This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Modelling of the Research and Innovation Policies

MONROE - Modelling and evaluating the socio-economic impacts of research and innovation with the suite of macro- and regional-economic models

D4.3.2: Technical description of the R&I module of GEM-E3-RD model

March 2019: Public deliverable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Document Details

Authors	Kostas Fragkiadakis, Leonidas Paroussos, Pantelis Capros
Creation Date	09-2018
Date of Last Revision	03-2019
Version	7
Description	Final report

Version History

Version	Updated By	Date	Changes / Comments
1	Leonidas Paroussos	09-2018	Structure
2	Kostas Fragkiadakis	10-2018	Data and Econometric Estimations
3	Kostas Fragkiadakis	11-2018	Model Implementation on skills differentiation
4	Kostas Fragkiadakis	12-2018	Model Implementation on knowledge absorption
5	Kostas Fragkiadakis	01-2019	Model Implementation on public R&I decisions
6	Leonidas Paroussos	01-2019	Review
7	Pantelis Capros	03-2019	Review

Project Involvement

Project Director	Olga Ivanova
Project Manager	Iason Diafas
WP Manager	Leonidas Paroussos
Project Leads	E3M

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

1. Introduction

This report provides a technical description and the algebra related to the model developments that took place within the MONROE project. The GEM-E3 model has been extended so as to include: five labour skills, endogenous skills supply, endogenous knowledge absorption and stochastic public R&I decisions. This report is structured in the following way: i) the next section provides the technical description regarding the skills differentiation and endogenous labour skill supply, ii) the third section provides the technical description regarding the endogenous knowledge absorption and iii) the last section focuses on the public R&I decision in the new GEM-E3 model.

2. Skills differentiation and endogenous supply

The sets used in the skills differentiation and endogenous supply module of the new GEM-E3 model are presented in Table 2.1 and the subsets in Table 2.2.

Table 2.1: Sets in the skills differentiation and endogenous supply module

Set	Description
sk	Skill types: i) unskilled workers=1, ii) service and shop workers=2, iii) technicians=3, iv) clerks=4 and v) managers=5
pr	All sectors of the GEM-E3 model
r	All regions of the GEM-E3 model
t	Time period of the GEM-E3 model

Table 2.2: Subsets in the skills differentiation and endogenous supply module

Subsets	Description
Low[sk]	Low skilled types: i) unskilled workers, ii) service and shop workers
High[sk]	High skilled types: i) technicians, ii) clerks and iii) managers
$\Theta_1[pr]$:	All sectors except the power generation technologies and the electricity sectors
$\Theta_2[pr]$:	Set of the power generation technologies sectors
$\Theta_3[pr]$:	Set of the electricity Transmission and Distribution sector

Skills Demand

The optimal labour demand by skill is derived from the firms' cost minimization problem by using a constant elasticity of substitution (CES) production function under perfect competition. The nesting[1] of the CES production function depends on the substitution possibilities that characterize the production technology of each firm/production sector.

[1] The nesting for each branch can be found in the ANNEX of this report.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

The demand equations by skill type included in the model is:

$$LAV_{sk,pr,r,t} = \begin{cases} LAV_{sk,pr,r,0} \cdot e^{tgl_{sk,pr,r,t} \cdot (sn4_{pr,r,t}-1)} \cdot \dfrac{KL_{pr,r,t}}{KL_{pr,r,0}} \cdot \left(\dfrac{PKL_{pr,r,t}}{PKL_{pr,r,0}} \cdot \dfrac{PLAV_{sk,pr,r,0}}{PLAV_{sk,pr,r,t}}\right)^{sn4_{pr,r,t}} & pr \in \Theta_1 \\ & sk \in low \\ LAV_{sk,pr,r,0} \cdot e^{tgl_{sk,pr,r,t} \cdot (sn7_{pr,r,t}-1)} \cdot \dfrac{KLHS_{pr,r,t}}{KLHS_{pr,r,0}} \cdot \left(\dfrac{PKLHS_{pr,r,t}}{PKLHS_{pr,r,0}} \cdot \dfrac{PLAV_{sk,pr,r,0}}{PLAV_{sk,pr,r,t}}\right)^{sn7_{pr,r,t}} & pr \in \Theta_1 \\ & sk \in high \\ LAV_{sk,pr,r,0} \cdot e^{-tgl_{sk,pr,r,t}} \cdot \dfrac{Q_{pr,r,t}}{Q_{pr,r,0}} \cdot \left(tfp_{pr,r,t}\right)^{-1} & pr \in \Theta_2 \\ LAV_{sk,pr,r,0} \cdot e^{-tgl_{sk,pr,r,t}} \cdot \dfrac{DIST_{pr,r,t}}{DIST_{pr,r,0}} & pr \in \Theta_3 \end{cases}$$

where:

Name	**Type**	**Description**
$LAV_{sk,pr,r,t}$	Variable	Demand of Labour by skill type [sk], by sector [pr], by region [r] and by time [t]
$KL_{pr,r,t}$	Variable	Demand of Capital and Labour bundle by sector [pr], by region [r] and by time [t]
$KLHS_{pr,r,t}$	Variable	Demand of Capital and High skilled type Labour bundle by sector [pr], by region [r] and by time [t]
$Q_{pr,r,t}$	Variable	Production of products by sector [pr], by region [r] and by time [t]
$DIST_{pr,r,t}$	Variable	Transmission and distribution activity of the electricity sector [$pr \in \Theta_3$], by region [r] and by time [t]
$PKL_{pr,r,t}$	Variable	Unit price of the Capital and Labour bundle by sector [pr], by region [r] and by time [t]
$PLAV_{sk,pr,r,t}$	Variable	Unit price of Labour by skill type [sk], by sector [pr], by region [r] and by time [t]
$PKLHS_{pr,r,t}$	Variable	Unit price of Capital and High skilled type Labour bundle by sector [pr], by region [r] and by time [t]
$tgl_{sk,pr,r,t}$	Parameter	Technical progress of labour by skill type [sk], by sector [pr], by region [r] and by time [t]
$tfp_{pr,r,t}$	Parameter	Total factor productivity by sector [pr], by region [r] and by time [t]
$sn4_{pr,r,t}$	Parameter	Elasticity of substitution between the bundle of the Low skilled types and the bundle of the Capital and High skilled type Labour bundle by sector [pr], by region [r] and by time [t]
$sn7_{pr,r,t}$	Parameter	Elasticity of substitution between the bundle of the High skilled types and the Capital by sector [pr], by region [r] and by time [t]
$KL_{pr,r,0}$	Parameter	Demand of Capital and Labour bundle by sector [pr], by region [r] at the base year [0]
$KLHS_{pr,r,0}$	Parameter	Demand of Capital and High skilled type Labour bundle by sector [pr], by region [r] at the base year [0]
$Q_{pr,r,0}$	Parameter	Production of products by sector [pr], by region [r] at the base year [0]
$DIST_{pr,r,0}$	Parameter	Transmission and distribution activity of the electricity sector [$pr \in \Theta_3$], by region [r] at the base year [0]
$LAV_{sk,pr,r,0}$	Parameter	Demand of Labour by skill type [sk], by sector [pr], by region [r] at the base year [0]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Name	Type	Description
$PKL_{pr,r,0}$	Parameter	Unit price of the Capital and Labour bundle by sector [pr], by region [r] at the base year [0]
$PLAV_{sk,pr,r,0}$	Parameter	Unit price of Labour by skill type [sk], by sector [pr], by region [r] at the base year [0]
$PKLHS_{pr,r,0}$	Parameter	Unit price of Capital and High skilled type Labour bundle by sector [pr], by region [r] at the base year [0]

The technical progress of labour $tgl_{sk,pr,r,t}$ is econometrically estimated by utilising the EUROSTAT database, in particular linking the technical progress of labour with the skill levels of employees (identifying low, medium and high-skilled employees. Equation (1) has been used to estimate the labour productivity across the EU Member States.

$$\log(tgl_t) = a_1 \cdot shLS_t + a_2 \cdot shMS_t + a_3 \cdot shHS_t + \rho \cdot AR(1) + \varepsilon_t \qquad (1)$$

where:

Name	Type	Description
tgl_t	Endogenous Variable	Labour productivity per hour worked[2] (index 2010 = 100)
$shLS_t$	Exogenous Variable	Share of low skilled employees[3] to total employment[4]
$shMS_t$	Exogenous Variable	Share of medium skilled employees to total employment
$shHS_t$	Exogenous Variable	Share of high skilled employees to total employment
$AR(1)$	Exogenous Variable	Autoregressive part of order (1)

The EViews code used for the estimation of the labour productivity can be found in the annex (E-Views code on labour productivity estimation).

Skills Supply

The labour supply equation used in the GEM-E3 model is:

$$LFRC_{sk,r,t} = LFRC_{sk,r,0} + NLFRC_{sk,r,t} - OLFRC_{sk,r,t}$$

where:

Name	Type	Description
$LFRC_{sk,r,t}$	Variable	Labour force by skill type [sk], by region [r] and by time [t]
$NLFRC_{sk,r,t}$	Variable	New labour force by skill type [sk], by region [r] and by time [t]

[2] Available at: http://ec.europa.eu/eurostat/cache/metadata/EN/tsdec310_esmsip.htm.
[3] Available at: http://ec.europa.eu/eurostat/web/lfs/data/database.
[4] Total employment is computed as the sum of the employees with low skills (less than primary, primary and lower secondary education (levels 0-2)), of the employees with medium skills (upper secondary and post-secondary non-tertiary education (levels 3 and 4)), and of employees with high skills (tertiary education (levels 5-8)).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Name	Type	Description
$OLFRC_{sk,r,t}$	Parameter	Labour force removed from the labour force by skill type [sk], by region [r] and by time [t] (i.e. due to retirement)
$LFRC_{sk,r,0}$	Parameter	Labour force by skill type [sk], by region [r] at the base year [0]

In year *t*, the working age population, which belong to a specific age cohort[5], can select between getting a higher education level or become unskilled workers (attain the minimum "obligatory" education level) during its entire lifetime. Based on their education choice, the young people are included in the labour force at different points in time.

The new labour force ($NLFRC_{sk,r,t}$) is an endogenous cumulative variable that accumulates the working age population[6] that in the period t are added in the labour force of each skill type (households that have concluded education):

$$NLFRC_{sk,r,t} = NLFRC_{sk,r,t-1} + ETIME1_{sk} \cdot shEDU_{sk,r,t} \cdot INLFRC_{r,t} + ETIME2_{sk} \cdot shEDU_{sk,r,t-1} \cdot INLFRC_{r,t-1} + ETIME3_{sk} \cdot shEDU_{sk,r,t-2} \cdot INLFRC_{r,t-2}$$

where:

Name	Type	Description
$INLFRC_{r,t}$	Parameter	Exogenously given working age population that in the period t can be added in the labour force based on its' decision for education by region [r] and by time [t]
$shEDU_{sk,r,t}$	Variable	Shares of $INLFRC_{sk,r,t}$ for education by skill type [sk], by region [r] and by time [t] (representing households' decision for education)
$ETIME1_{sk}$	Parameter	Shares of allocation in time based on the education choice at the period t, by skill type [sk]
$ETIME2_{sk}$	Parameter	Shares of allocation in time based on the education choice at the period t-1, by skill type [sk]
$ETIME3_{sk}$	Parameter	Shares of allocation in time based on the education choice at the period t-2, by skill type [sk]

The model identifies one representative household per country/region. Household selects the share $shEDU_{sk,r,t}$ of available hours that will be directed to education in order to maximize its intertemporal labour income (taking into account unemployment levels). The mathematical formulation of the households' decision for schooling can be found in the Deliverable 3.4.1: *"Working paper describing the methodology to incorporate human capital and intangible assets in the CGE model of the MONROE project"*.

