WP3: Education, health and R&D: Impacts on smart growth

Task 5. THE RESEARCH OUTPUT OF UNIVERSITIES AND ITS DETERMINANTS: INTANGIBLE INVESTMENTS, SPECIALIZATION AND INEFFICIENCIES

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SEVENTH FRAMEWORK PROGRAMME

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Task 5: The research output of universities and its determinants: intangible investments, specialization and inefficiencies

AN ANALYSIS OF THE RESEARCH ACTIVITIES IN THE EU: SPECIALISATION AND PRODUCTIVITY

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INTRODUCTION

- The activities of the universities are mainly devoted to the generation of intangible assets/outputs.

- Researchers face three types of problems:

① The HEIs develop **several activities simultaneously**: teaching, research, knowledge transfer, etc.

② The productive processes of the activities are **multi-product →** produce **several outputs**

- Teaching outputs: graduates and postgraduates, etc.
- Research outputs: publications, patents, PhDs, etc.
- Knowledge transfer outputs: contracts with firms, technological assistance, etc.

③ It is necessary to take into account not only the **quantity** but also the **quality**

OUR PREVIOUS WORK

- Our previous work in the INDICSER project (Pastor, Serrano and Zaera, 2012) has proposed a university research output indicator (publications-based) that considers not only the quantity of publications but also their quality.

  - Pastor, J.M., L. Serrano and I. Zaera (2015): "The research output of European higher education institutions", Scientometrics, 102, 3, pp. 1867-1893.

- Results have shown **significant differences in research output quantity as well as in quality** of the EU countries.

- **It is necessary to explain the heterogeneity of the research output that remains unexplained →** we need some additional research to analyse the determinants of the research output of the universities.

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THE OBJETIVES

- We suspect that most of the heterogeneity of the aggregated research output can be explained in terms of the following determinants:

  - **Differences of intangible assets** (R&D expenditure) and
  - **Inefficiencies of the research institutions** themselves.
    - Inside the specific fields of science (FOS)
    - Specialization (composition) of the specific fields

- Our task is to answer the following questions :

  - Which are the determinants of the research output of the HEI?
  - To what extent do differences in terms of intangible investments, specialization of scientific fields and inefficiencies explain the differences in the research output among HEI?

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THE METHODOLOGY

To answer these questions we will use **shift-share analysis** and **a five-step approach based on the non-parametric methodology (DEA)** developed by the Ivie's research group (Maudos, Pastor and Serrano, 2000):

1. **Shift-share analysis** allows us to decompose the differences in the research output rate of growth into differences in research output growth of each specific field and differences of composition of the specific fields.

2. **Five-step methodology DEA-based** allow us the decompose the differences in the research output of universities in terms of **Intra-field inefficiency** (inefficiencies of the HEI institutions inside each specific field) and **specialization inefficiency** (inefficiencies of the HEIs due the composition or specialization).

   - This approach allows also to control the R&D investments

THE shift-share analysis

The differences in the scientific production growth for each country (P) against the EU during the period 2008-2012 will be broken down as follows:

$$D^{P}-D^{EU}=\sum_{j=1}^{7}\underbrace{\frac{1}{2}(\theta_j^{P}+\theta_j^{EU})(D_j^{P}-D_j^{EU})}_{\textit{Intra-field effect}}+\sum_{j=1}^{7}\underbrace{\frac{1}{2}(D_j^{P}+D_j^{EU})(\theta_j^{P}-\theta_j^{EU})}_{\textit{Composition effect}}$$

D_j^{EU} and D_j^{P} represent, respectively, the growth rate in 2008-2012 of scientific knowledge production area *j* to EU for each country *P*.

θ_j^{EU} and θ_j^{P} are the weight of scientific production area *j* in total scientific production of the EU and in each country respectively.

The **composition effect** is the result of being more (or less) specialized in the FOS with higher (or lower) rate of growth.

The **intra-field effect** is the result of having a higher (or lower) rate of growth in FOS

THE FIVE-STEP METHODOLOGY (I)

STEP 1: Research output inefficiency by scientific field

Using DEA, we calculate the **research output inefficiency** of the HEIs of each country **by scientific field** θ_i^n

$$
\begin{aligned}
& Max \quad \theta_i^n \\
& s.t. \\
& \sum_{r=1}^{R} \lambda_r Y_r^n \geq Y_i^n \theta_i^n \\
& \sum_{r=1}^{R} \lambda_r X_{rm}^n \leq X_{im}^n \quad m = 1,\dots,M \\
& \lambda_r \geq 0 \quad r = 1,\dots,R
\end{aligned}
$$

θ_i^n is the efficiency score of HEI of country *i* in the scientific field *n*, and represents the potential increase that HEI of country *i* could achieve in the output of the scientific field *n* without increasing the input vector (in our case R&D expenses and R&D personnel).

THE FIVE-STEP METHODOLOGY (II)

STEP 2: Scientific field efficient aggregated output

Using results of STEP 1, we calculate the scientific field efficient aggregated output of the HEI of each country (i.e. The aggregated output assuming that HEI are efficient in each scientific field)

$$\hat{Y}_i = \sum_{n=1}^{N} \hat{Y}_i^n = \sum_{n=1}^{N} Y_i^n \theta_i^n$$

However, being efficient in each scientific field does not guarantee being efficient in the aggregated scientific output.

Being efficient in aggregated production necessarily implies:

① being efficient in each scientific field (intra-field efficiency) and
② having a correct scientific field specialization of the output (composition efficiency).

THE FIVE-STEP METHODOLOGY (III)

STEP 3: Composition inefficiency

We calculate the **composition inefficiency**, the inefficiency that would exist even if no technical inefficiency exists in any scientific field

$$
\begin{aligned}
& Max \;\; \theta_i^{CE} \\
& s.t. \\
& \sum_{r=1}^{R} \lambda_r \hat{Y}_r \geq \hat{Y}_i \theta_i^{CE} \\
& \sum_{r=1}^{R} \lambda_r X_{rm} \leq X_{im} \quad m = 1,\ldots,M \\
& \lambda_r \geq 0 \quad r = 1,\ldots,R
\end{aligned}
$$

θ_i^{CE} is the efficiency score of HEIs of country *i* and represents the potential increase that HEI of country *i* could achieve in their output without increasing the input vector and assuming that they are achieving the maximum output (given the inputs) in each scientific field. Therefore, **composition inefficiency** captures the inefficiency associated with the scientific composition/specialization of the HEI.

THE FIVE-STEP METHODOLOGY (IV)

STEP 4: : Overall research output inefficiency

We can calculate the **overall inefficiency (θ_i)** by means of:

1) The ratio between the maximum attainable output $\hat{Y}_i^*$ and actual output Y_i:

$$\theta_i = \frac{\hat{Y}_i \ \ \theta_i^{CE}}{Y_i} = \frac{\hat{Y}_i^*}{Y_i}$$

2) The solution of this problem:

$$\begin{aligned}
& Max\ \theta_i \\
& s.t. \\
& \sum_{r=1}^{R} \lambda_r \hat{Y}_r \geq Y_i \theta_i \\
& \sum_{r=1}^{R} \lambda_r X_{rm} \leq X_{im} \quad m = 1,\ldots,M \\
& \lambda_r \geq 0 \quad r = 1,\ldots,R
\end{aligned}$$

THE FIVE-STEP METHODOLOGY (V)

STEP 5: Decomposing the overall inefficiencies

We can express the **overall inefficiency** (θ_i) as the product of two factors:

$$\theta_i = \frac{\hat{Y}_i^*}{Y_i} = \frac{\hat{Y}_i^*}{\hat{Y}_i}\frac{\hat{Y}_i}{Y_i} = \theta_i^{CE} \cdot \theta_i^{IE}$$

The first factor is the **composition inefficiency** (θ_i^{CE}) and represents the inefficiency due to the composition/specialization.

