Scientific productivity of public higher education institutions in Poland

A comperative bibliometric analysis

Joanna Wolszczak-Derlacz
Aleksandra Parteka

SPRAWNE PAŃSTWO
PROGRAM ERNST & YOUNG

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For most of the twentieth century economic policies focused on macroeconomic stability and the quality of institutions as factors necessary to ensure long-term economic growth and improve living conditions. However, recent decades shifted the attention: it was recognized that although these are necessary preconditions for economic success, it is the innovation that is of crucial importance. With the gradual transformation of contemporary economic model into knowledge-based economy, it is the ability to innovate that becomes the country's ultimate test of success in global competition.

Universities play an important role in the process as centers for the creation and dissemination of knowledge. They contribute to boosting productivity in the economy: through both teaching and research as well as cooperation with the stakeholders. In particular, the high quality of university researches and their relevance to the actual needs of the economy is crucial for the process of developing and implementing innovative solutions. The quality of research undertaken in universities is high on the agenda, also in Poland, as part of an increasingly important area of debate on the higher education development today.

This report, prepared as part of Ernst & Young's Better Government Program, is a valuable contribution to this debate. The authors compare the publishing activities of Polish universities with those in other EU countries and use the results as the starting point for answering the question of what factors determine the relatively poor score of Polish universities in this regard. The major advantage of the study is that it is one of the few papers on higher education in Poland that is based on non-aggregated university-level data. This allows for a more complete analysis of the examined relationships.

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List of Abbreviations

ARWU	Academic Ranking of World Universities
CPI	Consumer Price Index
CSO	Central Statistical Office of Poland (= GUS - Główny Urząd Statystyczny)
EPO	European Patent Organisation
EU	European Union
EU15	European Union of 15 countries (till 2004)
EU27	European Union of 27 countries (after 2007)
EUR	euro currency
fte	full time equivalent
GDP	Gross Domestic Product
HE	Higher Education
HEI	Higher Education Institution
HEIs	Higher Education Institutions
HES	Higher Education System
ISCED	International Standard Classification of Education
ISI	Institute for Scientific Information
JCR	Journal Citation Report
MSHE	Ministry of Science and Higher Education (= MNiSW – Ministerstwo Nauki i Szkolnictwa Wyższego w Polsce)
n.a.	not available
OECD	Organisation for Economic Cooperation and Development
PhD	Doctor of Philosophy
PLN	Polish zloty
PPP	Purchasing Power Parity
R&D	Research and Development
USD	American dollars

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Summary

In the recent years, a vivid discussion on the necessary reform of the educational system in Poland has provoked a debate on the quality of research done in Polish higher education institutions (HEIs). The numbers referring to the publication record (perceived as one of the basic indicators of scientific efficiency) are meaningful: in 2008, per each 100 academic staff members based in Polish HEIs, there appeared only 23 publications in internationally recognized scientific journals (listed in ISI Web of Knowledge) with at least one author claiming academic affiliation in Poland.[1] This means that, on average, an academic staff member employed in Polish academia has one publication in a high quality international journal in four years! For comparison, analogous indicators of publication record per academic staff member affiliated with universities from Western European countries such as Germany or Austria are two-three times higher. Taking into account the indicator of publications listed in Elsevier (1996-2008) per R&D personnel employed in higher education in Poland, it is two times lower than in UK or in Finland, three times lower than in Switzerland. Also the quality of Polish publications and their average impact measured by citation indicators, place Polish research far behind international standards –within the years 1996-2008 a scientific paper authored (co-authored) by Polish researcher(s) was on average cited 6 times, two to three times less frequently than papers published by Western European or American researchers.[2] The publication record is often perceived as a basic indicator of research output efficiency and visibility, so it is clear that, at least in the light of bibliometric measures, Polish science still lags behind. Similar backwardness appears when we consider patent activity or the amount of funds dedicated to R&D in Poland.

The main empirical question that we would like to answer is: why do Polish scientists find it so hard to meet the highest standards of European academic research? Several factors can be put forward as potential determinants of scientific output. For instance, academic staff members employed in Polish higher education institutions often complain about unsatisfactory financial resources dedicated to research activity or excessive teaching load, which consumes time and energy. The debate on the optimal size of institutions and the composition of employment has also emerged. However, the lack of solid quantitative analysis on the determinants of scientific efficiency makes it hard to draw precise conclusions. So far, we can only speculate on the sources of still rather unsatisfying visibility of Polish science in internationally recognised scientific journals. Similarly, the relative importance and

strength of various factors in influencing research productivity is unknown.

Up till now, most analysis of higher education systems (HES) have been performed at the national level and only recently more attention has been drawn to the collection of micro data, enabling evaluation of the performance of individual institutions. To the best of our knowledge, there is no study of this kind that takes into account Polish HEIs and draws on data characterizing single university units. Consequently, empirical studies of higher education in Poland are mainly qualitative and descriptive.

This report aims at presenting the case of scientific research done in Polish HEIs, with a particular – due to their role in applied knowledge creation - focus on technical universities. In order to allow full cross country comparability we concentrate on bibliometric indicators of research performance based on information on the publication record in internationally recognized journals. We draw on a micro-level database prepared especially for the purpose of this study, which gathers data on inputs and outputs of individual institutions constituting the Polish public system of higher education. Taking into account great heterogeneity within the system, we focus on research efficiency achieved by single university units. In order to provide a comparative study, we present HEIs in Poland in relation to HEIs from more developed European countries (namely: Austria, Finland, Germany, Italy, Switzerland and the United Kingdom) for which it was possible to collect analogous evidence. Such a broad view allows us to compare the research efficiency achieved by universities functioning within heterogeneous systems of high education and, hopefully, to indicate the sources of still rather poor research performance of HEIs in our country.