The choice on education of the working age population $INLFRC_{r,t}$ (that in the period t can be added to the labour force based on its' decision for education) is given by:

[5] We assume that the age cohort that decide its education is the young people at the age of 17..
[6] The model runs at a five year time step. It is assumed that the education choice also represents the period of the subsequent years (i.e. the choice at the year 2020 is assumed to represent the period 2016 – 2020).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

$$shEDU_{sk,r,t} = \begin{cases} \frac{1}{2 \cdot eG_{sk,r,t}} \cdot \left[1 - \frac{w_{sk=1,r,t} \cdot (1 - u_{sk=1,r,t}) \cdot (1+dr)^{eT_{sk}} + eC_{sk,r,t} \cdot dr \cdot (1+dr)^{eT_{sk}}}{w_{sk,r,t} \cdot (1 - u_{sk,r,t})}\right] & sk > 1 \\ 1 - \sum_{sk>1} shEDU_{sk,r,t} & sk = 1 \end{cases}$$

where:

Name	**Type**	**Description**
$eG_{sk,r,t}$	Parameter	The expected change in the future wage rate in relation to the education shares by skill type [sk], by region [r] and by time [t]
$w_{sk,r,t}$	Variable	Wage rate by skill type [sk], by region [r] and by time [t]
$u_{sk,r,t}$	Variable	Unemployment rate by skill type [sk], by region [r] and by time [t]
dr	Parameter	Discount rate
eT_{sk}	Parameter	Schooling years by skill type [sk] and by region [r]
$eC_{sk,r,t}$	Parameter	Education cost by skill type [sk], by region [r] and by time [t]

Labour Market

For each skill category the demand-supply mismatch results into a skill specific unemployment rate. The model assumes full labour mobility across sector for each skill type.

$$\sum_{pr} LAV_{sk,pr,r,t} = LFRC_{sk,r,t} \cdot (1 - u_{sk,r,t})$$

The supply of labour for each skill is determined via an empirically determined wage curve. The labour supply function is calibrated to a wage elasticity of -0.1. The wage function for each labour skill is:

$$w_{sk,r,t} = a_{sk,r,t} + \frac{b_{sk,r,t}}{(u_{sk,r,t} - \delta_{sk,r,t})^{sw_{sk,r,t}}}$$

where:

Name	**Type**	**Description**
$a_{sk,r,t}$	Parameter	Unemployment benefit/minimum wage by skill type [sk], by region [r] and by time [t]
$b_{sk,r,t}$	Parameter	Scale parameter in the wage curve by skill type [sk], by region [r] and by time [t]
$\delta_{sk,r,t}$	Parameter	Natural rate of unemployment by skill type [sk], by region [r] and by time [t]
$sw_{sk,r,t}$	Parameter	Elasticity parameter in the wage curve by skill type [sk], by region [r] and by time [t]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

The factor price of labour by skill takes into account the firms social security contribution:

$$PLAV_{sk,pr,r,t} = \left(1 - txfss_{pr,r,t}\right) \cdot w_{sk,r,t}$$

where:

Name	Type	Description
$txfss_{pr,r,t}$	Parameter	Social security tax rate by sector [pr], by region [r] and by time [t]

3. Endogenous knowledge absorption mechanism

The GEM-E3 model differentiates between public and private R&D expenditures. The public R&D expenditures are specified exogenously whereas the private R&D expenditures are decided endogenously by each firm. The R&D services are provided by a sector that is explicitly represented in the model as a separate activity and each firm decide its demand for R&D by maximizing its profits.

Each firm uses a constant elasticity of substitution (CES) production technology, the nesting of the CES production function depends on the substitution possibilities[7] that characterizes the production technology of each firm. The complete nesting structure and associated demand functions of the GEM-E3 model are available in the Annex[8]. Below we illustrate the one level case together with the respective derived demands:

$$Q_{i,r,t} = \bar{Q}_{i,r} \cdot \left(\sum \theta_{i,j,f,r,t} \cdot \left(\frac{QF_{i,f,r,t}}{\overline{QF}_{i,f,r}} \right)^{\rho} \right)^{\frac{1}{\rho}}$$

$$QF_{i,f,r,t} = \overline{QF}_{i,f,r} \cdot \frac{Q_{i,r,t}}{\bar{Q}_{i,r}} \cdot \left(\frac{\overline{PQF}_{i,f,r}}{\bar{P}_{i,r}} \cdot \frac{P_{i,r,t}}{PQF_{i,f,r,t}} \right)^{\sigma}$$

where

j: sector, r: region, t: time

$Q_{i,r,t}$: production in volume for activity i.

$\bar{Q}_{i,r}$: production in volume for activity i (base year).

$QF_{i,f,r,t}$: amount of production factor f used in production.

$\overline{QF}_{i,f,r}$: amount of production factor f used in production (base year).

$PF_{i,f,r,t}$: unit cost of factor f.

$\overline{PF}_{i,f,r}$: unit cost of factor f (base year).

$P_{i,r,t}$: unit cost of production for activity i.

$\bar{P}_{i,r}$: unit cost of production for activity i (base year).

---

[7] The subsitution elasticities for the EU countries are econometrically estimated Fragkiadakis K., Paroussos L., Kouvaritakis., Capros P. "Country econometric estimation of the elasticity of substitution ", WIOD, 2012. The elasticities for non-EU countries are taken from the GTAP database. A detailed overview of the elasticities used in the GEM-E3 model can be found at Capros et al (2013). The substitution elasticities between capital and energy for a number (12) of EU countries are based on the "Case study – Energy Resilience and Vulnerability in the EU and Other Global Regions", Richard L. et al (2017).

[8] The R&D sector is included in the material bundle in each nesting scheme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

$\theta_{i,j,f,r,t}$: share parameter
ρ: elasticity $\left(\rho = \frac{\sigma-1}{\sigma}\right)$
σ: elasticity of substitution

The derived demand for R&D by each sector is given by:

$$QRD_{i,f,r,t} = \overline{QRD}_{i,f,r} \cdot \frac{Q_{i,r,t}}{\bar{Q}_{i,r}} \cdot \left(\frac{\overline{PRD}_{i,f,r}}{\bar{P}_{i,r}} \cdot \frac{P_{i,r,t}}{PRD_{i,f,r,t}}\right)^{\sigma}$$

where

$QRD_{i,f,r,t}$: demand for R&D expenditures.
$\overline{QRD}_{i,f,r}$: demand for R&D expenditures in base year.
$PRD_{i,f,r,t}$: unit cost of R&D.
$\overline{PRD}_{i,f,r}$: unit cost of R&D in base year.

