{Y^{Ref}_{cit}}}} \cdot \widehat{\mathrm{KNOWj}}_{\mathrm{cit}}, \qquad \lambda_{\mathrm{jci}} = 1, \mathrm{j} = \mathrm{RD}, \mathrm{ICI}, \mathrm{OI}, \tag{31}$$

We call this effect the "*intensity effect*. It results from the increased capacity of the sector to absorb the growth of external knowledge, compared to the situation in the baseline.

Now, if all the sectors and EU countries increase their investment in innovation input *j*, it will change also the growth rate of knowledge externalities ($\Delta\widehat{\mathrm{KNOWj}}_{\mathrm{cit}}$).

It this case, which corresponds to our experiments, the growth rate of the sector will be modified by a second effect that we call the "*knowledge spillovers effect*":

$$\widehat{\Delta \mathrm{Y}^{\mathrm{A}}_{\mathrm{cit}}} = -\varepsilon^{D}_{cit} \cdot (1+m_{ci}) \cdot \alpha_{cit} \cdot \sum_{\mathrm{j}} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{\mathrm{jci}} \cdot \left(\frac{\Delta \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j^{Ref}_{cit}}}{\mathrm{Y^{Ref}_{cit}}}} \cdot \widehat{\mathrm{KNOWj}}_{\mathrm{cit}} + \frac{\frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}{\frac{\mathrm{j^{Ref}_{cit}}}{\mathrm{Y^{Ref}_{cit}}}} \cdot \Delta\widehat{\mathrm{KNOWj}}_{\mathrm{cit}} \right), \qquad \lambda_{\mathrm{jci}} = 1, \mathrm{j} = \mathrm{RD}, \mathrm{ICI}, \mathrm{OI}. \tag{32}$$

This last effect (at the right in the bracket) is only transitory as the growth of knowledge spillovers tends in long term to go back toward its level in the reference scenario. It illustrates the semi-endogenous growth properties of our modelling, while the "*intensity effect*" illustrates its "fully endogenous growth" ones that continue to play in long term.

But the reader must keep in mind that the "*ex-post*" effects will differ from these "*ex-ante*" effects just described. The relative competitiveness of the sectors and countries will be modified and there will be, in addition to knowledge spillovers, rent (or productivity) spillovers conveyed by the exchange of goods and services between them that will globally increase the positive impacts of innovations. Also, the pulling effect that have one innovation asset on two others will provoke changes in all innovations inputs intensities and externalities simultaneously, increasing the positive impacts. But negative indirect impacts will also occur. They will come mainly from the fall of the demand of production inputs provoked by the rise of TFP that will reduce activity and from the possible tensions on the labour market.

4.2- The distinct impacts of innovation inputs with pulling effects

For this first set of simulations (see Table 2) all the mechanisms that were introduced in the model are active and the parameters are all set to their defaults values. The objective is here to illustrate the distinct impacts of a 0.5 GDP point exogenous increase on either private R&D (T1605), ICT (T2605) or OI (T3605) investments.

We will focus first on the comparison of the short term and long term impacts of the alternative shocks introduced in the model on the EU GDP. There exists at least two ways for analysing the impacts on GDP. The first, as displayed on Conversely they are the less important for ICT investments as a large part of ICT capital goods are imported from outside Europe. After 2015 up to 2019 the initial gains in GDP begin to reduce as the financing of investments increases prices and decreases the external competitiveness of EU countries *vis-à-vis* the Rest of the World regions. In the case of ICT, the level of GDP is lower that in the reference scenario between 2017 and 2021, even if it begins to re-increase after 2018.

Figure 2 below, is to examine the % deviation of the GDP compared to its level in the reference scenario in the model, at different points of time.

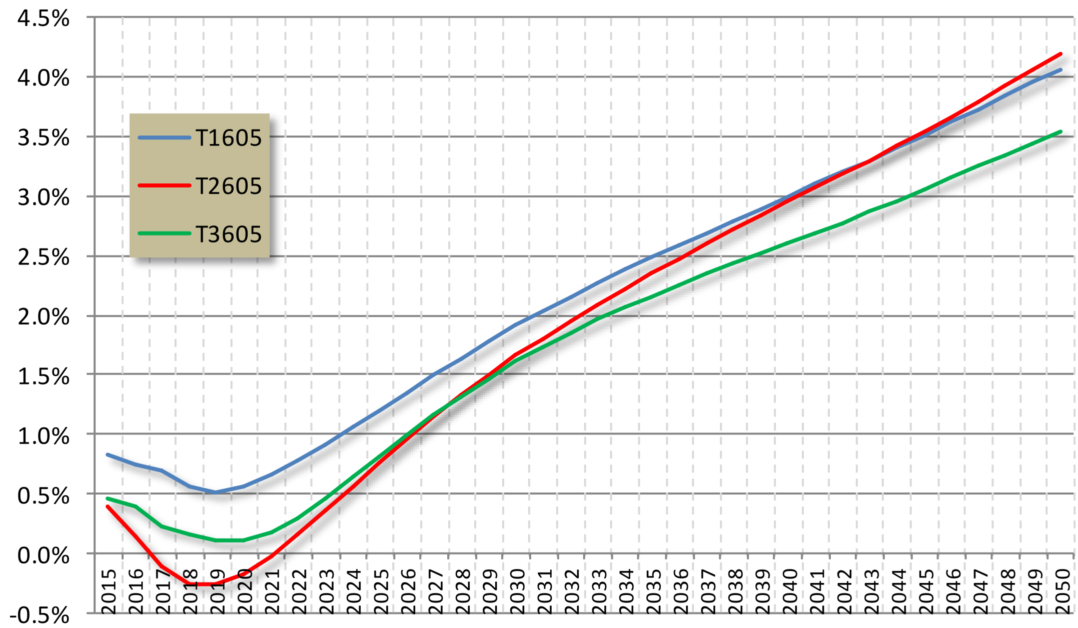
The first statement is that whatever the input increased, the effects in time describe three periods. We are used to call the first period, that goes from the first year of the shock (2015) up to 2019-2020, the “maturation” or “investment” phase”. The investments do not traduce already into important new process and product innovations in reason of the “maturation” delays introduced in the model. The main impacts on GDP come from the “multiplier” effect of investments that increase the final demand addressed to producers. These Keynesian effects are more important for R&D as it is the input the more intensive in employment.

Scenario name	General setting			Exogenous increase in GDP points of		
	Knowledge spillovers	Share of products innovations	Substitution elasticity between innovation components	RD	ICT	OI
T1605 - RD	YES	33%	0.25	0.5	0	0
T2605 - ICT	YES	33%	0.25	0	0.5	0
T3605 - OI	YES	33%	0.25	0	0	0.5

Table 2: Description of the first set of scenarios

Conversely they are the less important for ICT investments as a large part of ICT capital goods are imported from outside Europe. After 2015 up to 2019 the initial gains in GDP begin to reduce as the financing of investments increases prices and decreases the external competitiveness of EU countries *vis-à-vis* the Rest of the World regions. In the case of ICT, the level of GDP is lower that in the reference scenario between 2017 and 2021, even if it begins to re-increase after 2018.