The second factor is the **intra-field inefficiency** (θ_i^{IE}) and indicates the aggregate intra-field inefficiency.

- **OUTPUTS**: PUBLICATIONS BY FIELDS OF SCIENCE
  - **Citable documents** per country/year by field of science (FOS):
  - Source: ¿SCImago or Web of Science?

	SCIMAGO Scopus	WEB OF SCIENCE
Source database	Scopus (Elsevier B.V)	Inst. for Scientific Information
Indexed documents	55 millions	23 millions
Number of journals	22.000	12.000
Publishers	5.000	3.300
Countries of journals	97	71
Categories	304	220
Access	Open	Restricted

→

SCIMAGO (Scopus)

- More documents
- More journals
- More categories (social sciences are better represented)
- More geographical coverage

DATA

- **INPUTS**: R&D DATA by scientific field (Frascati Manual)
  - Intramural **R&D expenditure**: current and capital expenditure
  - **R&D personnel** (full-time equivalent): researchers and other

  - **Sectors** covered:
    - Higher education: universities
    - Government: public research organizations

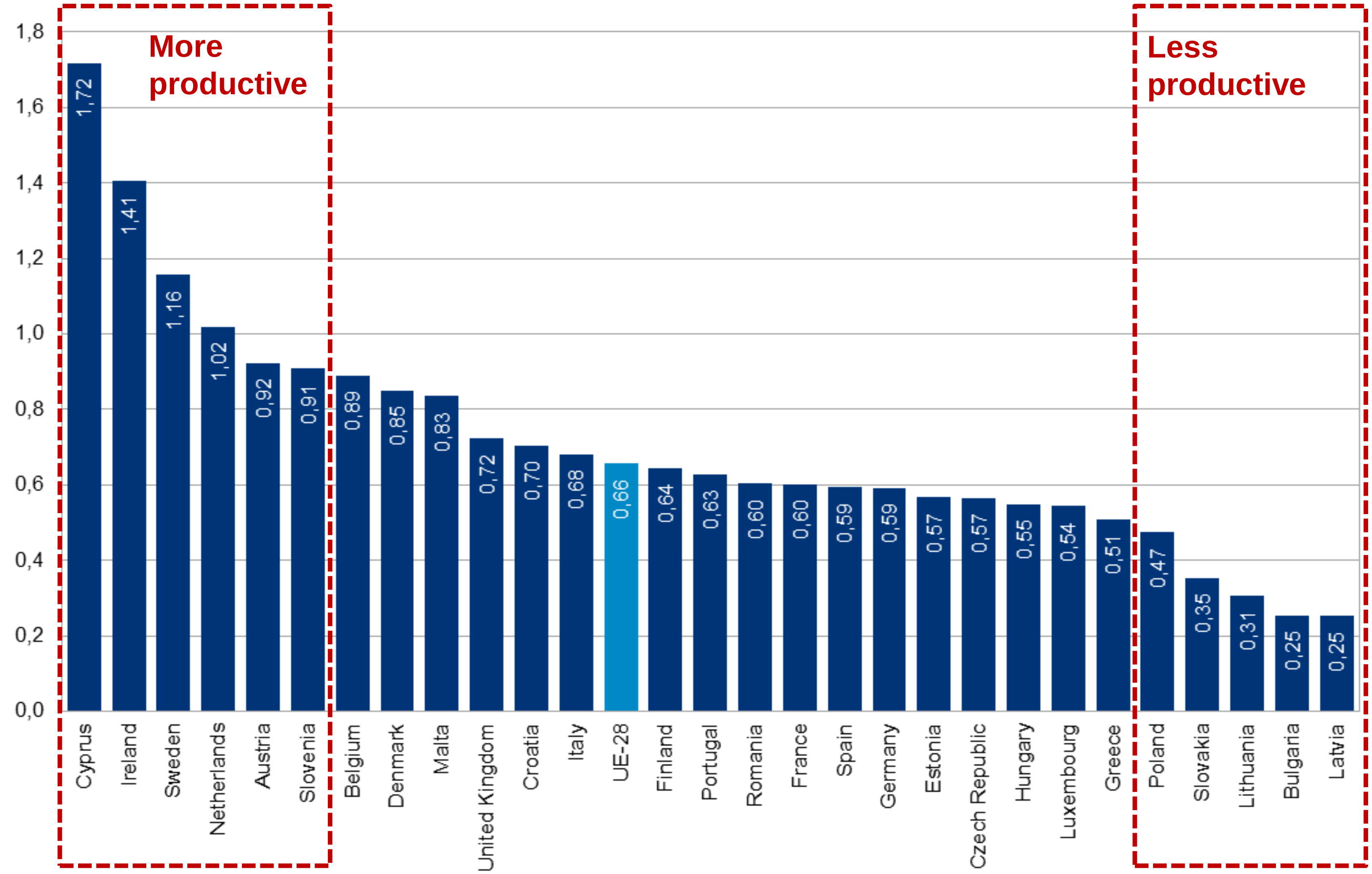
  - Data per country/year by **scientific field**
    - FOS1. Natural sciences
    - FOS2. Engineering and technology
    - FOS3. Medical and health sciences
    - FOS4. Agricultural sciences
    - FOS5. Social sciences
    - FOS6. Humanities

  - Source: Statistics on research and development (**Eurostat**)

THE FACTS

Figure 1. Scientific output related to R&D personnel in Government and Higher Education. EU countries. 2012

