NEMESIS Model: Full description

Introduction

NEMESIS (New Econometric Model for Evaluation by Sectoral Interdepency and Supply) is a model managed by SEURECO, a private company created by researchers from the laboratory ERASME (Équipe de Recherche en Analyse des Systèmes et Modélisations Économiques) of the École Centrale de Paris and the University of Paris-I-Panthéon-Sorbonne. Originally the model was financed by the FP6 and FP7 European framework programmes, in collaboration with the University of Maastricht, for innovation and knowledge economics, the laboratory ICCS E3M-LAB of the Polytechnique University of Athens, for energy and environment, and the Federal Planning Bureau, for the accounting framework, the econometric estimations, and software development. Since its first version in 2002, the mechanisms of the model have been regularly enriched by the different European consortia to which the SEURECO/ERASME team belongs to.

NEMESIS is a model for each EU country in interaction with the rest of the world regions. It is an econometric model, from neo-Keysesian inspiration, and the adjustment of prices and quantities in the model include various time lags, reflecting the adaptative structure of the expectations of the economic agents, and the existence of adjustment costs. These features, together with the absence of modelling of the capital market and with the rigidity of wages that is assumed, prevents the model from describing a general equilibrium, even in the long-run.

In NEMESIS, the macroeconomic growth is the result of the interactions between very heterogeneous production sectors, that provides a complex bottom-up dynamic to the model, that is combined with purely top-down forces, such as the influence of households aggregate final consumption - the model has only one representative category of consumers - and the role of the public sector from the fiscal and budgetary rules, the social contributions and redistribution mechanisms, the provision of the public services, and the public investments and structural policies.

The NEMESIS model is mainly grounded on empirics and econometrics, which allows a great level of detail, in terms of mechanisms and the number of variables the model includes, but this necessarily at the cost of a weakening of its theoretical grounds and of the overall coherence of the model, when compared for example to the QUEST III model that is developed at the European Commission by the Directorate-General for Economic and Financial Affaires (DG ECFIN)

Concerning the representation of innovation and long-run growth, the sectorial approach that is followed in NEMESIS nevertheless brings important addition to the variety of analysis that it provides compared to a pure macro model such as QUEST:

- The dynamics of the different economic sectors are very contrasted, and structural changes are pushed by two main forces. There first are demand-driven factors, and notably the assumption of the non-homothetic preferences of the consumers, consistent with the Engle law, with the result that the income share of the products evolves differently as the real disposable income of households increases. The second element, that was notably underlined by Pasinetti (see *e.g.* 1981, [55], and 1993, [56]), is driven by technical progress that occurs with various forces in the different sectors, leading to substitutions between products and the reallocation of employment among the different economic activities. The economic growth process that is described by the model is consequently not an equilibrium "balanced" growth path, and endogenous technical change acts

in the model as an acceleration of history, accelerating the decline of the less progressive sectors and speeding-up the growth of the most progressive ones.

- But, as found in the literature, there are also forces in the model, that tend, in the opposite direction, to reduce the extent of the structural transformation of the economy that is created by technical progress. These forces come from what Verspagen and De Loo (1999, [64], P. 218) called the "*equalization effect of R&D spillovers*", that concern mainly the effects of the rent spillovers embodied in the intermediate and investment goods used by the different sectors. Therefore, while pure knowledge spillovers tend to concentrate in few R&D industrial sectors, the latter diffuse strong productivity spillovers toward the user sectors of the technologies they produce, such as from the ICT sectors toward communication, finance and insurance, from the transport equipment sectors to transport services, or from consumer good technologies to wholesale and retail trade. These equalizing forces also have an international dimension, and for some countries the main channel for technology adoption is the import of high tech equipment.

Finally, another important original feature of the NEMESIS model is that it also represents, besides the effect of process innovation, the distinct impact that product innovations have on employment and economic performance. Is is an important point, as the econometric literature generally finds higher output and employment impacts for product than for process innovations. But as we will see, it also complicates the analysis as to the quantitative growth provoked by process innovations, it adds a qualitative component, conceptually at the core of the rent spillovers described above, that necessitates a specific modelling.

After a brief presentation of the general characteristics of the NEMESIS model, we will first detail the main features of the representation of innovation in the model and then the rest of the model, with, successively: the households' final consumption, the labour market, the external trade and the accounting framework.

General characteristics of the model

0.0.1 Model architecture and coverage

0.0.1.1 Model architecture

NEMESIS is composed of a system of sectoral detailed models for every EU-28 countries, and of less detailed models for the Rest of the World areas. Every country model includes an "economic core", that can be simulated in interaction with a detailed Energy/Environment module, NEEM (Nemesis Energy Environment Module). The presentation thereafter will focus on NEMESIS "economic core".

0.0.1.2 Geographical coverage

NEMESIS is a detailed macro sectoral simulation model for the EU economy. It includes every EU-28 countries[1] that can be simulated altogether or individually. The rest of the World is less detailed (see thereafter) but allows a thorough modelling of the external trade of EU with the other world regions that are regrouped as follows: Australia, Brazil, Canada, Switzerland, China, India, Indonesia, Japan, South Korea, Mexico, Norway, Russia, Turkey, Taiwan, USA and other.

Table 0.0.1: List of countries modelled in NEMESIS l

Country	Abbreviation	Country	Abbreviation
Austria	AT	Ireland	IE
Belgium	BE	Italy	IT
Bulgaria	BG	Lithuania	LT
Cyprus	CY	Luxembourg	LU
Croatia	HR	Latvia	LV
Czech Republic	CZ	Malta	MT
Germany	DE	The Netherlands	NL
Denmark	DK	Poland	PL
Estonia	EE	Portugal	PT
Spain	ES	Romania	RO
Finland	FI	Sweden	SE
France	FR	Slovenia	SI
Greece	GR	Slovakia	SK
Hungary	HU	The United-Kingdom	UK

In blue: eurozone' members.

0.0.1.3 Sectorial coverage

There are 30 production sectors of which one sector for agriculture, 6 utilities, 13 manufacturing industries, construction, 3 transport services industries, 6 groups of market services and non market services. The correspondence of NEMESIS nomenclature with the NACE Rev.2 is detailed in tables 0.3.1 and 0.3.2 in appendix.

[1] Croatia was recently introduced in the model and is not yet fully operational.

Table 0.0.2: List of sectors modelled in the NEMESIS model

Number	Sector	Number	Sector
01	Agriculture, etc.	16	Food, drink and tobacco
02	Other extraction	17	Textile, etc.
03	Oil & Gas extraction	18	Paper & printing products
04	Gas distribution	19	Rubber & plastic
05	Refined oil, etc.	20	Other manufactures
06	Electricity	21	Construction
07	Water supply	22	Distribution
08	Ferrous and non-ferrous metals	23	Lodging and Catering
09	Non metallic mineral products	24	Inland Transport
10	Chemicals	25	Sea & Air Transport
11	Metal products	26	Other transport services
12	Agricultural & Industrial machines	27	Communication
13	Office machines	28	Bank, Finance, Insurance & real estate
14	Electrical goods	29	Other market services
15	Transport equipment	30	Non-market services

In green: agriculture; in red: Utilities, in blue: Manufactured industries; in brown: Construction; in purple: Transport and in orange: services

For final consumption, the households split their expenditures between 27 different consumption functions, that are more adapted to analyse households behaviour. They are listed in table 0.0.3 and the mapping with the COICOP[2] is detailed in table 0.3.3.

0.0.2 Sectorial interdependencies

In a detailed sectoral model such as NEMESIS, the macroeconomic dynamics are driven by both intra-sectoral forces and their strong interactions. Indeed, the inter-linkage between sectors is a major part of the model scheme as it will drive the sectoral trends both in the short/medium term and in the long term. In NEMESIS, these sectoral interdependencies mainly consist in two kinds of interactions.

- The first kind of interactions is related to the exchanges of goods and services. Every sectors use goods and services that are produced by other sectors.
- The second kind of interactions relies on knowledge spillovers. The nature of interactions relying on knowledge and innovation is described in section 0.1.

For the interdependencies related to demand flows, they are related to different kinds of demands in NEMESIS, notably for energy (intermediate and final), intermediate products and investment. Each of them are addressed to one or more sectors, including also the intra-branch consumption. These interactions are depicted in figure 0.0.1. Starting from the different demands of inputs (intermediate and final energy, materials and investment, see section 0.1), they are distributed to all the sectors according to transfer matrices to make up a part of the total demand addressed to each sector. The allocation matrices are technical coefficients that split the input demands of a sector between suppliers

[2]COICOP: Classification of Individual Consumption by Purpose.

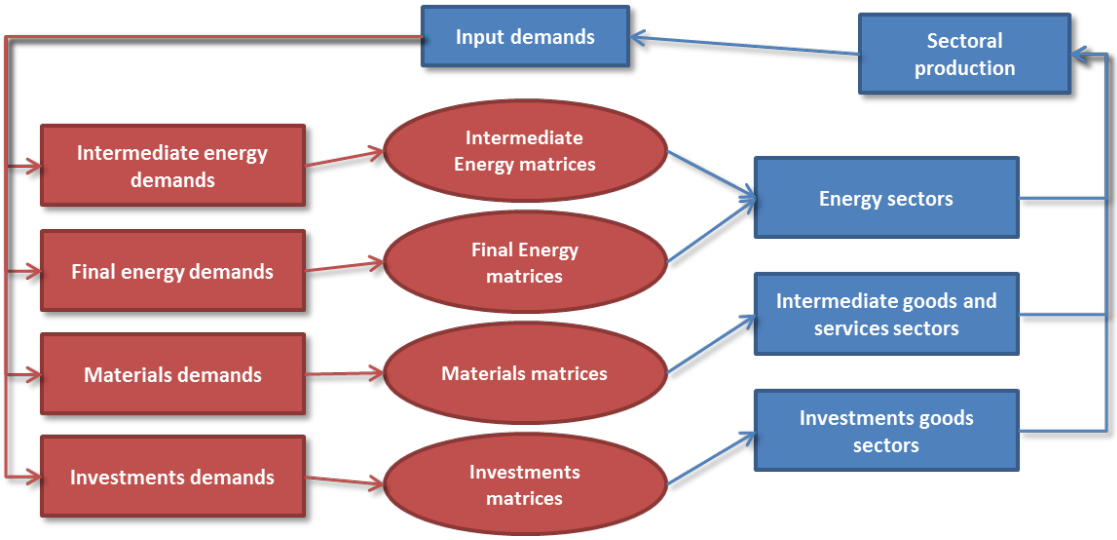
Table 0.0.3: List of households' consumption functions

Number	Consumption function	Number	Consumption function
01	Food	15	Domestic services
02	Beverages	16	Medical care and Education
03	Tobacco	17	Cars, etc.
04	Clothing and footwear	18	Petrol, etc.
05	Gross rent and water	19	Rail Transport
06	Electricity	20	Road Transport
07	Gas	21	Air Transport
08	Liquid Fuels	22	Other Transport
09	Other fuels	23	Communication
10	Furnitures, etc.	24	Equipment and accessories
11	Households' textile	25	Recreation
12	Major Appliance	26	Hotel and restaurant
13	Hardware	27	Misc. goods and services
14	Households' operation		

In blue: non-durable goods and services and in red: durable goods and services.

of it. These coefficients are calculated thanks to Input-Output tables from the WIOD dataset (Timmer et al., 2015 [63]).

Figure 0.0.1: Sectoral interdependencies related to demand flows



We assume constant coefficients for the allocation matrices and the demand of input k from sector i addressed to sector j ($Dk^j_{C,i}$) is defined as:

$$Dk^j_{C,i} = \beta k^j_{c,i} \cdot FACTDk_{C,i} \tag{0.0.1}$$

with $FACTDk_{C,i}$ the demand for input k from sector i and $\beta k^j_{c,i}$ the coefficient of the allocation matrices for input k.

0.0.3 Datasets

NEMESIS with its level of detail requires a big consolidated database of its functioning. Data are compiled from numerous sources[3] and are post-processed for ensuring their whole accounting coherency. The table 0.0.4 summarises the different datasets used the "economic core" economic of the model.

[3]The row dataset presented in this document are the ones used for the last version of the NEMESIS model and even if the row dataset used in NEMESIS are generally the same ones, they could differ according to model version.

Table 0.0.4: Main row datasets used in NEMESIS

Eurostat - Annual National Accounts ([25])
- Gross domestic product
- Households' consumption expenditure
- Government consumption expenditure
- Gross fixed capital formation
- Intra-EU Iimportations
- Intra-EU exportations
- Extra-EU importations
- Extra-EU exportations
- Changes in inventories
- Value added
- Production
- Intermediate consumption
- Compensation of employees
- Employment (persons and hours)
- Employees (persons and hours)
- Gross fixed capital formation
- Wages and salaries
- Consumption functions
Eurostat - Labour Force Survey ([28])
- Labour force by qualification (educational attainment)
- Unemployment rates by qualification (educational attainment)
Eurostat - Annual sectors Accounts ([27])
- Gross disposable income
- Households' investments
- Etc..
WIOD2016 ([63])
- Input/Output tables
- Sectoral importations and exportations
- Energy consumption (intermediate)
WIOD2013 ([63])
- Sectoral employment by qualification (educational attainment)
- Compensation of employees by qualification (educational attainement)
Eurostat - Statistics on Research and Development ([33])
- National R&D expenditures
- Sectoral private expenditures
- R&D personnal and researchers
OECD - Research and Development Statistics ([53])
- Business entreprise R&D expenditures
INTAN-Invest ([13])
- Intangible investments by industry (software and training)
DG TAXUD ([22, 23])
- VAT rates
- Excises duties
- Etc. . .

NB: Values on volumes are used to calculate prices (when relevant).

0.0.4 Main exogenous variables

The usefulness of a model relies on its ability to describe the impacts of the variations of exogenous variables (inputs of the model) on endogenous variables (outputs of the model), in a theoretically and empirically consistent way. The exogenous variables are of two types: those resulting from the incapacity of the model to represent every phenomena and that reflect the limitations of the model, and those that are by nature exogenous. The first type of exogenous variables regroups notably a set of assumptions related to interest rates, exchange rates, activity proxies for the rest of the world, prices of wholesale commodities and especially oil; demographic assumptions by country such as total population, population and participation rates to labour force by gender, by skill and by age per 5 years cohorts. The second type of exogenous variables is mainly composed of government-related decisions: assumptions on national policies and notably fiscal policies (indirect and direct taxes, social security benefits and contributions), government expenditures (defence, health, education, infrastructures, others expenditures) and investments, energy and environment assumptions as excises duties and other energy tax rates, CO2 taxation, and of course of European policies such as the FP.

The next sub-section describes now the way the exogenous variables intervening at the core of economic module of NEMESIS are taken into account.

0.0.4.1 World demand indicators and price

The Rest of the World (non EU countries) regions are not fully modelled in NEMESIS and it is necessary to make assumptions on the evolution of the world demand for the different products and on the world prices of the different commodities that are traded by EU countries.

The exogenous variables representing the demand addressed by the rest of the World to the EU economy are calculated from the WIOD2016 dataset (Timmer et al., 2015 [63]). From this dataset, that is an input/output matrix at the world level, we derive an indicator of the potential demands addressed by the rest of the world to the different economic sectors in every EU countries.

The methodology uses the World Input-Output Table (WIOT), that retraces the inter-industrial exchanges between sectors, with also the geographical origin of the products used. The combination of these matrices with assumptions on the growth of GDP in the different countries outside EU-28[4][5] allows to calculate vectors of addressed demands per country and per sector ($INDROW_{c,s}$) from the rest of world regions, that are introduced in the model.

The second set of exogenous variables is the price of the imported goods and services from the rest of the World ($PINDROW$), defined for each country and each sector. They are defined exogenously on the basis of past trends or on external studies when existing.

The last set of exogenous variables defining the general context of the World economy is related to the prices of raw materials and notably of fossil fuels energy (oil, gas and coal) that are generally taken in conformity with the DG ENER official assumptions.

[4]Including: Australia, Brazil, Canada, Switzerland, China, India, Indonesia, Japan, South Korea, Mexico, Norway, Russia, Turkey, Taiwan, USA and the rest of the World

[5]The expected growth of GDP for non-EU countries are exogenously defined and based on external studies, such as OECD (2014 [51]), Erumban and de Vris (2017 [21]) or Fouré et al. (2012 [34]).

0.0.4.2 Financial exogenous variables

In NEMESIS, the capital market is not modelled and the interest and exchange rates are both exogenous. It is therefore necessary to describe, in the reference scenario of the model, the financial context in which the EU economies are expected to operate in the future years. These assumptions can be modified for scenarios including specific evolutions on interest or exchange rates. A Taylor rule can also be used, when adapted, to govern the evolution of interest rates.

In NEMESIS, while all variables are defined in euros, we have to make assumptions on the exchange rate between the euro and the Rest of the World currencies and between the euro and the currencies of the EU countries that do not belong to the euro area (Bulgaria, Croatia, Czech Republic, Denmark, Hungary, Poland, Romania, Sweden and the United-Kingdom). These assumptions are all based on external studies, with as main focus the euro/dollar exchange rate.

For interest rates, that intervener mainly in the user cost of capital or in agents' accounts, NEMESIS distinguishes the short-term (Eurostat, 2017 [32]) from the long-term (Eurostat, 2017 [29]) rates, with projections based also on external studies or on specific assumptions related to the scenario definition.

0.0.4.3 European demography

The third set of key exogenous variables necessary to run the NEMESIS model is related to European demography. The demography is essential for the functioning of the labour market as it defines the labour force, and, to a lesser extent, for its influence on the final consumption of households (see section 0.2.1). The demographic data that are required by NEMESIS are the population by age groups and by qualification for each EU country. The age groups that are distinguished are:

- [0; 14]
- [15; 24]
- [25; 54]
- [55; 64]
- [65; 74]
- [75; max]

For the level of qualification, it is measured from two different levels of educational attainment:

- low-qualified including ISCED 0 to 4
- high-qualified including ISCED 5 to 8[6].

The historical data (2017 [30]), and the population projections by age groups come from Eurostat (2017 [31]), while the projection by qualification levels are derived from external studies such as KC et al. (2010 [42]) or KC and Lutz (2014 [43]).

[6]International Standard Classification of Education 2011.

