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The RHOMOLO-IO modelling framework: a flexible Input-Output tool for policy analysis

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Abstract

This Technical Report describes the features of the RHOMOLO-IO model and demonstrates its flexibility by showing a number of recent policy-relevant applications for which it has been used. Such applications include, for instance, the study of the European Globalisation Fund, of four TEN-T investment projects, of the European research and innovation regional funds, and of regulatory proposals on the energy union in the EU. The paper contains traditional input-output multipliers analyses applied to output, GDP, and employment, as well as consumption redistribution and trade analyses. The flexibility of the RHOMOLO-IO framework makes it useful for a wide range of policy-relevant studies and makes it a perfect complement to the spatial computable general equilibrium RHOMOLO.

The RHOMOLO-IO modelling framework: a flexible Input-Output tool for policy analysis

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1 Introduction

In recent years there has been a surge in the use of economic models for the ex-ante evaluation of the macroeconomic effects of both national and supranational public policies. The results of the economic simulations generated by such models help decision-makers to form better expectations on the effects of the planned policies. More in general, the scientific evaluation of programmes involving, for example, public investment and industry support is seen as an important part of the democratic process together with, among other things, media scrutiny and the influence of public opinion.

Thissen et al. (2019) describe the construction of a Multi-Regional Input-Output (MRIO) table for the EU28 at the NUTS 2 regional level. While the main purpose of such data is the base-year calibration of the spatial Computable General Equilibrium (CGE) model RHOMOLO (Lecca et al., 2018) developed by the European Commission's Joint Research Centre (JRC), the dataset itself can be exploited for additional uses.

This paper illustrates how the application of a standard Input-Output (IO) model, the so-called Leontief (1941, 1986) model, can generate a variety of results which can be of interest for both researchers and policy makers. The key idea behind the Leontief model lies in the representation of sectoral interdependence; in turn, this can be further extended to include inter-regional dependence by linking MRIO tables via trade flows of goods and services among regions (Isard, 1951; Moses, 1955 and 1960; Miller, 1966). This type of models has been mainly used in the field of environmental economics (see, for example, Yazan et al., 2017, and De Koning et al., 2016), but alternative applications are numerous in fields like economic growth (Jones, 2011), the business cycle (Acemoglu et al., 2012), and international trade (Johnson and Noguera, 2012).

RHOMOLO-IO is a label used to identify all the analyses carried out using the RHOMOLO-MRIO regional dataset, with several possible degrees of sectorial detail, by exploiting the full potential offered by the Leontief model and its extensions. This regional dataset is obtained through a complex procedure which can be briefly summarised as follows (the full procedure is explained in Thissen et al., 2019):

1) Eurostat data are used to construct national Supply and Use tables (SUTs) for all EU28 Member States with NACE rev. 2 sectors to the latest available year (as of August 2019, that year is 2013);

2) national SUTs are linked with trade flows of goods and services based on BACI-CEPII and UN-Comtrade datasets;

3) national SUTs are regionalised using regional data on production and consumption;

4) inter-regional IO tables for all the NUTS 2 regions of the EU28 are created with 65 NACE rev. 2 sectors. The resulting dataset can be exploited both for the base year calibration of the RHOMOLO model and for IO analysis.

The remainder of the report is organised as follows. In Section 2 we briefly illustrate the Leontief model and highlight its various potential uses. Section 3 focuses on the multiplier analysis and contains two policy applications in which RHOMOLO-IO was used to evaluate two different European investment projects related to transport infrastructures and to research and innovation (R&I) and low-carbon investments. Section 4 reports two analyses on employment, and Section 5 briefly summarises an analysis on consumption redistribution. Section 6 illustrates the trade analyses that can be carried out with RHOMOLO-IO in light of recent literature using the same methodology, and Section 7 concludes.

2 The Leontief model

The RHOMOLO-IO model uses data organised in IO tables defined as a set of sectorally-disaggregated regional economic accounts. The IO tables represent a snapshot of the flows of products and services produced and consumed in the economy in a single year. The basic principle of the IO tables is to identify and disaggregate all the monetary flows between industries (inter-industry expenditure flows), consumers, and suppliers of production factors in the economy.

Under a number of assumptions, IO tables can be used as the basis for an economic model where exogenous final demand drives total output (Leontief 1986, Miller and Blair 2009), with the transmission mechanisms linking the two being called multipliers. The multipliers quantify the knock-on effects throughout the economy on aggregate and sectorial activities generated by a certain exogenous change in final demand. In other words, IO multipliers allow to measure to what extent an increase (decrease) in final demand of one sector entails expansionary (contractionary) effects in the output of all sectors, including the perturbed sector. The activity generated by each sector resulting from the initial demand disturbance (which is the direct effect of the shock) is known as the indirect effect. In computational terms, the multiplier is calculated by summing the direct and the indirect effects and by dividing the result by the direct effect.

In order to represent formally the RHOMOLO-IO model, let's start by characterising sectoral output as follows:

$$x_i = \sum_{j=1}^{n} z_{ij} + y_i \qquad (1)$$

x_i is output of sector i; z_{ij} stands for transactions from sector i to sector j; y_i stands for sales from sector i to final demand users. Equation (1) simply means that output is given by the sum of intermediate sales and final demand. We could re-write equation (1) as follows:

$$x_i = \sum_{n=1}^{n} a_{in} x_n + y_i \qquad (2)$$

$\sum_{n=1}^{n} a_{in} x_n$ stands for intermediate sales (equivalently to $\sum_{j=1}^{n} z_{ij}$) expressed as output multiplying the technical coefficients a_{in}. The latter express the quantity of input i used to produce output x and is defined as the ratio between intermediate transactions divided by output: $a_{in} = {}^{z_{in}}/_{x_n}$. The fact that these coefficients are fixed means that constant returns to scale are assumed, and it is a way to represent the available production technology in the economy.

In matrix notation, we can re-write equation (2) as follows:

$$Y = [I - A]X, \qquad (3)$$

where X is the vector of outputs, Y is the vector of final demands, A is the matrix of technical coefficients (also called IO coefficients), and I is the identity matrix (with ones on the main diagonal and zeros elsewhere). For a given set of Ys, this is a set of n linear equations in the n unknowns $x_1, x_2, \ldots, x_n$ and hence it may or may not be possible to find a unique solution. In fact, a unique solution depends on whether or not $[I - A]$ is singular, that is its inverse exists. Assuming that it does, by pre-multiplying both sides of equation (3) by $[I - A]^{-1}$ we obtain the following:

$$X = [I - A]^{-1} Y \qquad (4)$$

$[I - A]^{-1}$ is either called the Leontief inverse or the total requirements matrix. The so-called open IO model assumes that Y is completely exogenous, which means that demand is not related to production. Equation (4) can be used to calculate the multipliers mentioned above: by modifying the exogenous demand vector one can calculate the output necessary to sustain such alternative demands. This analysis relies on three assumptions: (a) the supply-side of the economy is entirely passive; (b) there are no supply constraints, nor unused capacity; (c) the production technology for all sectors is represented by fixed coefficients (meaning that an increase in the production of any sector's output means a proportional increase in that sector's input requirements). The latter means that inputs substitutability is neglected.