Citable documents per R&D personnel

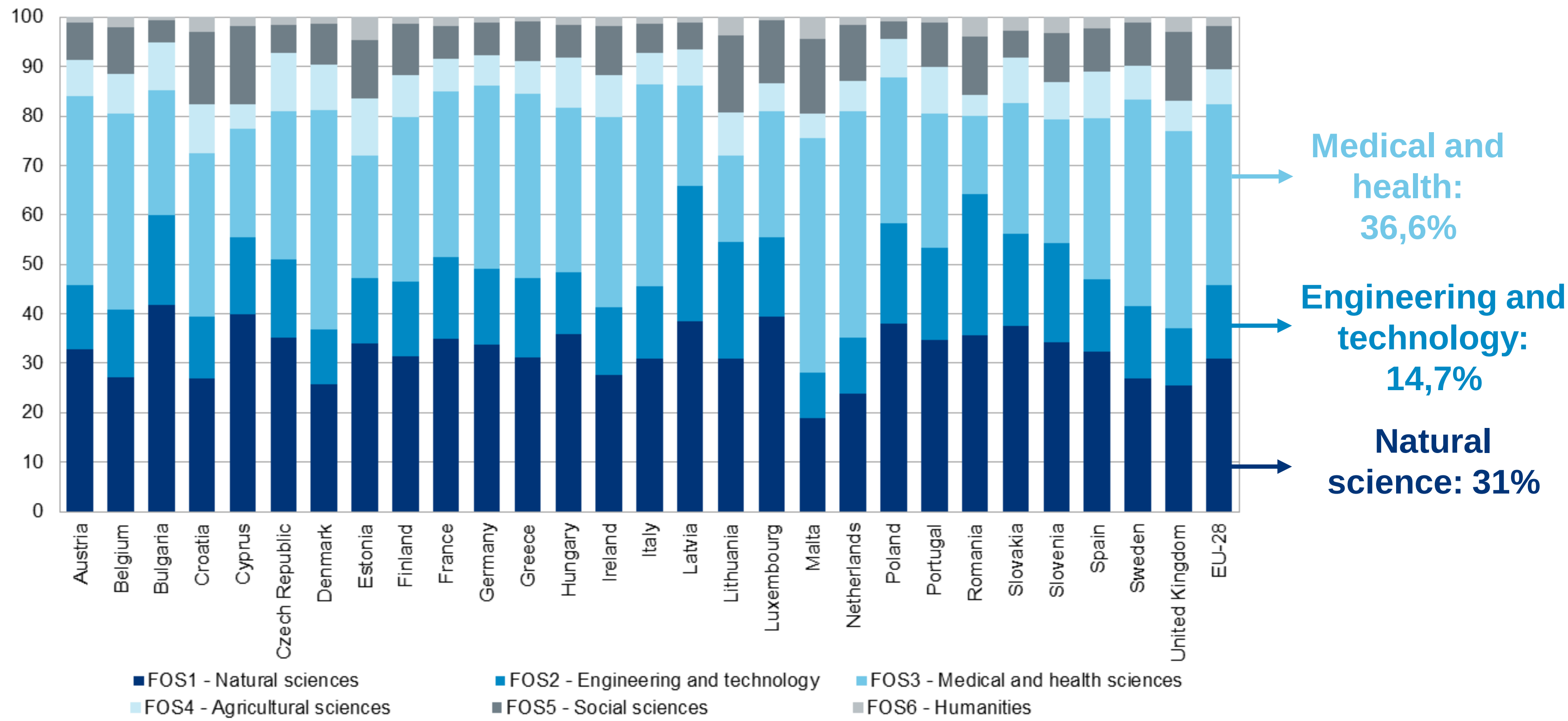


Source: SCImago Journal & Country Rank and Eurostat.

FACT 1: There are important differences in output per capita among the EU countries. (i.e. The scientific output per capita in Cyprus is 6.8 times more than the output of Latvia.)

THE FACTS

Figure 2. Distribution of scientific output by field of science. EU countries. 2012
Percentage

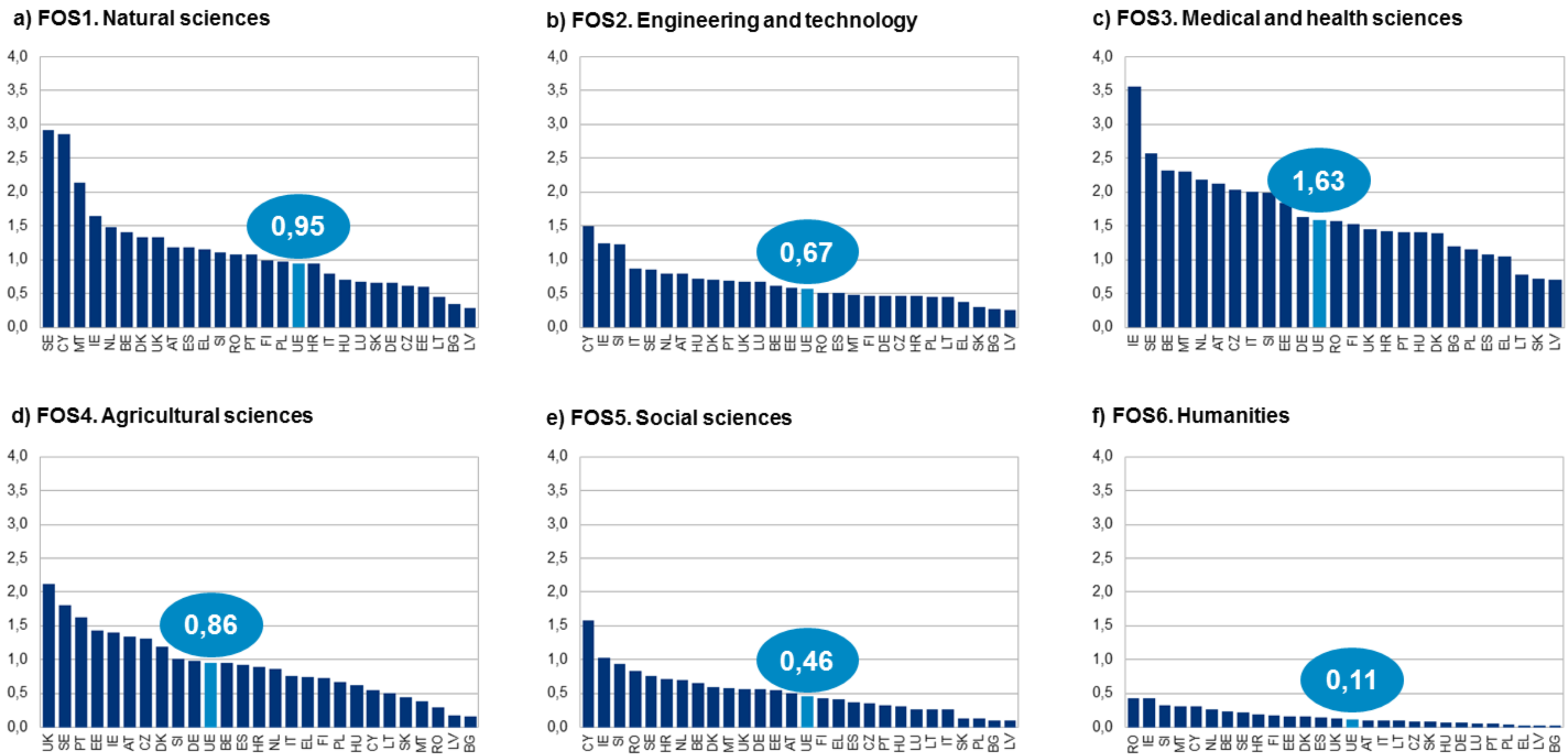


Source: SCImago Journal & Country Rank and own elaboration.

FACT 2: There are important differences in specialization in the fields of science (FOS). (i.e. the specialization of Estonia in Humanities is 2.6 times the EU average. UK is overspecialized in Social Sciences (60% higher than the EU average) and Humanities (70% higher than the EU average). Germany is under specialized in Humanities (40% lower than the EU average), etc.