0.0.5 The main endogenous variables

On the output side, NEMESIS can deliver results at EU27, country and regional NUTS2 levels for key economic indicators calculated by the model. There are three main layers of economic indicators: (i) macro-economic, such as GDP (European, National or Regional) and its counterparts (final consumption, investment, exports, imports, etc.), unemployment rates, ...; (ii) sectoral, such as production, value added and employment per NACE economic sector or sector clusters, and (iii) those related to agent accounts with five categories: Government, Non Financial Corporations, Financial Corporations, Households including NPIH, and outside.

Beyond economic indicators, the optional modules of NEMESIS provide many additional indicators. The NEMESIS Energy Environment Module (NEEM) gives detailed results on energy supply and demand by fuel type and technology, and on various pollutants emissions (CO2, SO2, NOX, HFC, PFC and CF6); it computes also a carbon price (Taxation or tradable permit price associated to a carbon constraint).

The inclusion in the model of detailed data on population and working force, allows finally NEMESIS to deliver many social indicators, such as employment, unemployment and labour force participation rates by gender,. All these indicators result from the mechanisms incorporated in NEMESIS.

0.0.6 NEMESIS general functioning in summary

The general functioning of the model is schematized by the graph 0.3.1 in appendix and we will summarise here its main characteristics.

0.0.6.1 The behaviour of economic agents

On the supply side, each sector is modelled with a representative firm that takes its decisions regarding the production and the use of factors, given its expectations on market expansion and input prices. The production is represented with nested constant elasticity of substitution (CES) functions combining five production factors: low skill labour, high skill labour, capital, energy and intermediate consumption. In addition, a particular feature of this model is that the firms integrate innovation in their decisions, allowing the improvement of their productivity and of their products, so that the technical progress is endogenous in the model. Innovation is the consequence of investments in three types of assets[7]: R&D, ICT and Other Intangibles (including software and training). The specification of the innovation process in the model allows to account for a large range of innovative activities and for the enabling feature of ICT that are considered as GPT. Furthermore, while R&D are mainly the matter of industrial sectors, the other innovative assets allow a more appropriate endogenisation of innovation in services sectors.

The pricing scheme for enterprises is defined by a monopolistic competition and the margin rates are assumed constant but different between sectors. Finally, interdependencies between sectors and

[7]However, for many utilizations the decision on innovative factors is exogenised. It is the case for RD investments because the endogenisation process of the model is too coarse for many policy applications: absence of uncertainty, financial constraints, ... It is the case for the FP assesssment.

countries are caught up by a collection of convert matrices describing the exchanges of intermediary goods and capital goods as well as the exchange of knowledge spillovers.

The active population is divided in two qualification levels and the level of workers per qualification results from the demand from firms, which depends on wages and relative prices of factors.

On the demand side, the representative household's aggregate consumption is calculated depending on the disposable income which comes from wages, from the revenues of the capital as well as from taxes and redistribution. Variables covering child and old-age dependency rates are also included in an attempt to capture any change in consumption patterns caused by an ageing population. The unemployment rate is used, in the short-term equation (only), as a proxy for the degree of uncertainty in the economy. Then, the total aggregated households consumption is split into 27 different consumption sub-functions taking into account the relative prices, substitution elasticities and the specific nature of the products: durable/non durable,...

The external trade by country in NEMESIS takes two directions: intra-EU trade and trade with the rest of the world. The exports are driven by two main effects in the model: (i) an income effect which accounts for the economic activity in the other regions and (ii) a price effect which accounts for the competitiveness of the considered country with respect to other EU-countries and the rest of the world. Exports are also influenced by structural competitiveness from the quality adjusted prices on which all the demand functions are based in NEMESIS (see sub-section 0.1.6). Regarding imports, the drivers are similar: the income effect is captured by internal demand, and the price effect by the ratio between the (quality adjusted) imports price and the (quality adjusted) price of domestic producers.

0.0.6.2 The dynamic of the model

The dynamic of the model is the result of exogenous drivers such as the world demand, exchange and interest rates, world commodity prices, internal policy drivers, and of endogenous reactions of the different agents. The endogenous dynamic is based, as usually for the econometric models, on behavioural equations of which the "long term" represents the desired or optimal values, which can change at any moment, and the "short term", a progressive adjustment towards these optimal values.

We know quite well the reasons why the adjustment is not instantaneous: the adjustment costs would be too important in case of fast movements. It is clearly the case for employment, investment or other productive factors.

For final consumption, the adaptation to revenue and to prices is not instantaneous because it is a "permanent revenue" hypothesis that prevails.

In fact, we must distinguish three sources of dynamic that appear in the model's equations with lagged variables: The flow stock technical relationship, the building of a decision variable (expectations for instance) and the adaptation to a desired or optimal value.

Flow stock technical relationship

If we except the evolution of the labour force, that is in the long term an exogenous variable, two main productive factors that are accumulated drive the macro economic path: The capital and the knowledge. These two endogenous variables print their dynamics by the transformation of flows of investments into stocks of productive factors.

The flow of physical investment is transformed into stock of physical capital in one year. The flow of investment in innovative factors is transformed in innovation after the "maturation" lag of about 4 or 5 years. This delay is important for the interpretation of FP simulation results. We must add also the flow of obsolescence of capital and knowledge.

The expectations on decision variables

All the behaviour of agents are based on expectations: It is the case for decisions of productive firms and of households. In NEMESIS, the system is based on "adaptative" expectations that make the expectations depend on the observed evolution of past variables, according to an error correction mechanism where, at every moment, the evolution of "expectations" depends on the slack that can be observed at the preceding period, between the realization of variable and its expectation (correction) of the long term growth variables.

In this way are computed expectations on prices, quantities, revenues that are in the core of all decisions. These ECM methods introduce a dynamic that we will explicit later. In any case they introduce lag variables, contrarily to the rational expectations approach (or perfect foresight in the deterministic case) which are based on forward looking variables.

Behavioural equations

Then for the behavioural equations of the model, there is the same logic.

In a first time, the agents determine their desired or optimal long term values and then their optimal adjustments. It is the case for all the demands for productive factors, investment, capital, knowledge, etc, but also for the pricing behaviours, internal prices, export prices, ..., and for the consumption functions.

The econometric method for dynamic

We see that these lags are important for the simulations and the analysis of results. For the innovation policies and the FP more specifically, the maturation is important but also the other lags such as the consumption one for instance. The innovations arrival that lower prices and improve quality, must wait before meeting the corresponding demand.

Then the estimation of the lags is important. We have tried to adopt, whenever it was possible, an error correction mechanism that is well adapted to the dynamic adjustment process of the model. It is the case, for instance, for the consumption function, where is estimated at first the co-integration long term equation and then the dynamic equation (Cf. infra).

However, the annual data and the rather short time series are not well adapted to ECM methods, also, in many circumstances, we did replace ECM by a partial adjustment process, considering, nevertheless, the long term optimal growth of the variables.

0.1 Supply block and innovation mechanisms

On the supply side, the main characteristics of NEMESIS are the following:

1. Each sector is modelled with a representative firm that takes its decisions regarding the production and the use of factors, given its expectations on market expansion and input prices. The production is represented with nested constant elasticity of substitution (CES) functions combining five ordinary production factors: capital, low qualified labour, high qualified labour, energy and intermediate consumptions (KLEM).

2. A particular feature of the model is that the firms integrate innovation in their decisions, allowing the improvement of their productivity and of their products, so that the technical progress is endogenous in the model. Innovation is the consequence of investments in three types of assets: R&D, ICT and Other Intangibles (including software and training). While R&D are mainly the matter of industrial sectors, the other two assets allow endogenizing more appropriately innovation in services sectors.

3. Besides the transaction of production goods (capital and intermediate), interdependencies between sectors and countries are caught up by knowledge spillovers that modify the productivity of innovation assets.

4. The pricing of enterprises is defined by a monopolistic competition and the margin rates are assumed constant but differ between sectors.

0.1.1 The nested CES framework

The figure 0.1.1 draws the nested structure of the production functions. In each sector, the production (in yellow) results from the combination of four variable inputs (in green) and two quasi-fixed input (in red). The variable inputs are Materials (M), Energy (E) , Low Qualified Labour (L_L) (ISCED 1 to 4) and High Qualified Labour (L_H) (ISCED 5 and 6). The quasi-fix inputs are the physical capital stock (K) and the innovation services (A). The other inputs (in white) are the compound inputs - or "intermediate outputs" - corresponding to the different levels of the nested CES function.

In this current version of the production nesting, innovation services intervene at the first level, meaning that they influence proportionally the use of the ordinary production factors, represented by the variable $X = KLEM$ that groups together the physical capital stock, the two categories of labour, the energy and the materials. The impact of innovation on the production function for (X) is consequently Hick's neutral as it does not affect the balance between production factors. The innovation function producing A will be detailed in section 0.1.2.

Regarding the next levels combining the inputs for producing X, at the second stage materials are combined with the intermediate output KLE, that is produced from all other inputs than materials.

This choice was made for the reason that materials, that include raw materials, intermediate components and different business services, are generally few substitutable to other inputs, especially in sectors producing goods intensive in raw materials and intermediate components.

At the third level, low qualified labour (L_L) is associated to the compound input KL_HE. This choice of inputs grouping reflects the strong structural trends towards, on the one hand, the substitution of high qualified labour to low qualified labour in many production activities, and the capital deepening impact on labour productivity. Then the fourth level where high qualified labour (L_H) is separated from the compound input KE for capital and energy, is used to represent the substitution possibilities between this second labour input and capital. Capital and energy are finally combined at the last level of the production nesting. The energy input considered is final energy that is used to bring power to the production process, and it does not include intermediate uses of energy, that are considered proportional to the level of final output (Y), and that concern basically only the sectors Non Ferrous Metal Products, Basic Chemicals and Construction.

These assumptions on the nesting of the different inputs have actually important consequences on the substitution possibilities of the different inputs, as two inputs in a common bundle are by definition gross substitutes. Nevertheless, they may prove to be net complementarity inputs, in the global process of producing the final output (Y), depending of the parameters values, as it occurs for example for capital and energy in some energy intensive sectors.

The five levels of the nested CES production function have the following mathematical specifications:

For the first level:

$$Y = C \cdot \left[\delta_A^{1+\rho_Y}.A^{-\rho_Y} + \delta_X^{1+\rho_Y}.X^{-\rho_Y}\right]^{-\frac{1}{\rho_Y}} \tag{0.1.1}$$

with : C, a scale parameter, δ_A the share parameter for A representing theoretically the cost of innovation services in the total cost of producing Y, δ_X, similarly, the share parameter for X with by definition $\delta_X = 1 - \delta_A$, and ρ_y, the parameter defining the partial substitution elasticity between innovation services and X as $\sigma_Y = \frac{1}{1+\rho_Y}$.

For the other levels of the nesting, the same apply for the definition of factor shares, and we have respectively the following expressions for the CES functions, from top to bottom:

$$X = \left[\delta_M^{1+\rho_X}.M^{-\rho_X} + \delta_{KLE}^{1+\rho_X}.KLE^{-\rho_X}\right]^{-\frac{1}{\rho_X}} \tag{0.1.2}$$

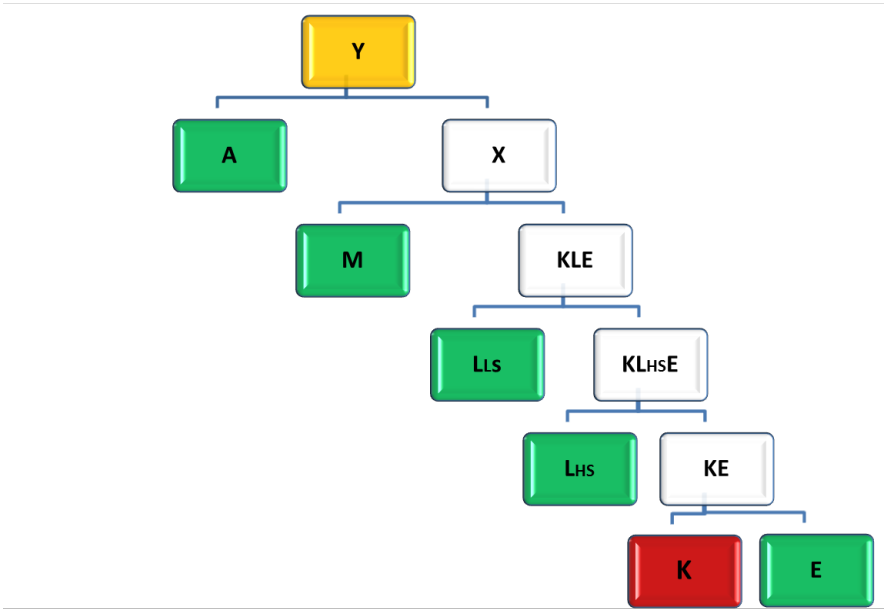
with $\sigma_X = \frac{1}{1+\rho_X}$, the partial substitution elasticity between M and the compound input KLE,

$$\begin{aligned} KLE \quad = \quad & \left[\delta_{L_L}^{1+\rho_{KLE}}.{L_L}^{-\rho_{KLE}}\right. \\ + \quad & \left.\delta_{KL_HE}^{1+\rho_{KLE}}.KL_HE^{-\rho_{KLE}}\right]^{-\frac{1}{\rho_{KLE}}} \end{aligned} \tag{0.1.3}$$

with $\sigma_{KLE} = \frac{1}{1+\rho_{KLE}}$, the partial substitution elasticity between L_L and the compound input KL_HE,

with $\sigma_{KL_HE} = \frac{1}{1+\rho_{KL_HE}}$, the partial substitution elasticity between L_H and the compound inputs KE and,

Figure 0.1.1: The nested CES production functions



$$KE = \left[\delta_K^{1+\rho_{KE}} . K^{-\rho_{KE}} + \delta_E^{1+\rho_{KE}} . E^{-\rho_{KE}}\right]^{-\frac{1}{\rho_{KE}}} \tag{0.1.4}$$

with $\sigma_{KE} = \frac{1}{1+\rho_{KE}}$, the partial substitution elasticity between K and E.

0.1.2 The innovation mechanisms

The innovation mechanisms of NEMESIS have been significantly improved in the context of the EC FP7 research programmes DEMETER and SIMPATIC and in the H2020 project I3U (Le Mouël, et al., 2016 [46]). In the new version of the model[8], the innovations in the different sectors and countries, do not result any more 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 model distinguishes furthermore, as in the previous various (Brécard et al., 2006 [7]), product and process innovations.

The theoretical concepts were inspired by the semi-endogenous and fully endogenous growth theories (Ha & Howitt, 2007 [35]) that emerged in the second half of the 90s, that were bridged with the concept of ICT as GPT proposed first by Bresnahan and Trajtenberg (1995 [8]). In this new framework, besides investments in R&D, externalities arise 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.

In a practical way, the modifications introduced in the model bear on two main points: (1) the

[8]This new version was first used in 2017 to support the ex-post assessment of FP7 and the interim evaluation of H2020 European Framework Programme (European Commission, 2017 [12]).

modification of innovation functions of the sectors that are now three dimensional, and (2) the modelling of knowledge externalities relative to the different innovation assets.

The calibration was based of the existing empirical studies (see Le Mouël *et al.*, 2016 [46]), notably on the impacts of R&D, ICT and Other Intangible (OI hereafter) investments, on productivity and employment, at macro, sectoral and micro levels.

This new version of the model allows to better represent innovation in service sectors and the diversity of the innovation strategies that are adopted by the different countries and production sectors. It enriches also considerably the range of R&I policies that can be assessed with the model.

0.1.2.1 Three dimensional innovation functions

The innovations of a sector (i), in a country (c), A_{cit}, is a CES combination (with constant returns to scale) of three sub-innovations, denoted as the innovation components. One is linked to investments in R&D, (AR_{cit}), another relies on the investments in ICT, (AT_{cit}), and the last one is related to the investments in OI, (AI_{cit}). Then,

$$\begin{aligned} A_{cit} = \quad & SC_{Aci} \cdot \Big[\delta_{ARci}^{1+\rho_{Aci}}.{AR_{cit}}^{-\rho_{Aci}} \\ & +\delta_{ATci}^{1+\rho_{Aci}}.{AT_{cit}}^{-\rho_{Aci}} + \delta_{AIci}^{1+\rho_{Aci}}.{AI_{cit}}^{-\rho_{Aci}}\Big]^{-\frac{1}{\rho_{Aci}}} \end{aligned} \tag{0.1.5}$$

with SC_{Aci} a scale parameter, δ_{ARci}, δ_{ATci} and δ_{AIci} the distribution parameters and $\sigma_{Aci} = \frac{1}{1+\rho_{Aci}}$, the substitution elasticity between AR_{cit}, AT_{cit} and AI_{cit}.

The three innovation components are defined as follows:

$$Aj_{cit} \quad = \quad SC_{Ajci} \cdot {KNOWj_{cit}}^{\lambda_{jci} \cdot \frac{j_{cit}}{VA_{cit}}}, \tag{0.1.6}$$

with $j = R, T, I$, and SC_{Ajci} scale parameters.

They are positive functions of a specific knowledge stock, $KNOWj_{cit}$, and of a specific knowledge absorption capability, $\lambda_j \cdot \frac{j_{cit}}{Y_{cit}}$. This knowledge absorption capability is, with $\lambda_j > 0$, a linear positive function of the intensities of the investments (relative to production) in R&D, ICT or OI.

0.1.2.2 Knowledge variables

Regarding knowledge variables, $KNOWj_{cit}$, they are modelled as weighted sums of the stocks of assets[9] (R&D, ICT or OI) belonging to all sectors and countries, by using the methodologies developed in the DEMETER and SIMPATIC projects, and that present the advantage to measure these externalities at the same time in the inter sectoral and in the international dimensions.