The report is composed of five parts and is structured in the following way. We first present the importance of scientific research and its specificity in the Polish academia versus the European trends, given particular institutional and legal frameworks. Then, in Chapter 2, we describe the approach adopted in the present analysis, the related literature and the research questions to be answered. Chapter 3 contains detailed information on adopted methodology and data. The core of the report is presented in Chapter 4 that is entirely devoted to the empirical analysis of research productivity and its determinants. We test all the causal claims, introduced previously, one by one, quantifying the impact of various factors on the research performance in Polish and, for comparison, foreign academic units. Whenever possible, we show the results of a quantitative study in a simple manner and also provide a technical section (in the Appendices)

on the estimation results - intended for readers familiar with econometric modelling. Additionally, the quantitative analysis is complemented by qualitative description of relations of HEIs with their external environments. The final fifth chapter contains conclusions and a set of recommendations that we would like to propose to the policy makers. References and appendices can be found at the end of the report.

Our results suggest that especially financial resources (not only in terms of their magnitude, but also their sources) and the teaching burden strongly determine research productivity. The impact of these two factors on average research output is not negligible: we find that, *ceteris paribus*, a 10% increase in funding per capita could be linked to a rise in research productivity done at Polish HEIs by around 40%. It is not surprising, if we take into account the fact that the average funding per staff member in Polish HEIs is at least two times lower than that in Italy or in Switzerland. Additionally, in Polish HEIs the vast majority of funds (more than 80%) goes for didactic-related activities and is of the public nature; we show that public funds are typically less productive than competitive research grants. Then, *ceteris paribus*, a decrease in teaching load by 10% could be associated with up to 16% improvement in research efficiency. The impact of these two factors (funding and teaching load) is also confirmed in case of foreign university units, albeit in case of Poland their influence on research productivity is stronger.

Among other factors having an impact on scientific output we can distinguish several other university-specific factors. As far as the role of fund concentration in big units is concerned, larger HEIs in Poland (and in other European HEIs) appear to be more research productive in terms of the number of publications per academic staff member. It hints to a possibility of economies of scale in higher education.

Moreover, taking into account staff composition, a greater proportion of professors can be associated with higher scientific productivity but this relation between the share of professors in total academic staff and research productivity of a given unit is stronger in European sample than in case of Poland. Also major share of PhD students goes hand in hand with better research performance.

Furthermore, more heterogeneous HEIs (with more faculties) appear to perform better in terms of research efficiency (this result, however, can be linked to the aforementioned effect of size of units with more faculties). Finally, in case of Poland, older university units with longer traditions and stronger positions in the academic network appear to

perform better. However, in the European sample this relationship is not so straightforward. As far as aspect linked to the HEIs' location are concerned, most research productive Polish HEIs are traditionally located in big cities or agglomeration while a link between location in richer regions and research performance in Western European HEIs is more ambiguous (strong European universities are located also far from core economic locations).

Finally, comparing technical universities to university units, on average HEIs with clear technical and applied orientation appear to perform better in the light of bibliometric indicators. The rise in the number of publications per academic staff member of Polish technical universities was also more pronounced than universities. However, it may reflect the difference in publication activity across disciplines (e.g. applied science versus humanities – traditionally less oriented on publications in academic journals).

Our report should be treated as an attempt to provide quantitative evidence on research efficiency along with its main determinants and not as the complete picture of complicated relations that characterise academic research. Being aware of the intricate nature of input/output relations in higher education, we have been selective in treating the subject, deciding not to cover several 'immeasurable' aspects (such as the role of institutional surrounding or soft factors influencing research efficiency) that should rather be approached in a descriptive manner. At the end of the report we propose future directions of research. Nevertheless, we strongly believe that answering our research questions could give important indications to the policy makers involved in the reform of higher education system in Poland. We hope that our report will serve as an additional contribution to the debate on the future of Polish academia.

1. Introduction

1.1. Academic research as a key factor of human capital creation

„In the global knowledge economy, people's skills, learning, talents, and attributes – their human capital – have become key to both their ability to earn a living and to wider economic growth. Education system can do much to help people to realise their potential, but when they fail it can lead to lifelong social and economic problems" (OECD, 2007 s. 21)

It is well understood that the major determinants of XXI century economic growth are not physical assets but intangibles such as education, knowledge and science. The incorporation of human capital and R&D sector into endogenous growth models (Lucas, 1988; Romer, 1990; Aghion and Howitt, 1992 and Jones, 1995) has changed not only the theory, per se, but has also been of a great importance from the political perspective.

Role of scientific research and human capital

The proposition that human capital and research play a central role in the so-called knowledge-based economy (as opposition to resources-based economy) emerged also in the European context. In particular, Lisbon strategy has indeed expressed an ambitious aspiration of Europe to become *"the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion."*. To achieve this goal, the European Commission states that Europe *"... simply must have a first-class university system - with universities recognized internationally as the best in the various fields of activities and areas in which they are involved"* (European Commission, 2003 p. 22). It gave rise of a policy debate about universities in Europe: their role (teaching versus research), funding, governance and efficiency.