The total demand for R&D is used to build the R&D cumulative stock which is linked with the total factor productivity. In the model total factor productivity is composed from an endogenous ($tfp^{endo}_{pr,r,t}$) and an exogenous part ($tfp^{exo}_{pr,r,t}$). The endogenous part of tfp is composed of i) the learning by doing ($tfpLD_{pr,r,t}$), ii) the learning by research ($tfpLRHC_{pr,r,t}$), iii) the knowledge spillovers ($tfpSPILL_{pr,r,t}$), iv) the human capital stock measure and v) the tfp of the previous period ($tfpLAG_{pr,r,t}$):

$$tfp_{pr,r,t} = tfp^{exo}_{pr,r,t} \cdot tfp^{endo}_{pr,r,t}$$

$$tfp^{endo}_{pr,r,t} = tfpLD_{pr,r,t} \cdot tfpLRHC_{pr,r,t} \cdot tfpSPILL_{pr,r,t} \cdot tfpLAG_{pr,r,t}$$

Human capital index

The availability of Human Capital is essential to enable productivity growth induced by R&D and knowledge spillovers. The index of human capital stock (the HC variable) is constructed based on the shares of each skill type to the total labour force. The index is expressed by the following formula:

$$HC_{r,t} = \sum_{sk}\left[\frac{w_{sk,r,t-1}}{\min\limits_{c} w_{sk=1,c,0}} \cdot \frac{LFRC_{sk,r,t-1}}{\sum_{sk} LFRC_{sk,r,t-1}}\right]$$

where: $\frac{w_{sk,r,t}}{\min\limits_{c} w_{sk=1,c,0}}$, are the weights corresponding to relative annual earnings between each category and country and therefore indicating that the respective skills embodied at each skill type are more productive as those in the lowest skill type (sk=1).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Absorption rates

The R&D capacity of firms is linked to human capital availability through:

$$tfpLRHC_{pr,r,t} = \left(\frac{\sum_{pr} cumRD_{pr,r,t}}{\min_c \sum_{pr} cumRD_{pr,c,0}}\right)^{\beta_{LR}} \quad and \;\; \beta_{LR} = \gamma_{LR} \cdot ln\left(\frac{HC_{r,t}}{\min_c HC_{c,0}}\right)$$

where:

Name	Type	Description
$tfpLRHC_{pr,r,t}$	Variable	The total factor productivity attributed to the link between the human capital and the cumulative R&D capacity by sector [pr], by region [r] and by time [t]
$cumRD_{pr,r,t}$	Variable	The cumulative R&D capacity linked with human capital by sector [pr], by region [r] and by time [t]
$HC_{r,t}$	Variable	The human capital index by region [r] and by time [t]
β_{LR}	Parameter	The elasticity of the cumulative R&D stock with respect to total factor productivity, which is a function of the human capital stock.
γ_{LR}	Parameter	The relation of the human capital stock with the learning by research rate.
$cumRD_{pr,r,0}$	Parameter	The linked with human capital cumulative R&D capacity by sector [pr], by region [r] at the base year [0]
$HC_{r,0}$	Parameter	The human capital index by region [r] at the base year [0]

The cumulative R&D expenditures are expressed by the following formula (which takes into account that the GEM-E3 model has a 5 year time step):

$$CUMRD_{pr,r,t} = (1-\delta RD)^{\Delta t} \cdot CUMRD_{pr,r,t-1} + RD_{pr,r,t-1} \cdot \left[\frac{(1-\delta RD)^{\Delta t+1} - 1}{(1-\delta RD) - 1} - 1\right]$$

where:

Name	Type	Description
$RD_{pr,r,t}$	Variable	The R&D intermediate demand by sector [pr], by region [r] and by time [t]
δRD	Parameter	The R&D depreciation rate
Δt	Parameter	Time step

Each sector decides on its R&D expenditures based on its production function and the corresponding share of R&D expenditures in intermediate demand. The R&D sector is represented as a separate production sector in the GEM-E3 model.

The capacity of firms to absorb knowledge spillovers is linked to human capital availability through:

$$tfpSPILL_{pr,r,t} = \left(\frac{\sum_{pr} cumSPILL_{pr,r,t}}{\min_c \sum_{pr} cumSPILL_{pr,c,0}}\right)^{\beta_{SPILL}} \quad and \;\; \beta_{SPILL} = \gamma_{SPILL} \cdot ln\left(\frac{HC_{r,t}}{\min_c HC_{c,0}}\right)$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

where:

Name	Type	Description
$tfpSPILL_{pr,r,t}$	Variable	The total factor productivity which is attributed on the link between the human capital and the spillovers by sector [pr], by region [r] and by time [t]
$cumSPILL_{pr,r,t}$	Variable	The linked with human capital cumulative spillovers by sector [pr], by region [r] and by time [t]
β_{SPILL}	Parameter	The elasticity of the cumulative spillovers with respect to total factor productivity, which is a function of the human capital stock.
γ_{SPILL}	Parameter	The interaction of the human capital stock to the elasticity of the cumulative spillovers on total factor productivity
$cumSPILL_{pr,r,0}$	Parameter	The linked with human capital cumulative spillovers by sector [pr], by region [r] at the base year [0]

Spillovers are proxied by applying the bilateral imports shares to the R&D expenditures by country so as to capture all sectors. This measure is used to approximate the knowledge absorption from the innovations produced by foreign countries. It is assumed that the rate of absorption is analogous to bilateral trade shares. The spillovers measure is expressed by the following formula:

$$cumSPILL_{pr,r,t} = \sum_{c} \frac{BTR_{pr,r,c,0}}{\sum_{cc} BTR_{pr,r,cc,0}} \cdot cumRD_{pr,c,t}$$

where:

Name	Type	Description
$BTR_{pr,r,c,t}$	Parameter	The bilateral imports of country r from country c, by sector [pr] at the base year [0]