Thus, IO multipliers allow measuring how an increase in final demand for the output of one sector entails expansionary effects on the output of intermediate sectors which, due to such demand change, increase their own demand for their intermediates inputs. The activity generated by the sum of these demands for intermediate inputs is known as the indirect effect. The multipliers calculated by including both the direct and indirect effects of an exogenous change in final demand are normally referred to as type I multipliers.

By relaxing the assumption of fully exogenous final demand, type II multipliers can be obtained which also include induced effects. A common way to model this is to close the model with respect to households and make household consumption endogenous and related to production (income). Based on the assumption of a constant savings rate for different levels of income, type II multipliers allow capturing in the model the additional effects of household income generation through payments for labour and the associated consumer expenditures on goods and services produced by the various sectors. This additional expansionary effect is known as the induced effect.

Thus, there are two types of IO multipliers:

- Type I multiplier: direct effect (initial spending) plus indirect effect (demands for intermediate inputs) divided by initial spending;
- Type II multiplier: direct and indirect effects plus induced effect (household spending based on the income earned from the direct and indirect effects) divided by initial spending.

Generally, it is more interesting to analyse the economic impacts of changes in final demand in terms of either increased income (household earnings) or value added (GDP) generated rather than simply gross output. Focusing on the latter, the GDP multiplier is defined as the value added share in each unit of gross output produced in the economy as follows:[1]

$$v_{in} = {}^{V_{in}}/_{x_n} = 1 - \sum_n A_{in} \qquad (5)$$

The GDP multiplier (also called value added coefficient) v_{in} can also be calculated as one minus the direct intermediate input share of all the suppliers sectors. Note that this multiplier is directly related to the output variation meaning that once the new level of output (due to any demand-side shock) is obtained, the new output value has to be multiplied by the GDP multiplier in order to quantify the impact on GDP.

[1] We do not show the income multiplier calculation as the only difference with the GDP multiplier lies in using compensation of employees rather than value added in equation (5).

The IO multiplier analysis can be useful to understand the potential impact of changes in final demand for certain products and sectors. Certain sectors will be associated with higher indirect (and induced) effects than others, permitting to form ideas about the sectoral interdependencies of the economy.

2.1 The multi-regional IO framework: a two regions/one sector example

In a multi-regional accounting framework, gross output in region *r* and sector *i*, $X_r(i)$, is given by the sum of intermediate and final demand goods. Formally, and rewriting (1), in equilibrium the following relationship holds:

$$X_r(i) = \sum_s \sum_j z_{r,s}(i,j) + \sum_s y_{r,s}(i) \tag{6}$$

$z_{r,s}(i,j)$ is the intermediate inputs matrix that contains the intermediate goods produced in region *r* and sold in destination *s* that can be mapped by origin and destination sectors (*i* and *j*, respectively); $y_{r,s}(i)$ represents the total final demand goods *i* produced in region *r* and consumed in region *s*.

In order to provide a better intuition for the model, we present a two regions/one sector analytical framework in which both regions trade intermediate and final goods. For *r*,*s* = 1,2 it follows that gross output of each region is such that $x_r = \sum_s y_{r,s}$ where $x_1 = x_{11} + x_{12}$ and $x_2 = x_{21} + x_{22}$. The output produced in region 1, is therefore divided into the output used in the same region x_{11}, and the output needed to satisfy the demand of good and services of region 2, x_{12}. The accounting relationship is such that $x_s = a_{ss}x_s + a_{sr}x_r + y_{ss} + y_{rs}$, where the elements on the right hand side are, respectively, the domestic intermediate input purchased domestically, the intermediate input purchase abroad, the domestic final demand goods, and the final demand goods imported from abroad, respectively.

As in the classical Leontief model, gross output $X = \{x_{rs}\}$ has to satisfy the relationships of equation (4) where I is the identity matrix, $A = \{a_{r,s}\}$ and *x*= $\{x_{rs}\}$. The gross output of each region can be decomposed as follows:

$$\begin{bmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \end{bmatrix} = \begin{bmatrix} I - a_{11} & -a_{12} \\ -a_{21} & I - a_{22} \end{bmatrix}^{-1} \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \tag{7}$$

This multi-regional framework permits to broaden the possibilities offered by the analyses carried out with the Leontief model and include the quantification of output, GDP, and employment related to inter-regional and international trade (see Arto et al, 2015, for an application on the exports of the countries of the European Union).

The following section illustrates a couple of examples in which the multiplier analysis has been used for policy-relevant studies using EU regions' data. The rest of the report will be devoted to showcase some additional and alternative uses of the IO framework.

3 Two RHOMOLO-IO multiplier analyses

3.1 The evaluation of four TEN-T projects

The RHOMOLO-IO model has been recently used by the JRC in collaboration with the Directorate-General for mobility and transport (DG MOVE) to analyse four projects pertaining to the TEN-T Programme. The TEN-T programme consists of hundreds of projects whose purpose is to ensure cohesion, interconnection, and interoperability of the trans-European transport network, as well as access to it. The projects include all modes of transport such as road, rail, maritime, inland waterways, and air. The aim of the programme is to establish and develop the key links and interconnections needed to eliminate existing bottlenecks to mobility, fill in missing sections and complete the main routes, especially the cross-border sections, and improve interoperability on major routes.

Public investments such as those needed to implement the TEN-T projects affect the economic performance of regions by influencing demand, capital accumulation, productive capacity, and by generating spillover effects. For the current programming period (2014-2020), the Connecting Europe Facility (CEF) is one of the EU instruments developed to direct investment into European transport, energy, and digital infrastructures including the TEN-T projects, with a total of about €500 billion of funds. The regional RHOMOLO-IO multiplier analysis is an ideal tool to form an idea on the potential demand-side economic effects related to investments on specific industries and regions.

In particular, the following four projects (financed during the 2014-2020 programming period) have been subject of an ex-ante impact evaluation carried out with the RHOMOLO-IO model:

a) the Baltic - Adriatic corridor;
b) the North Sea - Baltic corridor;
c) the North Sea - Mediterranean corridor;
d) the Rhine - Danube corridor.

Each of these four projects involves investments in transport infrastructures in a number of NUTS 2 regions pertaining to different EU member states over the full programming period that is from 2014 to 2020 (in fact 2022 when taking into account the N+2 rule). Figures 1a, 1b, 1c, and 1d show the amount of TEN-T investments over those seven years related to each of the four projects listed above expressed in percentage of the 2013 GDP of the regions involved in the projects.