For R&D, the knowledge variable of the sector i in country c, $KNOWR_{cit}$, is defined by the sum of R&D capital stocks $SR_{p,s,t-\Delta}$ from all countries/sectors (p, s), weighted by a coefficient of diffusion $\Psi_{p,s \to c,i}$ reflecting the relative propensity of the knowledge from a sector s in country p to be useful

[9]The depreciation rates used are identical to Corrado *et al.* (2012 [14]): 15 % for R&D, 0.315 for ICT, 0.315 for Softwares and 0.4 for Training.

to innovate in sector i in country c. We consider also that the R&D investments start producing knowledge after a delay Δ that we fix equal to two years.

$$KNOWR_{c,i,t} = \sum_{p,s} \Psi_{p,s \to c,i} \times SR_{p,s,t-\Delta} \tag{0.1.7}$$

We apply the same methodology to the ICT capital and to OI capital where the coefficient of diffusion is $\Theta_{p,s \to c,i}$ with,

for ICT capital:

$$KNOWT_{c,i,t} = \sum_{p,s} \Theta_{p,s \to c,i} \times ST_{p,s,t-\Delta} \tag{0.1.8}$$

and, for OI capital:

$$KNOWI_{c,i,t} = \sum_{p,s} \Theta_{p,s \to c,i} \times SI_{p,s,t-\Delta} \tag{0.1.9}$$

Public investments in R&D ($PIRD$) are taken into account and allocated towards the different sectors according to a grand fathering distribution[10] and are considered productive after a longer lag than private R&D (2 years later) so that $SR_{p,s,t} = (1 - \delta_{RD})\, SR_{p,s,t-1} + IRD_{p,s,t} + \propto_{p,s} PIRD_{p,t-2}$.

The diffusion parameters are calibrated using matrices based on patent citations between sectors and countries[11]. These matrices combine the citations between patents allocated by technology class and country with the OECD concordance table (Johnson, 2002 [40]) 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 choices of the method to build these matrices were the following:

1. The sectors manufacturing a technology are sectors that spent R&D investments for this technology and they receive knowledge externalities coming from inventions by sectors that manufacture other technologies. From this perspective, patents allocated to their Industry Of Manufacturing (IOM) reflect the output of the R&D efforts realized by these sectors and the citations between patents belonging to IOM may be considered as indicators of the knowledge externalities between sectors as IOM.

2. The externalities related to the use of ICT and to OI may reflect network externalities or, assuming that ICT and OI are important inputs of organizational changes, these externalities may also reflect the diffusion of organizational innovations (the development of a new online distribution channel for instance). As these types of invention are not patentable, it is not possible to use the same matrix than for R&D externalities. Nevertheless these inventions are assumed here to be strongly related to the use of technical innovations. So, it can be assumed that sectors using the same type of technologies should have similar production methods and therefore similar

[10] i.e. they are proportional to the share of each sector in the overall business R&D expenditure.

[11] These matrices were developed by Meijers and Verspagen (2010 [**?**]) in the framework of the DEMETER project, see also Belderbos and Mohnen (2013 [3])

organizational strategies and their intangible investments, as well as their ICT investments, may be highly related. The matrices defined by patent citations allocated by SOU are thus retained. According to this approach, the more two SOU cite each other, the more they are using the same technology and, therefore, the more one sector can benefit from the innovations of the other in that field.

For the calculus of the spread parameters, several methodological issues have to be considered:

Regarding first externalities in R&D, the degree to which the knowledge produced in sector s in country p, is potentially useful for the sector i in the country c, is measured with the help of the patent citations between IOM. This means that the more patents belonging to (c,i) have a propensity to cite patents belonging to (p,s), the more an innovation in (p,s) is potentially useful for (c,i) and, therefore, the more R&D engaged in (p,s) may generate knowledge externalities to (c,i).

Notwithstanding, the raw number of citations between (c,i) and (p,s) must be controlled by the size in terms of patents of these two sectors. Indeed, the more patents are filed by (p,s), the more patents from (p,s) will be cited by patents from (c,i) and, conversely, the more patents are filed in (c,i), the more patents from (c,i) will cite patents from (p,s) for a given propensity to cite. Therefore raw citations do not only reflect the propensity of an innovation in (p,s) to affect the innovation capacity of (c,i), but also integrates the innovation activity of these two sectors which will already be taken into account by R&D investments. Thus, in order to avoid double counting, the raw number of citations is controlled by the number of patents belonging to these two sectors. In addition, this coefficient is normalised such that the sum $\sum_{p,s}\Psi_{p,s\to c,i}=1$. The spread[12] parameter from (p,s) to (c,i) is then defined as:

$$\begin{aligned}\Psi_{p,s\to c,i} &= \frac{C^{IOM-IOM}_{c,i\to p,s}}{N^{IOM}_{c,i}\times N^{IOM}_{p,s}} \Big/ \left(\sum_{u,v}\frac{C^{IOM-IOM}_{c,i\to u,v}}{N^{IOM}_{c,i}\times N^{IOM}_{u,v}}\right) \\ &= \frac{C^{IOM-IOM}_{c,i\to p,s}}{N^{IOM}_{p,s}} \Big/ \left(\sum_{u,v}\frac{C^{IOM-IOM}_{c,i\to u,v}}{N^{IOM}_{u,v}}\right)\end{aligned} \tag{0.1.10}$$

This final coefficient represents the propensity of an innovation from (p,s) to be used to invent in sector (c,i). By this way, knowledge is supposed to be non exclusive and non-rival[13].

For externalities in ICT and OI, the spread parameters are built with matrices where patents are allocated across sectors according to there Sector Of Use (SOU):

$$\begin{aligned}\Theta_{p,s\to c,i} &= \frac{C^{SOU-SOU}_{c,i\to p,s}}{N^{SOU}_{c,i}\times N^{SOU}_{p,s}} \Big/ \left(\sum_{u,v}\frac{C^{SOU-SOU}_{c,i\to u,v}}{N^{SOU}_{c,i}\times N^{SOU}_{u,v}}\right) \\ &= \frac{C^{SOU-SOU}_{c,i\to p,s}}{N^{SOU}_{p,s}} \Big/ \left(\sum_{u,v}\frac{C^{SOU-SOU}_{c,i\to u,v}}{N^{SOU}_{u,v}}\right)\end{aligned} \tag{0.1.11}$$

Note that if the spread parameters are identical for ICT and OI, the resulting knowledge matrices

[12] 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.

[13] It is not the case if the studies that measure these coefficients simply as $\Psi_{p,s\to c,i} = {}^{C_{c,i\to p,s}}/_{C_{p,s}}$, where $C_{p,s}$is the total number of citations received by (p,s).

are different since these parameters weight the respective stocks of ICT and OI.

0.1.2.3 Process and product innovations

In NEMESIS, the innovations are by assumption produced "in-house" and they cannot be sold and exchange on a market. There are not an asset that can be capitalised, but a flow of services that is produced according to the equation 0.1.5 above.

Innovations are also supposed to begin producing their effects after a delay of one year. Then, two effects of innovations are distinguished in NEMESIS:

- From equation 0.1.1, the first level of the nested CES production function, they act as "process innovations", that decrease ex-ante the use of X_{cit}, the compound input for ordinary production factors, per unit of output, Y_{cit}, with an elasticity α_{ci};
- Innovations increase also, *ex-ante*, the quality of products, with an elasticity $\alpha_{ci}^{'}$, but without decreasing the use of X_{cit} per unit of output, Y_{cit}.

At each date t, the representative firm of the sector i in country c, chooses the amount of innovations services that maximises its expected inter-temporal profit flows, Π_{cit}, by solving the following program:

$$\begin{aligned} \underset{\{A_{cit}\}}{MAX}\ \Pi_{cit} &= E_t \sum_{s=t}^{\infty} \left\{ \left(\frac{1}{1+a_c} \right)^{s-t} \cdot \left[(P_{y_{cis}} \cdot Y_{cis} \right. \right. \\ &- \left. \left. TC_{Xcis}^{ST}(.) - P_{Acis} \cdot A_{cis} \right) \right] \cdot (1 - \tau_{\pi_c}) \right\} \end{aligned}$$

where E_t is the expectation function, a_c the actualisation rate, $P_{y_{cis}}$, the price of output, $P_{A_{cis}}$ the price of innovation services, $\tau_{\pi_c}$the corporate taxation rate and where $TC_{Xcis}^{ST}(.)$ is the short term total cost of using the bundle of ordinary production factors X_{cis} - that-is-to-say, for A fixed to its current level, and not already optimised.

As firms' customers have a taste for quality, their demand is increasing whenever the quality adjusted price of products, $\frac{P_{y_{cis}}}{Q_{cis}}$, is decreasing, with $Q_{cis} = A_{cis-1}^{\alpha_{ci}^{'}}$ ($\alpha_{ci}^{'} > 0$), the quality index of output, and $\varepsilon_{pci} = \frac{dln(P_{ycis} \cdot Y_{cis})}{dln(Q_{cis})} > 0$, the elasticity of sales with respect to quality. This matches for example with the following demand function[14]:

$$Y_{cis} = Y_0 \cdot \left[\frac{\left(\frac{P_{Ycis}}{Q_{Ycis}} \right)}{\left(\frac{\overline{P}_{Ycis}}{\overline{Q}_{Ycis}} \right)} \right]^{-\varepsilon_{pci}} \cdot D_{cis}^{\varepsilon_d} \tag{0.1.12}$$

where $\overline{P}_{Y_{cis}}$represents the average price of competitors, $\overline{Q}_{cis}$ is a measure of the average quality of the products of competitors, $-\epsilon_{pci} < 0$, is the elasticity of demand to the relative prices adjusted from quality, D_{cis}, is the aggregated demand addressed to national producers, domestic and external, and

[14]The actual sectoral demand functions of NEMESIS are additive functions summing the different uses of a product, where imports are subtracted to obtain the demand addessed to domestic firms. We have therefore for a good i, $Y_{cit} = ADDINTCONSQ_{cit} + ADDCONSQ_{cit} + ADDINVQ_{cit} + ADDGOVQ_{cit} + DSTOCK_{cit} + EXPTOTQ_{cit} - IMPTOTQ_{cit}$, where the total demand addressed to the sector (Y_{cit}) is equal to the use of sector i output for respectively, intermediate consumption, households final consumption, investment, public consumption, stocks variation and exports less imports. The output of the sector adjusts exatly to the level of the demand in the model.

Y_0 is a scale parameter. Furthermore, if ϵ_d, that represents the elasticity of firm's output to aggregate demand, equals 1, the market share of the sector stays constant, as long as its relative competitiveness, measured by the ratio $\frac{\left(\frac{P_{Ycis}}{Q_{Ycis}}\right)}{\left(\frac{\overline{P}_{Ycis}}{\overline{Q}_{Ycis}}\right)}$, stays also constant.

The particularity of this profit maximisation problem is that we have a decision variable, the innovation services, A_{cis}, that plays two roles: It reduces the use of ordinary production factors and then their user cost, $\frac{\partial TC^{sT}_{Xcis}(.)}{\partial A_{cis}} < 0$, and it allows the firm increasing its turnover (as $\frac{\partial P_{Y_{cis}}.Y_{cis}}{\partial A_{cis}} > 0$), through the test for quality of customers.

Expressing now the first order optimality conditions, for $s = t$, we have:

$$\frac{\partial \Pi_T}{\partial A_{cit}} = E_t\left[\frac{\partial\left(P_{Y_{cit+1}}.Y_{cit+1}\right)}{\partial A_{cit}} - \frac{\partial TC^{ST}_{Xcit+1}(.)}{\partial A_{cit}}\right] - w_{Acit} = 0 \tag{0.1.13}$$

where the user cost of innovations, w_{cit}, is equal to:

$$w_{Acit} = P_{Acit} \cdot (1 + a_c)\,. \tag{0.1.14}$$

As innovations have two distinct effects, equation 0.1.13 cannot be solved analytically in A_{cit}.

The solution that is used in NEMESIS is to redefine the user cost of innovations as:

$$\widetilde{w}_{A_{cit}} = w_{A_{cit}} - E_t\left(\frac{\partial\left(P_{Y_{cit+1}}.Y_{cit+1}\right)}{\partial A_{cit}}\right), \tag{0.1.15}$$

where $E_t\left(\frac{\partial\left(P_{Y_{cit+1}}.Y_{cit+1}\right)}{\partial A_{cit}}\right) = E_t\left(\varepsilon_{pci} \cdot \alpha'_{ci} \cdot \frac{Y_{cit+1}}{A_{cit}} \cdot P_{Y_{cit+1}}\right)$ is the *ex-ante* marginal impact of investing in innovation on expected sales.

We then proxy $\widetilde{w}_{A_{cit}}$ by $(1 - sp_{ci}) \cdot w_{A_{cit}}$, with $sp_{ci} = \frac{E_t\left(\frac{\partial(P_{Ycit+1} \cdot Y_{cit+1})}{\partial A_{cit}}\right)}{E_t\left(\frac{\partial(P_{Ycit+1} \cdot Y_{cit+1})}{\partial A_{cit}}\right) - E_t\left(\frac{\partial(TC^{ST}_{Xcit+1})}{\partial A_{cit}}\right)}$ defined as the "share" of product innovations in the total marginal revenues expected *ex-ante* by the firms from their innovations, that is fixed to 33% in the model (for every sectors and countries).

With this "modified" expression for the user cost of innovations, we can now easily solve equation 0.1.13 in A_{cit}, by assuming that at a previous step, the firm already optimised the use of the X_{cit}, the compound input of ordinary production factors, for the current level of output, Y_{cit}, and the current available flow of innovation services, A_{cit-1}, such as from equation 0.1.1:

$$X^{ST*}_{cit} = \left[\frac{Y^{-\rho_Y}_{cit} - C^{-\rho_Y} \cdot \delta_A^{1+\rho_Y} \cdot {A_{cit-1}}^{-\rho_Y}}{\delta_X^{1+\rho_Y}}\right]^{-\frac{1}{\rho_Y}} \tag{0.1.16}$$

where X^{ST*}_{cit} is the short term optimal value of X_{cit}.

The unit cost of using X^{ST*}_{cit} expresses itself, by using the dual of equation 0.1.2, as:

$$w_{Xcit} = \left[\delta_M . w^{1-\sigma_X}_{Mcit} + \delta_{KLE} . w^{1-\sigma_X}_{KLEcit}\right]^{\frac{1}{1-\sigma_X}} \tag{0.1.17}$$

with w_{Xcit}, the unit cost of using X, and where w_{Mcit} and w_{KLEcit} are respectively the user costs of the intermediate inputs and of the compound input KLE.

We get similarly, by using recursively the dual of the nested CES production functions, for the unit cost of KLE:

$$w^{tc}_{KLE_t} = \left[\delta_{L_L}.w^{1-\sigma_{KLE}}_{L_{Lt}} + \delta_{KL_HE}.w^{tc^{1-\sigma_{KLE}}}_{KL_HE_t}\right]^{\frac{1}{1-\sigma_{KLE}}} \tag{0.1.18}$$

for the total unit cost of KL_HE:

$$w_{KL_He_t} = \left[\delta_{L_H}.w^{1-\sigma_{KL_HE}}_{L_{Ht}} + \delta_{KE}.w^{tc^{1-\sigma_{KL_HE}}}_{KE_t}\right]^{\frac{1}{1-\sigma_{KL_HE}}} \tag{0.1.19}$$

and for w_{KE} , the total unit cost of KE:

$$w_{KE_t} = \left[\delta_K.w^{1-\sigma_{KE}}_{K_t} + \delta_E.w^{1-\sigma_{KE}}_{E_t}\right]^{\frac{1}{1-\sigma_{KE}}} \tag{0.1.20}$$

with w_{L_Lcit}, w_{L_Hcit}, w_{Kcit} and w_{Ecit} respectively the user costs of low skilled labour, high skilled labour, physical capital and energy.

Having define all these variable, we can now express the short term total cost of using X as:

$$TC^{ST}_{Xcit}(.) = w_{Xcit} \cdot X^{ST*}_{cit}, \tag{0.1.21}$$

with w_{Xcit} defined by equation 0.1.17 and X^{ST*}_{cit} by equation 0.1.16.

Then by using equation 0.1.13, we get finally the optimal demand for A:

$$A^*_t = E_t\left\{C^{\sigma_Y-1} \cdot \frac{\delta_A}{\delta_X} \cdot \left(\frac{\widetilde{w}_{Acit}}{w_{Xcit+1}}\right)^{-\sigma_Y} \cdot X^{ST*}_{cit+1}\right\}. \tag{0.1.22}$$

By using now equation 0.1.2, $E_t\left(X^{ST*}_{cit+1}\right)$ can be re-expressed, classically, as:

$$E_t\left(X^{ST*}_{cit+1}\right) = E_t\left(C^{-\frac{\rho_Y}{1+\rho_Y}} \cdot \delta_X \cdot \left(\frac{w_{Xcit+1}}{P_{Ycit+1}}\right)^{-\sigma_Y} \cdot Y_{cit+1}\right) \tag{0.1.23}$$

and we obtain finally for A, from equations 0.1.22 and 0.1.23:

$$A^*_{cit} = E_t\left\{C^{-\frac{\rho_Y}{1+\rho_Y}} \cdot \delta_A \cdot \left(\frac{\widetilde{w}_{Acit}}{P_{Ycit+1}}\right)^{-\sigma_Y} \cdot Y_{cit+1}\right\}. \tag{0.1.24}$$

The optimal demand for innovation is therefore simply a positive function of expected demand (or output) and a negative function of the ratio between the innovation services "modified" user cost and the production price, with an elasticity $-\sigma_Y$.

The demands for innovation components are then determined as the set of the three inputs that minimises the user cost of the innovations. Using the dual of equation 0.1.5, we get:

$$Aj^*_{cit} = SC^{\sigma_{Aci}-1}_{Aci} \cdot \delta_{AJci}.\left(\frac{P_{Aj_{cit}}}{P_{A_{cit}}}\right)^{-\sigma_{Aci}}.A^*_{cit}, \tag{0.1.25}$$

with $j = R,T,I$, $P_{A_{cit}} = \left[\delta_{ARci}.P^{1-\sigma_{Aci}}_{ARcit} + \delta_{ATci}.P^{1-\sigma_{Aci}}_{ATcit} + +\delta_{AIci}.P^{1-\sigma_{Aci}}_{AIcit}\right]^{\frac{1}{\sigma_{Aci}-1}}$, and where $P_{Aj_{cit}}$, the unit cost of the innovation components, will be defined later.

These demands are positive functions of the desired level of innovation services and negative functions of the ratio between the user cost of the respective innovation components and the one of innovation services, with an elasticity $-\sigma_{Aci}$.