Figure 3. Scientific output related to R&D personnel in Government and Higher Education by field of science. EU countries. 2012

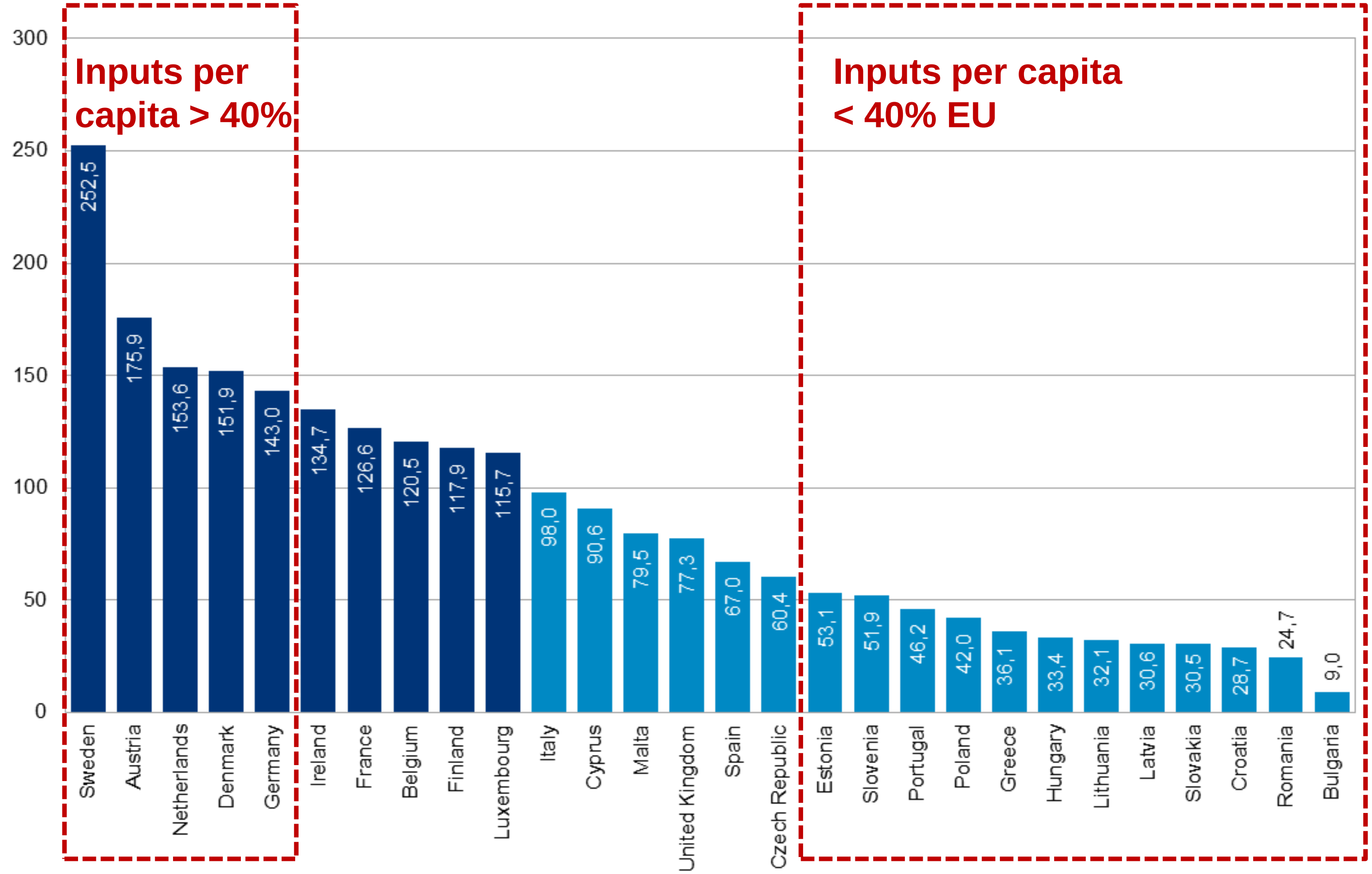
Citable documents per R&D personnel



Source: SCImago Journal & Contry Rank and own elaboration.

FACT 3: There are important differences in productivity among the FOS. The productivity of FOS3 (Medical sciences) is 14 times higher than FOS6 (Humanities). The productivity of FOS1 (Natural sciences) is 8.6 times higher than FOS6

Figure 4. R&D expenditure per R&D personnel. Government and Higher Education. EU countries. 2012
EU-28=100



Source: SCImago Journal & Country Rank and Eurostat.

FACT 4: There are important differences in R&D expenditure per capita (i.e. R&D pc in Sweden is 2.2 times the EU average and 25 times higher than in Bulgaria).

CONCLUSIONS:

FACT 1: There are important differences in output per capita among the countries.

There are **3 possible factors causing** these differences:

FACT 2: Differences in specialization among the countries
FACT 3: Differences in output per capita among the FOS.
FACT 4: Differences in R&D expenditure per capita among the countries.

We will calculate to what extent do differences in terms of specialization, differences in efficiency inside the scientific fields and differences in R&D per capita explain the differences in the research output among HEIs of the EU countries.

RESULTS: shift-share analysis

Shift-share of citable documents

Differences in the scientific output growth of the countries against the EU. 2008-2012

	INTRA-FIELD EFFECT	COMPOSITION EFFECT	TOTAL	INTRA-FIELD EFFECT	COMPOSITION EFFECT	TOTAL
Austria	3,2%	-0,7%	2,4%	129,8%	-29,8%	100,0%
Belgium	2,4%	0,0%	2,4%	100,2%	-0,2%	100,0%
Bulgaria	-14,6%	2,2%	-12,4%	118,0%	-18,0%	100,0%
Croatia	6,9%	-0,4%	6,5%	105,8%	-5,8%	100,0%
Cyprus	53,9%	-9,6%	44,3%	121,8%	-21,8%	100,0%
Czech Republic	12,2%	-2,7%	9,5%	128,0%	-28,0%	100,0%
Denmark	16,1%	-0,6%	15,5%	104,2%	-4,2%	100,0%
Estonia	20,1%	2,7%	22,8%	88,3%	11,7%	100,0%
Finland	-3,5%	-0,1%	-3,5%	98,2%	1,8%	100,0%
France	-7,6%	0,0%	-7,6%	99,4%	0,6%	100,0%
Germany	-3,5%	-0,7%	-4,2%	83,4%	16,6%	100,0%
Greece	-12,3%	-1,2%	-13,5%	91,0%	9,0%	100,0%
Hungary	-15,0%	-0,6%	-15,6%	95,9%	4,1%	100,0%
Ireland	9,3%	-0,1%	9,2%	100,6%	-0,6%	100,0%
Italy	0,3%	-2,2%	-1,9%	-16,1%	116,1%	100,0%
Latvia	34,0%	-4,9%	29,1%	116,8%	-16,8%	100,0%
Lithuania	-9,9%	-3,7%	-13,6%	73,0%	27,0%	100,0%
Luxembourg	88,5%	2,4%	90,9%	97,4%	2,6%	100,0%
Malta	31,4%	3,8%	35,1%	89,3%	10,7%	100,0%
Netherlands	5,3%	1,2%	6,5%	81,7%	18,3%	100,0%
Poland	5,7%	-3,8%	1,9%	298,2%	-198,2%	100,0%
Portugal	29,5%	-2,2%	27,3%	108,2%	-8,2%	100,0%
Romania	46,2%	-11,8%	34,4%	134,2%	-34,2%	100,0%
Slovakia	-5,2%	-1,1%	-6,2%	82,6%	17,4%	100,0%
Slovenia	7,4%	0,1%	7,5%	98,1%	1,9%	100,0%
Spain	10,7%	-0,6%	10,1%	106,0%	-6,0%	100,0%
Sweden	3,8%	-0,2%	3,6%	105,5%	-5,5%	100,0%
United Kingdom	-6,6%	2,6%	-4,0%	164,0%	-64,0%	100,0%
EU28	-	-	-	**107,3%**	**-7,3%**	**100,0%**