The funds involved represent a significant amount of money with respect to the yearly GDP of the regions, even though it should be kept in mind that the funds are to be spent over the full programming period. The first column of Table 1 reports the total investments planned from 2014 onwards in billions of euros associated with each project under analysis.

Figure 1a. Total investments relative to GDP, Baltic - Adriatic corridor

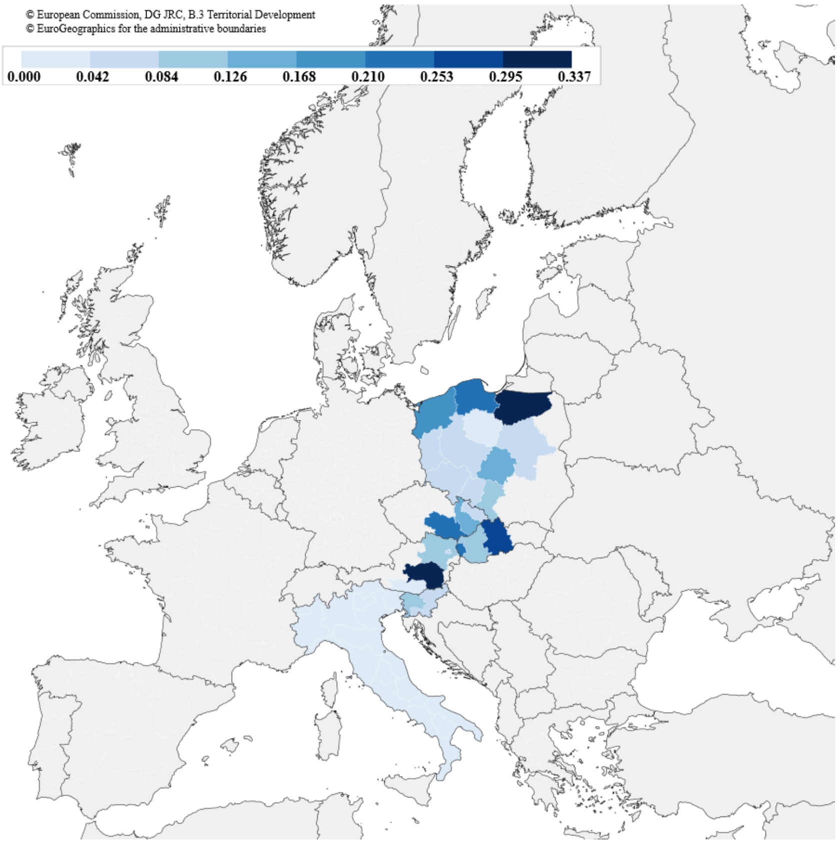


Figure 1b. Total investments relative to GDP, North Sea - Baltic corridor

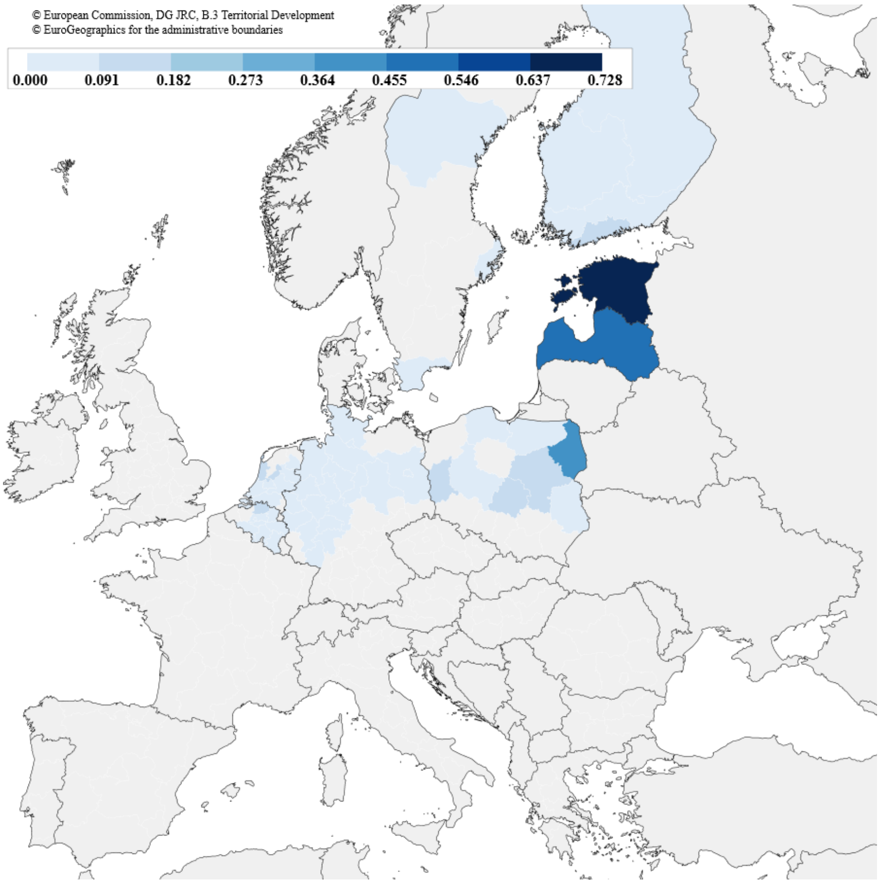


Figure 1c. Total investments relative to GDP, North Sea - Mediterranean corridor

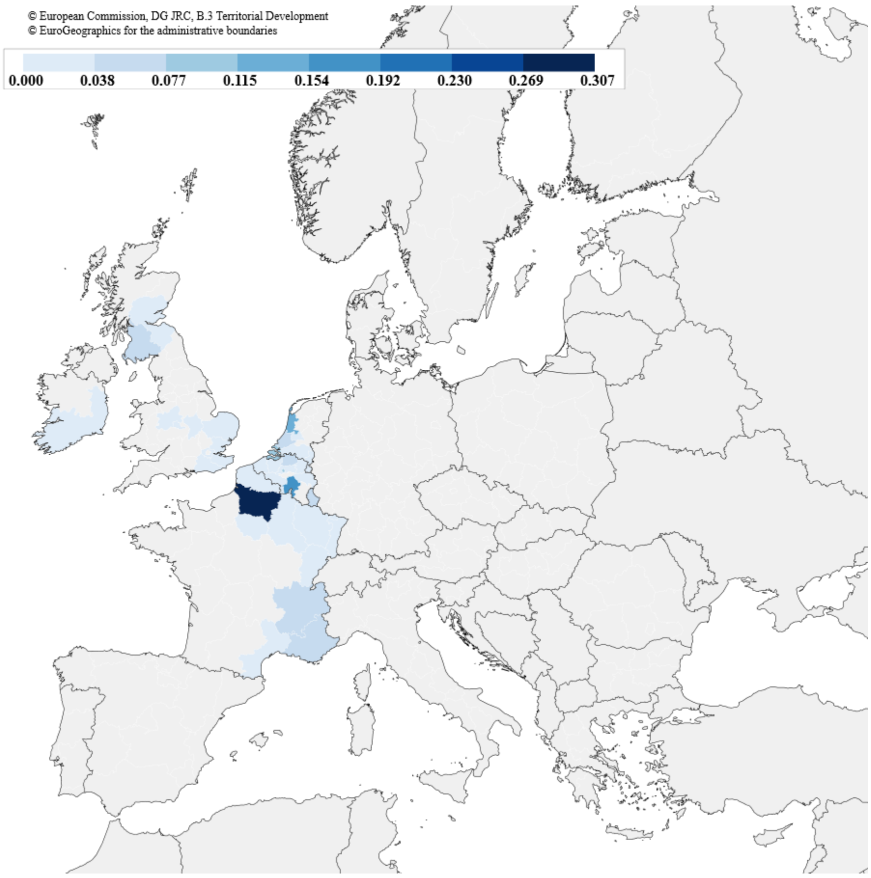
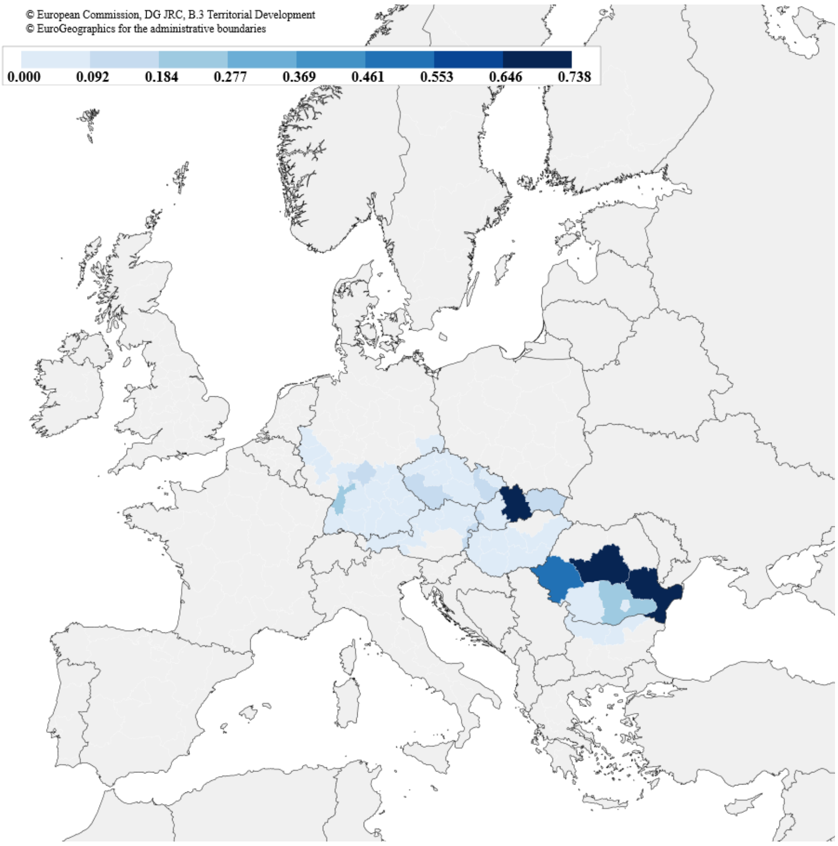


Figure 1d. Total investments relative to GDP, Rhine - Danube corridor



The RHOMOLO-IO multiplier analysis considers an exogenous increase in final demand, in this case the TEN-T investment, and estimates both its direct and the indirect effects (type I multipliers). The multipliers allow calculating both the output and the GDP changes associated with the investment in the transport infrastructures envisaged in the four projects. The estimated macroeconomic effects of the projects are contained in Table 1 and are reported both in billions of € and in terms of output and GDP multipliers, respectively.

Table 1. Output and GDP effects of the TEN-T investments for the four projects under analysis

	Investments	Change in output		Change in GDP	
	Billion €	Billion €	multiplier	Billion €	multiplier
a) Baltic - Adriatic	74.5	140.672	1.89	63.717	0.86
b) North Sea - Baltic	98.7	180.078	1.82	78.827	0.80
c) North Sea - Mediterranean	70.0	123.044	1.76	58.247	0.83
d) Rhine - Danube	91.9	170.533	1.86	79.688	0.87

Source: DG MOVE (Investments) and RHOMOLO-IO calculations.