The total factor productivity is linked with the previous period total factor productivity through the $tfpLAG_{pr,r,t}$:

$$tfpLAG_{pr,r,t} = \left(tfp_{pr,r,t-1}\right)^{\rho_{r,t}}$$

where:

Name	Type	Description
$\rho_{r,t}$	Parameter	The first order autoregressive part of the total factor productivity

Econometric Estimations

Cross country data for the EU 27[9] member states for the period 2005-2016 and data for R&D expenditures for China, USA, Korea, Japan and Russia have been utilized to estimate econometrically the parameters γ_{LR}, γ_{SPILL} and $\rho_{r,t}$. Panel data techniques are used to estimate (at the level of total economy) the relationship between the total factor productivity and the

[9] Malta is excluded due to lack of data on gross value added in chain linked volumes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

ability of the total economy to absorb R&D and spillovers knowledge. The estimated equation with random cross section effects and fixed time period effects is:

$$ln(TFP_{r,t}) = \gamma_0 + \gamma_1 \cdot ln\left(\frac{HC_{r,t}}{\min\limits_{c,t} HC_{c,t}}\right) \cdot ln\left(\frac{CUMRD_{r,t}}{\min\limits_{c,t} CUMRD_{c,t}}\right) + \gamma_2 \cdot ln\left(\frac{HC_{r,t}}{\min\limits_{c,t} HC_{c,t}}\right) \cdot ln\left(\frac{CUMSPILL_{r,t}}{\min\limits_{c,t} CUMSPILL_{c,t}}\right) + \rho \cdot ln(TFP_{r,t-1}) + u_{r,t}$$

Based on the data available[10] the estimates of the parameters γ_{LR}, γ_{SPILL} and $\rho_{r,t}$ to be used in the GEM-E3 model are: $\gamma_{LR} = 0.000878$, $\gamma_{SPILL} = 0.014236$, and $\rho_{r,t} = 0.954733$. A detailed representation of the econometric techniques and the methodology used to estimate the absorption rates of the learning by research and spillovers can be found in the Deliverable D3.4.2 of the MONROE project.

4. Public R&D decision

Public R&D expenditures are assumed to increase the global stock of knowledge by sector. The stock of knowledge accumulates according to the following function:

$$cumPBRD_{pr,t} = cumPBRD_{pr,t-1} \cdot (1 - \delta PBRD)^{\Delta t} + \sum_r PBRD_{pr,r,t} \cdot \left[\frac{(1 - \delta PBRD)^{\Delta t+1} - 1}{(1 - \delta PBRD) - 1} - 1\right]$$

where:

Name	Type	Description
$cumPBRD_{pr,t}$	Variable	The cumulative stock of public knowledge by sector [pr] and by time [t]
$PBRD_{pr,r,t}$	Variable	The R&D public expenditures by sector [pr], by region [r] and by time [t]
$\delta PBRD$	Parameter	Depreciation rate of public knowledge

The cumulative stock of knowledge interacts with the unit cost of production of clean energy technologies (namely solar PV, wind turbines, electric vehicles, batteries, biofuels) via a total factor productivity by assuming a learning curve, where the total factor productivity is the output of learning-by research:

$$tfpPBRD_{pr,r,t} = \left(\frac{cumPBRD_{pr,t}}{cumPBRD_{pr,0}}\right)^{\lambda_{pr,t}(\omega)}, \lambda_{pr,t}(\omega) = -\frac{log\left(1 - LR_{pr,t}(\omega)\right)}{\log(2)}$$

[10] All the data used in the estimation process can be found in the excel file that accompanies this deliverable.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

where:

Name	Type	Description
$cumPBRD_{pr,0}$	Parameter	The cumulative stock of public knowledge by sector [pr] at the base year [0]
$\lambda_{pr,t}(\omega)$	Variable	The elasticity that captures the percentage reduction in costs associated with an increase in learning measured as cumulative knowledge by sector [pr] and by time [t]
$LR_{pr,t}(\omega)$	Variable	The uncertain learning by research rate by sector [pr] and by time [t]
ω	Variable	A random number drawn from a normal distribution with mean value equal to the deterministic learning rates and standard deviation equal the 1/3 of the mean.

The total factor productivity is modified so as to take into account the effect on total factor productivity from the public R&D expenditures:

$$tfp_{pr,r,t} = tfp_{pr,r,t}^{exo} \cdot tfp_{pr,r,t}^{endo} \cdot tfpPBRD_{pr,t}$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

References

Capros, P., Van Regemorter, D., Paroussos, L., Karkatsoulis, P., Fragkiadakis, K., Tsani, S., Charalampidis, I., Revesz, T. (2013). GEM-E3 Model Documentation. Joint Research Centre, Luxembourg, Publications Office of the European Union, 2013. (JRC83177, EUR 26034 EN, ISBN 978-92-79-31463-6, ISSN 1831-9424).

Fragkiadakis K., Paroussos L., Kouvaritakis N., Capros P., (2012), "A Multi - Country Econometric Estimation of the Constant Elasticity of Substitution". Paper presented at the Final WIOD Conference: Causes and Consequences of Globalization, Groningen, The Netherlands, April 24-26.

GTAP: https://www.gtap.agecon.purdue.edu/

R. Lewney, S. Perkins, K. Fragkiadakis, L. Paroussos, P. Capros (2017), "Case study – Energy Resilience and Vulnerability in the EU and Other Global Regions", Technical report on the Macroeconomics of Climate and Energy Policies, European Commission, DG ENER