Europe has a long tradition to carry research at universities and/or with a strong cooperation with higher education institutions – their activities account for 80% of the fundamental research pursued in Europe (European Commission, 2003). Even though the number of agents involved in the knowledge creation has risen, universities are present at all stages of knowledge creation- starting from the knowledge production, diffusion through the process of education and, finally, application. Academic research becomes even more important in the view of so-called 'third mission' of universities – collaboration of academia with business and environment – that can enhance knowledge spillover and its practical application. Consequently, research performed within higher education systems is an essential factor of economic growth and progress.

1.2. Polish Higher Education System in the European context

There is no unique or common European model of Higher Education System (HES). Concrete education solutions vary from country to country and are embedded in a specific historical and political context. From the point of view of great heterogeneity of higher education systems in Europe, international programs such as: the Bologna process, Lisbon strategy and the initiative to create the European Education and Research Area are well understood.

Theoretically, there are at least two main countervailing forms of universities organisation: so-called Humboldtian model and the Anglo-Saxon model. The former combines research and teaching into the basic university's mission, while the latter model is more teaching- and student-oriented (Agasisti and Catalano, 2006).

As far as the positioning of Polish HEIs within the heterogeneous European system of higher education is considered, several key features should be analysed: basic characteristics regarding ownership and nature of a given HEI (general, technical, applied etc.), funding scheme, university governance, tuition fee versus support for students and barriers to academic career. Table in the Appendix 1 summarises the structure of the higher education systems in each country which we take into account in our study – we present Poland versus HEIs of: United Kingdom, Germany, Austria, Finland, Italy and Switzerland (see Section 3.3 for details concerning data issues). Despite the restricted country coverage, it should be noted that all main different higher education systems are taken into account. Below we present the main differences between Polish system of tertiary education and foreign counterparts.

1.2.1. Basic features

Within analysed countries, the public nature of universities is prevailing. Nevertheless, private HEIs are widespread.[3] In Poland there are almost three times more private HEIs than public ones, but the private sector is composed of smaller units, focused mainly on teaching (not free of charge, as opposed to public units). In 2008 there were 131 public higher education institutions where more than 65% of all students were enrolled and 325 private institutions where 34% of all students were enrolled (GUS, 2009a).

Polish HES visibly divides HEIs into: universities (composed of social and theoretical sciences faculties), technical universities (focused

Structure of Polish HEIs

on engineering sciences), and special purpose units such as: medical universities (previously called 'medical academies'), maritime schools, academies of arts, academies of sport etc. In particular, medicine and pharmacy faculties which in other European countries constitute parts of universities along with other faculties, in Poland form separate higher education institutions. Technical universities are also present in: Austria, Finland, Germany, Italy and Switzerland.

Additionally, in some countries along with university system there exists non-university higher education sector (the first row of the table in the Appendix 1), for example: universities of applied science in Switzerland or Fachhochschule in Germany and in Austria. The main task of these non-university institutions is mainly to provide technical and professional training, rather than to conduct research.[4]

1.2.2. Funding system

Funding system of HEIs

The characteristics of a funding system are of a particular importance because the magnitude of funds, their sources and procedure of distribution across different HEIs are crucial for the achievement of the goals set to the system of higher education (efficiency, research productivity, high quality of teaching etc.).

From the macro perspective, expenditures on HE (ISCED 5A and ISCED 5B[5]) for OECD countries in 2006 represented between 0.9 to 2.9 per cent of GDP. Even though the share of expenditure on educational institutions as a percentage of GDP in Poland (1.3%) is comparable to more developed European countries' standards, the picture changes dramatically when we express the expenditure in relative terms– annual expenditure on educational institutions per student in Poland (5224 USD, PPP) is among one of the lowest values among the OECD countries (OECD, 2009).

Moreover, countries differ substantially if we consider the source of funds. Bonaccorsi and Daraio (2007) distinguish between three main sources of funding HEIs common for the developed countries: government, private sector and student fees. In the group of seven countries analyzed in our report, the UK has the highest share of private sources (34%), while Finland has the lowest (less than 5%). In Poland, 29.6% of total expenditures originate from private sources, the rest comes from the public system (OECD, 2009).

Direct public funding of HEIs coming from the government (national or local) can be divided into two main streams: general allocation in the form of grants for teaching and operational activities, or grants for

research. It is evident that the procedure of allocating public funds to public and government-dependent private HEIs differs mainly in case of teaching grants and funds for research (second row of the table in Appendix 1).

Almost all European countries use 'funding formulas' to calculate the magnitude of public grants to HEIs destined to cover teaching and/or ongoing operational activity and, in certain cases, research (for details see: Eurydice, 2008, p. 50-60). The criteria used for awarding public teaching-related grants are linked mainly to the number of students or degrees awarded.[6] Additionally, in some countries, in the formulas there appear characteristics connected to the number of academic staff (Poland), rental costs of universities (Finland), location (United Kingdom – England) or costs borne in the previous years (Poland).

Details of the funding algorithm used to allocate teaching-related financial resources to public HEIs in Poland is defined by the Ministry of Science and Higher Education (MSHE) and published in the form of a legal act (Dziennik Ustaw nr 89, poz. 544). Currently adopted funding scheme emphasizes factors connected to the number of students and academic staff, but not for example to the quality of teaching, and thus promotes big units.