In all cases the output multipliers are slightly below 2, meaning that for each € spent in the TEN-T programme, almost two € of output are generated within the EU economy. The GDP effects are also sizeable and comparable with the foreseen investment. It is a standard result for the GDP effects to be smaller than the output effects (see Section 2), given that the initial demand increase (in this case the investment in transport infrastructure) includes consumption of both intermediate and final goods, so that not all of it involves elements entering directly into the calculation of GDP. By eliminating the purchases of intermediate inputs in each production stage, the multiplier measures the net contribution of final demand to the economy's GDP.

It should be noted that these effects only take into account the demand-side mechanisms featured in the RHOMOLO-IO model and neglect any supply-side effect which, since the projects entail the construction and upgrading of large transport infrastructures, may be sizeable. In fact, the expected economic effects generated by the projects analysed here published by DG MOVE are substantially higher than those contained in Table 1. In particular, according to the document of the European Commission (2017) entitled "Delivering TEN-T, Facts & figures September 2017", the four projects should generate until 2030, respectively: a) 535 billion €; b) 715 billion €; c) 299 billion €; and d) 725 billion €.

3.2 The evaluation of R&I and low-carbon investment in Apulia, Italy

Di Comite et al. (2018) illustrate the analysis carried out to evaluate the R&I and low-carbon investments carried out under the European and Structural Investment Funds (ESIF) programme in Apulia, Italy, during the 2014-2020 programming period. Here we only report the main table containing the RHOMOLO-IO results of that analysis, highlighting that the main points of interest for the purposes of the present report are related to the sectoral detail of the analysis, and to the fact that in this case both type I and type II multipliers have been estimated. The RHOMOLO-IO analysis is used to have an initial idea of the potential demand impact of a regional investments strategy.