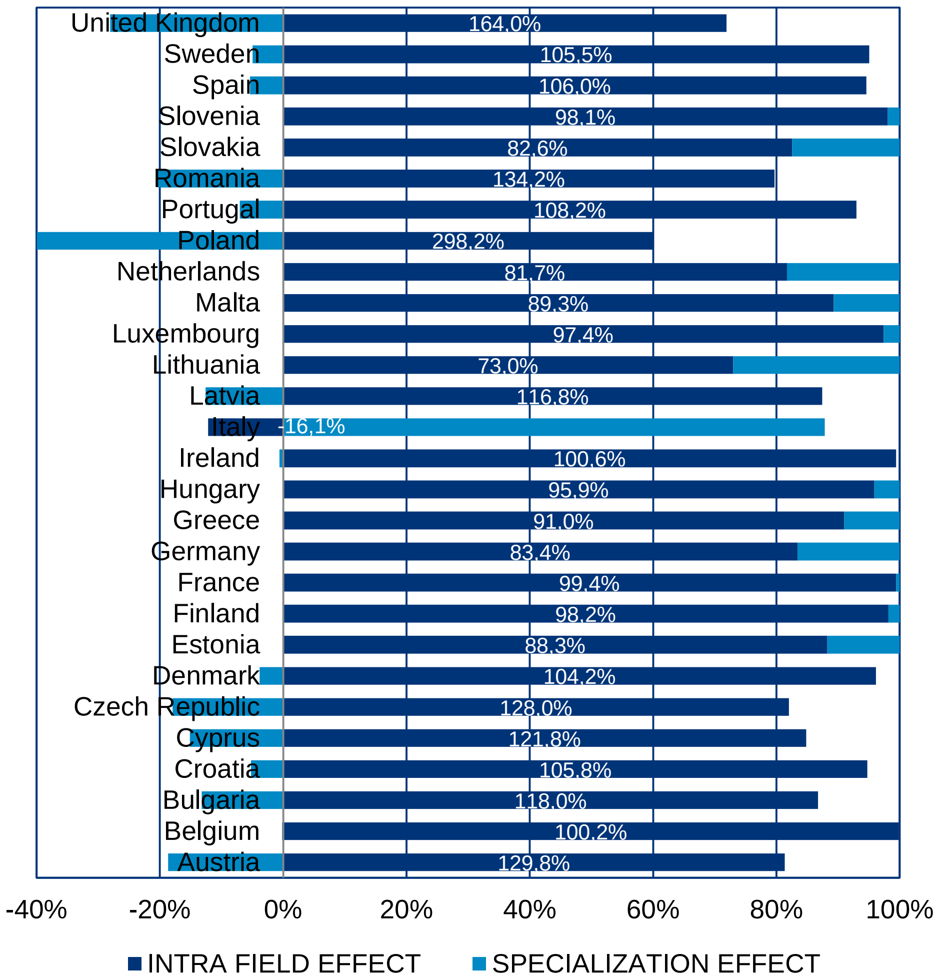
Most of the differences in the scientific output growth of the countries are due to differences in the output growth of each scientific field.

The **intra-field effect** is higher than the **composition effect** in all the countries (with the only exception of Italy).

So, in most of the countries the differences in the composition against the EU only explain a small proportion of the output growth differences. The **composition effect** is not important.

RESULTS: shift-share analysis

Shift-share of citable documents
Differences in the scientific output of the countries against the EU countries. 2008-2012



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RESULTS: shift-share analysis

Shift-share of citable documents

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Croatia	6,9%	-0,4%	6,5%	105,8%	-5,8%	100,0%
Cyprus	53,9%	-9,6%	44,3%	121,8%	-21,8%	100,0%
Czech Republic	12,2%	-2,7%	9,5%	128,0%	-28,0%	100,0%
Denmark	16,1%	-0,6%	15,5%	104,2%	-4,2%	100,0%
Estonia	20,1%	2,7%	22,8%	88,3%	11,7%	100,0%
Finland	-3,5%	-0,1%	-3,5%	98,2%	1,8%	100,0%
France	-7,6%	0,0%	-7,6%	99,4%	0,6%	100,0%
Germany	-3,5%	-0,7%	-4,2%	83,4%	16,6%	100,0%
Greece	-12,3%	-1,2%	-13,5%	91,0%	9,0%	100,0%
Hungary	-15,0%	-0,6%	-15,6%	95,9%	4,1%	100,0%
Ireland	9,3%	-0,1%	9,2%	100,6%	-0,6%	100,0%
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Slovakia	-5,2%	-1,1%	-6,2%	82,6%	17,4%	100,0%
Slovenia	7,4%	0,1%	7,5%	98,1%	1,9%	100,0%
Spain	10,7%	-0,6%	10,1%	106,0%	-6,0%	100,0%
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EU28	-	-	-	**107,3%**	**-7,3%**	**100,0%**

In some countries, the **composition effect** is relatively significant and **positive**. That's the case of Estonia or Netherlands. These countries are specialized in those scientific fields with higher scientific output growth.

In other countries, the **composition effect** is relatively significant and **negative**. That's the case of Germany and specially Italy. These countries are specialized in those scientific fields with lower scientific output growth.

RESULTS: shift-share analysis

Shift-share of citable documents

Differences in the scientific output growth of the countries against the EU. 2008-2012

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In other countries, the **intra-field effect** is relatively significant. That's the case of Austria, Czech Republic, Romania and specially UK and Poland.

The scientific output growth of these countries are mainly explained by the scientific output growth in each scientific field.

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RESULTS: The five-step methodology

	Overall efficiency (θ)	Composition efficiency (θ^{CE})	Intra-field efficiency (θ^{IE})
Belgium	1,22	1,03	1,19
Bulgaria	1,08	1,00	1,08
Czech Republic	1,54	1,00	1,54
Denmark	1,52	1,00	1,52
Germany	1,04	1,02	1,02
Estonia	2,01	1,00	2,01
Ireland	1,06	1,00	1,06
Greece	1,23	1,00	1,23
Spain	1,22	1,00	1,22
Croatia	1,20	1,00	1,20
Italy	1,28	1,00	1,28
Cyprus	1,12	1,00	1,12
Latvia	4,04	1,07	3,78
Lithuania	2,53	1,01	2,50
Luxembourg	2,83	1,17	2,42
Hungary	1,42	1,00	1,42
Malta	2,20	1,00	2,20
Netherlands	1,13	1,00	1,13
Austria	1,49	1,07	1,40
Poland	1,13	1,00	1,13
Portugal	1,17	1,05	1,12
Romania	1,03	1,00	1,03
Slovenia	1,12	1,00	1,12
Slovakia	2,22	1,04	2,13
Finland	1,78	1,01	1,77
Sweden	1,03	1,00	1,03
United Kingdom	1,00	1,00	1,00
Weighted Average	**1,18**	**1,01**	**1,17**
Simple average	**1,54**	**1,02**	**1,51**

On average, given the actual used resources, the **scientific output of the HEI** in the EU **could increase around 18%** if the inefficiencies were removed.