With the optimal demands for the innovation components, the optimal investments in R&D, ICT and OI, j^*_{cit}, can be obtained by inverting equation 0.1.6, for $j = R, T, I$, and by using the following semi-log form:

$$j^*_{cit} = \left[\frac{ln(Aj^*_{cit}) - ln(SC_{Ajci})}{ln(KNOWj_{cit})}\right] \cdot \frac{Y_{cit}}{\lambda_{jci}} \tag{0.1.26}$$

which gives, by replacing Aj^*_{cit} by its expression (equation 0.1.25):

$$j^*_{cit} = \left[\frac{ln(C_{ci}) - \sigma_{Aci} \cdot ln\left(\frac{P_{Aj_{cit}}}{P_{A_{cit}}}\right) + ln(A^*_{cit})}{ln(KNOWj_{cit})}\right] \cdot \frac{Y_{cit}}{\lambda_{jci}}, \tag{0.1.27}$$

with C_{ci} a positive constant.

We see from equation 0.1.27 that the desired intensity of the different innovation inputs, $\frac{j^*_{cit}}{Y_{cit}}$, will increase whenever the desired level of innovation services increases, and decrease whenever the growth rate of knowledge externalities increases. The reason of this later property is that knowledge increasing the productivity of the innovation inputs, if knowledge grows, less innovation inputs are needed for producing a given level of innovation services. The desired intensity for the different innovation inputs will be also influenced negatively by their relative user costs. We must underline that this equation, in reason of its semi-log form, is very difficult to calibrate and different normalisations are used in order to control the force of the different effects just described.

Lastly, the user cost of innovation components are obtained by using the optimality conditions for innovation activities that imply, for $j = R, T, I$:

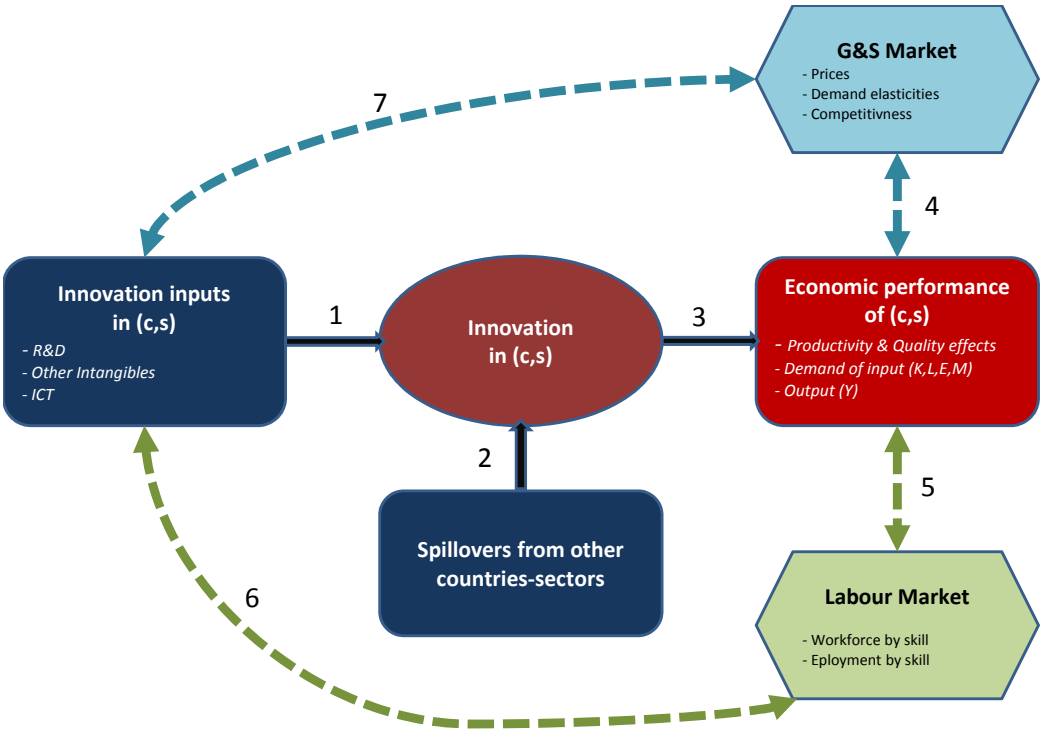
$$\frac{\partial\left(P_{Aj_{cit}} \cdot J_{cit}\right)}{\partial j_{cit}} = P_{j_{cit}}, \tag{0.1.28}$$

from which it results:

$$P_{Aj_{cit}} = P_{j_{cit}} \cdot \frac{Y_{cit}}{\lambda_{ci}} \cdot \frac{1}{Aj^*_{cit}} \tag{0.1.29}$$

The way this new framework to represent innovation in NEMESIS acts in the whole economic system is finally summed-up by the figure 0.1.2. The innovations of each sector in each country result from the investments in the three innovation components, as explained above, and, in addition to the own investments of the country-sector (c,s), investments in innovation inputs by other countries-sectors generate spillovers and increase the ability of the considered (c,s) to innovate. The combination of these two elements - the own expenditures in innovation inputs and the spillovers - generates innovations (arrows 1 and 2) which lead to an increase of the economic performance (3) of the sector in terms of productivity and to an increase of the demand through a quality effect (4). The interaction between the innovation performance of the sector and the good and services market (5) determines the output of the sector. And the interaction between the labour market and both activities of production and of innovation (6 and 7) leads to the determination of employment. Finally, innovations by the producers of

Figure 0.1.2: Innovation and economic feedbacks



the enabling technology (ICT producers in our case), lead to a decrease in the price of this technology, which, in return, diminishes the cost of innovation inputs and thus the cost of innovation for the users of the enabling technology.

0.1.3 Endogenous growth properties

This sub-section analyzes more closely the endogenous growth properties resulting from the new innovation mechanisms that were introduced in the model. For that, lets start by expressing the long term growth rate of sectoral output in NEMESIS. Differentiating first the equation for sectoral output (equation 0.1.1) in natural logarithms with respect to time, we obtain:

$$\frac{dln\left(Y_{cit}\right)}{dt} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \frac{dln\left(A_{cit}\right)}{dt} + \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{dln\left(X_{cit}\right)}{dt} \tag{0.1.30}$$

with:

$$\varepsilon_{A_{cit}}^{Y_{cit}} = \frac{\partial ln\left(Y_{cit}\right)}{\partial ln\left(A_{cit}\right)} = SCY_{ci}^{-\rho Y_{ci}} \cdot \delta A_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{Y_{cit}}{A_{cit}}\right)^{\rho Y_{ci}} \tag{0.1.31}$$

the elasticity of sectoral output with respect to innovations services (A), and:

$$\varepsilon_X^{Y_{cit}} = \frac{\partial ln\left(Y_{cit}\right)}{\partial ln\left(X_{cit}\right)} = SCY_{ci}^{-\rho Y_{ci}} \cdot \delta X_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{Y_{cit}}{X_{cit}}\right)^{\rho Y_{ci}} \tag{0.1.32}$$

the elasticity of sectoral output with respect to the bundle of traditional production inputs (X).

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

1. An endogenous one, driven by the growth of innovation services:

$$\frac{dln\left(Y_{cit}^A\right)}{dt} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \frac{dln\left(A_{cit}\right)}{dt} \tag{0.1.33}$$

2. and an exgenous one, driven by the growth of traditional production factors:

$$\frac{dln\left(Y_{cit}^E\right)}{dt} = \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{dln\left(X_{cit}\right)}{dt} \tag{0.1.34}$$

such as we have in definitive:

$$\frac{dln\left(Y_{cit}\right)}{dt} = \frac{dln\left(Y_{cit}^A\right)}{dt} + \frac{dln\left(Y_{cit}^E\right)}{dt} \tag{0.1.35}$$

We see from equation (0.1.35) that the endogenous growth rate of sectoral output can be assimilated to a "pure" TFP effect, as do generally the empirical studies. We have therefore:

$$\frac{dln\left(Y_{cit}^A\right)}{dt} = \frac{dln\left(TFP_{cit}\right)}{dt} = \frac{dln\left(Y_{cit}\right)}{dt} - \frac{dln\left(Y_{cit}^E\right)}{dt} \tag{0.1.36}$$

or equivalently:

$$\frac{dln\left(TFP_{cit}\right)}{dt} = \frac{dln\left(Y_{cit}\right)}{dt} - \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{dln\left(X_{cit}\right)}{dt} \tag{0.1.37}$$

Under this first interpretation, the problem of empirical studies becomes to measure to what extent the growth of TFP, that-is-to-say the slack between the growth of output and the growth of traditional production factors, can be explained by investments in innovation inputs, such as R&D and the related knowledge externalities.

In reality, the TFP indexes that can be computed from economic data, summarize many different effects, and the joint influence of many mechanisms, as we will detail now.

We can, from our modeling approach, define first the "TFP effect" as *minus* the elasticity of the demand of production inputs with respect to innovations services, that expresses from equation 0.1.1 by keeping Y_{cit} constant:

$$\alpha_{cit} = -\frac{\partial ln\left(X_{cit}\right)}{\partial ln\left(A_{cit}\right)} = \frac{\varepsilon_A^{Y_{cit}}}{\varepsilon_X^{Y_{cit}}} \tag{0.1.38}$$

We see that this "TFP effect" is different from the definition given by equation 0.1.37 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.

The second effect of innovations services in NEMESIS is linked to the increase of the demand addressed to the firms provoked by the gradual improvement of the characteristics of their products (from equation E23 in table 0.1.2). This "Quality effect" is defined as:

$$\frac{dln\left(Q_{cit}\right)}{dt} = \alpha_{cit}^{'} \cdot \frac{dln\left(A_{cit}\right)}{dt} \tag{0.1.39}$$

In each sector, the *quality* of output is supposed to evolve in time proportionally (with a coefficient m_{ci}) to the "TFP effect" such as we have:

$$\alpha_{cit}^{'} = \ m_{ci} \cdot \alpha_{cit} \tag{0.1.40}$$

In NEMESIS these two distinct innovations (or *innovations effects*) act on the sectoral output of firms through the price elasticity of demand, $\varepsilon_{cit}^{D} < 0$:

1. Process innovations will reduce the unit cost of the firms with an elasticity α_{cit} and, as firm will by assumption reduce proportionally their price, increase demand with the elasticity: $-\varepsilon_{cit}^{D} \cdot \alpha_{cit}$.
2. Product innovations will increase demand with the elasticity: $-\varepsilon_{cit}^{D} \cdot \alpha_{cit}^{'}$

As at equilibrium the level of output equates the level of demand, the growth rate of output provoked by the growth of innovations, that-is-to-say, the "endogenous" growth rate of output, $\frac{dln\left(Y_{cit}^{A}\right)}{dt}$, will then be equal to:

$$\frac{dln\left(Y_{cit}^{A}\right)}{dt} = \left(-\varepsilon_{cit}^{D} \cdot \alpha_{cit} - \varepsilon_{cit}^{D} \cdot \alpha_{cit}^{'}\right) \cdot \frac{dln\left(A_{cit}\right)}{dt} = -\varepsilon_{cit}^{D} \cdot \left(1 + m_{cit}\right) \cdot \alpha_{cit} \cdot \frac{dln\left(A_{cit}\right)}{dt} \tag{0.1.41}$$

This "endogenous" growth rate of sectoral output does not measure simply a pure TFP effect, as in equation 0.1.38, and it is the on the contrary the resultant of three combined effects:

1. A TFP effect through the elasticity α_{cit} ;
2. A quality effect through the elasticity $\alpha_{cit}^{'} = \ m_{ci} \cdot \alpha_{cit}$;
3. And a demand effect through the elasticity ε_{cit}^{D}.

It can also 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 0.1.5 that gives the mathematical expression of innovation services, with respect to time:

$$\frac{dln\left(A_{cit}\right)}{dt} = \sum_{j} \varepsilon_{Aj_{cit}}^{A} \cdot \frac{dln\left(Aj_{cit}\right)}{dt}, \ j = RD, \ ICT, \ OI \tag{0.1.42}$$

with:

$$\varepsilon_{Aj_{cit}}^{A} = SCA_{ci}^{-\rho A_{ci}} \cdot \delta Aj_{ci}^{1+\rho A_{ci}} \cdot \left(\frac{A_{cit}}{Aj_{cit}}\right)^{\rho A_{ci}} \tag{0.1.43}$$

By assuming that the investment rates of innovation assets (in % of production) at sectoral level are constant in the long term, the growth rates of innovation components can themselves be further decomposed from equation 0.1.6 as:

$$\frac{dln\left(Aj_{cit}\right)}{dt} = \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{dln\left(KNOWj_{cit}\right)}{dt} \tag{0.1.44}$$

We then get by substituting 0.1.44 in 0.1.42:

$$\frac{dln\left(A_{cit}\right)}{dt} = \sum_{j} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{dln\left(KNOWj_{cit}\right)}{dt},\ j = RD,\ ICT,\ OI \tag{0.1.45}$$

and by substituting 0.1.45 in 0.1.41:

$$\frac{dln\left(Y^{A}_{cit}\right)}{dt} = -\varepsilon^{D}_{cit} \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_{j} \varepsilon^{A}_{Aj_{cit}} \cdot \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{dln\left(KNOWj_{cit}\right)}{dt},\ j = RD,\ ICT,\ OI \tag{0.1.46}$$

A few general comments on the implications of the last equation 0.1.46 on the properties of the endogenous growth (of output) in NEMESIS can be useful at this stage:

- 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 modeling 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 of knowledge externalities that expend with the growth of population. This property of the semi-endogenous growth models was simply extended in NEMESIS to other sources of externalities than R&D. The consequence is that the endogenous growth rate in NEMESIS is strongly dependent on the assumptions made on the growth of knowledge externalities in the reference scenario of the model. We assume generally in the reference scenario, that goes up to 2050, that the investment rates of the innovation assets stay constant in the medium (say 2025) to long term (2050), and that knowledge growth follows the growth of world GDP.

- Secondly, the approach used is NEMESIS conforms to the *Shumpeterian* or *Fully endogenous II* approach initiated by Aghion and Howitt (1998 [1]), Dinopoulos and Thompson (1998 [19]) and Peretto (1998 [57]): the long term endogenous growth rate is an increasing function of the investment 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, decomposes in two effects:

  1. the rise of the ability of firms to exploit existing knowledge (*intensity effect*)
  2. and the creation of new knowledge that increases the intrinsic productivity of innovation inputs (*knowledge effect*) .

These two effects can play very different roles depending on the sector, the country or the innovation input considered.

0.1.4 Sum-up of the innovation mechanisms/equations introduced in NEMESIS

The set of equations implemented in NEMESIS to represent innovation at sectoral level is finally summed-up in the table 0.1.1. It comprises 23 equations[15] that decompose in four categories of equations or variables:

1. Behavioral equations or decisions variables, that result from the maximization of expected inter temporal profit by firms;
2. Update equations or 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 innovative 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 TFP effects of innovations 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).

As displayed in table 0.1.2 on the 23 equations there are only 7 behavioral equations[16] and variables that can be directly impacted by the implementation of policy measures in the model.

To complete the overview of these innovation mechanisms in NEMESIS, we displayed in table 0.1.1 the analytical expression of the equations introduced in the model. For simplicity, we give only the optimal expression for the decision variables[17], corresponding to the variables with a star. 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 to simplify the presentation, but are active in the model and make its dynamic.

0.1.5 The demand for ordinary production factors

The system of demands for the ordinary production factors can be achieved in least in two different ways, that are equivalent in the long term:

- The first is based on the distinction between (1) the short term profit maximisation problem of the firm: the choice of variable factors, when the level of quasi-fix factors, here physical capital,

[15] 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.

[16] 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^*).

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

Table 0.1.1: Sum-up of the equations intervening at the "core" of the innovation module of NEMESIS

Type of Equation/ Variable	Name/Description	Nb of Equations/ Variables of this Type	Comments
Behavioural Equations/ Decision Variables	RD^*, ICT^*, OI^*: Optimal demands for innovation inputs $ARD^*, AICT^*, AOI^*$: Optimal demand for innovation components A^*: Optimal demand for innovation services	7	Result from firms' optimal decisions for maximizing inter-temporal profit. There is no market for innovations that are produced "in-house" in NEMESIS
Update Equations/ State variables	$ARD, AICT, AOI$: Actual levels of innovation components A: Actual level of innovation services $SRD, SICT, SOI$: Actual stocks of innovation assets $KNOWRD, KNOWICT, KNOWOI$: Actual stocks of knowledge	10	Result from past decisions and represent the actual values used by the firms at time t
Prices	$PARD, PAICT, PAOI$: Price of innovation components PA: Price of innovation services	4	There analytical expression results from the resolution of the system of equations
Transmission equations	X: Demand of production inputs (TFP effect) Q: Product innovations (Quality effect)	2	It is the demand for the bundle of production inputs X makes the link between innovation and production decisions of the firms in NEMESIS from the TFP impacts of innovations. They are a fix proportion in NEMESIS (the quality effect is proportional to the TFP effect)

Table 0.1.2: Analytical expression of the equations at the core of the innovation module of NEMESIS

Variable description	Equation	Nb
Optimal demands for innovation inputs	$j^*_{cit} = \left[\frac{ln(C_{ci}) - \sigma A_{ci} \cdot ln\left(\frac{PAj_{cit}}{PA_{cit}}\right) + ln\left(A^*_{cit}\right)}{ln(KNOWj_{cit})}\right] \cdot \frac{Y_{cit}}{\lambda j_{ci}}$, 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	$A^*_{cit} = SCY_{ci}^{\sigma Y_{ci}-1} \cdot \delta A_{ci} \cdot \left(\frac{\tilde{\omega} A_{cit}}{PY_{cit}}\right)^{-\sigma Y_{ci}} \cdot Y_{cit}$, with $\tilde{\omega} A_{cit}$ the user cost of innovation services	(E7)
Actual levels of innovation components	$\mathrm{Aj_{cit}} = \mathrm{SCA_{jci}} \cdot \mathrm{KNOWj_{cit}}^{\lambda_{jci} \cdot \frac{\mathrm{j_{cit}}}{\mathrm{Y_{cit}}}}$	(E8-E10)
Actual level of innovation services	$\mathrm{A_{cit}} = SCA_{ci} \cdot \left(\delta ARD_{ci}^{1+\rho A_{ci}} \cdot ARD_{cit}^{-\rho A_{ci}} + \delta AICT_{ci}^{1+\rho A_{ci}} \cdot AICT_{cit}^{-\rho_{Aci}} + \delta OI_{ci}^{1+\rho A_{ci}} \cdot AOI_{cit}^{-\rho_{Aci}}\right)^{-\frac{1}{\rho A_{ci}}}$	(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: $KNOWICT_{cit} = \sum_{p,s} \Theta \mathrm{ICT}_{p,s\to c,i} \times SICT_{p,s,t-\Delta}$ For OI: $KNOWOI_{cit} = \sum_{p,s} \Theta \mathrm{OI}_{p,s\to c,i} \times SOI_{p,s,t-\Delta}$	(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)

cannot be adjusted and (2) and its long term problem: the choice of quasi-fix factors maximising the long term inter temporal actualised profit.