Table 2. Type I and Type II multipliers - Apulia region

	Final demand change	Sector indirect effect	Industrial support effect	Type-I output multipliers	Type II output multipliers	Type I GDP multipliers	Type II GDP multipliers
Agriculture	1	0.107	1.150	2.257	3.919	0.706	1.223
Manufacturing & Construction	1	0.433	0.427	1.860	2.618	0.379	0.614
Transport & Trade	1	0.213	0.638	1.851	3.961	0.614	0.959
Business Services	1	0.223	0.218	1.442	2.211	0.670	0.909
Public Services	1	0.073	0.446	1.519	4.151	0.827	1.646

Source: Di Comite et al., 2018.

Table 2 reports the Type-I and Type-II multipliers, together with the transmission mechanism of indirect effects obtained with RHOMOLO-IO. The highest Type-I multiplier is associated with the agricultural sector (2.257), meaning that investments in this sector may be expected to have the greatest impact on the rest of the regional economy. However, when household final demand is considered endogenous so that induced effects are included in the analysis (Type-II multipliers), we see that the Other Services sector (essentially public services) has the highest multiplier (4.151) and, consequently, is the sector associated with the highest impact on the economy via the additional effects of household income generation.

To provide some guidance on the interpretation of the multipliers, let us consider an increase of €1 in final demand of the Agriculture sector. The Type-I multiplier for this sector shows that a change in final demand of €1 induces an increase in total output of €2.257. In other words, in order to produce an additional unit of output in the target sector, the national economy's output must increase by an additional €0.107 in order to provide inputs to the agriculture sector itself, and in turn an increase of €1.15 in all stages of the production chain to provide inputs to the suppliers of the sector under concern is needed. The effects captured by the Type-I multiplier are the direct effect (1.00), the indirect effect on the sector where a change of final demand is assumed (0.107), and the industrial support effects (1.15). The sum of all these effects gives us the Type-I output multiplier, highlighting the importance of considering the inter-industry linkages in an economic impact analysis.

The last two columns of Table 2 report the GDP (value added) associated with the R&I and low carbon investment in Apulia. Looking at the Type-II multipliers, the effect of €1 invested in Agriculture generates an increase in total value added of €1.223 (including direct, indirect, and induced effects).

4 Two RHOMOLO-IO employment analyses

4.1 The evaluation of the European Globalisation Fund (EGF)

The EGF supports people losing their jobs due to major structural changes in world trade patterns related to globalisation, for instance when large companies shut down or production moves outside the EU. The EGF has a maximum annual budget of €150 million for the programming period 2014-2020 and it can fund up to 60% of the cost of projects designed to help workers made redundant to find another job or set up their own business.

As a general rule, the EGF projects take place where more than 500 workers[2] are made redundant by a single company, including its suppliers and downstream producers, or if a large number of workers are laid off in a particular sector in one or more neighbouring regions. EGF projects are managed and implemented by either national or regional authorities, and each project runs for two years. The EGF differs from the ESIF

[2] It is possible that this threshold will be reduced in the future, as current applications involve cases in which between 108 and 6120 workers are made redundant and are based on whether or not the restructuring event has a significant impact (Source: DG EMPL - we thank Josefina Capdevila Penalva for her feedback and suggestions on this part of the analysis).

(mentioned in section 3.2 for the Apulia analysis) because it takes a strategic, long-term perspective in anticipating and managing the social impact of industrial change through activities such as life-long learning. Given the EGF objectives, it is reasonable to assess its effectiveness in terms of employment creation.

This impact assessment exercise carried out with the RHOMOLO-IO model has only been performed for selected case studies and its only aim is to quantify the regional socio-economic benefits in terms of total employment derived from the implementation of the EGF (see European Commission 2018a). Building on the multiplier analysis explained above, the analysis differentiates between the direct employment impact due to the implementation of the EGF and the indirect employment generated along the supply chain.

The RHOMOLO-IO estimation of the EGF indirect employment makes use of the sector specific and the total regional employment multipliers associated with the direct jobs generated after the EGF implementation. Moreover, the MRIO nature of the system not only extends the supply-chain coverage to all sectors that might be impacted by the program, but also allows for the inclusion in the analysis of the inter-regional spill-over effects. Indeed, the results reveal that accounting for the indirect effects matters for the evaluation or the effectiveness of the EGF in terms of employment creation.

Out of the 23 projects under analysis, two are at the country level (in France and in Finland) while all other projects affect individual NUTS 2 regions. Figure 2 reports the total employment impact together with the re-employment rates for each case study, whereby the total impact is divided in direct and indirect employment effects. Note that the direct effect is an input for the analysis based on the magnitude of the policy funding. Essentially, the RHOMOLO-IO multipliers (Type-I) are used to estimate the indirect effects associated with the jobs created by the EGF projects. Two scenarios are considered: for the first (top left panel), sector-specific multipliers are used (*SS_multiplier*), so that the working assumption is that EGF beneficiaries found a job in the same sector where they used to work before. In the second scenario (bottom left panel), the total regional multiplier is applied (*TR_multiplier*), thus relaxing the assumption on the sector where beneficiaries are reallocated.