Table 1 shows the structure of revenues (by type) in Polish public HEIs. The biggest share of operating revenues is in the form of teaching-related funds (above 80% in 2008) which, in case of public HEIs, come mainly from the government as teaching grants (74%). In case of technical universities, the proportion of teaching-related revenues in overall operating activity revenues is lower than in case of universities (71.2% versus 83.1%, respectively), but larger share of it (80%) is due to the governmental didactic fund than in case of universities (67.8%).

Theoretically, higher education in Poland is free of charge in public sector institutions and in case of full-time day courses - which is guaranteed by The Constitution of the Republic of Poland. However, HEIs conduct intensive part time courses or studies that are run during weekends, which have to be paid for by students and have become a considerable sources of funding for these universities. Consequently, tuition fees constitute between 13.2% (in case of public technical universities) to 22% (public universities) of all teaching revenues (Table 2). Kwiek (2009) argues that this 'privatization' of public HEIs in Poland (almost half of all fees paid for higher education are directed to the public sector) questions the notion of "free" public sector.

Structure of revenues

Table 1. Structure of operating activity revenues in Polish public HEIs, in %, by type (2008)

	Operating activity revenues	of which				
		Revenues (teaching activity)	Revenues (research activity)	Revenues (rationed economic activity)	Revenues from sale of goods and materials	Other operating activity revenues
Total public HEIs	100	80,6	14,1	0,7	0,2	3,9
Universities	100	83,1	12,0	0,0	0,1	4,3
Technical universities	100	71,2	24,1	0,4	0,1	3,2

Source: GUS (2009a), Table 5.2, p 320.

Table 2. Structure of revenues (teaching activity) in Polish HEIs, in %, by sources (2008)

	Revenues from teaching activity	of which			
		allocation from the budget	funds from the gminas budget and other public funds	fees for teaching activities	others
Total public HEIs	100	74,0	0,2	18,2	7,6
Universities	100	67,8	0,3	22,1	9,7
Technical universities	100	79,9	0,1	13,2	6,8

Source: GUS (2009a), Table 6.2, p. 324.

1.2.3. University governance

University governance in Poland

Additionally, the governance structure of HEIs is expected to influence their performance. In the second row of the table in the Appendix 1 we present particular governance schemes across analysed countries. University governance refers mainly to: the relationship between different stakeholders (including the executive head of the institution, staff, students, parents, governments, etc.), their responsibilities and hierarchy. In Poland the Rector, elected and appointed by an institutional-level body composed solely of internal stakeholders (academic body - the Senate[7]), is an executive head of every Polish HEI. Rector is the representative and the manager of a HEI, supervises teaching and research activities. On the contrary, in Austria and in the United Kingdom, the institutional body which appoints the executive head is composed solely of external stakeholders (Austria) or has a majority of external stakeholders (UK). Additionally, in Poland, the position of executive head is not open to public competition as in Germany, Austria, Finland or the United Kingdom. Polish Rector is elected by the Senate and must be a staff member (typically a professor) from within the institution. It means that the governance of public HEIs in Poland depends on their internal forces and is largely independent from the

external surrounding which implies a large degree of autonomy of a single HEI, but also allows practically no possibility to appoint external expert to govern the institution. Opinions of external experts (e.g. Dąbrowa-Szefler and Jabłecka-Prysłopska, 2006; World Bank, 2004) on the university governance system in Poland are not very favourable. The main underlined weakness is the lack of managerial competence of HEIs' executive heads.

Lack of managerial competence

Important differences relate to remuneration schemes. The rules of compensating academic staff, together with the procedures of setting the salary scale, the level of salary and additional benefits vary considerably across European countries. The procedure of defining salary scale is carried out either at the central level (Poland, Germany, Italy) or at the level of single institutions (Austria). In Finland, the pay scales are negotiated by the state and the institutions, while in the UK – agreed between the Universities and Colleges Employers Associations (UCEAs) and the unions, representing staff in higher education. In Polish public universities, salary is established by the Rector of each institution, according to the guidelines of MSHE that provide basic salary brackets for each academic position (calculated as the percentage of a base amount stated in the official Budget Act, changeable every year). Professors get 391,8% of the base amount, adjuncts (academic staff members with a PhD title) - 261,2% and assistants - 130,6 %[8]. For instance average gross salary without any bonuses and additional income (e.g. research grants) at Gdansk University of Technology in 2009 was between 511 €/month for an assistant (without PhD) to 1395 €/month for a full professor (for comparison average professor's salary in the UK – 7315 €/month). In general, salaries paid at Polish HEIs are extremely uncompetitive and, as a result, many of those that could perform good research do not stay in academia or work at university but also search for some form of an additional job, devoting less time to research activity.

Salaries

Additionally, working time of staff employed in the academia varies greatly, depending on the type of post, country specific rules etc. In Poland teaching load varies across HEIs and also depends on the status of an academic staff member (there are those responsible both for teaching and research, as well as academic staff members with sole teaching duties). Teaching load for academic staff with teaching and research duties ranges between 120 and 240 hours per academic year (typically 30 working weeks), depending on the stage of the career. Young researchers have considerably higher teaching load (even twice as many hours than professors) which reduces the amount of time they could devote to doing research. Academic staff members responsible only for teaching have to teach between 240 hours and 360 hours per academic year. Other categories of academic staff (language teachers, instructors and other similar posts) are obliged to teach between 300

Teaching responsabilities

and 540 hours per academic year. Note that aforementioned rules are set by the Polish law[9] and define the general teaching load. In reality, it is often that the academic staff members teach even more hours per year than these rules say (in a form of 'additional hours' taught within daily studies if the number of academic staff is not sufficient to cover all hours or in a form of part-time courses during weekends).