Figure 2: Scenarios T1605, T2605, T3605: Change in GDP in % compared to reference scenario

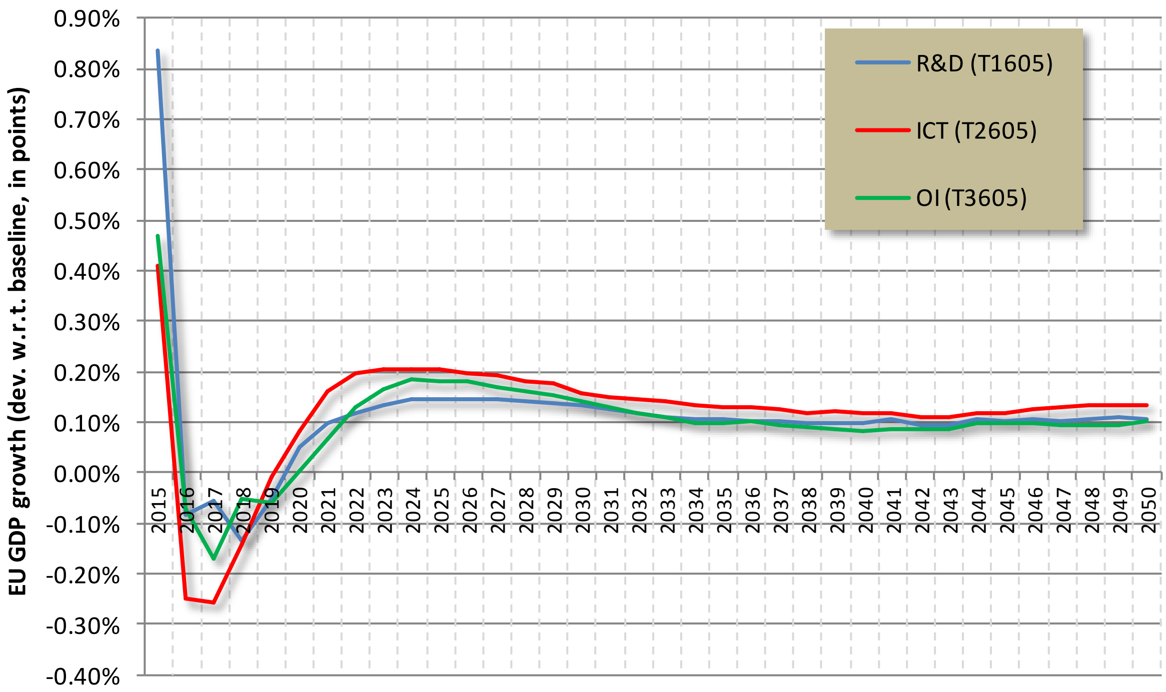


The second period, that begins after 2019-2020 and that goes about up to 2035, is the "innovation" phase. In this period the knowledge spillovers provoked by the investments grow fast and the rate of arrival of new innovations reaches gradually its maximum. The main effects on GDP come from the new process and product innovations that rise the competitiveness of EU producers.

The third period, that begins approximately in 2035, is the "transition" period when the growth rate of GDP reaches its new long term growth path.

A second complementary way to look at the impacts on GDP is to compare this time, not the level, but the growth rate of GDP to its growth rate in the reference scenario of the model as displayed on Figure 3.

Figure 3: Points deviation of GDP compared to the reference scenario (T1605, T2605, T3605)



The curves on this figure confirms the evolution in three phases we have just described. We see notably that after 2035 the annual growth rate of GDP is increased by about 0.1% per year in the case of R&D, 0.12% for ICT and 0.09% for OI investments.

In the long term, we can therefore conclude from this first set of simulations that ICT investments are the innovation inputs that have the greater impact on the growth of EU GDP in the long term, but this first statement must be now nuanced on different points.

First, the different assets have "pulling" effects one on the others and the literature indicates that these effects should be particularly strong for ICT investments. The Table 3 displays the "pulling" effects that were measured by the model for each of the simulations.

Scenario name	Investments in GDP points			
	RD	ICT	OI	Total
T1605 - RD	0.50	0.10	0.18	0.78
T2605 - ICT	0.17	0.50	0.26	0.93
T3605 - OI	0.12	0.10	0.50	0.72

Table 3: "Pulling" effects calculated by the model (T1605, T2605, T3605)

For R&D we see that increasing exogenously the investments of 0.5 GDP points leads in the long term (after 2035) to 0.1 GDP point additional investment in ICT and to 0.18 GDP point additional investment in OI. The total rise of investment in innovation inputs is not of 0.5 but of 0.78 GDP points, each € invested in R&D leading in the long term to 0.56 additional € investment in the two other innovation inputs.

For OI, the pulling effect on ICT investments is identical than for R&D but the pulling effect on R&D is inferior to the one of R&D on OI investments. Each € invested in OI leads in average to 0.44 € additional investment in the two other assets.

For ICT, as suggested by the theoretical and the empirical literature, the pulling effect is very important both on OI and R&D investments. Each € invested increases OI by 0.52 € and R&D by 0.34 € and total investments in the two assets by 0.86 €.

The relative amplitude of the GDP impacts of the different inputs are therefore strongly influenced by these pulling effects, that play with different amplitudes.

The next question is "Are these measured impacts on GDP in line with the findings of the empirical studies on R&D and innovation"?

For R&D we see that rising the intensity by 0.5 GDP point at EU level leads with the model to a 0.1 % increase of the GDP growth rate, which is well inside the interval given by the empirical literature. For the other innovation inputs the results look also in phase with the output and TFP elasticities calculated by the empirical literature, but that will need additional confirmations as we underlined in section 3.3[24].

Focusing now on the employment we see on Figure 4 that the impacts are very contrasted depending of the input targeted by the shock.

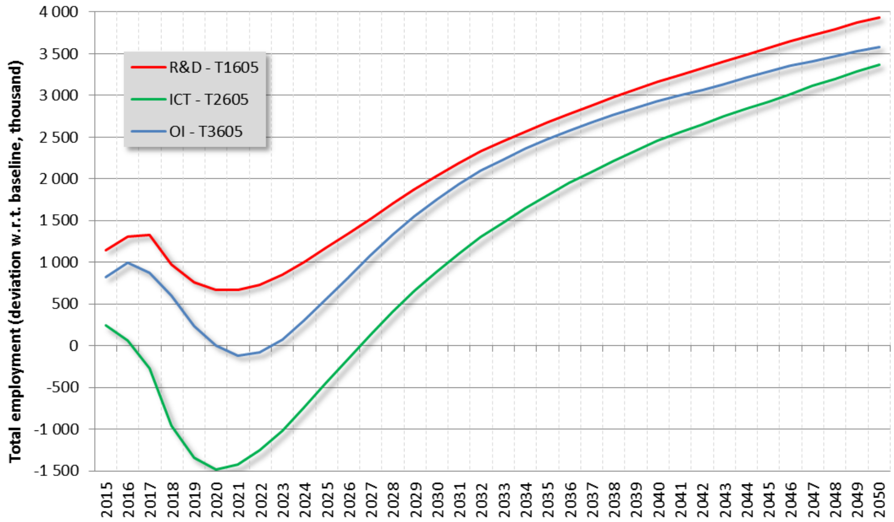
While for R&D the impact on employment is always positive, with already more than 1.1 million jobs creations the year of the shock (2015), the impacts for ICT is very limited in 2015 (0.2 million) and then becomes negative with a pick of about 1.5 millions jobs destruction in 2020. At this date the jobs creations are about 0.7 million in the case of R&D and we have limited job destructions (inferior to 0.1 million) in the case of OI investments. After 2020 the level of employment re-increases in every scenarios but the difference in the relative impacts remains very important up to

24 More precisely, in the reference scenario of NEMESIS the intensities of innovation inputs are kept constant close to their 2012 values. The global intensity is about 5.4% of GDP EU average, with 1.3% for private R&D, 0.7% for Public R&D, 1.1% for ICT and 2.2% for OI. It induces an endogenous growth rate of GDP/capita in the model of about 0.5-0.6% per year in EU average. The endogenous growth rate of TFP is itself of about 0.3-04% per year

2050. There is a difference of about 0.6 million jobs in the best performing case (R&D) against the less performing one (ICT).