- The second is based on the use of the long term dual of the nested CES production functions, where by assumption all inputs, including physical capital, are variable and can be instantaneously adjusted. The demand of the different production factors are then obtained, starting from the top of the nesting, by successive profit maximisation (or alternatively, cost minimisation) problems.

While the first solution is the more elaborated and the more convenient for the analysis of the short to medium term, it is more difficult to implement in a model as NEMESIS, and it is not used and still under calibration for the moment. We therefore continue using the second approach, already retained with the previous version of the model.

From this approach, we get classically the following optimal demands for the different production inputs and intermediate outputs:

From the second level for X:

$$M^*_{cit} = C^{-\frac{\rho_X}{1+\rho_X}} \cdot \delta_M \cdot \left(\frac{w_{Mcit}}{w_{Xcit}}\right)^{-\sigma_X} \cdot X_{cit}, \tag{0.1.47}$$

and:

$$KLE^*_{cit} = C^{-\frac{\rho_X}{1+\rho_X}} \cdot \delta_{KLE} \cdot \left(\frac{w_{KLEcit}}{w_{Xcit}}\right)^{-\sigma_X} \cdot X_{cit}. \tag{0.1.48}$$

From the third level for KLE:

$$L^*_{Lcit} = C^{-\frac{\rho_{KLE}}{1+\rho_{KLE}}} \cdot \delta_{L_L} \cdot \left(\frac{w_{L_Lcit}}{w_{KLEcit}}\right)^{-\sigma_X} \cdot KLE^*_{cit}, \tag{0.1.49}$$

and:

$$KL_HE^*_{cit} = C^{-\frac{\rho_{KLE}}{1+\rho_{KLE}}} \cdot \delta_{KL_HE} \cdot \left(\frac{w_{L_Lcit}}{w_{KLEcit}}\right)^{-\sigma_X} \cdot KLE^*_{cit}. \tag{0.1.50}$$

From the fourth level for KL_LE:

$$L^*_{Hcit} = C^{-\frac{\rho_{KL_LE}}{1+\rho_{KL_LE}}} \cdot \delta_{L_H} \cdot \left(\frac{w_{L_Hcit}}{w_{KL_LEcit}}\right)^{-\sigma_X} \cdot KL_LE^*_{cit}, \tag{0.1.51}$$

and:

$$KE^*_{cit} = C^{-\frac{\rho_{KL_LE}}{1+\rho_{KL_LE}}} \cdot \delta_{KE} \cdot \left(\frac{w_{Kecit}}{w_{KL_LEcit}}\right)^{-\sigma_X} \cdot KL_LE^*_{cit}. \tag{0.1.52}$$

From the fifth level for KE:

$$K^*_{cit} = C^{-\frac{\rho_{KE}}{1+\rho_{KE}}} \cdot \delta_K \cdot \left(\frac{w_{Kcit}}{w_{KEcit}}\right)^{-\sigma_X} \cdot KE^*_{cit}, \tag{0.1.53}$$

and:

$$E^*_{cit} = C^{-\frac{\rho_{KE}}{1+\rho_{KE}}} \cdot \delta_E \cdot \left(\frac{w_{Ecit}}{w_{KEcit}} \right)^{-\sigma_X} \cdot KE^*_{cit}. \tag{0.1.54}$$

We see that the optimal demands for the different individual input (K^*_{cit}, L^*_{Lcit}, L^*_{Hcit}, E^*_{cit}, M^*_{cit}) and intermediate outputs (KLE^*_{cit}, $KL_HE^*_{cit}$, KE^*_{cit}), are all negative functions (1) of their relative user cost compared to the user cost of the intermediate output they contribute to produce, and (2) positive functions of the quantity (of the intermediate output) to produce.

The way innovations from their "TFP effects" will modify these demands is as follows:

X, A and Y are linked from equation 0.1.1, the production function of the final output at the first level of the CES nesting, such as we have:

$$\triangle ln\,(Y) = \varepsilon^Y_A \cdot \triangle ln\,(A) + \varepsilon^Y_X \cdot \triangle ln\,(X)\,, \tag{0.1.55}$$

where ε^Y_A and ε^Y_X are respectively the elasticities of final output with respect to A (equation 0.1.31) and to X (equation 0.1.32).

We can therefore, from equation 0.1.55, express the low of motion of X in function of the evolutions of Y and A:

$$\triangle ln\,(X) = \frac{\triangle ln\,(Y) - \varepsilon^Y_A \cdot \triangle ln\,(A)}{\varepsilon^Y_X}. \tag{0.1.56}$$

We see from equation 0.1.56 that whenever A is growing ($\triangle ln\,(A) > 0$), the use of ordinary production factors X per unit of final output Y will be reduced. Then it will reduce proportionally the used of materials (M) and of the intermediate output (KLE) from equations 0.1.47 and 0.1.48, and recursively, of all the other individual inputs and intermediate outputs, from equations 0.1.49 to 0.1.54.

It is this equation 0.1.56 that is used in NEMESIS to "transmit" the "TFP effects" of innovations.

0.1.6 Production, market and "perceived" prices

A last important feature of NEMESIS, on the supply side, is the pricing behaviour and the dichotomy between "actual" prices and "perceived" prices that the "quality effects" of innovations introduce in the model.

Concerning first the production prices, that are the prices that the firms consider for all its production and factor demand choices, we assume in NEMESIS that the firm applies a constant mark-up over its total operational unit cost, such as we have:

$$P_{Ycit} = (1 + TM_{ci}) . \frac{\sum_j w_{jcit} \cdot j_{cit}}{Y_{ci}},\ j = K,\ E,\ L_L,\ L_H,\ E,\ M \tag{0.1.57}$$

where P_{Ycit} is the production price[18] and TM_{ci} the mark-up rate, that differs between countries

[18] We add usually in this equation the influence of the utilisation rate of production capacity, that, from Taddei *et al.* (1992 [62]), can be defined as the ratio between the level of current output, and the maximum output that could be obtained (by increasing infinitely variable inputs) from the installed physical capital stock, K_{cit-1}(that is proportional

and sectors.

For a given firm or sector i, the market price, that-is-to-say the price at which the firm will sell its product, will reflect also the influence of the different taxes, notably VAT, such as:

$$P^M_{Ycit} = P_{Ycit} \cdot (1 + tax_{cit}) \tag{0.1.58}$$

with P^M_{Ycit} the market price and where we assume here, for simplicity, that all the taxes (tax_{cit}) are *add valorem*.

These production and market prices, are those that allow, from the "price accounting chain" of the model, the calculus the GDP in value, with also all their counterparts: final private and public consumptions, investment, imports and exports.

The difficulty is now that, in the model, the customers of the firms, whether households and government for final consumption, firms, households and government for investments, and foreign countries for exports, all take their decisions regarding the quality adjusted prices (P^Q_{Ycit}) of the products that express:

$$P^Q_{Ycit} = \frac{P^M_{Ycit}}{Q_{cit}} \tag{0.1.59}$$

and that we call the "perceived" prices.

As for the illustrative demand function given by equation 0.1.12 above, the decisions to use goods and services produced domestically or imported, and the substitutions between the different production and consumption goods, all will be made by comparing the quality adjusted prices of the different products.

The consequence is that the model calculates two polar measures for GDP in volume.

The first one, the GDP in ordinary units, GDP_{ct}, corresponds to the one usually calculated by national accounting systems, including the correction for the improvement in quality for certain products, such as ICTs, that are currently applied.

The second one is the GDP "adjusted" from quality, includes in its measure the variation in quality of the different good and services that is calculated by the model when simulating a scenario. If we call Q_{GDPct} this quality index of GDP, we have therefore, for the GDP adjusted from quality (GDP^Q_{ct}):

$$GDP^Q_{ct} = GDP_{ct} \cdot Q_{GDPct}. \tag{0.1.60}$$

Not that the GDP adjusted from quality will be always superior to the GDP calculated in volume (or "ordinary units") in a scenario increasing innovation and products quality[19].

For GDP price, we can similarly as for production price distinguish between the "ordinary" price, P_{GDPct}, and the GDP price adjusted from quality, $P^Q_{GDPct} = \frac{P_{GDPct}}{Q_{GDPct}}$.

to this later). This allows to better represent the evolution of prices during the business cycle. But is is not used when focusing on innovation policies, as this definition of utilisation rate of production capacities is not anymore valid in scenarios that modify the intrinsic productivity of variable inputs (from process innovations) and of the capital stock (from quality innovations), and keeping it leads generally to spurious simulation results.

[19]Note that the national accounting systems also apply some corrections for quality improvement, such as for ICTs. This correction is implicitly included in the reference scenario NEMESIS, when we assume generally that the growth of innovations in constant over forward-looking scenario.

This "quality adjusted" price will be therefore always inferior to the "ordinary" price in a scenario increasing product innovations.

Not also that the GDP in value, $GDPV_{ct}$, is identical, whatever the definitions retained for GDP and for its price:

$$GDPV_{ct} = P_{GDPct} \cdot GDP_{ct} \equiv P^{Q}_{GDPct} \cdot {GDP^{Q}}_{ct}. \tag{0.1.61}$$

The question is now "What definitions retain for GDP, GDP price and all the accounting variables calculated by the model, when presenting the simulation results"?

Our choice is to present all the results in "ordinary" units, as it is the way that reflects the more adequately the accounting rules currently is use in the different EU countries. Doing that, we certainly understate, when assessing innovation policies with NEMESIS and presenting the results, the impacts on GDP and on economic activity, and it is solely for employment and environmental variables, for which only one measure exists, that the presentation of results do not depend on the choice that is finally retained.

0.1.7 Some indications on calibration

This last section provides some informations on the calibration of different equations of NEMESIS for production (see table 0.1.4**)** and innovation (see table **0.1.3),** presented in the different sections above.

Concerning first the innovation mechanisms, the calibration was based on the most recent econometric studies on the impact of R&D, ICT and OI investments on economic performance and employment (see Le Mouël *et al.*, 2016 [46], for more details).

Concerning first R&D, the most important feature is, as illustrated notably by Kancs and Silverstovs (2016 [41]) 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 *et al.* (2009 [37]), 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 centered on 0.08 or so" .The survey of Hall *et al.* (2009) shows in summary:

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

1. That output elasticities to private R&D 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. The output elasticities of R&D are positively correlated to the R&D investment intensities;

5. The marginal rate of returns to R&D tends to equalize between firms, sectors and countries, which is a consequence of the fourth point above.

A recent meta-analysis by Donselaar and Koopmans (2016 [20]), focusing on 38 studies[22] performed after 1980 and containing 1214 output elasticities, confirm these general findings, with also an average output elasticity of 0.08. Another meta-study by OECD (2015 [52]), that summarizes the results of 200 studies, finds an output elasticity of private R&D of 0.12, comparable as well to Hall et alii (2009, *ibid*).

On the size of elasticities between firms and sectors, the study of Smeets Kristova *et al.* (2017 [60]) confirms the results of Kancs and Silverstovs (2016) and Ortega-Argilés *et al.* (2015 [54]), that "According to expectations the estimated R&D elasticities differ across sectors with the highest values recorded for high-tech manufacturing". And the same is found also for countries, with higher R&D productivity in the more developed and more R&D intensive countries, as initially illustrated by Coe and Helpman (1995 [11]) and Soete and Verspagen (1993 [61]).

Nevertheless, the survey by Hall, Mohnen and Mairesse (2009), the meta-analysis of Donselaar and Koopmans (2016) and a recent study by Eberhardt *et al.* (2012 [**?**]), show all that the estimated elasticity drop importantly when the analysis takes into account the spillovers between industries and countries. And to take the words of Cameron (1998 [9]), "One of the more important distinctions between the various studies is the extent to which they have attempted to model knowledge spillovers".

When including knowledge externalities in the analysis, the studies (from Hall et al. 2009 survey) 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.

The modeling of R&D and innovation in NEMESIS has been therefore designed to keep in line with these first key findings on empirical literature. Firstly, the impact of investing in R&D, or in other innovation inputs, is a positive function of the investment rate. Secondly, we also introduced an

[21] This average R&D intensity of course varies depending the scope of the study.
[22] 17 micro, 7 meso and 15 macro level studies (including 1 study containing both macro and meso elasticities).

non-linear relationship between the intensity of this input (in % of production or value-added) and its economic impacts, close from the empirical finding of Kancs and silverstovs (2016 [41]), that we do not detail here (see Le Mouël *et al.*, 2016 [46]). Thirdly, in the model, the impact of knowledge spillovers will be more important in the countries and sectors that invest the more in innovation inputs, with also generally greater impacts of international knowledge spillovers for small countries.

For the other innovation inputs, the literature is poorer, but it tends to confirm that ICT and OI investment have similar impacts, in terms of economic returns, than R&D, which conducted us to model and calibrate the impacts of the three innovations inputs that are included in NEMESIS, symmetrically.

For ICT and OI, the key empirical findings are the following:

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 centered around 0.08. For OI, the number of empirical studies stays very limited and it is only very recently that time series based on national accounting methods are available, notably with the development on the INTAN-INVEST database. OI investments recover also very diverse things while in our definition they are limited to two categories: firms specific human capital (investments in training) and investments in software. The available studies conclude, nevertheless, that there exists also "excess" returns associated to OI investments, notably with training, while the strong contribution of software to productivity growth was already recognized by the development of the growth accounting literature[23] and by the econometric studies that include often software, besides hardware, in their definition of ICT capital.

3. Lastly, the most recent empirical studies tend to support the hypothesis that there exists strong complementarities between investments in ICT and investments in different kinds of complementary intangible assets. There exists also empirical evidence of complementarities between, on the one hand, ICT and OI investments and, on the other hand, R&D investments, but they appear to be more indirect and to result from networks effects and from the strategic complementarities existing between the different production sectors.

The analytical simulations performed with the model (see again Le Mouël *et al.*, 2016) confirm also the "ripple" effect that one innovation assets have on the others and notably investments in ICT from their GPT feature and the strategic complementarities between the different production sectors, illustrated above from the results of the econometric literature.

Another important point of the empirical literature, that the analytical simulations with NEMESIS well illustrate, is the contrasted economic and employment impacts that have process and product innovation. The empirical literature shows therefore (e.g. Hall, 2011 [36]) that the impact of product innovations on firms revenue growth rate is always positive, while the impact of process innovations is

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

always small, or negative, the same being true equally for the employment impacts of innovations. Hall (2011 *ibid.*) confirms this result by applying the CDM model (1998 [15]) to a set of 15 EU manufacturing firms using the CIS 3 survey, with both weak or negative estimated impacts of process innovations on real revenue and employment, and conversely, strong positive impacts of product innovations.

Similarly, surveying in great details the empirical literature on the impacts on employment of process and product innovations, Peters *et al.* (2014 [58]) show that the employment impacts of process and organizational innovations are smaller than the effects of product innovations, in all phases of business cycle, with also high productivity impacts and employment reduction in manufacturing of process and organisational innovations, and for organisational innovations in service sectors. Investigating more closely the distinct impacts that have innovations on employment in service industries, Damijan and Star (2014 [16]) find that similarly than for industry, empirical studies generally find a positive impact of product innovations, and a negative impact of process innovations, and no major differences between industry and service seem to emerge from the literature (see also also Harrison et al., 2014 [38]; Bogliacino and Pianta, 2010 [5]).

It is therefore crucial, when endogenising innovation in applied macro models, to consider both the process-improving and product-creating impacts of innovations.

Lastly, for the case of ordinary production factors, the calibration is simplest as we need only to estimate the value of the substitution elasticities for the different levels of the nested production functions. We have to notice also that in the model lags, reflecting adjustments and desadjustment costs, are added in the demand equations for the traditional production factors (K, L_L, L_H, E, M), that were presented in sub-section 0.1.5, and that are only the long term optimal targets. The table **0.1.4** displays the typical values that are used in NEMESIS for factors' substitutions elasticities.

Table 0.1.3: List of key parameters intervening in the innovation chain of NEMESIS

Parameters description	Parameter value or method calculation	Nb
Spread parameters for knowledge externalities. Measure the strength and direction of inter-sectoral and inter-national spillovers	$\Phi RD_{p,s\to c,i}$, $\Phi ICT_{p,s\to c,i}$, $\Phi OI_{p,s\to c,i}$ Calculation based of the methodologies developed in the context of DEMETER and SIMPATIC projects described in section 2.1.2	(P1-P3)
Spread parameter for public R&D. Measure the strength and direction of knowledge spillovers from public research	$\propto_{ps} = \frac{RD_{ps t_0}}{RD_{p t_0}}$ Grandfathering assumption: The more a sector invest in R&D (in % of total private R&D expenditure) the more it benefits from public research	(P4)
Productivity parameters of innovation inputs. Modify proportionally the impact of the different innovation input on the growth of innovations	λRD_{ci}, λICT_{ci}, λOI_{ci} Their default value in NEMESIS is set to 1	(P5-1 -3)
Substitution elasticity between the different innovation components. Measure the degree of complementarity between the innovation components in the production of innovation services	σA_{ci} The default value is 0.25 in NEMESIS	(P6)
Distribution parameters of innovation components. Influence the elasticity of innovation services to the growth of innovation components and knowledge externalities	δRD_{ci}, δICT_{ci}, δOI_{ci}, They are positively related to cost of each innovation input in the total cost of producing innovation services in NEMESIS. They sum to 1 NEMESIS	(P7-P9)
Substitution elasticity between innovation components and the bundle of traditional production factor in the equation for sectoral output. The value of this elasticity is not critical in NEMESIS. Influences mainly the elasticity of innovation services to their user cost.	σY_{ci} Set to 1 in NEMESIS	(P10)
Distribution parameters of innovation services and of the bundle of traditional production factors	δA_{ci},	

Table 0.1.4: Value of substitution elasticities of the nested CES production functions

Parameter	Description	Value/Range	Comment
σ_Y	Substitution elasticity between innovation services, A and the compound input for ordinary production factors, X	1	Calibrated
σ_X	Substitution elasticity between materials, M and the compound input KLE	0.4/[0.2; 0.6]	Estimates, mean values across sectors ± 1 standard deviation
σ_{KLE}	Substitution elasticity between low qualified labour, L_L and the compound inputKL_HE	0.5/[0.3; 0.7]	Estimates, mean values across sectors ± 1 standard deviation
σ_{KL_HE}	Substitution elasticity between high qualified labour, L_H and the compound input KE	0.5/[0.3; 0.7]	Estimates, mean values across sectors ± 1 standard deviation
σ_{KE}	Substitution elasticity between physical capital, K and energy, E	0.4/[0.1; 0.6]	Estimates, mean values across sectors ± 1 standard deviation

0.2 Rest of the model

0.2.1 Households' final consumption

In 2015, the final consumption of households represented around 55% of the EU GDP, with significant variations between members states, from 29% in Luxembourg to 69% in Cyprus (Eurostat, 2017 [26]). Thus, the modelling of the households' consumption is crucial.