1.2.4. Reforms

The alternations to be reintroduced

All European universities are under pressure to change (De Boer and File, 2009; Kwiek, 2009), mainly due to rising competition (within and across countries) and the need to adapt to new social and market conditions (such as a relative decrease in public funding or demographic changes). In all European countries, HE system has been under profound changes (see sixth row of the table in Appendix 1), most of them with the aim of strengthening HEIs' autonomy.

New solutions for higher education

At the moment (2010), Poland is in the process of introducing a new strategic policy concerning the system of higher education. The issue of upcoming reform in Poland has provoked a vivid discussion in the scientific and non-scientific environment.[10] Further, in March 2010, MSHE presented "Project of the Changes in Laws on Higher Education"[11] with the main components of planned reform. The main changes announced by the MSHE refer to: strengthening of university's autonomy; concentration of funds in so-called 'flagship institutions' (the limited number - 3 per year - of leading HEIs); new (easier) career development (e.g. simplification of the habilitation procedure); bigger clarity of employment procedure; impediment of multiply job holding by academic staff members; sustaining free of charge education for full-time studies leading to a first qualification, but introducing paid education in case of second and further qualifications (only the best students willing to educate in the second field of study would not have to pay for it); and increasing the financial support for students. The need for the reform was expressed in many critical reports on the state of the Polish higher education system.[12] The new strategy for higher education has been completed by the consortium of Ernst&Young and IBnGR[13] (the report has been announced on February the 3rd, 2010 (second version: March the 1st, 2010).[14] An alternative strategy (KRASP, 2009) was announced by the Conference of Rectors on December the 2nd 2009.[15]

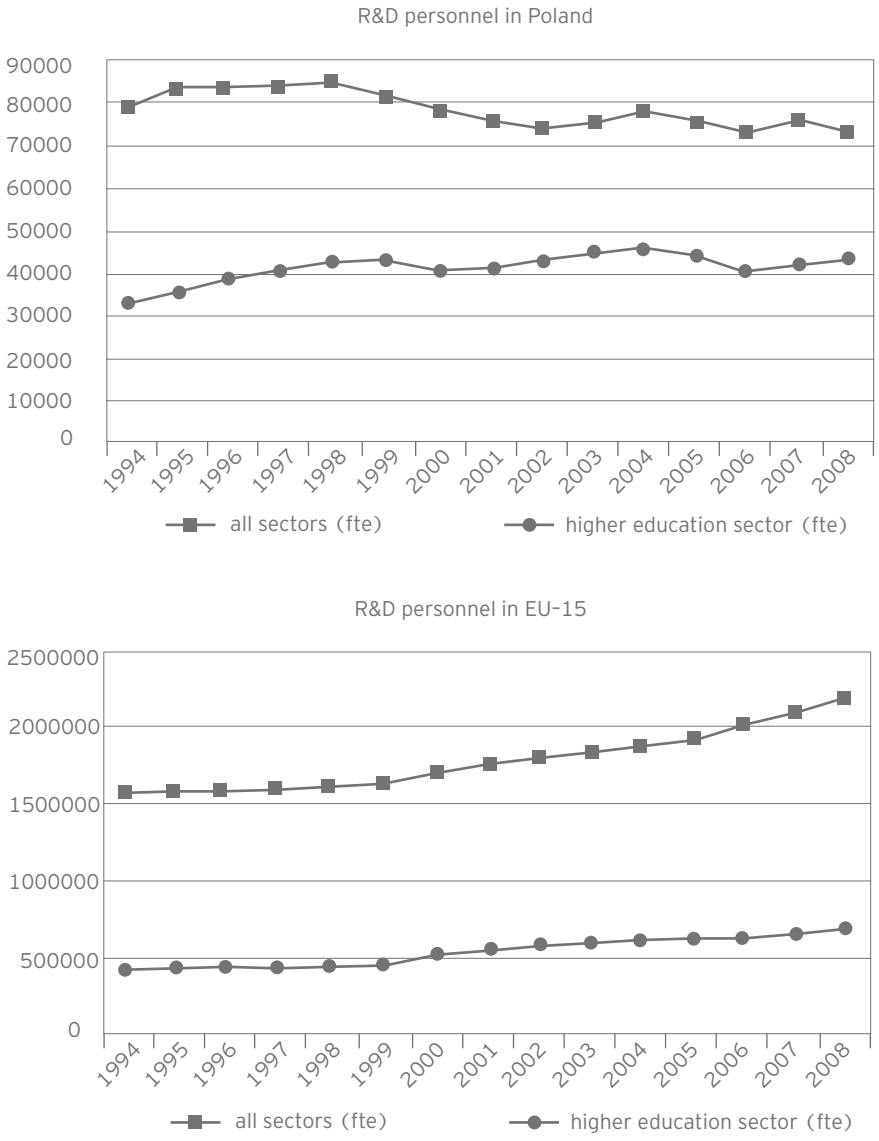
1.3. Research sector at public HEIs in Poland

1.3.1. Main features

The number of research and development (R&D) personnel employed in higher education sector in Poland was constantly growing within the

years 1994-2008 (Figure 1) – its growth is especially interesting if we consider general decrease in persons employed in R&D in all sectors since 1998. As a result, the proportion of R&D staff in Polish higher education sector increased from 41% in 1994 to 58% in 2008. For comparison, in EU-15 countries both total number of R&D personnel and R&D personnel employed in higher education system were increasing and the proportion of the latter in total remained rather constant (about one-third: 27% in 1994 and 32% in 2008) and lower than in Poland.