One major reason of these contrasted impacts is that the distribution of the three inputs in production sectors are themselves very contrasted. R&D is concentrated in manufacturing and exporting sectors, ICT investment in labour intensive service industries while OI are more homogeneously spread in the different production sectors. For example (Figure 5), R&D investment boost importantly annual long term labour productivity growth in intensive industrial sectors such as Transport Equipments, Chemicals (including pharmaceutical) and High Tech industries notably the ICT sectors.

Figure 4: Impacts on total employment (deviation w.r.t. baseline, in thousand; T1605,T2605 and T3605)



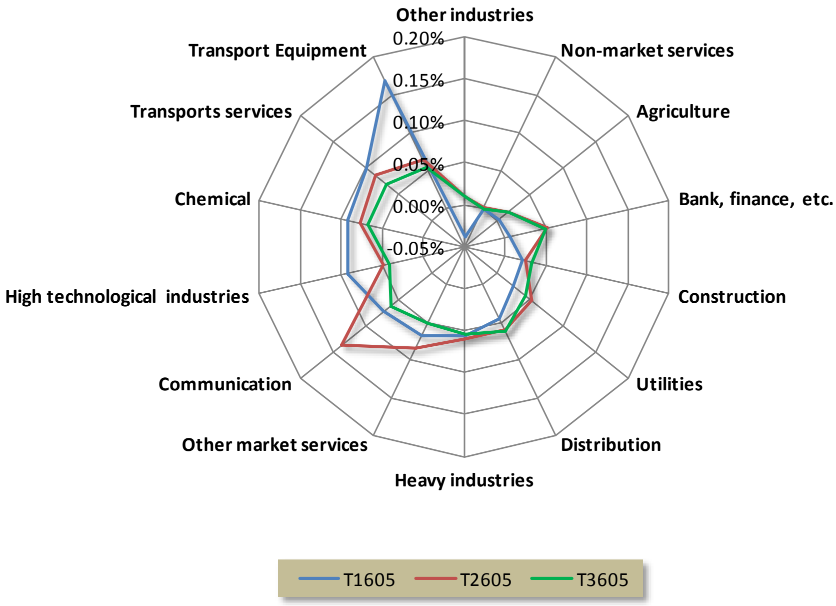


Figure 5: Impacts on long term annual growth rate of labour productivity in EU-28 sectors (deviation w.r.t. baseline in difference; T1605,T2605 and T3605)

By contrast the impacts of ICT investments on labour productivity are less important for ICT than for R&D in most industrial sectors, but more important in many service industries such as Communications, Distribution, Energy Utilities and in Other Market Services. Therefore, concentrating productivity gains in service sectors, very intensive in employment and operating principally on the domestic market, may lead to losses in employment in these sectors in the short to medium term, from the simulations and the mechanisms of the NEMESIS model[25].

4.3- The role of complementarities and pulling effects

We look now at the implications of changing value of the substitution elasticity between the three innovation inputs. Different simulations were run with values ranging from close to zero (0.01) – perfect complementarity – to close to one (0.99) – perfect substitutability (Table 4).

			Private R&D	ICT	OI	Total
R&D	**T1705**	**0.01**	0.50	0.11	0.20	0.80
	T1605	**0.25**	0.50	0.10	0.18	0.78
	T1805	**0.5**	0.50	0.09	0.16	0.75
	T1905	**0.75**	0.50	0.06	0.12	0.69
	T11005	**0.99**	0.50	0.05	0.08	0.63
ICT	**T2705**	**0.01**	0.19	0.50	0.29	0.98
	T2605	**0.25**	0.17	0.50	0.26	0.93
	T2805	**0.5**	0.15	0.50	0.22	0.87
	T2905	**0.75**	0.13	0.50	0.17	0.80
	T21005	**0.99**	0.11	0.50	0.10	0.71
OI	**T3705**	**0.01**	0.14	0.11	0.50	0.75
	T3605	**0.25**	0.12	0.10	0.50	0.72
	T3805	**0.5**	0.10	0.08	0.50	0.69
	T3905	**0.75**	0.08	0.07	0.50	0.65
	T31005	**0.99**	0.06	0.04	0.50	0.60

Table 4: Substitution elasticity between innovation components and “pulling” effects

The first effect of changing the elasticity is to modify the pulling effect that one asset as on the investment in the two others. For R&D the pulling effect on the two other assets is of 0.28 GDP point, for a substitution elasticity of 0.25 as we saw above. It is nearly unchanged (0.3 GDP point) when lowering the substitution elasticity to 0.01. If on the contrary we increase it from 0.25 to 0.5, the pulling effect is also only marginally changed (0.25 GDP point against 0.28 in the default case). The pulling effect decreases to 0.19 for an elasticity of 0.75 and to 0.13 for an elasticity of 0.99. Between the two extreme cases – perfect complementarity (T1705) and perfect complementarity (T11005) – the pulling effect is reduced about 45% (1-0.13/0.3). In the more acceptable or plausible range of values for this elasticity, say between 0.25 and 0.75, the amplitude of reduction of the pulling effect is limited to about 30% (1-0.19/0.28). For ICT and OI, the statements are similar. The importance of the pulling effect does not seem do change that much depending on the acceptable values for the substitution elasticity.

[25] The distinct impacts of the innovation inputs of labor productivity will be again more contrasted if we remove the “pulling” effects between them, as in the next section.

As a consequence, when looking at the results on Table 5, we observe that the long term GDP impacts change only slightly with the value the elasticity, at least in the interval [0.25; 0.75]. The value of this elasticity is therefore not “critical”. It is true for EU GDP but we can check that it is true also for the main other socio-economic indicators calculated by the model.

This reasons of this result that looks counter-intuitive is that the main vector of complementarities between innovation inputs are the knowledge spillovers. In our experiments the rise of knowledge spillovers decreases the cost of the input targeted by the 0.5 GDP shock (R&D for example), that translates also in the cost of the corresponding innovation component.

		Elasticity of substitution	GDP*	Long-run GDP growth (2030-2050)**
R&D	**T1705**	**0.01**	3.9%	0.11%
	T1605	**0.25**	4.1%	0.11%
	T1805	**0.5**	4.3%	0.11%
	T1905	**0.75**	4.3%	0.11%
	T11005	**0.99**	4.3%	0.11%
ICT	**T2705**	**0.01**	4.4%	0.13%
	T2605	**0.25**	4.2%	0.13%
	T2805	**0.5**	4.1%	0.12%
	T2905	**0.75**	3.9%	0.11%
	T21005	**0.99**	3.6%	0.10%
OI	**T3705**	**0.01**	3.6%	0.10%
	T3605	**0.25**	3.5%	0.10%
	T3805	**0.5**	3.3%	0.09%
	T3905	**0.75**	3.0%	0.08%
	T31005	**0.99**	2.7%	0.08%
**: % deviation w.r.t. baseline, in 2050*				
***: average annual growth, deviation w.r.t. baseline, in % points*				

Table 5: Substitution elasticity, pulling effects and GDP impacts.

The more innovation inputs are complementary (low value of the substitution elasticity) the less the fall in the relative cost of the targeted input decreases the investment in the two other inputs through the direct “substitution’ effect. It is the influence of that “direct” substitution effect that is measured by the changes in the different figures of Table 4 when moving the value of the substitution elasticity.