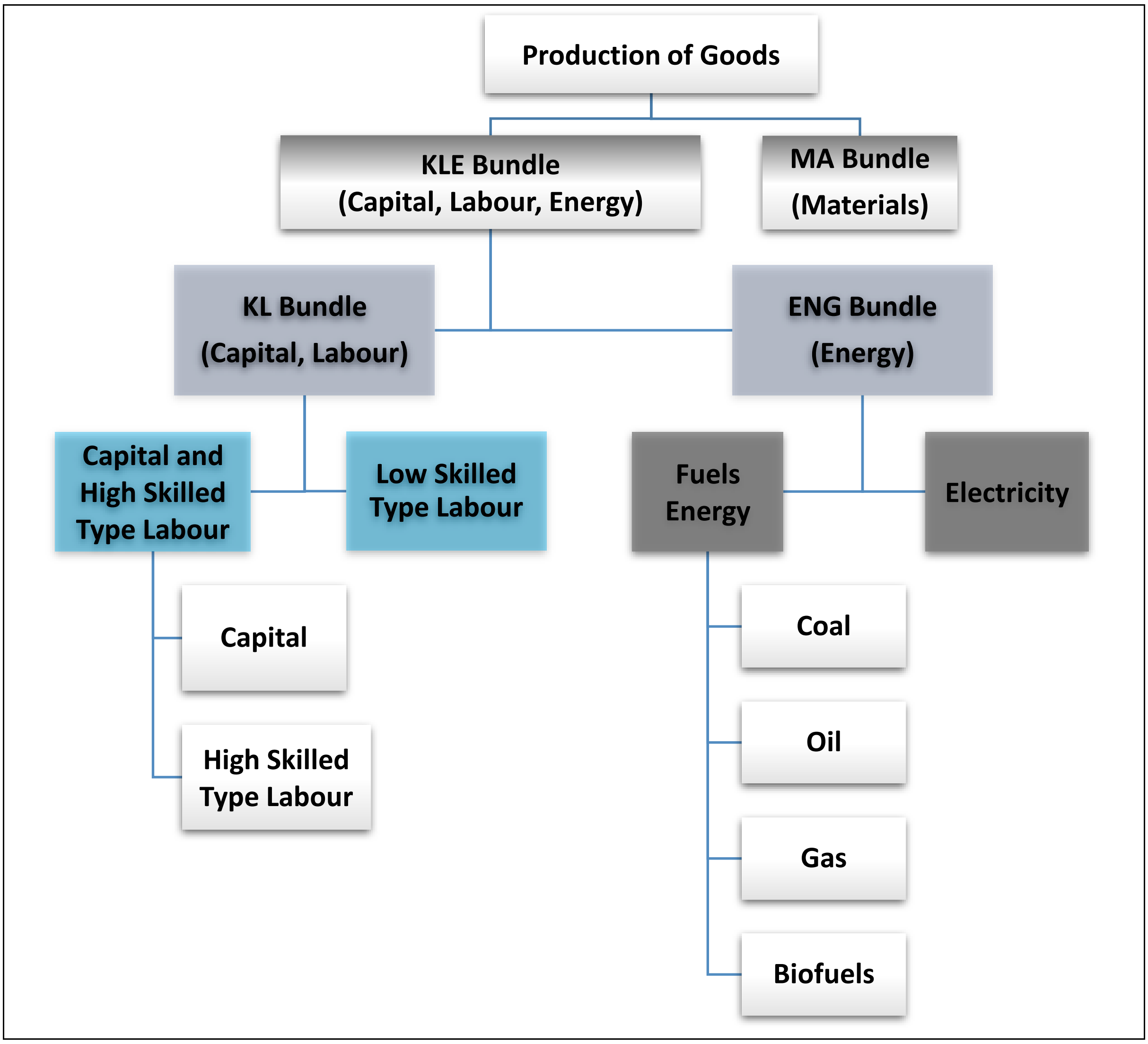
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

ANNEX

Nesting production functions by branch

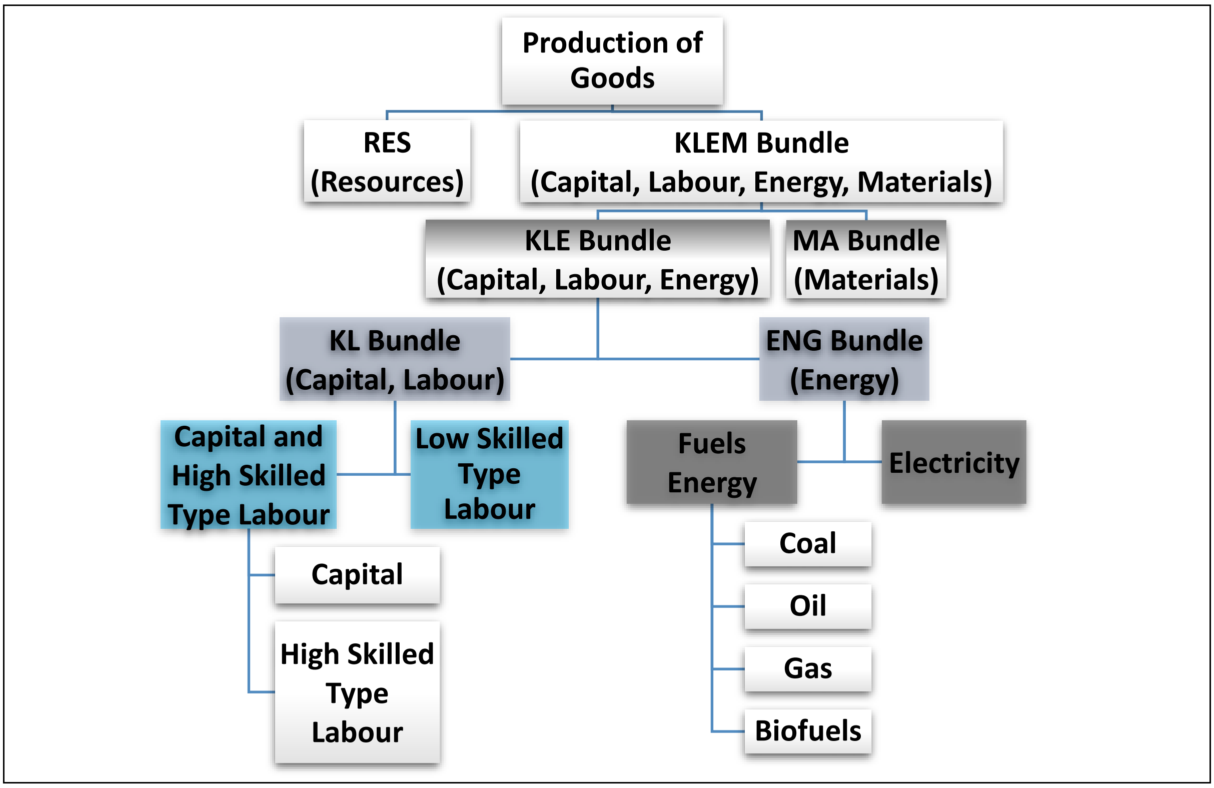
Domestic activity in GEM-E3-MONROE model is defined by branch. The nesting structure of the different activities included in the model are presented below. A detailed representation including the algebraic formulation can be found in the Deliverable 3.4.1: Working paper describing the methodology to incorporate human capital and intangible assets in the CGE model of the MONROE project.