In NEMESIS, the households' consumption computation follows two steps. The first stage calculates the total aggregated consumption from the disposable income, the part which is not used for consumption constituting savings that split between investments in real estate and in financial or monetary assets. At the second stage, the aggregate consumption is allocated among 27 consumption functions.

0.2.1.1 The aggregated households' consumption

Based on Davidson *et al.* (1978 [17]), we link the aggregate household's consumption to income and wealth by an Error Correction Model. Three additional determinants of the households' consumption are also taken into account: interest rates, inflationary pressures and the unemployment rate which is used as a proxy to measure the degree of uncertainty of the expected revenues. as usually the consumption function distinguish the long term relationship (equation 0.2.1) and the short-medium term dynamics (equation 0.2.2).

The co-integrating long term equation takes the following form:

$$\begin{aligned} &\ln\left(\frac{CQ_c}{POP_c}\right) \\ &= lrsc0_c \\ &+lrsc1 \cdot \ln\left(\frac{\frac{GDI_c}{PCT_c}}{POP_c}\right) \\ &+lrsc2 \cdot \ln\left(\frac{POPRET_c}{POP_c}\right) \\ &+lrsc3 \cdot \ln\left(\frac{POPCHI_c}{POP_c}\right) \\ &+lrsc4 \cdot (RRLR_c) \end{aligned} \tag{0.2.1}$$

And the dynamic equation is:

$$
\begin{aligned}
&\Delta \ln\left(\frac{CQ_c}{POP_c}\right) \\
&= crsc0_c \\
&+crsc1 \cdot \Delta \ln\left(\frac{\frac{GDI_c}{PCT_c}}{POP_c}\right) \\
&+crsc2 \cdot \Delta \ln\left(\frac{POPRET_c}{POP_c}\right) \\
&+crsc3 \cdot \Delta \ln\left(\frac{POPCHI_c}{POP_c}\right) \\
&+crsc4 \cdot \Delta(RRLR_c) \\
&+crsc5 \cdot \Delta \ln\left(\frac{PCT_c}{PCT_c^{-1}}\right) \\
&+crsc6 \cdot \Delta \ln(U) \\
&+crsc7 \cdot \Delta \ln\left(\frac{CQ_c^{-1}}{POP_c^{-1}}\right) \\
&+crsc8 \cdot ERR^{-1}
\end{aligned}
\tag{0.2.2}
$$

With CQ_c: the total households' consumption, POP_c: the population of the country c, GDI_c: the Households' Gross Disposable Income, PCT_c: the consumers price, U: the unemployment rate, $POPRET_c$: the retired population, $POPCHI_c$: the child population, $RRLR_c$: the interest rate and ERR: the error term.

Furthermore, the following parameter restrictions are imposed: $lrsc1 = 1$, $lrsc4 < 0$, $crsc1 > 0$, $crsc4 < 0$, $crsc5 < 0$, $0 < crsc6 < 1$ and $0 > crsc7 > -1$.

The value estimated for the different parameters are displayed in table 0.2.1.

0.2.1.2 Allocation of the aggregate consumption

On this basis, the macroeconomic consumption is disaggregated, at the second stage, between the 27 consumption functions. The allocation method is based on the work done by Bracke and Meyermans (1997 [6]). The econometric allocation system stems from the theory of the rational consumer and is implemented with a CBS parametrization of the system (Keller and van Driel, 1985 [44])[24]. The equation takes into account, as explanatory variables of the allocation, the relative prices, the total income and demographic changes. This allocation runs through several steps by assuming separability between different groups of consumption components. At first, the consumer decides the respective shares that will be allocated to non-durable and durable goods. Then, within each group, the consumption is split between subgroups, etc. These successive steps unfold until the finest disaggregation level in 27 components, as depicted by the figure 0.2.1.

Mathematically, the allocation of consumption function f in the group F is defined as follows:

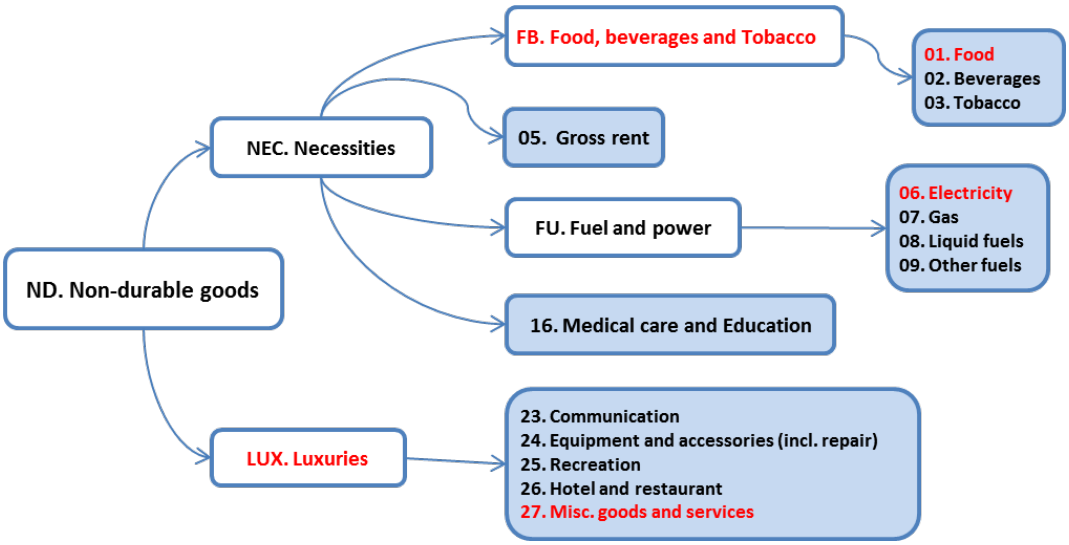
[24]The version implemented in NEMESIS is a hybrid between the Almost Ideal Demand System (AIDS, Deaton and Muellbauer, 1980 [18]) and the Rotterdam system (Barten, 1969 [2]).

Table 0.2.1: Value of of parameters for final consumption

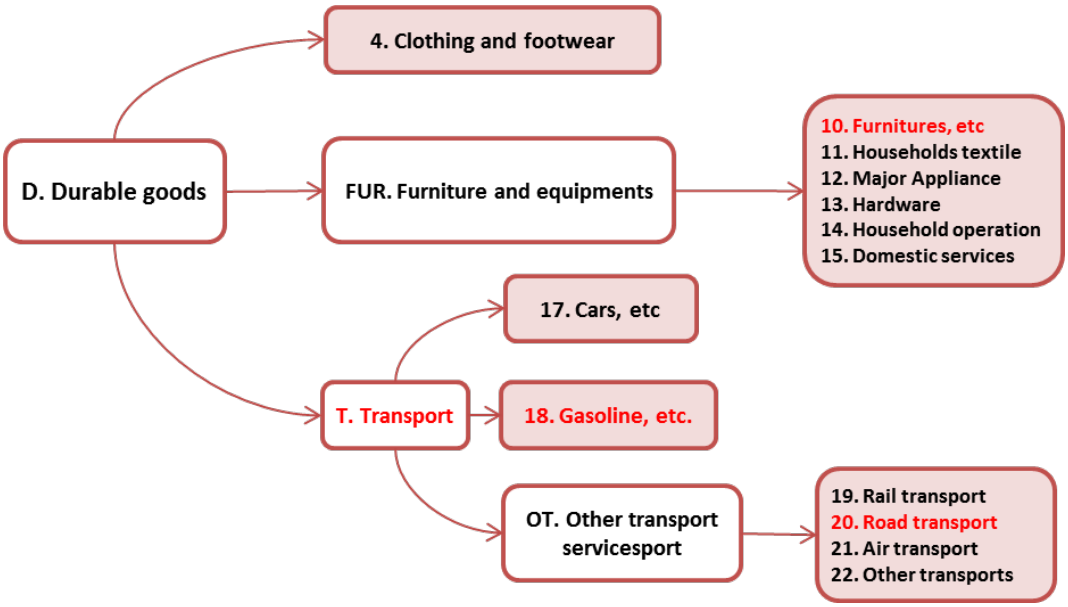
Parameter	Description	Value, Range	Comment
Parameters of the short term dynamic			
$crsc1$	Elasticity of consumption to real disposable income	0.7	Estimated
$crsc2$	Elasticity of consumption to share of retired in total population	0.2	Estimated
$crsc3$	Elasticity of consumption to share of children (age inferior to 15) in total population	-0.343	Estimated
$crsc4$	Elasticity of consumption a to real interest rate	-0.016	Estimated
$crsc5$	Elasticity of consumption to consumption price	-0.020	Estimated
$crsc6$	Elasticity of consumption a to unemployment rate	-0.001	Estimated
$crsc7$	Autoregressive coefficient of consumption	0.158	Estimated
$crsc8$	Coefficient associated to the error term	-0.249	Estimated
Parameters of the long term relationship			
$lrsc1$	Elasticity of consumption to real disposable income	1	Constrained to 1
$lrsc2$	Elasticity of consumption to share of retired in total population	-0.038	Estimated
$lrsc3$	Elasticity of consumption to share of children (age inferior to 15) in total population	-0.125	Estimated
$lrsc4$	Elasticity of consumption to real interest rate	-0.078	Estimated

Figure 0.2.1: Allocation of the aggregate consumption

(a) Allocation of Non Durable Goods



(b) Allocation of Durable Goods



In red the consumption functions assuring the accounting identities.

Table 0.2.2: Value of of parameters for final consumption allocation system

Parameter	Description	Value, Range	Comment
$\rho_f^{C,F}$	Elasticity of consumption sub-category f to total consumption of upper-group F	[0.8; 1.2]	Mean/max values across functions
$\rho_{c,f,g}^{P,F}$	Cross-price elasticities for consumption sub-categories f	[-0.1; 0.3]	Mean/max values across functions
$\rho_{c,f}^{W,F}$	Elasticity of consumption sub-category f to the share of working-age population in total population	[-0.2; 0.2]	Mean/max values across functions
$\rho_{c,f}^{ret,F}$	Elasticity of consumption sub-category f to the share of retired in total population	[-0.1; 0.3]	Mean/max values across functions
$\rho_{c,f}^{Tr}$	Value of time trend for consumption sub-category f	[-0.1; 0.1]	Mean/max values across functions

$$\begin{aligned}\ln\left(\frac{C_{c,f}^{AL}}{POP_c}\right) &= \rho_{c,f}^{0,F} + \rho_f^{C,F}\cdot\ln\left(\frac{C_{c,F}^{AL}}{POP_c}\right) + \sum_{g\epsilon F}^{g\neq h}\rho_{c,f,g}^{P,F}\cdot\left(\frac{PCONS_{c,g}}{PCONS_{c,h}}\right) \\ &\quad + \rho_{c,f}^{W,F}\cdot\ln\left(\frac{POPWORK_c}{POP_c}\right) + \rho_{c,f}^{ret,F}\cdot\ln\left(\frac{POPRET_c}{POP_c}\right) \\ &\quad + \rho_{c,f}^{tr}\cdot TR\end{aligned} \tag{0.2.3}$$

with C^{AL}, the consumption allocation function, $PCONS_f$, the consumption price of the consumption function f, $POPWORK$, the working age population, TR, a trend and h is the index of the function that allows the accounting identity of the group F.

And the consumption function is then defined with the following equation allowing the accounting identity:

$$C_{c,f} = \frac{C_{c,f}^{AL}}{\sum_{f=1}^{27} C_{c,f}^{AL}}\cdot CQ_c \tag{0.2.4}$$

The table 0.2.2 gives indications on the value of the parameters that are used.

0.2.1.3 Consumption by function to consumption by product

The consumption per category is then allocated to consumption by product using a consumption transition matrix assuming fixed coefficient.

$$ADDCONSQ_{c,s} = \sum_{f=1}^{27} (mcons_{c,f,s} \cdot C_{c,f}) \tag{0.2.5}$$

With $ADDCONSQ_{c,s}$, the addressed consumption demand to product from sector s for country c, C_f, the consumption function f, and $mcons_{c,f,s}$ the matrix coefficient.

This transition matrix is also used for calculating consumption price per category using sectoral production and import prices to which VAT taxes and excises duties are added:

$$\begin{aligned} PCONS_{c,f} = &[VATCP_{c,f} + EXCIPAH_{c,f} + \\ &\sum_{s=01}^{30} (mcons_{c,f,s} \cdot CONS_{c,f} \cdot PADDDEM_{c,s})\Big] \\ &/ \Big[C_{c,f} + VATCP_{c,f}^{T_{cal}} + EXCIPAH_{c,f}^{T_{cal}}\Big] \end{aligned} \tag{0.2.6}$$

Where $PCONS_f$ is the price of the consumption function f, $VATCP_f$ and $EXCIPAH_f$ respectively VAT taxes and excises duties on commodity f in country c, $PADDDEM_{c,s}$ the price of product from sector s in country c and T_{cal}, the base year used for the calibration.

0.2.2 Labour market

In this section, we present the functioning of the labour market. While the labour demand is determined by the optimisation of the production function, the supply is based on population projections by skill and age. The interaction of labour demand and supply is specified in the model by a wage bargaining process following an "*augmented Phillips curve*". We first describe the specification of the wage setting specification and then we will explain the determination of the labour supply.

0.2.2.1 Wage determination

The specification of the labour market is controversial for a long time and this controversy is both theoretical and empirical. In particular, there is a conflict among the proponents of the Phillips curve and those of the Wage Setting/Price Setting (WS/PS) models for which the wage bargaining is realised with respect to its level and not to its rate of growth as suggested in the Phillips curve (Layard *et al.,* 1991 [45]; Blanchard and Katz, 1999 [4]; Chagny *et al.,* 2002 [10] and Heyer *et al.,* 2007 [39]). According to the WS/PS model, wages would be determined with respect to a reservation wage representing a sort of income opportunity of workers outside the firm. While the main controversy against the Phillips curve relies on its theoretical foundation, the main arguments against the WS/PS models are based on the unrealistic hypotheses underlying the reservation wage. As explained in Chagny *et al.* (2002 [10]), several justifications of the reservation wage were mentioned in the literature. The first is based on the price of leisure attributed by individuals (L'Horty and Sobczak, 1996 [47] and 1997 [48]) but it leads to a non stable unemployment rate. The second defines the reservation wage as the unemployment benefits (Layard *et al.,* 1991 [45], L'Horty and Sobczak, 1996 [47]), explaining the deviation of the unemployment by trade unions or by the replacement rate which is empirically not relevant. A third version links the reservation wage to the labour productivity (Layard *et al.* 1991 [45]; Blanchard and Katz, 1999 [4]) but, as it assumes that either the productivity for domestic works or the unemployment benefits vary in the same way than the labour productivity, the hypotheses are unrealistic. Finally, a fourth definition that fixes the reservation wage equal to a lagged wage (Manning, 1993 [49] or Blanchard and Katz, 1999 [4]) seems to be more founded and is compatible with a Phillips curve (Chagny *et al.*, 2002 [10]). Therefore, in line with Heyer *et al.* (2007 [39]), we retained a Phillips curve for NEMESIS.

Our specification is based on the model developed by Chagny *et al.* (2002 [10]) that we extend in order to take into account the NEMESIS specificities, in particular the sectoral dimension and the distinction between high-qualified and low-qualified workers.

The equation is:

$$\begin{aligned} \triangle w_{i,l,c,t} = \quad & Z_{i,l,c} + a_{c,l}(L)\triangle pc_{l,c,t} \\ & -b_{1,c,l}(L)U_{l,c,t} - b_{2,c,l}(L)(U_{l,c,t} - UT_{l,c,t}) \\ & +d_{c,l}(L)\triangle \pi_{i,l,c,t} + \epsilon_{i,l,c,t} \end{aligned} \tag{0.2.7}$$

Where t is a time index, c is a country index, l corresponds to the labour qualification, i is a sector index and $Z_{i,l,c}$ represents institutional variables.

All variables are expressed in logarithms except the unemployment rate (U) which is expressed in

level. $\triangle w$ is the growth rate of nominal wage ($w - w_{-1}$), $\triangle p^e$ is the expected inflation (it is equal to $\triangle p$ if expectations are perfect). UT corresponds to the trend-setting unemployment rate. Due to lack in data we have limited our estimated sample to 19 countries (instead of 27) and 28 sectors (instead of 30). Institutional variables $Z_{i,l,c}$ are treated as country-sector fixed effect.

Regarding the estimations, several hypotheses have been done concerning the data. First, there is no available data for $w_{i,l,c,t}$ that distinguishes different kinds of labour. For that purpose, we used data on labour compensations by skill provided by the EU-KLEMS database (EU-KLEMS, 2011 [50]) and we assumed that their variations equal those of wages by skill. Secondly, unemployment is given at macro level so we assumed that workers are mobile through sectors and therefore unemployment rate is naturally not defined by sector. Data are mainly taken from Eurostat (Eurostat, 2012 [24]). We used a set called *'Unemployment rates by sex, age groups and highest level of education attained (%)'*. We used the 15-64 years old age group and we converted ISCED classification into NEMESIS low and high skill classification. Thirdly, $pc_{l,c}$ is taken from the OECD database: '*Consumer price indices (MEI)*' for all countries except for Slovenia. Since database is not available for Slovenia, we used prices from Eurostat (with lower time coverage). Finally, $\pi_{i,l,c}$, the labour productivity, is calculated as usual, *i.e.* the value-added divided by the number of hours worked. Data has been mainly taken from the EU-KLEMS database.