But the fall of the cost of the input targeted by the shock, from the rise of knowledge spillovers related to this asset, transfers also into the cost of innovation services that decreases. Firms decide consequently investing more in innovation services which provokes a rise of the investment in the two inputs not targeted by the shock. This is the “expansion” effect that plays in the inverse direction than the direct substitution effect and proves, from the simulation results, to be the strongest of the two effects in order of magnitude.

Finally other complementarities exist in the model between the three innovation inputs, as the strategic complementarities between ICT users and ICT producers, that may also explain why the

ICT are the input with the strongest pulling effects on the two others.

4.4- Removing the pulling effects and the role of knowledge spillovers

We analyze here more in detail the distinct impacts that have the three innovation inputs on the growth rate of GDP.

		Inter-sectoral spillovers	Intra-sectoral spillovers	GDP*	GDP growth**
Private R&D	T1105	Yes	Yes	2.6%	0.04%
	T1205	No	Yes	2.3%	0.04%
	T1305	Yes	No	2.2%	0.05%
	T1405	No	No	1.8%	0.05%
ICT	T2105	Yes	Yes	1.9%	0.04%
	T2205	No	Yes	1.5%	0.04%
	T2305	Yes	No	1.0%	0.04%
	T2405	No	No	0.4%	0.04%
OI	T3105	Yes	Yes	2.5%	0.06%
	T3205	No	Yes	1.5%	0.05%
	T3305	Yes	No	1.6%	0.06%
	T3405	No	No	0.7%	0.06%

*: % deviation w.r.t. baseline in 2050

**: point deviation w.r.t. baseline in 2050

Table 6: GDP impacts without pulling effects and role of knowledge spillovers

The idea is to remove totally the pulling effects that one asset have on the two others in the simulation experiments. For that we delete the equations E1-E3 for the demand of innovation inputs and in the simulations, all the innovation inputs are consequently exogenous. The input shocked is increased exogenously 0.5 GDP point and the level of the two other inputs are kept constant to their values in the reference scenario of the model.

The first scenario for R&D (Table 6), T1105, is identical to the scenario T3605 presented in the section 4.2 above with that difference that this time there is no pulling effects of the increased investments in R&D on the investments in ICT and in OI. This scenario, even not realistic, allows consequently to isolate perfectly the specific impacts that have the investments in R&D on EU GDP.

We observe first that removing the pulling effects reduces very importantly the impacts on GDP. In 2050, the gains in GDP establish to 2.6% against 4.1% when the pulling effects on the two other inputs play (scenario T1605, figures 8). In the scenarios T3605, about one third (1-2.6/4.1) of the EU

GDP gains were therefore not attributable to the rise of R&D investments, but to the rise of the investments in the two other assets provoked by the pulling effects. The difference between the two simulation cases is more important for the impacts of the long term growth rate of GDP. It is increased 0.04% in the current scenario against 0.1% in the preceding one. The reduction of the impact is this time about 60% (1-0.04/0.1).

The scenario T2105 does the same than the scenario T1105 but this time for the case of ICT. We see that for ICT removing the pulling effects reduce more importantly the impacts on EU GDP that in the case of R&D. The GDP gains in level reach in 2050 1.9% against 4.2% in T2605 (fall of more than 50%) and the impacts of the long term GDP growth is of 0.04% against 0.12% in T2605 (fall of two thirds). The scenario T3105 that does finally the same for the case of OI show that OI is the input whose the impacts on EU GDP are the less influenced by the pulling effects. Their suppression reduces only 25% the impacts on the level of GDP (2.5% against 3.5%) and of 33% the impacts of the long term GDP growth rate (0.06% against 0.09%).

The other simulation results displayed in Table 6 aim this time analyzing the role played by the knowledge spillovers associated to the different inputs on the impacts measured for GDP. For R&D, the simulation T1205 removes in addition to pulling effects, as in the case T1105, the effect of inter-sectoral spillovers relative to R&D, by suppressing part of equations E15. These inter-sectoral spillovers origin both from national and foreign sources (limited to other EU countries here). Similarly, the simulation T1305 removes the impacts of intra-sectoral spillovers (between firms of the same sector in the country and in the other countries) and the simulation T1405 all spillovers.

The first observation is that knowledge spillovers do no impact the long term growth rate of GDP in our experiments. On the contrary, they impacts importantly on its level. For instance for R&D the impact on the long term growth rate of GDP is roughly unchanged when removing all spillovers, but the impacts on the level of GDP are reduced in 2050 from 2.6% (T1105) to 1.8% (T1405) with a fall of about one third[26]. For ICT the impacts on the level of GDP in 2050 are reduced about 80% when removing all spillovers sources (T2405 against T2105) while for OI they are reduced about 70% (T3405 against T3105).

The fact that removing knowledge spillovers do not impact the long term growth of EU GDP is intriguing but one must keep in mind that conversely, in NEMESIS, there is no endogenous growth without growth in knowledge externalities. And if the knowledge externalities do not grow in the reference scenario of the model, the impacts of the long term GDP growth rate of rising the intensities of innovation inputs will be null, as illustrated by equation 21.

4.5- The importance of product innovations

These last experiments, presented in Table 7 (for GDP) and Table 8 (for employment), illustrate role played by product innovations. We first remove totally product innovations and keep only process innovations (scenario T11205) and then we keep the same amount of process innovations and increase progressively the number (share) of product innovations (scenarios T11035 to T11505). To alleviate the presentation, we present only the results obtained for the case of R&D, the results for ICT and OI being similar.

[26] For R&D the role played by knowledge spillovers is in reality more important if we account also for externalities from public research.

In our default calibration setting, that is summarized in Table 2, we fixed the share of product innovations to 0.33%: process innovations are 2 more times important (in number) than product innovations. It corresponds in Table 7 and Table 8 to the case T1105, we have just studied in section 4.4.

As for scenario T1105 in all the simulations presented here the pulling effects were removed and the equations E1-E3 for the demand of innovation inputs are suppressed. The R&D is increased exogenously 0.5 GDP point and the level of the two other inputs are kept constant to their values in the reference scenario of the model.

In scenario T11405 (see Table 7), product innovations are totally removed while the "quantity" of process innovations is identical that in our central scenario T1105: it is normalized to 1. Starting with the results for GDP, we see that when removing totally product innovations it reduces considerably the impacts on GDP, whatever the time horizon considered. In 2050 the increase of EU GDP is reduced 2.6 points (about two thirds) compared to the situation in our central scenario T1105, where this share is set to 33%. During the "investment " period (2015-2020), the negative impacts on the GDP annual growth rate are nearly doubled : they reach -0.09 point against only -0.05 in T1105. Similarly, in the "maturation" (2020-2035) and the "transition (2035-2050) periods the positive impacts on GDP are this time reduced about 50%.

	Quantity of innovations				GDP*	GDP growth**		
	Process innovations (1)	Product innovations (2)	Total innovations (1) + (2)	Share of products innovations (2)/(1+2)		2015-2020	2020-2035	2035-2050
T11405	1	0.00	1.00	0%	1.2%	-0.09%	0.04%	0.02%
T1105	1	0.50	1.50	33%	2.6%	-0.05%	0.09%	0.04%
T11505	1	1.00	2.00	50%	4.0%	-0.01%	0.15%	0.07%

*: % deviation w.r.t. baseline, in 2050

**: change in annual average growth rate compared to ref. scenario in % points

Table 7: The impact of product innovations (GDP)

The reason of these higher negative GDP impacts is the short term, and reduced positive ones in the medium to long term, is that when removing product innovations, process innovations reduce production costs and it will gradually compensate the financing of the extra R&D expenditures, but they have also a direct negative impact on employment and on the demand for the other production inputs that lead to recessive effects. As we checked, the result will be the similar if we would increase the elasticities α_{cit} that measures the "strength" of process innovations at sectoral level. The only way to avoid these negative impacts would be to increase the price elasticity of demand ε_{cit}^{D}, to allow a higher response to the price decrease provoked by process innovation, but it won't be consistent with the consumption behaviour of the different economic agents in the model.