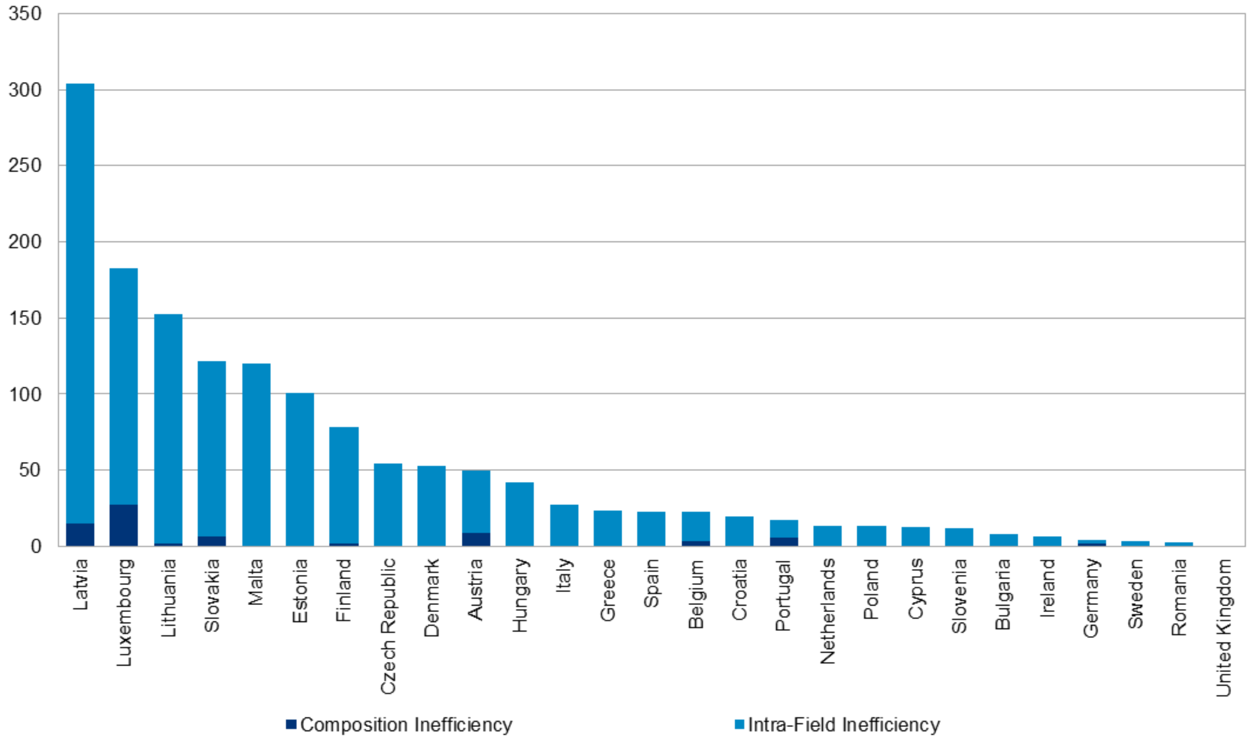
In some countries, the actual output could be increased by a factor of 2 or more (Latvia, Luxembourg, Lithuania, Malta, Slovakia).

Most of the inefficiencies come from inefficiencies **inside each specific field**, on the contrary, the **inefficiencies associated with the composition are much less significant**.

Composition inefficiencies hardly represent 5.5% of the overall inefficiencies. Unlike Intra-field inefficiencies that represent 94.5% of the overall inefficiencies.

RESULTS: The five-step methodology

Figure 5. Level of scientific output inefficiencies: composition vs. intra-field inefficiency. 2012
Percentage

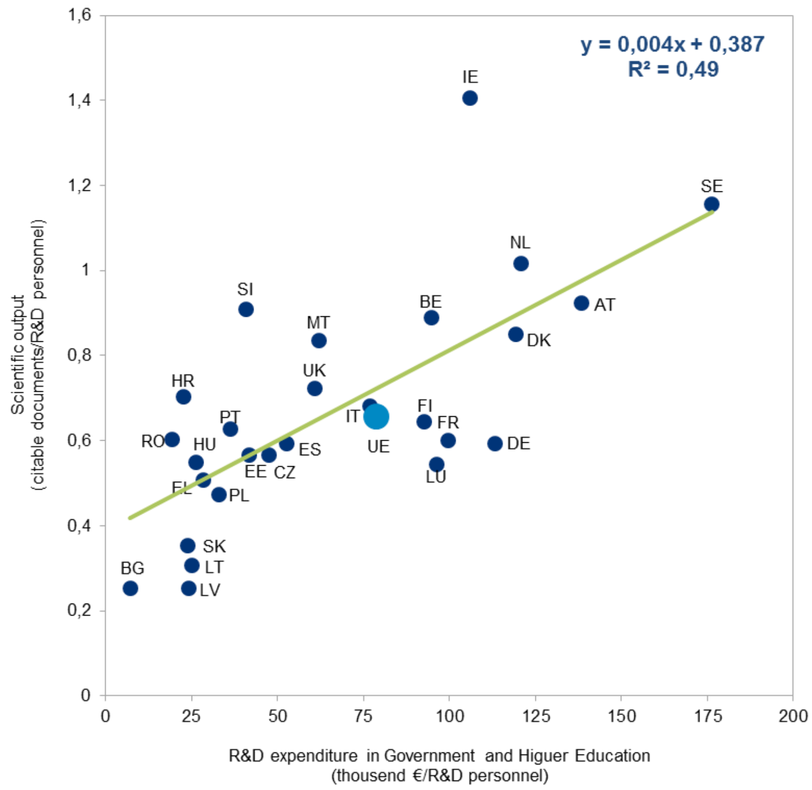


Latvia is the most inefficient country. Its research output could be increased 304%.
UK is the most efficient country. Its research output is the maximum attainable. It has the most suitable specialization and it is efficient in all the FOS.
Composition efficiency is negligible in most of the countries with the exception of Germany that represents 51.2% of their inefficiencies, Portugal (30.9%), Austria (16,8%) or Luxembourg (15.1).

RESULTS: The five-step methodology

Is the specialization or the inefficiencies the origin of the heterogeneity in research output per capita?

Figure 6. Scientific output vs. R&D expenditure. EU countries. 2012

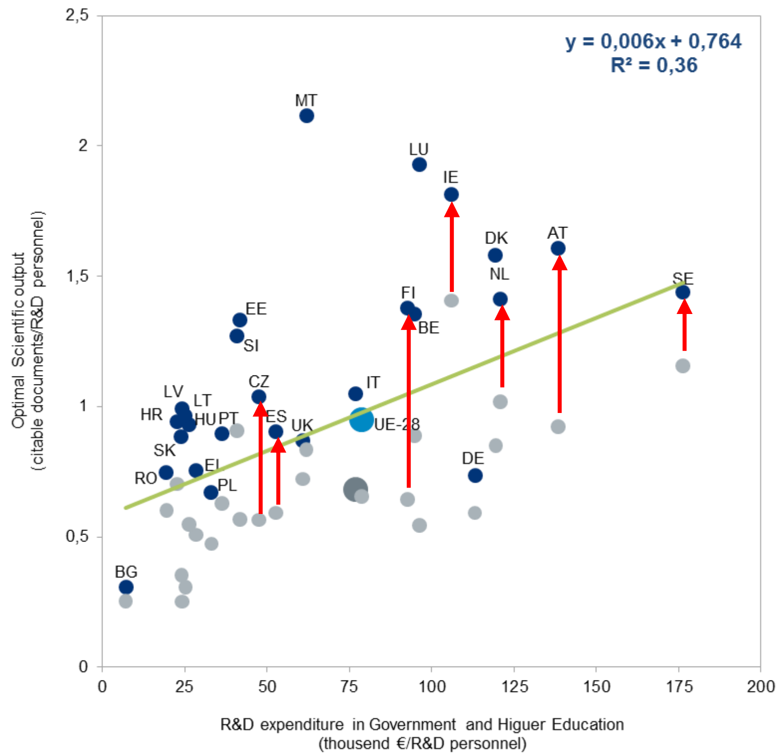


We observe a positive relationship between R&D (intangibles) per capita and research output per capita. The higher the R&D per capita, the higher the research output per capita. What happens when we remove the effect of specialization and the effect of inefficiencies?