Figure 1. R&D personnel (total and in higher education sector) in Poland and in EU-15 (1994-2008)



Note: fte - full time equivalent

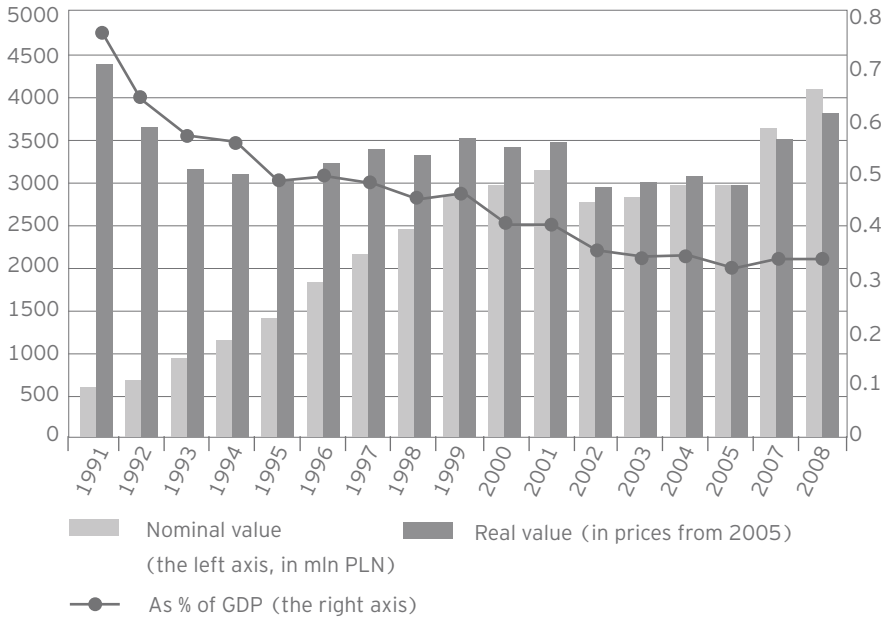
Source: own elaboration with the data from Eurostat.

Moreover, in Poland R&D activity is mainly performed by the public sector: 60% of Polish R&D is financed by the government, in relation to averages of 40% in EU and 34% in OECD countries (OECD 2008). The main beneficent of public R&D funds in Poland are HEIs: in 2007 they accounted for 46% of all public expenditure on R&D and 65.9% of total employment in R&D (GUS, 2009b). Despite the fact that HEIs are the main recipients of public R&D funds, the share of research activities in HEIs' revenues is very low (Table 1) which does not lead to a very optimistic image of research conditions at Polish public HEIs.

Sources of funding

Figure 2 presents the science budget expenditure between 1991-2008. Even though there was an increase in the nominal expenditure, it was accompanied by a stagnation of expenditure on science expressed in real terms (here expressed in constant 2005 prices) and even a drop when the expenses are expressed as per cent of GDP (0.8% of GDP in 1991 an 0.35% in 2008).

Figure 2. Budget expenditures on science between 1991-2008 in millions of PLN and as % of GDP.



Source: own elaboration based on the data from: Annual reports on budget spending, Part 28: Science, Ministry of Science and Higher Education, various editions (Raport z wykonania budżetu Część 28. Nauka).

As already stated, Polish system is characterised by general centralization of research funding under the auspices of MSHE. Table 3 indicates the following possible sources of research funds for HEIs:

- statutory funding (for public HEIs 44% of total research revenues, at universities - 57%, at technical universities - 34%) – position (2) in Table 3;

- funds for grants and goal-oriented project – positions (3) +(4) (between around 20% of total research revenue at universities to 30% at technical universities);
- other ministerial funds (for example: funds for financing international cooperation) around 12% of total research revenues: position (5) +(7);
- sales of R&D to third parts (10% to 20% at universities and technical universities, respectively): position (6).

Generally speaking, in case of Polish public HEIs, the governmental funding of research in 70% is due to institutional funding while 30% comes in the form of competitive grants. The statutory funding is allocated according to the assessment procedure while the grants are awarded within the ministerial competitions through the process of a peer review.

Table 3. Revenues from research activity of Polish public higher education institutions and their structure by sources of financing, in %, 2008

	Revenues (research activity) (1)	Funds for financing statutory activity (2)	Funds for realization of research projects (3)	Funds for realization of goal-oriented project (4)	Funds for financing international cooperation (5)	Sales of other experimental R&D (6)	Funds for Minister's projects and programs (7)
All public HEIs	100	44,1	23,1	1,8	10,2	17,8	1,2
Universities	100	57,2	20,0	0,2	11,6	9,7	0,6
Technical universities	100	34,0	26,1	3,0	12,0	21,3	1,8

Source: GUS (2009a), Table 7, p. 327

As far as the awarding of scientific titles is concerned (Table 4) Poland is characterised by large number of doctoral degrees with respect to the titles reflecting the movement towards higher, than doctoral, stages of scientific career (in Poland: doctorate – habilitation – professorship). Habilitation procedure is complex and lengthy, the bureaucratic procedure alone (not taking into account the time needed for real scientific progress) can last for as long as 2-3 years.[16] The title of a full professor is on average granted to ten times less scientists than the doctoral degree.