	Quantity of innovations				Employment*	Employment growth**		
	Process innovations (1)	Product innovations (2)	Total innovations (1) + (2)	Share of products innovations (2)/(1+2)		2015-2020	2020-2035	2035-2050
T11405	1	0.00	1.00	0%	0.3%	-0.07%	0.01%	0.00%
T1105	1	0.50	1.50	33%	1.2%	-0.04%	0.05%	0.01%
T11505	1	1.00	2.00	50%	2.1%	0.00%	0.08%	0.02%

*: % deviation w.r.t. baseline, in 2050

**: change in annual average growth rate compared to ref. scenario in % points

Table 8: The impact of product innovations (Employment)

When, on the opposite side, the quantity of process innovation is increased to reach 50% of all innovations- always keeping the amount of process innovations constant at 1 - (scenario T11405), the impact on the level of GDP is increased 2.4 point in 2050 (about 50%), compared to T1105 and the rise of the long term GDP annual growth rate during the "maturation" (2020-2035) and the "transition (2035-2050) periods is also increased about 50%. We see therefore that the GDP impacts increase about proportionally to the number of product innovations that are introduced in the model.

These last results confirm the very important role played by this "sharing" between product and process innovation that is controlled in the model by the value of the parameters m_{ci}. For employment (Table 8) the conclusions are similar: the impacts increase about proportionally to the number of product innovations that are introduced in the model.

4.6- On convergence in GDP/capita

To conclude the presentation of these simulation experiments a last important point to examine is the type of convergence in GDP/capita implied by our modelling. Surveying the development of the empirical and theoretical literature on endogenous growth, Howitt (2004) underlines notably that when introducing international technology transfers from trade or international knowledge spillovers, like in our approach, the theory suggests that this convergence should occurs, "(...) making it consistent with the observation of convergence in growth rates over the past half-century."

The theory and the empirics show moreover that the countries that do not invest much in technology and in R&D "(...) are not able to benefit from technology transfer, (and) will not converge in growth rates but will instead grow more slowly than the technology leaders, even in the long run". Investment in education and the level of educational attainment of the workforce are another important channel of technology transfers from both empirical (Griffith et al., 2001) and theoretical (Howitt et al., 2002) studies.

All these results suggest that per capita income of the countries won't convergence systematically but rather that countries that have strong interactions between them and share similar characteristics, will converge in growth rate and per capita income. It is the club-convergence hypothesis illustrated notably by Quah (1996).

In the case of European countries (see appendix), one observe in the case of R&D an East-West and a North-South European divide pointed by R. Veugelers (2014). Most of eastern and southern countries have an R&D effort well below the EU average, while most of the countries belonging to the central and northern Europe groups are situated over this EU average. This European divide exists also for investments in education and in OI but not for investments in ICT.

When increasing the R&D intensity simultaneously in all EU countries by 0.5 GDP point, as in the scenario T1605, the NEMESIS simulation results show (Figure 6) that the countries from the east of Europe, which are also the less R&D intensive in average, encounter the more important impacts in terms of GDP growth. It traduces a catch-up effect these countries accomplishing in the scenario a very important R&D effort compared to their initial historic situation. Their ability to absorb knowledge spillovers (pre-existing or occurring in the T1605 scenario) is notably considerably increased compared to the situation in the reference scenario. This catch-up phenomenon is observable also for the countries from south Europe well above the EU average in terms of R&D intensity. The question is finally the realism of these evolutions and the real possibility of these countries to introduce the structural reforms that will incite firms increasing such importantly their R&D efforts.

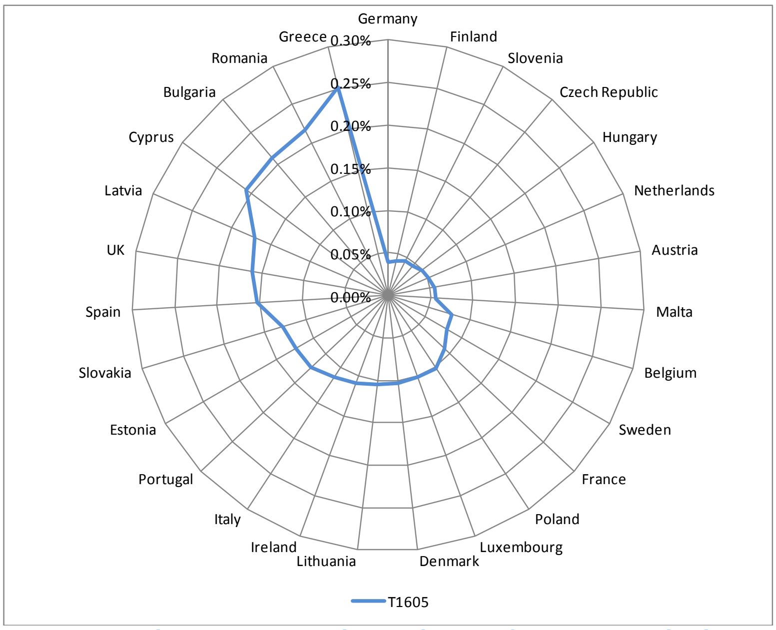


Figure 6: Impacts on long term annual growth rate of GDP per capita (T1605 - R&D)

In the case of a rise of investment in ICT (scenario T2605, Figure 7) it is this the countries from the north of Europe, that are also among the more intensive in R&D that encounter the greatest impact on their long term GDP growth. These countries beneficiate notably very importantly, compared to eastern and southern countries, of the strong pulling effects that ICT investments have on R&D.

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growth.

Figure 7: Impacts on long term annual growth rate of GDP per capita (T2605 - ICT)

In the last case of a rise of OI investments (T3605, Figure 8) the simulation results display again the catch-up phenomenon of eastern and southern countries obtained for R&D. The reason are similar: these countries accomplish in the scenario a very important investment effort compared to their initial historic situation allowing them to better absorb international knowledge externalities.

Figure 8: Impacts on long term annual growth rate of GDP per capita (T2605 - OI)

These last results confirm therefore that the innovation mechanisms introduced in NEMESIS are in phase with the club-convergence hypothesis illustrated by the recent literature on endogenous growth.

5. Conclusion/Future perspectives

We presented in this paper the new innovation module of NEMESIS that is currently developed in the context of the EC research project I3U. Compared to the previous version based on the sole R&D input (Brécard et al., 2006) this new version allows notably to better represent the new forms taken by innovation in the recent years. They concern essentially organizational innovations which development is accelerating with the fast expansion of broadband infrastructure and ICT investments. The bulk of innovation is not any more related to R&D investment by high-tech sectors but to new marketing or organizational methods, new workplace organizations, new linkages between producers or between producers and customers, etc, allowed by ICT investments and investments in OI assets (Softwares and Training in our modelling).

This new representation of innovation allows at the same time to better represent the way firms innovate in the information age, and the interactions among the different production sectors of the economy, notably between manufacturing and services. These later sectors, that were considered as not progressive become themselves progressive from adaptations of ICT technologies (Jorgenson et al., 2008, Colecchia and Shreyer, 2002a,b, Bosworth and Triplett, 2007, van Ark, O'Mahony and Timmer, 2008) and their investment in complementary intangible assets, notably human capital (Corrado et al., 2012).