Nesting of the agriculture, industry and services sectors

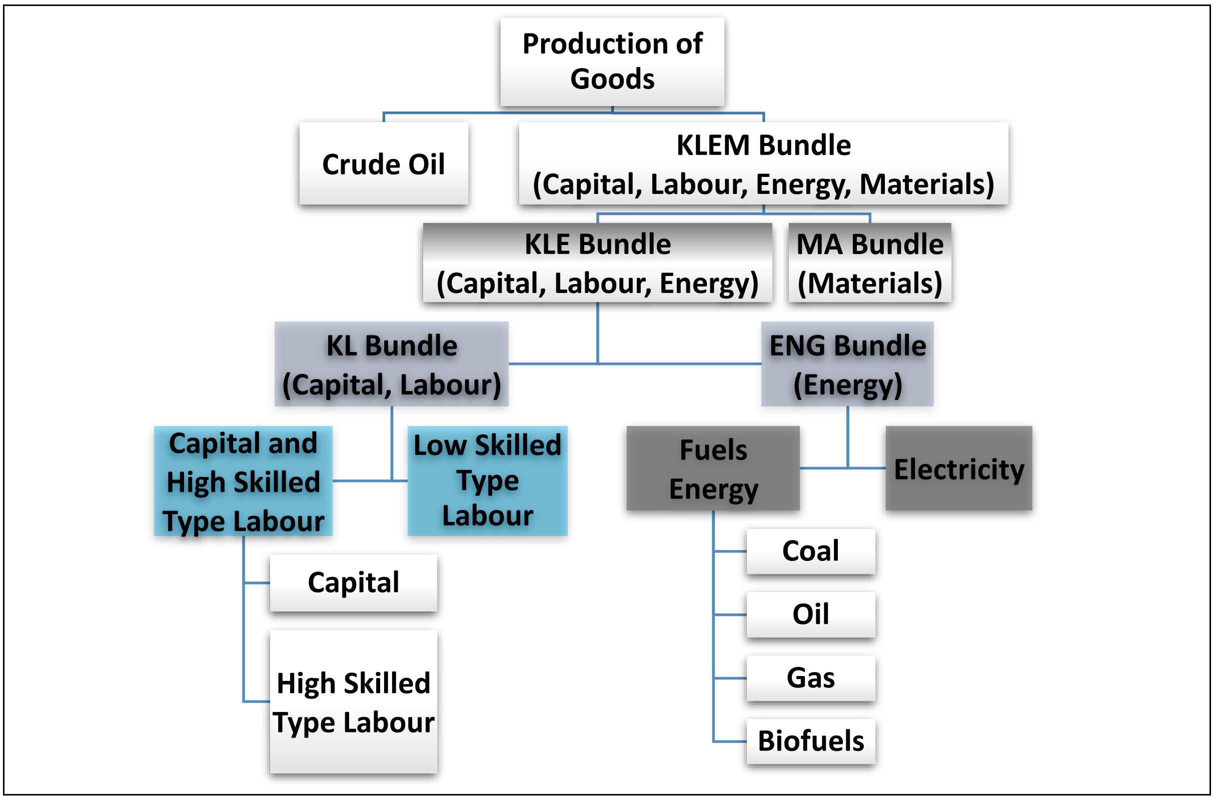


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Nesting of the resource sectors