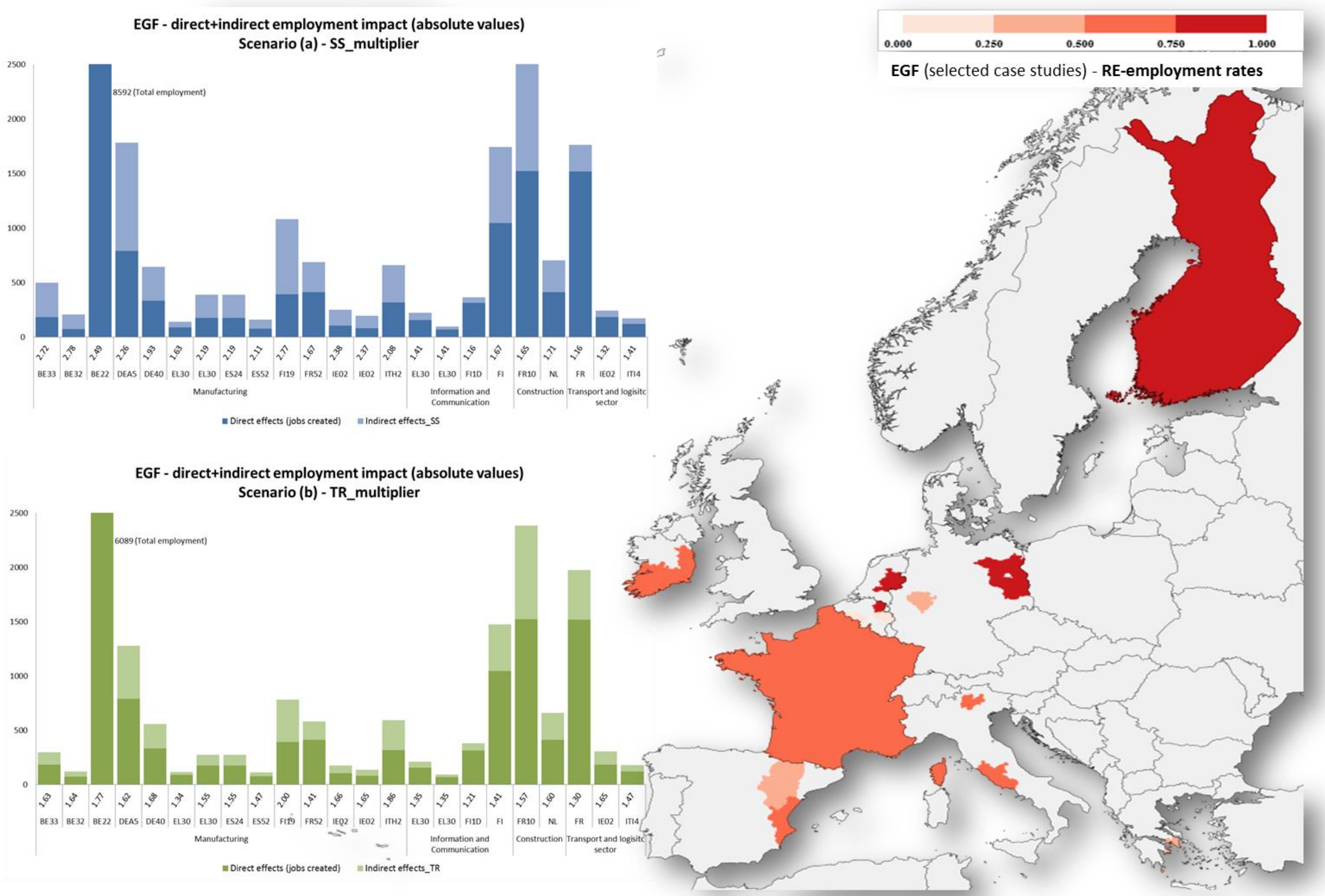
Re-employment rates give a first intuition of the EGF program potential effectiveness showing that in more than half of the selected case studies (65%, that is 15 out of 23) the rates are above 0.5 (that is, more than one out of two persons found a job thanks to the EGF project), and in 30% of them (7 out of 23) the rates are higher and lie between 0.75 and 0.88.

According to the first scenario, the higher indirect jobs contribution is estimated to be in those case studies attached to the manufacturing sector. The employment multipliers in such cases lie between 1.67 and 2.78, probably due to the high complexity of the supply chains characterising industrial activities with the presence of significant backward linkages magnifying the indirect impact. On the other hand, the smallest indirect job contributions are found for projects related to the services sector, which has smaller backward linkages along the supply chain. Although numbers change across the two scenarios, the overall result is confirmed when using total regional multipliers rather than sector-specific ones.

The lower panel of Figure 2 shows a lower contribution of indirect employment due to the use of the regional multiplier: this is essentially a weighted average of the sectoral multipliers and thus its use reduces the sectors supply chains differences, leading to lower impacts across the board. Nevertheless, indirect jobs account from a minimum of 20% up to 50% of the total jobs generated, corresponding to employment multipliers ranging between 1.21 and 2.00.

We believe that the RHOMOLO-IO analysis highlights the importance of indirect employment creation when evaluating the effectiveness of a policy such as the EGF, emphasising the significant role played by the complex supply chains of the EU economies.

Figure 2: EGF total employment impacts and re-employment rates for the selected case studies



4.2 The coal regions in transition

Alves Dias et al. (2018) analysed the decreasing role of coal for energy production and consumption in the EU and noticed that six member states still relied on coal to meet at least 20% of their energy demand. Since the need to reduce greenhouse gas emissions is leading to the active discouragement of coal power generation with stringent post-2020 emission requirements and other measures, it is of interest to European policy makers to understand the potential negative impacts of the ongoing shrinkage of the coal sector on employment and the economy in regions hosting hard coal and lignite mining activities and coal-fired power plants. As of 2018, 103 NUTS 2 regions of the EU (in 21 EU Member States) are hosting a total of 207 coal power plants (which on average are 35 years old), while there are 128 active coal mines in 41 regions (in 12 EU Member States).

Given an estimate of 237,000 full time equivalents directly employed by the coal sector (the majority being in coal mining, about 185,000 - source: Alves Dias et al., 2018), the RHOMOLO-IO model has been used to estimate indirect employment impacts using the type I multipliers – a similar exercise to the one on EGF illustrated in section 4.1.

Besides extending the supply chain coverage to all sectors that might be impacted by changes in coal mining and coal power plants activities, the indices used are assessed both within country (intra-regional) and also considering spillover effects among countries (inter-regional). The results, reported in Table 3 below, differentiate between these two types of indirect jobs related to the coal sector.

Table 3. Indirect jobs in coal-related activities in the EU

Country	Intra-regional	Inter-regional	Country	Intra-regional	Inter-regional
Austria	769	1943	Italy	906	3970
Bulgaria	9452	15220	Netherlands	1777	3995
Croatia	339	385	Poland	48746	87760
Czech	10018	19229	Portugal	344	1229
Denmark	1019	2429	Romania	6194	10101
Finland	1693	3240	Slovakia	1189	2058
France	525	1237	Slovenia	1270	1833
Germany	14089	34366	Spain	5107	9643
Greece	1843	4166	Sweden	275	573
Hungary	2255	4735	United Kingdom	2133	6276
Ireland	280	378	TOTAL	110223	214766

Source: Alves Dias et al. (2018).

Essentially, the numbers under the "intra-regional" label represent the jobs that a country would lose should it shut down its coal-related activities. The numbers of jobs of the "inter-regional" column also include the indirect jobs that would be lost due to the shutting down of the coal activities in the rest of the EU (the difference between the two columns permits to gauge the importance of the trade effects on employment indirectly related to coal activities). Thus, the total number of indirect jobs at risk due to the disappearence of the coal sector can be estimated by summing the inter-regional numbers, for a total of about 215,000 full time equivalents. For more details on this analysis, see Alves Dias et al. (2018).

5 A RHOMOLO-IO consumption redistribution analysis

Christensen et al. (2018) analysed the potential macroeconomic effects of the third pillar of the Investment Plan for Europe, namely the regulatory proposals regarding the Capital Markets Union, the Single Market Strategy, the Digital Single Market, and the Energy Union. The RHOMOLO-IO model has been used to analyse one aspect of the latter, namely to study the system-wide effects of a 30% reduction in the consumption of energy in the EU. The key assumption is that this reduction resulted from behavioural changes of economic agents driven by the incentives set up by the European policies regarding energy consumption.