Our modelling approach, based on the endogenous growth theories à la Romer (1986) and on the concept of ICT as GPT proposed first by Bresnahan and Trajtenberg (1995), is at our knowledge the first attempt to extend the range of innovation inputs in a large scale macro-sectoral simulation model used for the assessment of R&I policies. The main assumption underlying our modelling is that there exists, as for R&D, specific knowledge spillovers associated to the investments realized in ICT and OI that we model explicitly. While our first simulation experiments show that the model results are in phase with the key findings of the recent literature on innovation, they stay nevertheless very preliminary as the required data from national accounting sources stay very scarce and the empirical literature on ICT and OI as well.

This new version of NEMESIS enriches finally considerably the range of R&I policies that can be assessed with the model, that is currently mobilized in I3U to achieve an assessment of the European Innovation Union. In I3U we will notably modify the "by-default" calibration of the model, presented in this paper, that will be adapted to represent the specificities of the sectors and countries that will be studied. It will be based on in-depth direct assessments of the 34 commitments of the Innovation Union from micro works, that will be the inputs that will allow NEMESIS to calculate after their socio-economic and environmental indirect impacts. The micro works will allow notably to recalibrate three sets of "parameters" that prove very important for the assessment of R&I policies: (1) the additionality or leverage effect of the different European R&I policies on investments in innovation inputs, (2) the specific knowledge spillovers they provoke and (3) the way they modify the productivity of knowledge.

Micro and Macro prove therefore to be very complementary approaches for the assessment of R&I policies, notably from the Meso detailed sectoral modelling of NEMESIS that bridges usefully these former, as illustrated in this paper.

6. References

Aghion, P. and Howitt, P., "*A model of growth through creative destruction*", Econometrica, vol. 60, n°2, pp. 323-351, 1992.

Aghion, P. and Howitt, P., "*Endogeneous Growth Theory*", MIT Press, Cambridge, 1998.

Analytical Business Enterprise Research and Development Database, 2014.

van Ark, B. and O'Mahony, M. and Timmer, M.P., "*The productivity gap between Europe and the United States: Trends and causes*", Journal of Economic Perspectives, vol. 22, n°1, pp. 25-44, 2008.

Barcenilla-Visus, S. and Lopez-Pueyo, C. and Sanau, J., "*Semi-Endogenous Growth Theory Versus Fully-Endogenous Growth Theory: a Sectoral Approach*", Mimeo. University of Zaragoza, 2010.

Belderbos, R. and Mohnen, P., "*Intersectoral and international R&D spillovers*", SIMPATIC 7th FP project, SIMPATIC working paper n°02, 2013.

Biagi, F., "*ICT and productivity: A review of the literature*", European Commission - Joint Research Unit - Institute for Prospective Technological Studies, JRC Technical Reports - Digital Economy Working Paper 2013/09, 2013.

Bogliacino, F. and Pianta, M., "*Profits, R&D, and innovation - a model and a test*", Industrial and Corporate Change, vol. 22, n°3, pp. 649-678, June, 2013

Bosworth, B.P. and Triplett, J.E., "*The early 21st century US productivity expansion is still in services*", International Productivity Monitor, vol. 14, pp 3, 2007.

Brécard, D. and Fougeyrollas, A. and Le Mouël, P. and Lemiale, L. and Zagame, P., "*Macro-economic consequences of European research policy: Prospects of the Nemesis model in the year 2030*", Research Policy, vol. 35, n°7, pp. 910-924, 2006.

Bresnahan, T.F. and Brynjolfsson, E. and Hitt, L.M., "*Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence*", Quarterly Journal of Economics, vol. 117, n°1, pp. 339-376, 2002.

Bresnahan, T.F. and Trajtenberg, M., "*General purpose technologies: engines of growth?*", National Bureau of Economic Research Cambridge, Mass., USA, 1995.

Brynjolfsson, E. and Hitt, L. M., "*Computing Productivity: Firm-Level Evidence*", Review of economics and statistics, vol. 85, n°4, pp. 793-808, 2003.

Castellacci, F., Gulbrandsen, M., Thune, T-M., Kowalski, A-M., Napiórkowski, T., Vučković, V., Čučković, N., Weresa, N-A. and Karbowski, A., "*Literature Review and Data Collection*", I3U working paper D2.1, 2015

Cincera, M. and Santos, A., "*Literature Review and Data Collection*", I3U working paper D3.1, 2015

Cohen, Wesley M. and Levinthal, Daniel A., "*Innovation and Learning: the Two Faces of R&D*", The Economic Journal, vol. 99, pp. 569-596, Septembre, 1989.

Colecchia, A. and Schreyer, P., "*La contribution des technologies de l'information et des communications à la croissance économique dans neuf pays de l'OCDE*", Revue économique de l'OCDE, n°1, pp. 165-186, 2002.

Corrado, C. and Haskel, J. and Jona-Lasinio, C. and Iommi, M., "Intangible Capital and Growth in Advanced Economies: Measurement Methods and Comparative Results", IZA, 2012.

Corrado, C. and Haskel, J. and Jona-Lasinio, C., "*Knowledge Spillovers, ICT and Productivity Growth*", Imperial College, Discussion Paper 2014/5, 2014.

Crass, D. and Licht, G. and Petters, B., "*Intangible Assets and Investments at the Sector Level: Empirical Evidence for Germany*", in "*Intangibles, Market Failures and Innovation Performance*", Springer International Publishing, chap. 4, pp. 57-111, 2014.

Crépon, B. and Duguet, E. and Mairesse, J., "*Research, Innovation and Productivity: An Econometric Analysis At The Firm Level*", Economics of Innovation and New Technology, vol. 7, n°2, pp. 115-158, 1998.

Crespi, G. and Criscuolo, C. and Haskel, J., "*Information Technology, Organisational Change and Productivity*", CEPR Discussion paper n°6105, 2007.

Damijan, J. P. and Kostevc, C. and Stare, M., "*Impact of innovation on employment and skill upgrading*", SIMPATIC 7th EU Project, Working paper n°7, March, 2014.

Danguy, J., and van Polttelsberghe de la Potterie, B. "*Patent fees for a sustainable EU patent system*", World Patent Information, vol. 33, n°3, pp. 240-247, 2011.

Dinopoulos, E. and Thompson, P., "*Schumpeterian Growth Without Scale Effects*", Journal of Economic Growth, vol. 3, n°4, pp. 313-335, 1998.

Dutta, S. and Folta, T. B. (2016). "*A comparison of the effect of angels and venture capitalists on innovation and value creation*", Journal of Business Venturing, vol. 31, n°1, pp. 39–54. doi:10.1016/j.jbusvent.2015.08.003

European Commission, 2011, "H2020 ex-ante impact assessment report", http://ec.europa.eu/research/horizon2020/pdf/proposals/horizon_2020_impact_assessment_report.pdf

Evenson, R., "International Invention: Implications for Technology Market Analysis", R& D, Patents, and Productivity, University of Chicago Press, 1984.

Fougeyrollas A., Koléda, G., Le Mouël P. and Zagamé, P., 2013, Horizon 2020 2014 Call for Proposals: An Ex-ante Assessment of Economic Impacts with the NEMESIS Model, EC publication

Griffith, Rachel, Stephen Redding and John Van Reenen (2001) "Mapping the Two Faces of R&D:

Productivity Growth in a Panel of OECD Industries," August, unpublished.

Grossman, G.M. and Helpman, E., "Innovation and growth in the global economy", MIT press, 1991.

Guo, D. and Jiang, K., "*Venture capital investment and the performance of entrepreneurial firms: Evidence from China*", Journal of Corporate Finance, vol. 22, pp. 375-395, 2013.