RESULTS: The five-step methodology

Is the specialization or the inefficiencies the origin of the heterogeneity in research output per capita?

Figure 7. Optimal Scientific output vs. R&D expenditure. EU countries. 2012



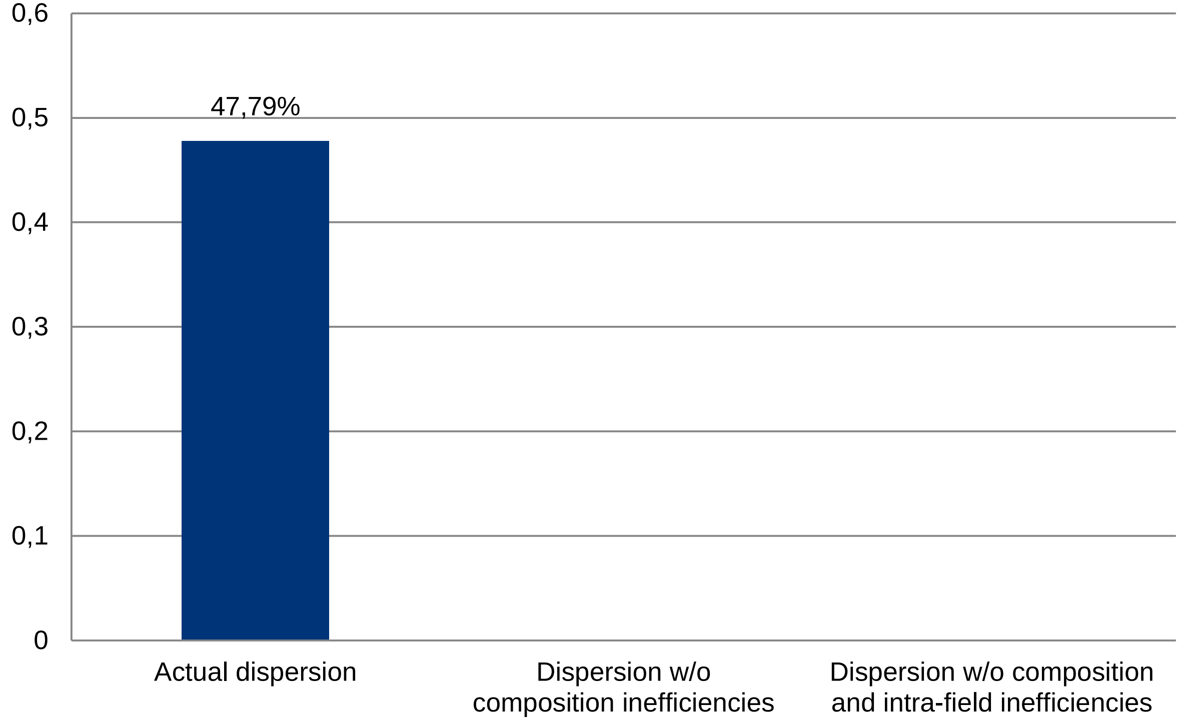
When we retrieve the effect of the specialization and inefficiencies, still there are a high level of heterogeneity in output per capita. Thus, specialization and inefficiencies are not the main origin of the heterogeneity in research output per capita → most of the origin of the heterogeneity is due to heterogeneity in the amount of resources per capita.

RESULTS: The five-step methodology

Is the specialization or the inefficiencies the origin of the heterogeneity in research output per capita?

Figure 8. Dispersion of the research output per capita

Deviation coefficient EU28



The heterogeneity of the output per R&D personnel is very high. The deviation coefficient is 47.8%

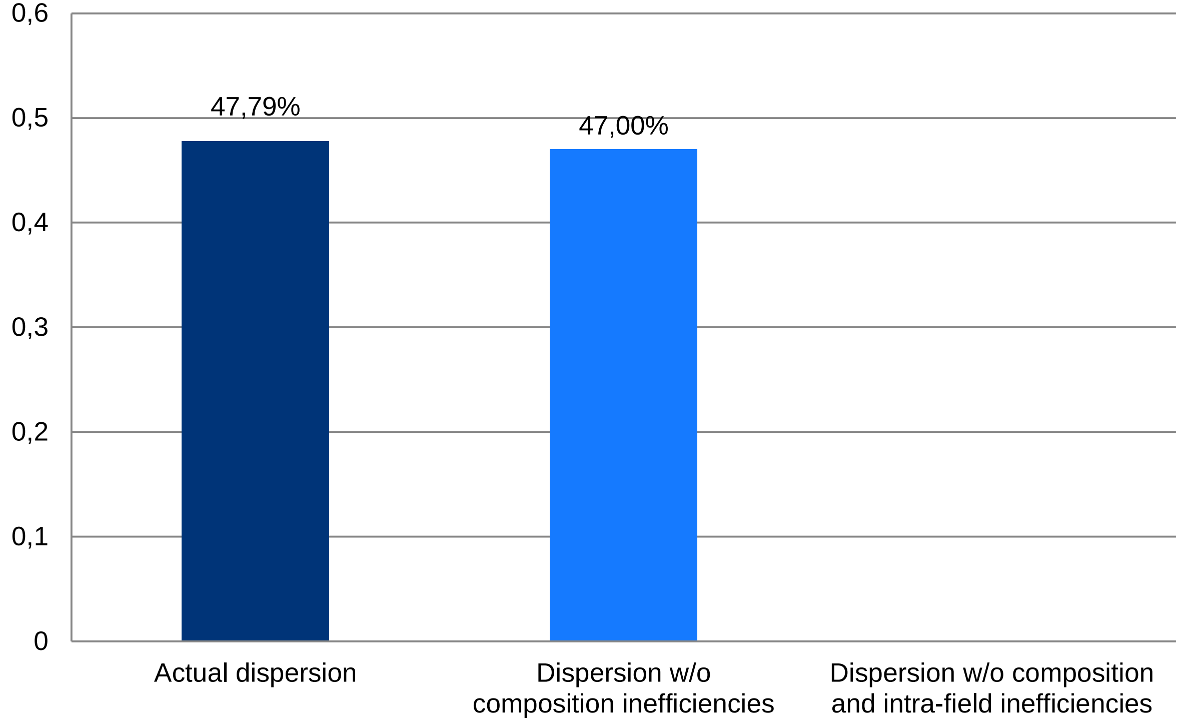
¿What happens to the heterogeneity if we **remove the composition inefficiencies**?

RESULTS: The five-step methodology

Is the specialization or the inefficiencies the origin of the heterogeneity in research output per capita?

Figure 8. Dispersion of the research output per capita

Deviation coefficient EU28



When we retrieve the effect of the specialization inefficiencies, still there is a high level of heterogeneity in output per capita. The deviation coefficient only decreases 1.7%, from 47.8% to 47%.