Table 4. Titles of professor and other scientific degrees awarded within the period 1995-2007

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prof.	367	543	479	524	630	470	680	789	578	521
HabPhD	628	829	755	829	755	915	829	923	803	934
PhD	2300	2400	2600	3500	4000	4400	4400	5450	5460	5722

	2005	2006	2007
Prof.	503	397	585
HabPhD	955	860	771
PhD	5917	6072	5616

Note: Prof – professors; HabPhD –doctors with habilitation; PhD – with doctoral degree

Source: GUS (2009b).

1.3.2. The competitiveness of Polish scientific research – aggregate evidence [17]

1.3.2.1. Academic rankings

Rankings

In the international context, the competitiveness of scientific research is usually analysed through comparison of its output such as: publication or citations records; PhD students; or patents and licences. Indices are usually expressed in per capita terms in order to allow comparisons between countries of a different dimension (for details on research output measurement see Section 3.2). Additionally, several rankings of universities are available where, however, research effectiveness is only one of the factors taken into account, along with e.g. the quality of infrastructure, staff qualifications etc. According to the Academic Ranking of World Universities 2010 (ARWU[18], also known as 'Shanghai ranking'), none of the Polish HEIs is among top 100 best European HEIs; University of Warsaw and Cracow Jagiellonian University are ranked between 301-400 position among top 500 world HEI (regional rank: 124-168), which means practically no change with respect to the previous edition of the ranking.[19] According to another ranking: Higher Education Evaluation and Accreditation Council of Taiwan Performance Ranking of Scientific Papers for World Universities[20] (focusing on scientific position and employing bibliometric indicators) these two Polish universities are ranked 364 and 353 (respectively) among the Top 500 universities (in Natural Sciences Top 300: positions 184 and 287, respectively) – no other Polish universities are present in the ranking of top 500[21]; while the Technical University of Warsaw, as the only Polish technical university, was ranked on 288th position in Engineering Top 300 ranking.[22]

1.3.2.2. Bibliometric indicators

Unfortunately, Poland has a very scarce tradition of high quality and influential research, reflected in lower visibility of Polish researchers in internationally recognized journals. According to ISI Web of Knowledge, in 2008 authors claiming affiliation in Poland published 14,785 articles in journals listed in ISI (for comparison Germany: more than 58,000, UK: more than 55,000, Spain more than 34,000). Aggregated bibliometric indicators from SCImago 2007 JCR[23], based on information contained in Scopus-Elsevier publications, database confirm this picture (see Table 5).

Table 5. Aggregated bibliometric indicators – Poland versus selected European countries and the USA

	Total number of documents included in SCImago JCR [per year, average 1996-2008] (1)	Number of documents included in SCImago JCR per R&D personnel in higher education sector [per year, average 1996-2008] (2)	Cities per document [average 1996-2008] (3)	H-index* [1996-2008] (4)	International cooperation (ratio of documents which affiliation includes more than one country address) [average 1996-2008] (5)
Poland	16083	0,37	6,6	208	33,1
Italy	46795	0,76	12,3	432	34,3
United Kingdom	95574	0,59	14,8	619	35,3
Finland	9553	0,60	15,1	273	39,9
Austria	10023	0,84	13,6	281	46,0
Switzerland	19025	1,16	18,6	422	52,6
Germany	87122	0,86	13,5	542	39,6
United States	331349	-**	17,3	1023	25,2

Note: *country's number of articles that received at least h citation (see Note 35). ** data on the number of researchers unavailable.

Source: own elaboration based on SCImago 2007 JCR - SCImago Journal and Country Rank (http://www.scimagojr.com). Number of R&D personnel (fte – full time equivalent) from Eurostat.

It turns out that within the years 1996-2008 the annual number of Scopus-Elsevier publications with at least one Polish affiliation was 5-6 times lower than in case of Germany or the UK. Taking into account disciplines, the majority of documents authored by Polish researchers listed in SCImago in 2008 belonged to medicine (16%); physics and astronomy (13%); and biochemistry, genetics and molecular biology (12%) which reflects the relatively strongest position of Polish science in these areas. Of course, the quantity of publications depends on the

Publication statistics

size of the countries and the number of people involved in research activity. Still, rescaling the data with information on R&D sector, the indicator of publications per R&D personnel employed in higher education in Poland is two times lower than in the UK or in Finland, three times lower than in Switzerland (third column of Table 5). Also the quality of Polish publications and their average impact measured by citation indicators (number of cities per document and h-index – columns 3 and 4 of Table 5) place Polish research far away from international standards. On average a Polish paper was cited 6 times, two-three times less frequently than papers published by western European or American researchers.