Ha, J. and Howitt, P., "*Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory*", Journal of Money, Credit and Banking, vol. 39, n°4, pp. 733-774, 2007.

Hall, B., "*Innovation and productivity*", National Bureau for Economic Research, Working Paper n°17178, 2011.

Hall, B. H and Mairesse, J. and Mohnen, P., "*Measuring the Returns to R&D*", National Bureau of Economic Research, Working paper n°15622 , 2009.

Harrison, R. and Jaumandreu, J. and Mairesse, J. and Peters, B., "*Does innovation stimulate employment? A firm-level analysis using comparable micro-data from four European countries*", International Journal of Industrial Organization, vol. 35, n°C, pp. 29-43, 2014.

Howitt, P., "Endogenous Growth, Productivity and Economic Policy: A Progress Report", International Productivity Monitor, n° 8 Spring 2004.

Howitt, Peter and David Mayer-Foulkes (2002), "R&D, Implementation and Stagnation: A Schumpeterian Theory of Convergence Clubs," NBER Working Paper No. 9104, August.

Jones, C., "*R&D-Based Models of Economic Growth*", Journal of Political Economy, vol. 103, n°4, pp. 759-784, 1995.

Johnson, D.K.N., "*The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use*", OECD Science, Technology and Industry working papers, 2002.

Jorgenson, D.W. and Ho, M.S. and Stiroh, K.J., "*A retrospective look at the US productivity growth resurgence*", The Journal of Economic Perspectives, vol. 22, n°1, , pp 3-24, 2008.

Kancs, d'A. and Siliverstovs, B., "*R&D and non-linear productivity growth*", Research Policy, vol. 46, pp. 634-646, 2016.

Kortum, S., "*Equilibrium R&D and the Patent - R&D Ratio: U.S. Evidence*", American Economic Review, vol. 83, n°2, pp. 450-457, 1993.

Kortum, S., "*Research, Patenting, and Technological Change*", Econometrica, vol. 65, n°6, pp. 1389-1419, 1997.

Laincz, Christopher A and Peretto, Pietro F., "*Scale Effects in Endogenous Growth Theory: An Error of Aggregation Not Specification*", Journal of Economic Growth, vol. 11, n°3, pp. 263-288, 2006.

Lopez, J and Mairesse, J., "*Influences des Investissements en TIC et R&D sur la Productivité: Une Analyse Empirique sur un Panel Non-Stationnaire*", 2nd ICTNET Workshop, London, 2011.

Mackiewicz, M., Richter, S., Scoppetta, A. and Vidovic, H., "*Literature Review and Data Collection*", I3U working paper D6.1, 2015.

Meijers, H. and Verspagen, B., "*Construction of Technology Flow Matrices*", DEMETER 7th FP project, DEMETER Working Paper n°1.2a, 2010.

Muldur, U., Corvers, F., Delanghe, H., Dratwa, J., Heimberger, D., Sloan, B., Vanslembrouck, S. (2006): "A New Deal for an Effective European Research Policy: The Design and Impacts of the 7th Framework Programme", SPRINGER.

O'Mahony, M and Peng, F., "*Workforce Training, Intangible Investments and Productivity in Europe: Evidence from EU KLEMS and the EU LFS*", SERVICEGAP Discussion Paper, 2010.

Peretto, P., "*Technological Change and Population Growth*", Journal of Economic Growth, vol. 3, n°4, pp. 283-311, 1998.

Peters, B. and Dachs, B. and Dünser, M. and Hud, M. and Köhler, C. and Rammer, C., "*Firm growth, innovation and the business cycle: Background report for the 2014 competitiveness report*", ZEW - Zentrum für Europäische Wirtschaftsforschung, Series ZEW Expertises, n°110577, 2014.

Polder, M. and Leeuwen, G. van and Mohnen, P. and Raymond, W., "*Product, Process and Organizational Innovation: Drivers, Complementarity and Productivity Effects*", CIRANO-Scientific Publications 2010s-28, 2010.

Quah, Danny T. (1996) "Convergence Empirics Across Economies with (Some) Capital Mobility," Journal of Economic Growth 1, March, pp. 95-124.

van Reenen, J. and Bloom, N. and Draca, M. and Kretschmer, T. and Sadun, R. and Overman, H. and Schankerman, M., ''*The Economic Impact of ICT*", Final Report for the European Commission, 2010

Romer, P. "*Increasing Returns and Long-Run Growth*", The Journal of Political Economy, Vol. 94, No. 5. (Oct., 1986), pp. 1002-1037.

Roth, F. and Thum, A.-E., "*Does Intangible Capital Affect Economic Growth?*", Does Intangible Capital Affect Economic Growth?, CEPS Working Documents n°335, 2010.

Segerstrom, P.S., "*Endogenous Growth Without Scale Effects*", American Economic Review, vol. 88, n°5, pp. 1290-1310, 1998.

Sissons, A., "More than Making Things: A New Future for Manufacturing in a Service Economy", Work Foundation, London, 2011.

Soete, L., "*The costs of a non-innovative Europe: the challenges ahead*", 2010

Srholec, M. and Verspagen, B., "*The Voyage of the Beagle into Innovation: Explorations on Heterogeneity, Selection, and Sectors*", Industrial and corporate change, vol. 21, n°5, pp. 1221-1253, 2012.

Stiroh, K.J., "*Reassessing the Impact of IT in the Production Function: a Meta-Analysis*", American Economic Review, vol. 92, n°5, pp. 1559-1576, 2002.

Stiroh, K.J., "*Information technology and the US productivity revival: what do the industry data say?*", Federal Reserve Bank of New York, mimeo, 2002.

Ulku, H, "*An Empirical Analysis of R&D-Based Growth Models*", mimeo, Manchester University, 2005.

Reinhilde Veugelers, "Undercutting the Future? European Research Spending in Times of Fiscal Consolidation". Technical report, Bruegel Policy Contribution, 2014.

Zachariadis, M., "*R&D, Innovation, and Technological Progress: A Test of the Shumpeterian Framework without Scale Effect*", Canadian Journal of Economics, vol. 36, n°3, pp. 566-586, 2003.

7. Appendix

Sectoral re-aggragation used in this paper	NEMESIS Sector
Agriculture	01
Utilities	04 + 05 + 06 + 07
Heavy industries	08 + 09 + 11 + 18 + 19
Chemical	10
High technological industries	13 + 14
Transport Equipment	15
Other industries	12 + 16 + 17 + 20
Construction	21
Distribution	22
Transports	24 + 25 + 26
Communication	27
Bank, finance, etc.	28
Other market services	23 + 29