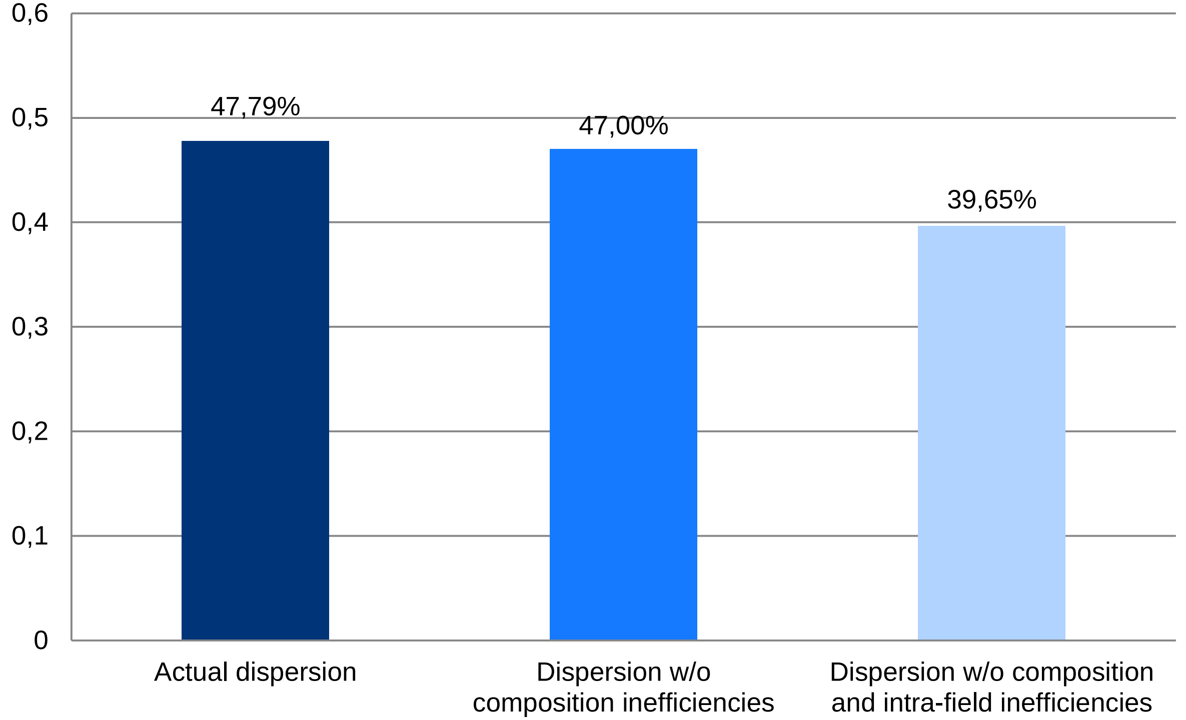
¿What happens to the heterogeneity if we also **remove the intra-field inefficiencies**?

RESULTS: The five-step methodology

Is the specialization or the inefficiencies the origin of the heterogeneity in research output per capita?

Figure 8. Dispersion of the research output per capita

Deviation coefficient EU28



When we remove the effect of the specialization and the intra-field inefficiencies, still there is a high level of heterogeneity in output per capita. The deviation coefficient only decreases 17%, from 47.8% to 39.6% → **most of the origin of the heterogeneity is due to heterogeneity in the amount of resources per capita.**

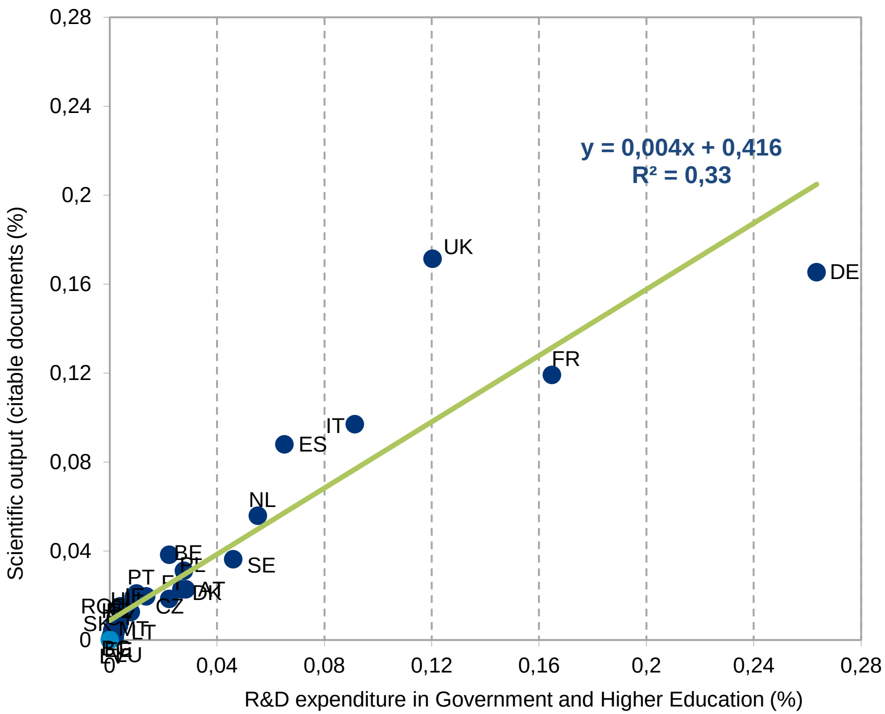
CONCLUSIONS

- We have analyzed the determinants of the research output of the HEI
  - Specialization
  - Inefficiencies inside scientific fields
  - Inputs (R&D expenses and R&D personnel)
- Shift-share analysis has shown that **most of the research output growth has been due to other factors than specialization.**
- DEA methodology has been used to explain the differences in research output. Results have shown that **most of the inefficiencies** come from inefficiencies **inside each specific fields**, on the contrary, the **inefficiencies associated with the specialization are much less significant**.
- If we remove the effect of specialization and intra field inefficiencies output would increase 18% and heterogeneity would decrease 17% → This means that 83% of the **inequality/heterogeneity of the research output per capita is due to the heterogeneity of the used inputs** (R&D – intangibles per capita).

POLICY IMPLICATIONS (I)

But…. Is it only a matter of more financial resources?

YES: Those countries that invest more money in R&D obtain more research output.



NO: Some countries are getting more value for the money allocated to R&D than others (small countries like Bulgaria, Croatia, Romania or large countries like UK, Spain or France). The weight of these countries in terms of publications is larger that their weights in terms of R&D expenditure. On the opposite side the largest EU countries (Germany or France) : % publications < % R&D expenditure

POLICY IMPLICATIONS (II)

- These results should encourage **policy makers to design policies** that improve the research output of those countries which, given the amount of resources that they devote, obtain poorer results (**efficiency):**

① **EUROPE 2020** has already designed some actions to promote research (train enough researchers to meet their national R&D targets and to promote attractive employment conditions in public research institutions, creation of knowledge alliances between universities and business, etc.).

② **Regarding the increase in the efficiency** appropriate incentives for HEIs and researchers should be designed to promote the efficient use of financial and human resources

WP3: Education, health and R&D: Impacts on smart growth

Task 5. THE RESEARCH OUTPUT OF UNIVERSITIES AND ITS DETERMINANTS: INTANGIBLE INVESTMENTS, SPECIALIZATION AND INEFFICIENCIES

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April, 23-24, London

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SEVENTH FRAMEWORK PROGRAMME

Ivie