After having translated the reduction in energy consumption into energy expenditure savings, the simulation strategy entails a redistribution of such savings to the consumption of other goods and services other than energy, maintaining income fixed. Basically, the change (reduction) in energy consumption expenditure is matched by an equal and opposite change (increase) in non-energy expenditure of households (for a similar application, see Lecca et al., 2014). Results are presented as percentage changes in GDP with respect to the baseline with the time profile and the scenarios coming from the projections of the European Council.

Table 4. GDP impact (percentage change from the base year values)

	2020	**2025**	**2030**
Low scenario	0.060	0.160	0.250
Central scenario	0.091	0.243	0.380
High scenario	0.115	0.307	0.480

Source: Christensen et al. (2018).

The effects summed up by Table 4 rely on the assumption that consumers use the resources saved through well-implemented energy efficiency policies in the consumption of non-energy goods and services, with unchanged preferences (consumption shares) and income. For more details on this analysis, please refer to Christensen et al. (2018) which was also referred to in the communication COM(2018) 771 on the Investment Plan for Europe by the European Commission (2018b).

6 A RHOMOLO-IO trade analysis

The economic literature has recently witnessed a surge in interest in the quantification of the national or regional degree of dependence on trade with external countries and regions. Due to the fact that trade in intermediate inputs accounts for about two thirds of international trade, conventional trade statistics are unable to quantify correctly such dependence. As a result, the value added content of trade is a better indicator when trying to understand the real economic importance of trade and cross-border production linkages. MRIO data permit to compute trade in value added, and statistics like the ratio of value added to gross exports (VAX ratio) are now commonly used in international economics analyses (Timmer et al., 2015; Johnson and Noguera, 2012; Hummels et al., 2001).

Los et al. (2017) have used such IO methodology to quantify the level of dependency on EU final demand of the UK regions with the following procedure. The estimation of regional dependence on foreign demand for final products relies on a MRIO table, and RHOMOLO-IO is the perfect tool for such an analysis as it includes all the NUTS 2 EU regions plus the rest of the World. In order to quantify the level of dependence of a certain EU region (called y for the sake of argument), it is sufficient to modify the A matrix of equation (4) by setting to zero all the trade links of region y to the rest of the EU and then calculate the inverse of such new matrix. Also, all the trade links between y and the rest of the EU from the final demand vector should be set to zero (notice that Los et al., 2017, only do the latter due to different focus of their analysis). These new matrix and vector should be used to calculate the new production X^{y*} in region y, which can then be used to quantify the level of dependence of such region as: $1-\frac{X^{y*}}{X^{y}}$. Such indicator can be calculated for single regions, for entire countries, as well as for groups of regions and countries and can also be sector-specific depending on the needs of the analysis. Figure 3 below illustrates the needed modification to the MRIO data in order to carry out the analysis, the cells with the content in red being the ones that have to be set to zero in order to calculate the indicator of dependence.

Figure 3. Stylised MRIO table highlighting the procedure to calculate the region *y*'s dependence

	Rest of the EU	Region y	Rest of the World	Final demand: rest of the EU	Final demand: region y	Final demand: rest of the World	Gross output
Rest of the EU	Z^{EU_EU}	Z^{EU_y}	Z^{EU_ROW}	F^{EU_EU}	F^{EU_y}	F^{EU_ROW}	X^{EU}
Region y	Z^{y_EU}	Z^{y_y}	Z^{y_ROW}	F^{y_EU}	F^{y_y}	F^{y_ROW}	X^{y}
Rest of the World	Z^{ROW_EU}	Z^{ROW_y}	Z^{ROW_ROW}	F^{ROW_EU}	F^{ROW_y}	F^{ROW_ROW}	X^{ROW}
Value added	W^{EU}	W^{y}	W^{ROW}				
Gross output	X^{EU}	X^{y}	X^{ROW}				

This methodology permits to use the RHOMOLO-IO framework to quantify the level of interdependencies of the regions and countries forming the EU with a higher degree of precision with respect to the standard trade statistics which make use of imports and exports data and put them in relation with GDP such as the standard openness index calculated as: $\frac{(imp+exp)}{GDP}$. Such an analysis applied to the regions of Italy (used here as a mere representative example) and calculated over GDP rather than output yields the results contained in Table 6 below.

The results contained in panel a) of Table 5 suggests that the GDP of the regions of central and Northern Italy is the most dependent on trade of both intermediate and final goods with the rest of the EU, with values above the 11.01% recorded for Italy as a whole recorded in the cases of the smaller border regions such as Trentino, Alto Adige, and Friuli. Most Southern regions such as Abruzzo, Molise, Campania, Sardegna, and Sicilia (basically, all but Calabria due to the presence there of the important port of Gioia Tauro, the largest Italian port for containers' shipping), are characterised by a lower dependence with the rest of the EU.

Table 5. GDP dependence of Italian regions (a) and sectors (b) on the rest of the EU markets

Panel a

Region	GDP dependence	Region	GDP dependence	Region	GDP dependence
Piemonte	8.14%	Puglia	7.15%	Veneto	9.98%
Val D'Aosta	10.68%	Basilicata	7.07%	Friuli	15.24%
Liguria	8.03%	Calabria	14.77%	Emilia Romagna	9.62%
Lombardia	6.22%	Sicilia	6.41%	Toscana	10.16%
Abruzzo	6.91%	Sardegna	8.86%	Umbria	12.82%
Molise	6.26%	Trentino	18.02%	Marche	11.14%
Campania	5.17%	Alto Adige	15.92%	Lazio	9.37%

Source: own calculations.

Panel b

Sector	GDP dependence	Sector	GDP dependence
A: Agriculture, forestry…	21.10%	J: Information and communication	12.52%
B, D, E: Mining and quarrying + Electricity, gas… + Water supply, sewerage…	10.36%	K-L: Financial and insurance activities, real estate	6.33%
C: Manufacturing	28.59%	M, N: Professional activities + Administrative and support service activities	13.73%
F: Construction	1.29%	O-Q: Public administration and defence + Education + Health	0.33%
G-I: Wholesale and retail trade + Transportation + Accommodation and food service	4.16%	R-U: Arts + Other services + Activities of households as employers… + Activities of extraterritorial org. and bodies	2.06%

Source: own calculations.

As for the sectorial information contained in panel b) of Table 5 (please note that the letters indicate the economic sectors according to the NACE revision 2.0 classification used by, among others, Eurostat), the lowest dependence on the rest of the EU is recorded in the cases of services related to public administration, education, and health, as well as in the construction sector which appears to rely on domestic markets rather than international ones. Four of the RHOMOLO-IO sectors are characterised by values above the Italian level of dependence: agriculture and forestry, information and communication, professional and administrative activities, and manufacturing, with the latter being unsurprisingly the sector most dependent on the rest of the EU.