Table 9: NEMESIS sectoral re-aggregation

NEMESIS	NACE Rev.2	
1 Agriculture		
	A01	Crop and animal production, hunting and related service activities
	A02	Forestry and logging
	A03	Fishing and aquaculture
2 Coal and Coke		
	B05	Mining of coal and lignite
	B07	Mining of metal ores
	B08	Other mining and quarrying
	B9.9	Support activities for other mining and quarrying
3 Oil & Gas Extraction		
	B06	Extraction of crude petroleum and natural gas
	B9.1	Support activities for petroleum and natural gas extraction
4 Gas Distribution		
	D35.2	Manufacture of gas; distribution of gaseous fuels through mains
	D35.3	Steam and air conditioning supply
5 Refined Oil		
	C19	Manufacture of coke and refined petroleum products
6 Electricity		
	D35.1	Electric power generation, transmission and distribution
7 Water Supply		
	E36	Water collection, treatment and supply
8 Ferr & non Ferrous Metals		
	C24	Manufacture of basic metals
9 Non Metallic Min Products		
	C23	Manufacture of other non-metallic mineral products
10 Chemicals		
	C20	Manufacture of chemicals and chemical products
	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
11 Metal Products		
	C25	Manufacture of fabricated metal products, except machinery and equipment
12 Agr & Indus Machines		
	C28	Manufacture of machinery and equipment n.e.c.
13 Office machines		
	C26	Manufacture of computer, electronic and optical products
14 Electrical Goods		
	C27	Manufacture of electrical equipment
15 transport Equipment		
	C29	Manufacture of motor vehicles, trailers and semi-trailers
	C30	Manufacture of other transport equipment
16 Food. Drink & Tobacco		
	C10-C12	Manufacture of food products; beverages and tobacco products
17 Tex.. Cloth & Footw.		
	C13-C15	Manufacture of textiles, wearing apparel, leather and related products
18 Paper & Printing Products		
	C17	Manufacture of paper and paper products
	C18	Printing and reproduction of recorded media
19 Rubber & Plastic		
	C22	Manufacture of rubber and plastic products
20 Other Manufactures		
	C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	C31_C32	Manufacture of furniture; other manufacturing
	C33	Repair and installation of machinery and equipment
	E37-E39	Sewerage, waste management, remediation activities

Table 10: NEMESIS sectoral nomenclature

NEMESIS	NACE Rev.2	
21 Construction		
	F	Construction
22 Distribution		
	G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
	G46	Wholesale trade, except of motor vehicles and motorcycles
	G47	Retail trade, except of motor vehicles and motorcycles
23 Lodging & Catering		
	I	Accommodation and food service activities
24 Inland Transports		
	H49	Land transport and transport via pipelines
25 Sea & Air Transport		
	H50	Water transport
	H51	Air transport
26 Other Transports		
	H52	Warehousing and support activities for transportation
27 Communication		
	H53	Postal and courier activities
	J58	Publishing activities
	J59_J60	Motion picture, video, television programme production; programming and broadcasting activities
	J61	Telecommunications
28 Bank. Finance & Insurance		
	K64	Financial service activities, except insurance and pension funding
	K65	Insurance, reinsurance and pension funding, except compulsory social security
	K66	Activities auxiliary to financial services and insurance activities
	L	Real estate activities
	N77	Rental and leasing activities
29 Other Market Services		
	J62_J63	Computer programming, consultancy, and information service activities
	M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities
	M71	Architectural and engineering activities; technical testing and analysis
	M72	Scientific research and development
	M73	Advertising and market research
	M74_M75	Other professional, scientific and technical activities; veterinary activities
	N78	Employment activities
	N79	Travel agency, tour operator reservation service and related activities
	N80-N82	Security and investigation, service and landscape, office administrative and support activities
	S95	Repair of computers and personal and household goods
	S96	Other personal service activities
30 Non Market Services		
	O	Public administration and defence; compulsory social security
	P	Education
	Q86	Human health activities
	Q87_Q88	Residential care activities and social work activities without accommodation
	R90-R92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
	R93	Sports activities and amusement and recreation activities
	S94	Activities of membership organisations

Table 11: NEMESIS sectoral nomenclature (following)

The data

For R&D, the main data sources are EUROSTAT, OECD STAN (ANBERD), and INTAN-INVEST (Corrado et al. , 2012, Database 2014 version). When the data were not available according to the "product field" approach, a transposition methodology from "main activities" approach to "product field" approach has been used. This methodology has been established with the help of databases covering both approaches.

For ICT, including data on investments in Information Technologies (IT) and Communication Technologies (CT), the data are taken from the EU-KLEMS database (Timmer et al. [27]), which provides detailed sectoral data for the main European countries.

Data on OI come from INTAN-INVEST (Corrado et al., 2012) which provides information for 10 sectors in 14 European countries for the period 1995-2010. A large range of intangible categories are available in this database (10, including R&D), but only "Softwares" and "Training" have been used to build the IO variables.

The geographical and sectoral coverage of the databases is generally narrower than that of the model, forcing us to built missing data. The adopted methodology was as follows:

- When the sectoral data were not detailed enough, we assumed that the intensity of the asset, in % of value-added, was identical, in every sub-sectors, and equal to the intensity of the aggregated sector.
- When the data for a country were not available, we used the average sectoral intensities of the group of countries it belongs to, by using the 4 countries' groups : Northern Countries, Central Europe, Southern Countries and Eastern Countries.

The data cover the period 1995 to 2010. After 2010, the data were extrapolated up to 2050 by Keeping constant the R&D, ICT and OI intensities in % of value-added, in every sectors and every countries. Consequently, the projected aggregated intensity of R&D, ICT or OI could vary over time due to sectorial composition effects.

	RD	ICT	OI	Total
Austria	2.82%	1.06%	1.75%	5.63%
Belgium	2.25%	0.95%	1.92%	5.12%
Bulgaria	0.63%	1.17%	1.95%	3.75%
Cyprus	0.43%	1.29%	1.64%	3.36%
Czech Republic	1.76%	1.11%	1.86%	4.73%
Germany	2.87%	0.96%	1.96%	5.78%
Denmark	3.04%	1.80%	4.33%	9.17%
Estonia	2.23%	1.14%	1.91%	5.28%
Spain	1.23%	1.66%	1.59%	4.48%
Finland	3.47%	1.08%	2.26%	6.81%
France	2.24%	0.71%	2.87%	5.82%
Greece	0.71%	1.30%	0.72%	2.72%
Hungary	1.24%	1.08%	3.33%	5.65%
Ireland	1.55%	1.21%	1.60%	4.36%
Italy	1.24%	0.97%	1.33%	3.54%
Lithuania	0.91%	1.23%	1.50%	3.63%
Luxembourg	1.18%	1.31%	4.18%	6.67%
Latvia	0.66%	1.23%	2.65%	4.54%
Malta	0.82%	1.36%	2.12%	4.31%
Netherlands	1.97%	1.43%	2.55%	5.94%
Poland	0.89%	1.03%	1.22%	3.14%
Portugal	1.33%	1.59%	1.44%	4.36%
Romania	0.48%	1.07%	1.36%	2.91%
Sweden	3.28%	0.94%	3.16%	7.38%
Slovenia	2.48%	1.07%	2.60%	6.15%
Slovakia	0.80%	1.08%	3.18%	5.06%
United Kingdom	1.62%	1.29%	3.23%	6.14%
EU-28	**1.99%**	**1.10%**	**2.24%**	**5.33%**

Table 12: National intensities in innovation inputs in % of GDP, 2012

	Private R&D	ICT	OI	Total
Agriculture	0.3%	0.2%	0.2%	0.7%
Construction	0.1%	0.3%	1.1%	1.6%
Bank, finance, ins. & real estate	0.0%	0.7%	1.9%	2.6%
Distribution	0.4%	1.0%	2.5%	3.9%
Heavy Industries	1.4%	0.7%	2.7%	4.7%
Utilities	1.1%	1.1%	2.8%	4.9%
Other Industries	1.3%	0.8%	2.9%	5.1%
Other market services	1.7%	2.3%	4.6%	8.7%
Transports	2.6%	3.2%	3.9%	9.7%
Communication	1.0%	6.6%	5.3%	12.8%
High-tech. Industries	8.8%	0.7%	4.1%	13.6%
Chemical	12.3%	0.7%	2.0%	15.1%
Transport Equipment	16.7%	0.9%	3.4%	20.9%

Table 13: Sectoral intensities in innovation input in % of value-added, EU-28 average for 2012