Globally, estimations considering the hysteresis phenomena have not provided convincing results so that we retained a form of the Phillips curve without hysteresis in the model. In addition, in practical, the constraints imposed by the simulations of scenarios lead us to adapt the coefficients in order to consider the heterogeneous situations and to stay in a realistic range of unemployment rates. Nevertheless the values of coefficients that are implemented in the model are in line with the econometric literature (notably Chagny *et al.*, 2002 [10]). The average value of b_1 implemented in NEMESIS is about 0.35, the average value for $d_{c,l}(L)$ is about 0.33 and we retain a unit indexation of wages on prices, taking $a_{c,l}(L)$ equal to 1.

0.2.3 International trade

The international trade is obviously a crucial dimension of the NEMESIS model as it represents one of the most important interactions between countries in EU and with the rest of the World. In 2015, the degree of openness[25] of EU with the rest of the World was about 17% of EU GDP whereas the intra-EU degree of openness were about 26%. And in each members states, the total degree of openness ranged between 28% in the United-Kingdom and 200% of GDP in Luxembourg in 2015.

In the state of the art, the external trade in NEMESIS processes by pool, each modelled country exports to (and imports from) two pools that group together either extra-European countries or intra-European countries. Therefore, there is no description of the precise country of origin or of destination within these pools. One major drawback of this approach is that nothing insure, *a priori*, the equality between imports and exports inside a group. Concretely, as exports and imports are both estimated, the total intra-European imports are not necessarily equal to the total intra-European exports in volume. As underlined by Satchi (2004 [59]), it is not yet possible to estimate trade equations without bilateral data, so the most important constraint preventing a better representation comes from the availability of this data. Nevertheless, this "adding up" problem was partly solved by modifying the exports equations in order to insure the equilibrium between the sums of exports and the sums of imports *per* sector. This implicitly signifies that imports equations are better modelled than exports ones.

0.2.3.1 Intra-European trade

For the imports The modelling of imports in NEMESIS is relatively simple and it includes two main components:

1. the price effect that captures the competitiveness effect[26] that is represented by the ratio of the import price to the domestic price and
2. the volume (or income) effect that is proxied by the demands addressed to the sector

The equations for intra-European imports takes the following form:

$$\begin{aligned}&\ln(IMPEUQ_{c,s}) = \lambda^{impeuq} \cdot [limpeu0_{c,s} \\ &+limpeu1_s \cdot \ln(ADDDEMQ_{c,s}) \\ &+limpeu2_s \cdot \ln\left(\frac{PIMP_{c,s}}{PPROD_{c,s}}\right)\Big] \\ &+\left(1-\lambda^{impeuq}\right) \cdot \ln(IMPEUQ_{c,s}^{-1})\end{aligned} \tag{0.2.8}$$

with $ADDDEMQ_{c,s}$, the total domestic demand by product; $PIMP_{c,s}$, the price of imports and $PPROD_{c,s}$, the production price; .

The following parameter restrictions are used: $limpeu1 > 0$, $limpeu2 < 0$ and $0 < \lambda^{impeuq} < 1$.

The values of the elasticities used in the model as displayed in table 0.2.3.2.

[25] The degree of openess is measured as: $\frac{\sum_c EXP_c + \sum_c IMP_c/2}{\sum_c GDP_c}$. The dataset used for calculation is Eurostat (2017 [26]).

[26] See section 0.1 for detailed on the modelling of the quality in the price index in NEMESIS.

Exports equations Similarly, the exports equations include:

1. the volume (or income) effect taken into account through a demand variable that results from the demands of partners countries that are weighted by past trade intensities (in a matrix form, $INDACTEU_{c,s}$)
2. the price effect modelled with the ratio between the export price and an European price index that is a weighted variable of other EU countries export prices ($PINDICEXPEU_{c,s}$).

The equations for intra-European exports takes the following form:

$$\begin{aligned}&\ln(EXPEUQ_{c,s}) = \lambda^{expeuq} \cdot [lexpeu0_{c,s} \\ &+lexpeu1_s \cdot \ln(\tfrac{INDACTEU_{c,s}}{INDACTEU_{c,s}^{Tcal}}) \\ &+lexpeu2_s \cdot \ln\left(\tfrac{PEXP_{c,s}}{PINDICEXPEU_{c,s}}\right)\Big] \\ &+(1-\lambda^{expeuq}) \cdot \ln\left(EXPEUQ_{c,s}^{-1}\right)\end{aligned} \tag{0.2.9}$$

with

$$INDACTEU_{c,s} = \sum_{k}^{k\neq c} [mxeu_{c,k,s} \cdot (PRODQ_{k,s} + IMPTOTQ_{k,s} - EXPTOTQ_{k,s})] \tag{0.2.10}$$

$$PINDICEXPEU_{c,s} = \frac{\sum_{k}^{k\neq c} [mxeu_{c,k,s} \cdot (PEXP_{k,s}.EXPTOTQ_{k,s})]}{\sum_{k}^{k\neq c} \left[mxeu_{c,k,s} \cdot \left(PEXP_{k,s}^{Tcal}.EXPTOTQ_{k,s}\right)\right]} \tag{0.2.11}$$

and, $PINDICEXPEU_{c,s}$ an indicator of competing exports prices, $PEXP_{c,s}$, the export price, T_{cal}, the base year used for the calibration and $mxeu_{c,k,s}$ are weighting coefficients based on historical dataset. We use as parameter restrictions: $lexpeu1 > 0$, $lexpeu2 < 0$ and $0 < \lambda^{expeuq} < 1$.

The values of the elasticities used in the model as displayed in table 0.2.3.2.

0.2.3.2 Extra-European trade

The extra European trade vis-à-vis the rest of world follows broadly the same formalisation than intra-European trade and includes therefore the same effects as described above.

For the imports The equations for extra-European imports takes the following form:

$$\begin{aligned}&\ln(IMPROWQ_{c,s}) = \lambda^{imprwq} \cdot [limprw0_{c,s} \\ &+limperw1 \cdot \ln(ADDDEMQ_{c,s}) \\ &+limprw2_s \cdot \ln\left(\tfrac{PIMPROW_{c,s}}{PPROD_{c,s}}\right)\Big] \\ &+\left(1-\lambda^{imprwq}\right) \cdot \ln(IMPROWQ_{c,s}^{-1})\end{aligned} \tag{0.2.12}$$

with $ADDDEMQ_{c,s}$, the total domestic demand by product; $PIMPROW_{c,s}$, the price of imports from the rest of the World (exogenous) and $PPROD_{c,s}$, the production price; .

The following parameter restrictions are used: $limprow1 > 0$, $limprow2 < 0$ and $0 < \lambda^{impeuq} < 1$.

Exports equations The equations for extra-European exports takes the following form:

$$\begin{aligned}\ln(EXPROWQ_{c,s}) = \lambda^{exprwq} \cdot [&lexprw0_{c,s} \\ &+lexprw1_s \cdot \ln(\tfrac{INDROW_{c,s}}{INDROW_{c,s}^{Tcal}}) \\ &+lexprw2_s \cdot \ln\left(\tfrac{PEXP_{c,s}}{PINDROW_{c,s}}\right)] \\ &+(1-\lambda^{exprwq}) \cdot \ln\left(EXPROWQ_{c,s}^{-1}\right)\end{aligned} \tag{0.2.13}$$

with $INDROW_{c,s}$, the demand indicator from the Rest of the World (exogenous, see section) and $PINDROW_{c,s}$ an indicator of competing prices in the rest of the World (exogenous).

Parameter	Description	Value, Range	Comment
Intra-European imports			
λ^{impeuq}	Partial adjustment parameter	0.7	Calibrated
$limpeu1$	Elasticity to domestic demand	1, [0.7; 1.3]	Estimated, mean values ± 1 standard deviation
$limpeu2$	Elasticity to relative price	-0.7, [-0.4; -1]	Estimated, mean values ± 1 standard deviation
Intra-European exports			
λ^{expeuq}	Partial adjustment parameter	0.7	Calibrated
$lexpeu1$	Elasticity to domestic demand	1, [0.7; 1.2]	Estimated, mean values ± 1 standard deviation
$lexpeu2$	Elasticity to relative price	-0.8, [-0.5; -1.1]	Estimated, mean values ± 1 standard deviation
Extra-European imports			
λ^{imprwq}	Partial adjustment parameter	0.7	Calibrated
$limprw1$	Elasticity to domestic demand	1, [0.7; 1.2]	Estimated, mean values ± 1 standard deviation
$limprw2$	Elasticity to relative price	-0.6, [-0.4; -0.9]	Estimated, mean values ± 1 standard deviation
Extra-European exports			
λ^{exprwq}	Partial adjustment parameter	0.7	Calibrated
$lexprw1$	Elasticity to domestic demand	1, [0.7; 1.2]	Estimated, mean values ± 1 standard deviation
$lexprw2$	Elasticity to relative price	-0.7, [-0.4; -1]	Estimated, mean values ± 1 standard deviation

The values of the elasticities used in the model for extra-European imports and exports as displayed in table 0.2.3.2.

Table 0.2.3: Value of parameters for external trade: import and export prices

Parameter	Description	Value, Range	Comment
Export prices			
$lpexp1$	Elasticity to European price	0.2, [0.1; 0.3]	Calibrated at mean value
$lpexp2$	Elasticity to world price	0.2, [0.1; 0.3]	Calibrated at mean value
$lpexp3$	Elasticity to domestic price	0.6, [0.5; 0.7]	Calibrated at mean value
Import prices			
$lpimp1$	Elasticity to European price	0.3, [0.2; 0.4]	Calibrated at mean value
$lpimp2$	Elasticity to world price	0.3, [0.2; 0.4	Calibrated at mean value
$lpimp3$	Elasticity to domestic price	0.4, [0.3; 0.5]	Calibrated at mean value

0.2.3.3 Exports and imports prices

Exports and imports prices play a large role in determining trade volumes. The basic feature of trade prices in NEMESIS assumes that European countries operate in oligopolistic markets, following this assumption, importers and exporters set mark-ups on their prices, given the prices of their competitors. As mentioned above, the lack of data regarding import and export prices prevent the distinction between Intra-European and the Rest of the World. However, in order to take into account the possible trade barriers between the EU and the rest of the world, we set two different prices whose difference reflects precisely these trade barriers (import duties...) that multiply the global import and exports prices. Other partners prices are weighted in the same manner than for volume equations, exchange rates are directly taken into account in the European price index (making a clear distinction between intra and extra Euro zone) and in the ROW price index .

Export prices The majority of trade prices are treated in the same manner (with the notable exception of crude oil and gas, that are treated exogenously). The equations take the following forms:

$$\begin{aligned}&\ln(PEXP_{c,s}) = lpexp0_{c,s}\\&+lpexp1_s \cdot \ln(PINDICEXPEU_{c,s} \cdot EXCHR_c)\\&+lpexp2_s \cdot \ln(PINDROW_{c,s} \cdot EXCHR_c)\\&+lpexp3_s \cdot \ln(PPROD_{c,s})\end{aligned} \tag{0.2.14}$$

with $PINDICEXPEU_{c,s}$, the price index for competing exports in Europe (equation 0.2.11), $PINDROW_{c,s}$, the price index in the rest of the world (exogenous), $PPROD_{c,s}$, the production price and $EXCHR_c$, the exchange rate (exogenous and normalised to 1, the base year). The parameter restrictions are: $lpexp1_s + lpexp2_s + lpexp3_s = 1$.

Import prices

$$\begin{aligned}&\ln(PIMPc,s) = lpimp0_{c,s}\\&+lpimp1_s \cdot \ln(\tfrac{PINDICIMPEU_{c,s}}{EXCHR_c})\\&+lpimp2_s \cdot \ln(\tfrac{PINDROW_{c,s}}{EXCHR_c})\\&+lpimp3_s \cdot \ln(PPROD_{c,s})\end{aligned} \tag{0.2.15}$$

with

$$PINDICIMPEU_{c,s} = \frac{\sum_{k}^{k\neq c} [mmeu_{c,k,s} \cdot (PEXP_{k,s}.EXPTOTQ_{k,s})]}{\sum_{k}^{k\neq c} \left[mmeu_{c,k,s} \cdot \left(PEXP_{k,s}^{Tcal}.EXPTOTQ_{k,s}\right)\right]} \tag{0.2.16}$$

and $PEXP_{c,s}$, the export price, T_{cal}, the base year used for the calibration, $mmeu_{c,k,s}$, weighting coefficients based on historical dataset, $PINDROW_{c,s}$, the price index in the rest of the world (exogenous) and $EXCHR_c$, the exchange rate (exogenous and normalised to 1, the base year). The parameter restrictions are: $lpimp1 + lpimp2 + lpimp3 = 1$.

The values of the elasticities used in the model for import and export prices as displayed in table 0.2.3.

0.2.4 Accounting framework

The accounting framework of the model guaranties that each flow between agents has its counterpart, and that what is received by one economic agent is issued by another one.

In this process, the input/output tables of the model play an important role, by ensuring the concordance between the demands formulated by the different agents (firms, consumers, government, exports) and the demand addressed to producers, domestic and foreign**.** They transform and equilibrate the sums of factors demands, consumptions by product, household investments, government expenditure and foreign demand in equivalent addressed demands by product.

Concerning the institutional sectors accounts, they are established in NEMESIS on the basis of the Eurostat database (Eurostat, 2017 [27]). The huge database are checked (notably the aggregations, paid/received...) and corrected when errors are encountered. The sequence of accounts follows the European accounting framework ESA10[27]. The different institutional sectors that are represented are the General Government (GG), Households and Non-Profit Institutions Serving Households (HNPISH)[28], Financial Corporations (FC), Non-Financial Corporations (NFC), all of which are of course linked to the sectoral nomenclature of the model.

Agents accounts are implemented from the production account up to the Acquisition of non financial assets account (*i.e.* up to the b9 Net lending (+) /net borrowing (-)).

Regarding the public finances, the main taxes and subsidies are summed up in the table 0.2.4 and more information can be found in the European System Account (2013 [27]).

We focus here on the most important taxation part of the model, keeping in mind that one of the main difficulties in such sectoral model stems from the application of the appropriate taxation rate in each sector.

On that point, the VAT is probably the most difficult tax to be implemented in a model such as NEMESIS. Indeed, on the one hand, the sectoral disaggregation of the model allows a strict differentiation of the different VAT rates applicable to the different products and services, but on the other hand, calculating VAT rates applicable to each sector based on actual rates is tedious and need numerous assumptions concerning the sharing of each rate within each sector, taking into account existing exemptions. In addition, any change of a particular tax rate implies to recalculate *ex-ante* the implicit rate for each sector, inducing potential errors coming from *ex-post* substitution effects not taken into account. For that purpose, in the NEMESIS model, the implicit VAT rate is fully modelled on the basis of the actual VAT rates. The implicit rate at sectoral level is then the result of a linear combination of the different rates (0 rate, super reduced rate, reduced rate 1, reduced rate 2, normal rate and the parking rate) and of the different shares of each products in the consumption. The requested data are provided by the DG TAXUD (2017 [23]). In order to calculate the final consumption VAT rates as precisely as possible, the most disaggregated data of the COICOP nomenclature were used.

Taxes on products except VAT and import taxes were split into two broad taxes: (*i*) excises duties an consumption taxes (D214a) and (*ii*) other taxes on products (D214-D214a). The distinction between

[27]ESA: European System of Accounts

[28]Since the split of households and NPISH's was not possible for most countries, it had been decided not to separate them until data will be available.

Table 0.2.4: Main taxes and subsidies

D2	**Taxes on production and imports**
	Including value added taxes; taxes and duties on imports excluding VAT; Taxes on products except VAT and import taxes; Excises duties and consumption taxes; Other taxes on production
D3	**Subsidies**
	Including Subsidies on products and Other subsidies on production
D5	**Current taxes on income, wealth, etc.**
	Including Taxes on income and Other current taxes
D61	**Social contributions**
	Including social contributions and Imputed social contributions
D9	**Capital Transfers**
	Including Capital taxes and Investments grants

the different excises duties and there allocation between sectors were made possible using information provided by DG TAXUD, (2017 [22]), the same database was used for allocating the rest of Taxes on products, except VAT and import taxes. Besides, aside the three main Excises duties (alcoholic beverages, tobacco and mineral oil), several countries put in place other excises duties (electricity, non alcoholic beverage...), all of which had been incorporated in the model.

Finally, employers social contribution (D6111) are split into sectors using the sectoral data on wage and salaries and compensation of employees. The employees social contribution (D6112) as well as imputed social contribution (D612) are split between sectors depending on relative compensation of employees since no other data is available. And the social contributions by self and non-employed persons (D6113) are calculated only at the macroeconomic level. Then, each type of social contribution is allocated to institutional sectors account (Gov: general government, FC: financial corporations, NFC, Non Financial corporations, H&NPISH: Households and non profit institutions serving households) through fixed shares.

0.3 Concluding remarks

The presentation of NEMESIS was mainly focused on the supply block of the model, in order to give a better understanding for the simulations of R&I policies.

NEMESIS mechanisms are based on the belief that sectoral heterogeneity matters, especially for the analysis of medium-long term and structural policies. It is the case for energy and environment policies, fiscal policies, employment policies and mainly for R&I policies.

The production sectors are very heterogeneous in terms of innovation capability, but their interactive dynamic drives a macro economic track where the most progressive sectors carry the less advanced ones. Moreover, interactions between sectors are extended up to knowledge transfers.

For all these reasons, a detailed sectoral approach is necessary for R&I policies, although we know also that intra sectorial heterogeneity matters.

The design of the NEMESIS model is rather simple. On a main frame composed of national accounting equations are injected behavioural equations whether econometrically estimated, or calibrated on the results of econometric literature.

The innovation module of NEMESIS, based on the new endogenous growth approach, is calibrated with the results of published econometric literature on productivity or research, of ICT and of other intangible investments.

The simplicity in the design takes away the model from new applied models such as DSGE or heterogeneous agents based models. Contrarily to these models, NEMESIS is not based on strict optimisation conditions, but allows more flexibility to incorporate new behaviours and structural shocks on behavioural equations, while the accounting equations ensure the coherency of the whole functioning.

A detailed sectoral model is a heavy data consumer and the shortness of yearly temporal data requires very often the use of calibration. However, most of econometric methods are based on individual data that furnish robust estimations. But how to reconciliate the micro econometric results with sectorial calibration?