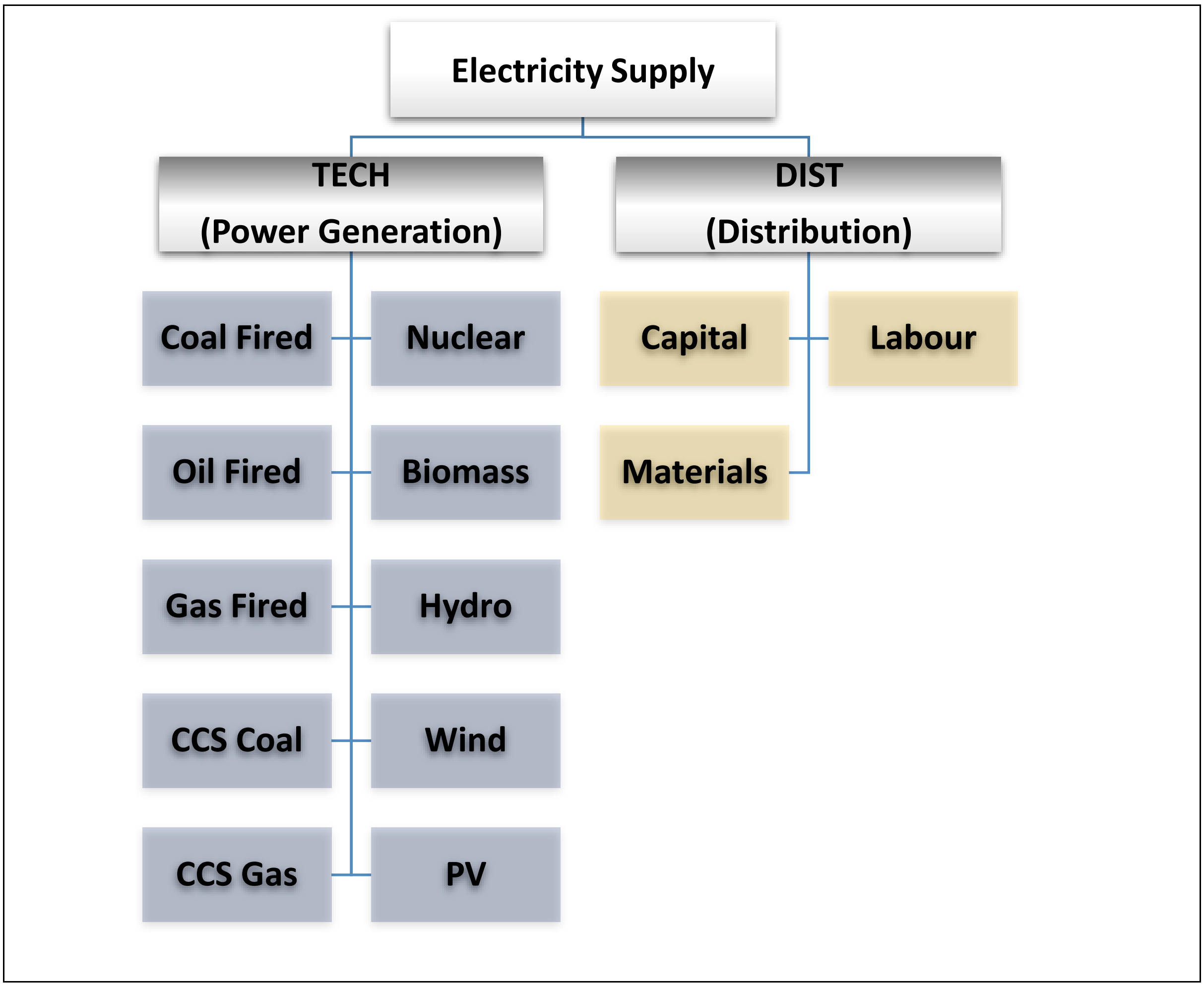


Nesting of the refineries sectors

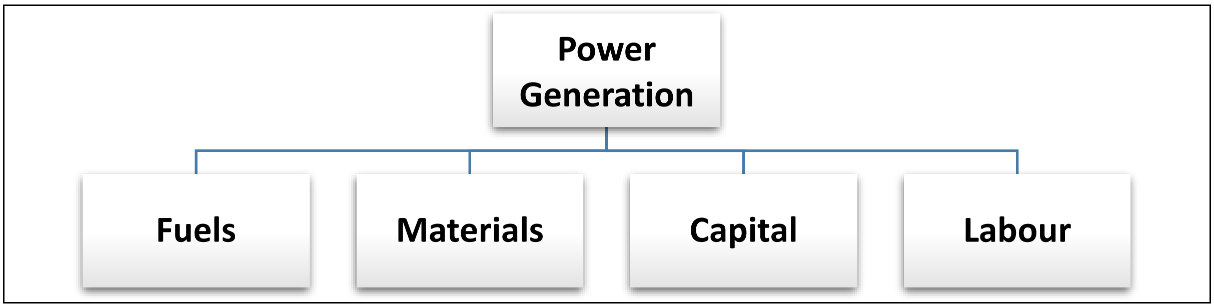


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

Nesting of the electricity supply sector



Nesting of the power producing technologies



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727114

E-Views code on labour productivity estimation

```
'Begin Loop [Different regions]
for %reg  AT_ BE_ BG_ CY_ CZ_ DE_ DK_ EE_ EL_ ES_ EU28_ FI_ FR_ HR_ HU_ IE_ IT_ LT_ LU_ LV_ MT_ NL_ PL_ PT_ RO_
SE_ SI_ SK_ UK_
GENR  {%reg}shLS = {%reg}LS / ({%reg}LS + {%reg}MS + {%reg}HS)
GENR  {%reg}shMS = {%reg}MS / ({%reg}LS + {%reg}MS + {%reg}HS)
GENR  {%reg}shHS = {%reg}HS / ({%reg}LS + {%reg}MS + {%reg}HS)
next
'Counter
!i = 0
'Begin Loop [Different regions]
for %reg  AT_ BE_ BG_ CY_ CZ_ DE_ DK_ EE_ EL_ ES_ EU28_ FI_ FR_ HR_ HU_ IE_ IT_ LT_ LU_ LV_ MT_ NL_ PL_ PT_ RO_
SE_ SI_ SK_ UK_
'Define a Table to store estimation results
table(180,14)  OLS_Estimates
'Define names of the variables dynamically
    %name = %reg
    %var0    = "TGL"
    %var1    = "shLS"
   %var2    = "shMS"
   %var3    = "shHS"
   %var4    = "GDP"
'Define the dependent and independent variables of the regression
        %DEP1 = %name + %var0
        %IND1  =  %name + %var1
        %IND2  =  %name + %var2
        %IND3  =  %name + %var3
        %IND4  =  %name + %var4
'.ls corresponds to least square,
equation eq{%name}.ls  log({%DEP1})  ({%IND1}) ({%IND2})  ({%IND3})  AR(1)
'Store the results of each regression i=1 for the first equation, i=2 for the second etc.
!i = !i + 1
'Store the name of the dependent variable
        OLS_Estimates(!i, 1) = %reg
'Store the estimation for the coefficient C(2) from the regression [substitution of elasticity]
        OLS_Estimates(!i, 2) = c(1)
'Store the standard error
        OLS_Estimates(!i, 3) = eq{%name}.@tstats(1)
'Store the estimation for the coefficient C(2) from the regression
        OLS_Estimates(!i, 4) = c(2)
'Store the t-statistic
        OLS_Estimates(!i, 5) = eq{%name}.@tstats(2)
'Store the estimation for the coefficient C(3) from the regression
        OLS_Estimates(!i, 6) = c(3)
'Store the t-statistic
        OLS_Estimates(!i, 7) = eq{%name}.@tstats(3)
'Store the estimation for the coefficient C(4) from the regression
        OLS_Estimates(!i, 8) = c(4)
'Store the t-statistic
        OLS_Estimates(!i, 9) = eq{%name}.@tstats(4)
'Store the R-squared
        OLS_Estimates(!i, 10) = eq{%name}.@r2
'Store the degrees of freedom
       OLS_Estimates(!i,11) = eq{%name}.@df
'Delete each time the dynamic object of the equation so as to have one table of results instead of multi equation objects
        delete eq{%name}
next
```