This type of analysis opens up an avenue of research on the importance of trade links both within the EU and between EU regions and countries with the rest of the World which could provide, for instance, a quantification of the economic importance of EU integration and of the single market. More in general, it is yet another possibility offered by the RHOMOLO-IO framework in the realm of policy support as well as for economic research at large.

7. Conclusions

This report offers an exhaustive theoretical background and an analytical description of the RHOMOLO-IO model with the aim to make the reader familiar with the foundations and potential relevance of the model. The RHOMOLO-IO model not only builds on the MRIO dataset used for the RHOMOLO model (Thissen et al., 2019), but it is also a flexible standalone tool for economic analysis capable of a wide range of economic analyses.

The RHOMOLO-IO model builds on the existing IO and MRIO literature and takes advantage of the regional dataset which includes information for 267 NUTS 2 regions of the EU and a residual region accounting for the activities of the rest of the World. The analytical possibilities of the model go beyond the typical IO multiplier analysis and include studies on employment, consumption redistribution, and trade. The report contains several examples of applications within such domains dealing with some of the most important policies of the EU such as the ERDF, the EGF, the TEN-T programme, and the transition towards clean energy production in Europe.

The quantification of the level of regional and national dependence on trade with the rest of the EU/World seems to offer a particularly promising stream of activities related, but not limited, to the analysis of Global Value Chains and VAX ratios. This may prove useful for a better understanding of the trade links among EU regions and between the EU and the rest of the World for both European policy makers and the research community in general.

References

Acemoglu, D., Carvalho, V.M., Ozdaglar, A., and Tahbaz-Salehi, A. (2012). The network origins of aggregate fluctuations. *Econometrica* 80(5), 1977-2016.

Alves Dias, P., Kanellopoulos, K., Medarac, H., Kapetaki, Z., Miranda-Barbosa, E., Shortall, R., Czako, V., Telsnig, T., Vazquez-Hernandez, C., Lacal Arántegui, R., Nijs, W., Gonzalez Aparicio, I., Trombetti, M., Mandras, G., Peteves, E., and Tzimas, E. (2018). EU coal regions: opportunities and challenges ahead. EUR 29292 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-89884-6, doi:10.2760/064809, JRC112593.

Arto, I., Rueda Cantuche, J., Amores, A., Dietzenbacher, E., Sousa, N., Montinari, L., and Markandya, A. (2015). EU exports to the World: Effects on employment and income. Scientific and Technical Research Reports no. JRC93237.

Christensen, M., Conte, A., Di Pietro, F., Lecca, P., Mandras, G., and Salotti, S. (2018). The third pillar of the Investment Plan for Europe: an impact assessment using the RHOMOLO model. JRC Working Papers on Territorial Modelling and Analysis No. 02/2018, European Commission, Seville, 2018, JRC113746.

De Koning, A., Huppes, G., Deetman, S., and Tukker, A. (2016). Scenarios for a 2°C world: a world trade-linked input-output model with high sector detail. *Climate Policy* 16(3), 301-317.

Di Comite, F., Diukanova, O., Mandras, G., and Gómez Prieto, J. (2018). The RHOMOLO economic impact assessment of the R&I and Low-Carbon ERDF investment programme in Apulia, Italy. JRC Working Papers on Territorial Modelling and Analysis No. 04/2018, European Commission, Seville, 2018, JRC114302.

European Commission (2017). Delivering TEN-T: Facts & figures, September 2017. Directorate General for Mobility and Transport (DG MOVE), Directorate B - Investment, Innovative & Sustainable Transport. Available here:
http://www.connectingeu.eu/documents/Delivering_TEN_T.pdf

European Commission (2018a). Impact Assessment accompanying the document Proposal for a Regulation of the European Parliament and the Council on the European Social Fund Plus (ESF+); Proposal for a Regulation of the European Parliament and the Council on the European Globalisation Adjustment Fund (EGF). SWD(2018) 289 final. Brussels, 30.05.2018.

European Commission (2018). Investment Plan for Europe: stock-taking and next steps. COM(2018) 771 final. Brussels, 22.11.2018.

Hummels, D., Ishii, J., Yi, K.M. (2001). The nature and growth of vertical specialization in world trade. *Journal of International Economics* 54, 75-96.

Isard, W. (1951). Interregional and regional input-output analysis: a model of space-economy. *The Review of Economics and Statistics* 33, 318-328.

Johnson, R.C. and Noguera, G. (2012). Accounting for intermediates: Production sharing and trade in value added. *Journal of International Economics* 86(2), 224-236.

Jones, C.I. (2011). Misallocation, economic growth, and input-output economics. NBER Working Papers No. w16742, National Bureau of Economic Research.

Lecca, P., McGregor, P.G., Swales, J.K., and Turner, K. (2014). The added value from a general equilibrium analysis of increased efficiency in household energy use. *Ecological Economics* 100(C), 51-62.

Lecca, P., Barbero, J., Christensen, M., Conte, A., Di Comite, F., Diaz-Lanchas, J., Diukanova, O., Mandras, G., Persyn, D., and Sakkas, S. (2018). RHOMOLO V3: A spatial modelling framework. EUR 29229 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-85886-4, doi: 10.2760/671622, JRC118661.

Leontief, W. (1941). *The Structure of American Economy, 1919-1929*. Cambridge, Mass., Harvard University Press.

Leontief, W. (1986). *Input-Output Economics*. Oxford University Press, Oxford.

Los, B., McCann, P., Springford, J., and Thissen, M. (2018). The mismatch between local voting and the local economic consequences of Brexit. *Regional Studies* 51(5), 786-799.

Miller, R. (1966). Interregional feedback effects in input-output models: some preliminary results. *Papers in Regional Science* 17(1), 105-125.

Miller, R.E. and Blair, P.D. (2009). Input-Output Analysis: Foundations and Extensions. Cambridge University Press, Cambridge, UK.

Moses, L. (1955). The stability of interregional trading patterns and input-output analysis. *The American Economic Review* 45, 803-826.

Moses, L. (1960). A general equilibrium model of production, interregional trade, and location of industry. *The Review of Economics and Statistics* 42, 373-397.

Thissen M., Ivanova O., Mandras G., and Husby T. (2019). European NUTS 2 regions: construction of interregional trade-linked Supply and Use tables with consistent transport flows. JRC Working Papers on Territorial Modelling and Analysis No. 01/2019, European Commission, Seville, 2019, JRC115439.

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R., and De Vries, G.J. (2015). An illustrated user guide to the World Input-Output Database: the case of global automotive production. *Review of International Economics* 23(3), 575-605.

Yazan, D.M., Mandras, G., and Garau, G. (2017). Environmental and economic sustainability o fintegrated production in bio-refineries: The thistle case in Sardinia. *Renewable Energy* 102, 349-360.