For that, NEMESIS uses theoretical results for achieving this compromise between micro econometrics and sectoral approach. For instance, the theory tells us that productivity of research at a sectoral level is proportional to the research intensity. Then, the global result on productivity is split in the different sectorial productivity according to this principle.

Such is nowadays the state of the art of the NEMESIS model, which is like all living models in constant evolution.

Bibliography

[1] Philippe Aghion and Peter Howitt. *Endogeneous Growth Theory*. MIT Press, Cambridge, 1998.

[2] A.P. Barten. Consumer allocation models: Choice of functional form. *Empirical Economics*, 18(1):129–158, 1993.

[3] R. Belderbos and P. Mohnen. SIMPATIC Project, Deliverable D7: Intersectoral and international R&D spillovers. Technical report, MERIT, 2013.

[4] Olivier Blanchard and Lawrence Katz. Wage dynamics: Reconciling theory and evidence. *American Economic Review*, 89:69–74, May 1999.

[5] F. Bogliacino and M. Pianta. Innovation and employment: a reinvestigation using revised pavitt classes. *Research Policy 39 (6)*, 623, 2010.

[6] Ingrid Bracke and Eric Meyermans. Specification and estimation of an allocation system for private consumption in Europe. FPB Working paper 03-97, Federal Planning Bureau - Economic analyses and forecasts, 1997.

[7] D. Brecard, A. Fougeyrollas, P. Le Mouel, L. Lemiale, and P. Zagame. Macro-economic consequences of European research policy: Prospects of the Nemesis model in the year 2030. *Research Policy*, 35(7):910–924, 2006.

[8] T. F. Bresnahan and M. Trajtenberg. «General Purpose Technologies: Engines of Growth». *Journal of Econometrics*, 65(1):83–108, 1995.

[9] G. Cameron. Innovation and growth: A survey of the empirical evidence. *Nuffield College, Oxford, July, http://hicks. nuff. ox. ac. uk/users/cameron/research/gpapers. html*, 3, 1998.

[10] O. Chagny, F. Reynes, and H. Sterdyniak. Le taux de chomage d'équilibre: Discussion théorique et évaluation empirique. *Revue de l'OFCE*, 81(4):205–244, 2002.

[11] David T Coe and Elhanan Helpman. International R&D Spillovers. *European Economic Review*, 39(5):859–887, 1995.

[12] European Commission. In-Depth Interim Evaluation of Horizon 2020, commission staf working document, swd(2017) 221 final - 222 final. Technical report, European Commission, 2017.

[13] Carol Corrado, Johnathan Haskel, Cecilia Jona-Lasinio, and Massimiliano Iommi. Intagibles and industry productivity growth: Evidence from the eu. Technical report, INTAN-Invest Paper, 2014.

[14] Carol Corrado, Jonathan Haskel, Cecilia Jona-Lasinio, and Massimiliano Iommi. *Intangible Capital and Growth in Advanced Economies: Measurement Methods and Comparative Results*. IZA, 2012.

[15] Bruno Crépon, Emmanuel Duguet, and Jacques Mairesse. Research, Innovation And Productivity: An Econometric Analysis At The Firm Level. *Economics of Innovation and New technology*, 7(2):115–158, 1998.

[16] J. P. Damijan, C. Kostevc, and M. Stare. Impact of innovation on employment and skill upgrading. The Warwick Economics Research Paper Series (TWERPS 339, SIMPATIC 7th EU Project, Working paper nÂ°7, March, 2014.

[17] James E.H. Davidson, David F. Hendry, Frank Srba, and Stephen Yeo. Econometric Modelling of the Aggregate Time-series Relationship Between Consumers' Expenditure and Income in the United-Kingdom. *The Economic Journal*, (88):661–692, 1978.

[18] Angus S. Deaton and John Muellbauer. An Almost Ideal Demand System. *American Economic Review*, 70(3):312–326, June 1980.

[19] Elias Dinopoulos and Peter Thompson. Schumpeterian Growth Without Scale Effects. *Journal of Economic Growth*, 3(4):313–335, 1998.

[20] P. Donselaar and C.C. Koopmans. The fruits of R&D: Meta-analyses of the effects of Research and Development on productivity. *Research Memorandum 2016-1, Vrije university*, 45:797–815, 2016.

[21] Addul Azzez Erumban and Klaas de Vries. Global Growth Projections for The Conference Board Global - Economic Outlook 2018. Economic Program Working papers series 17-02, Conference Board, 2017.

[22] European Comission - Directorate General for Taxation and Customs Union. Taxes in europe database v3. Database, 2017.

[23] European Comission - Directorate General for Taxation and Customs Union. Vat rates applied in the member states of the european union - situation at 1st january 2017. Technical report, DG TAXUD, 2017.

[24] Eurostat. Lfs series - detailed annual survey results. Database, June 2012.

[25] Eurostat. European system of accounts - esa2010. Technical report, Eurostat, 2013.

[26] Eurostat. Annual national accounts. Database, 2017.

[27] Eurostat. Annual sectors accounts - esa10. Database, 2017.

[28] Eurostat. Labour force survey. Database, 2017.

[29] Eurostat. Maastricht criterion interest rates. Database, 2017.

[30] Eurostat. Population. Database, 2017.

[31] Eurostat. Population projections. Database, 2017.

[32] Eurostat. Short-term interest rates. Database, 2017.

[33] Eurostat. Statistics on research and development. Database, 2017.

[34] Jean Fouré, Agnès Bénassy-Quéré, and Lionel Fontagné. The Great Shift: Macroeconomic Projections For the World Economy at the 2050 Horizon. Working paper 2012-03, CEPII, 2012.

[35] Joonkyung Ha and Peter Howitt. Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory. *Journal of Money, Credit and Banking*, 39(4):733–774, 2007.

[36] Bronwyn H Hall. Innovation and Productivity. Technical report, National Bureau of Economic Research, 2011.

[37] Bronwyn H Hall, Jacques Mairesse, and Pierre Mohnen. Measuring the Returns to R&D. Technical report, National Bureau of Economic Research, 2009.

[38] R. Harrison, J. Jaumandreu, J. Mairesse, and B. Peters. Does innovation stimulate employment? a firm-level analysis using comparable micro-data from four european countries. *International Journal of Industrial Organization*, 35:29–43, 2014.

[39] Eric Heyer, Frédéric Reynés, and Henri Sterdyniak. Structural and reduced approaches of the equilibrium rate of unemployment, a comparison between france and the united states. *Economic Modelling*, 24(1):42–65, 2007.

[40] D.K.N. Johnson. The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use. *OECD Science, Technology and Industry Working Papers*, 2002.

[41] d'A. Kancs and B. Siliverstovs. R&d and non-linear productivity growth. *Research Policy*, 46:634–646, 2016.

[42] Samir KC, Bilal Barakat, Anne Goujon, Vegard Skirbekk, Warren C. Sanderson, and Wolfgang Lutz. Projection of population by level of educational attainment, age, and sex for 120 countries for 2005-2050. *Demographic Research*, 22:383–472, 2010.

[43] Samir KC and Wolfgang Lutz. Demographic scenarios by age, sex and education corresponding to the ssp narratives. *Population and Environment*, 35(3):243–260, 2014.

[44] W.J. Keller and J. Van Driel. Differential consumer demand systems. *European Economic Review*, 27(3):375–390, 1985.

[45] Richard Layard, Stephen Nickell, and Richard Jackman. *Unemployment: Macroeconomic Performance and the Labour Market*. Oxford University Press, Oxford, UK, 1991.

[46] P. Le Mouel, B. Le Hir, A. Fougeyrollas, P. Zagame, and B. Boitier. Toward a macro-modelling of European Innovation Union: The contribution of NEMESIS model. In *9th Conference on Model-based Evidence on Innovation and DEvelopment (MEIDE) 16-17 June 2016 Moscow, Russia*, 2016.

[47] Yannick L'Horty and Nicolas Sobczak. Identification de la Courbe de Salaire et Déterminants du Chômage d'Équilibre Dans un Modèle de Négociation Salariale. resreport 96-7, Ministére de L'Economie et des Finances - Direction de la Prévision, 1996.

[48] Yannick L'Horty and Nicolas Sobczak. Les Déterminants du Chômage d'Équilibre: Estimation d'un Modèle WS-PS. *Économie & prévision*, 127(1):101–116, 1997.

[49] Alan Manning. Wage Bargaining and the Phillips Curve: the Identification and Specification of Aggregate Wage Equations. *The Economic Journal*, 103(416):98–118, 1993.

[50] M. O' Mahony and M. Timmer. Eu-klems database. Database, March 2011.

[51] OECD. Economic outlook. Technical Report 95/chap. 4, OECD, 2014.

[52] OECD. Effective innovation policies, in: The Innovation Imperative. Organisation for Economic Cooperation and Development. OECD Economics Department Working Papers 63, OECD, Dec. 2015.

[53] OECD. Business enterprise r-d expenditure by industry. Database, 2017.

[54] R. Ortega-Argiles, M.C. Piva, and M. Vivarelli. Productivity gains from r&d investment: Are high-tech sectors still ahead? *Economics of Innovation and New Technology*, 24:2014–222, 2015.

[55] L.L. Pasinetti. *Structural Change and Economic Growth.* University Press, Cambridge, 1981.

[56] L.L. Pasinetti. *Structural Economic Dynamic: A Theory of the Economic Consequences of Human Learning.* Cambridge Universoity Press, 1993.

[57] Pietro F Peretto. Technological change and population growth. *Journal of Economic Growth*, 3(4):283–311, 1998.

[58] B. Peters, B. Dachs, M. Dunser, M. Hud, C. Kohler, and C; Rammer. Firm Growth, Innovation and the Business Cycle. Technical report, Background Report for the 2014 Competitiveness Report, European Commission, May, 2014.

[59] M. Satchi. A note on adding-up restriction when modelling trade flows. *Economic Modelling*, 21(6):999–1002, Dec. 2004.

[60] Zuzana Smeets Kristkova, Cornelis Gardebroek, Michiel van Dijk, and Hans van Meijl. The impact of r&d on factor-augmenting technical change- an empirical assessment at the sector level. *Economic Systems Research*, 29:385–417, 2017.

[61] L. Soete and B. Verspagen. Convergence and divergence in growth and technical change: an empirical investigation. Technical report, Paper presented at the AEA annual meeting in Anaheim, Ca, January, 1993.

[62] Dominique Taddei, Simon Cueva, and Xavier Timbeau. Capacité de production et équilibre statique de sous-emploi en courte-moyenne période: L'impact des politiques de temps de travail. *Revue économique*, 43(1):31–54, 1992.

[63] Marcel P. Timmer, Erik Dietzenbacher, Bart Los, and Robert Stehrer. An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production. *Review of International Economics*, 23(3):575–605, 2015.

[64] B. Verspagen and I. De Loo. technology Spillovers between Sectors and ovet Time. *Technological Forecasting and Social Change*, 60:215–235, 1999.

Appendix

Nemesis sectoral nomenclature

Table 0.3.1: Correspondence between NEMESIS sectoral nomenclature and NACE Rev. 2 (1/2)

NEMESIS	NACE Rev.2	
1 Agriculture		
	A	Agriculture, forestry and fishing
2 Coal and Coke		
	B05	Mining of coal and lignite
	B07	Mining of metal ores
	B08	Other mining and quarrying
	B09	Mining support services activities
3 Oil & Gas Extraction		
	B06	Extraction of crude Petroleum and natural gas
4 Gas Distribution		
	D35.2	Manufacture of gas; distribution of gaseous fuels through mains
5 Refined Oil		
	C19	Manufacture of coke and refined petroleum products
6 Electricity		
	D35.1	Electric power generation, transmission and distribution
	D35.3	Steam and air conditioning supply
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 0.3.2: Correspondence between NEMESIS sectoral nomenclature and NACE Rev. 2 (2/2)

NEMESIS	NACE Rev.2	
21 Construction		
	F	Construction
22 Distribution		
	G	Wholesale and retail trade; Repair of motor vehicules 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
	H53	Postal and courier activities
27 Communication		
	J	Information and Communication
28 Bank. Finance & Insurance		
	K	Financial and Insurance activities
	L	Real estate activities
	N77	Rental and leasing activities
29 Other Market Services		
	M	Professional, scientific and technical 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
	Q	Human health and social work activities
	R	Arts, entertainment and recreation
	S94	Activities of membership organisations

NEMESIS consumption function nomenclature

Table 0.3.3: Correspondence between NEMESIS consumption function nomenclature and COICOP

NEMESIS		COICOP	
01	Food		
		01.1	Food
02	Beverages		
		01.2	Non-alcoholic beverages
		02.1	Alcoholic beverages
03	Tobacco		
		02.2	Tobacco
		02.3	Narcotics
04	Clothing and footwear		
		03	Clothing and footwear
05	Gross rent		
		04.1	Actual rentals for housing
		04.2	Imputed rentals for housing
06	Electricity		
		04.5.1	Electricity
07	Gas		
		04.5.2	Gas
08	Liquid Fuels		
		04.5.3	Liquid Fuels
09	Other fuels		
		04.5.4	Solid fuel
		04.5.5	Heat energy
10	Furnitures, etc.		
		05.1	Furniture and furnishings, carpets and other floor coverings
11	Households' textile		
		05.2	Household textiles
12	Major Appliance		
		05.3	Household appliances
13	Hardware		
		05.4	Glassware, tableware and household utensils
		05.5	Tools and equipment for house and garden
		05.6	Goods and services for routine household maintenance
14	Households' operation		
		04.3	Maintenance and repair of the dwelling
15	Domestic services		
		04.4	Water supply and miscellaneous services relating to the dwelling
16	Medical care and Education		
		06	Health
		10	Education
17	Cars, etc.		
		07.1	Purchase of vehicles
18	Gasoline, etc.		
		07.2	Operation of personal transport equipment
19	Rail Transport		
		07.3.1	Passenger transport by railway
20	Road Transport		
		07.3.2	Passenger transport by road
21	Air Transport		
		07.3.3	Passenger transport by air
22	Other Transport		
		07.3.4	Passenger transport by sea and inland waterway
		07.3.5	Combined passenger transport
		07.3.6	Other purchased transport services
23	Communication		
		08	Communication
24	Equipment and accessories		
		09.1	Audio-visual, photographic and information processing equipment
		09.2	Other major durables for recreation and culture
		09.3	Other recreational items and equipment, gardens and pets
25	Recreation		
		09.4	Recreational and cultural services
		09.5	Newspapers, books and stationery
		09.6	Package holidays
26	Hotel and restaurant		
		11	Restaurants and hotels
27	Misc. goods and services		

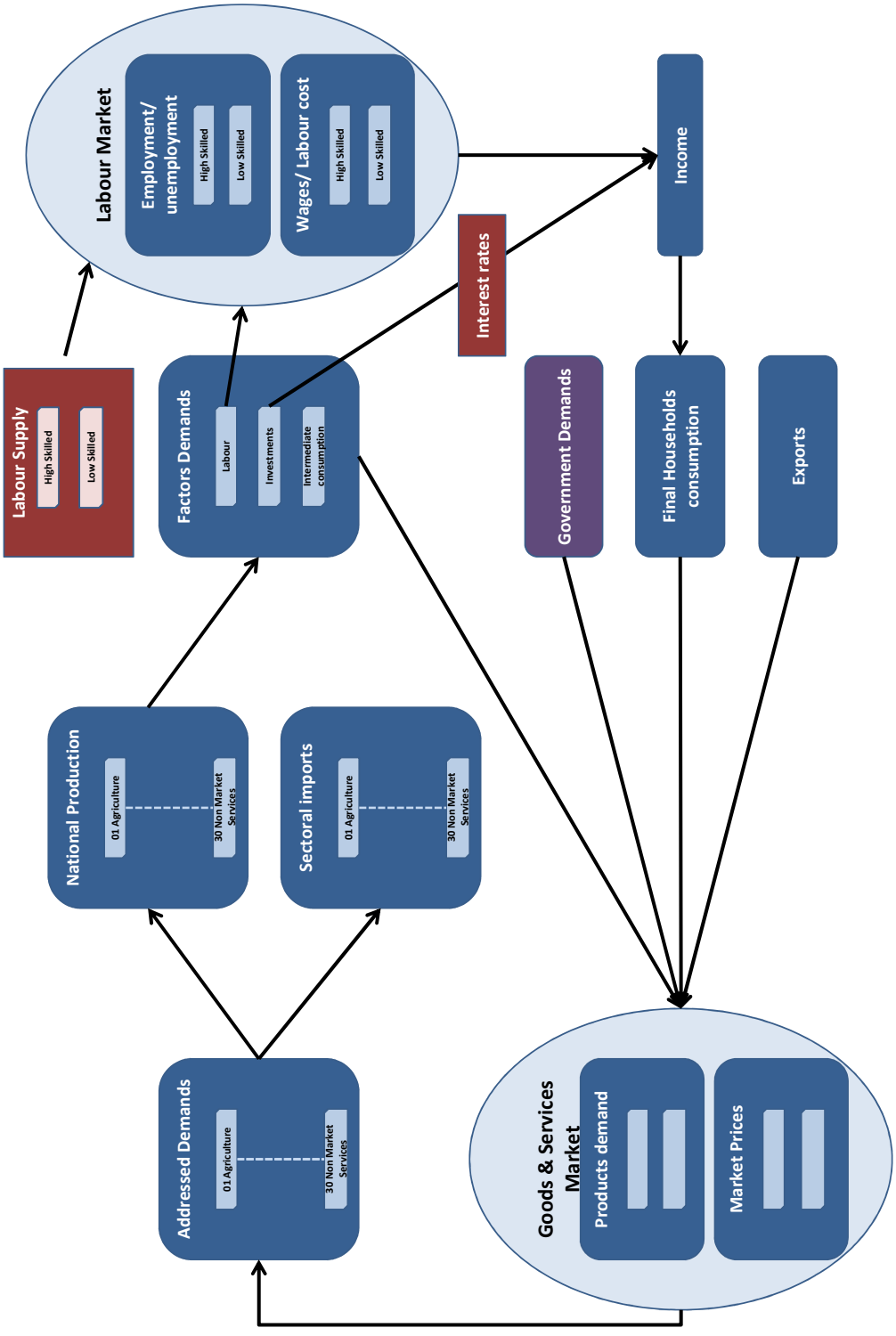


Figure 0.3.1: General functioning of NEMESIS