Very few Polish scientific journals are known worldwide: only 59 (out of 6598) were ranked in Journal Citation Reports-Science in 2008, only 13 of them have impact factor[24] higher than 1. Among 'highly cited researchers' classified within the years 1981-1999 (Thomson Reuters - ISI Highly Cited) only 2 were based in Poland.[25]

1.3.2.3. Patent activity

Patent applications

According to the OECD Patent Database (2008) in 2007 Poland was characterized by only 5 patents per million inhabitants - well below the OECD's average of more than 100 patents per million inhabitants. Additionally, Poland was not ranked by the share of patents owned by universities due to their negligible number. Restricting the comparison to the data on patent applications to the European agency (EPO[26]) and published by the Eurostat (Table 6) we can see that, indeed, patent capacity of Poland is extremely low: while within the years 1996-2007 on average EU countries applied for around 100 patents to EPO annually (per million of inhabitants), Poland had only 2 patent applications per million of people per year. If we compare this result to patent activity of highly innovative European countries like Germany (257 applications per million of inhabitants per year), Finland (242) or Switzerland (369) the difference is quite striking.

The only positive observation is that the number of the Polish patent applications was rising (below 1 per million of inhabitants till 1999, almost 4 in 2007) but the rising trend is typical for the EU in general (Figure 3).

However, the number of patent applications may reflect not only the innovation capacity but may depend also on the magnitude of funding devoted to R&D - thus we can compare the number of patent applications not in per capita terms but per milliards of EUR of the total R&D expenditure (Column (2) in Table 6). Unfortunately also in this

case Poland lags behind other European countries with significantly lower patent 'productivity' of R&D expenditure (57 patents per each milliard of euro spent on R&D in Poland compared to 295 in EU27).

Another reason for relatively low patent scores can be the extent to which business and universities collaborate in research and development (R&D). Polish universities, compared to other countries, do not collaborate intensively with business – it is confirmed by its 64th (over 136 countries listed) place in the ranking of university-industry collaboration in R&D performed by the World Economic Forum as innovation pillar of The Global Competitiveness Report 2010-2011.

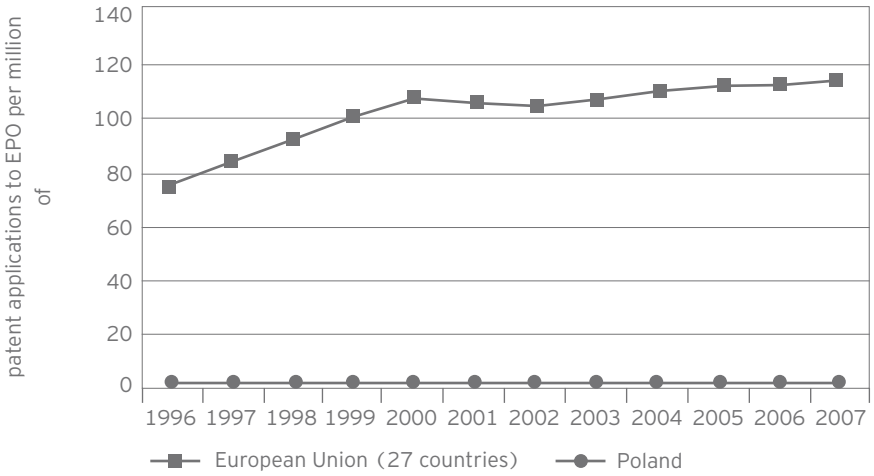
Table 6. Number of patent applications to the EPO (1996-2007) – Poland versus selected other European countries

	Total number of patent applications to EPO per million of inhabitants (1996-2007 annual average) (1)	Total number of patent applications to EPO by milliard EUR of total R&D expenditure (1996-2007 annual average) (2)
Poland	2,05	57,3
Italy	70,8	265,4
United Kingdom	89,6	167,1
Finland	241,9	262,3
Austria	155,4	168,1
Switzerland	368,9	127,6
Germany	257,2	288,9
United States	105,7	124,8
EU27	102,6	295,1

Note: EPO – European Patent Organisation

Source: own elaboration based on data from Eurostat.

Figure 3. Number of patent applications to the EPO per million of inhabitants (1996-2007) – Poland versus EU27 trends



Note: EPO – European Patent Organisation. EU27 values refer to average number of patent applications calculated across 27 current EU member states.

Source: own elaboration based on data from Eurostat.

It should be pointed out that country-level indicators hide a great within-countries heterogeneity as single HEIs differ in their research performance. In the following sections we will present in details our approach (based on the measurement of the research output at the level of universities) and, subsequently, present the evidence concerning research productivity determinants emerging from the micro data.

2. Our approach

2.1. Related literature

Subject of research

Higher education sector has been a subject of formal quantitative research for several years, covering mainly such topics as: estimation of rates of return to higher education, academic labour market, institutional behaviour, as well as higher education as an industry (for an overview see Ehrenberg, 2004). Bigger and bigger emphasis put on the fundamental role played by HEIs in forming human capital in modern economies, combined with increasing pressure put on public enterprises due to financial constraints, have resulted in bourgeoning literature on the efficiency assessment (the relation of outputs to inputs) of academic units.

Existing studies on the efficiency of higher education institutions have been mainly based on country-specific data and only a small sample of countries is covered, as apart from few exceptions (concerning, for example, HEIs in the UK or in Finland), micro data on HEIs is not easily obtainable and comparable across different countries/time periods. Among European countries, the UK has a particularly long and rich tradition in formal analysis of the efficiency and productivity of higher education sector (among others: Flegg et al., 2004; Glass et al., 1995; Izadi, 2002; Johnes 2006, 2008). Other country-specific studies on tertiary education systems' efficiency in Europe considered HEIs in: Italy (Abramo et al., 2008; Agasisti and Dal Bianco, 2006; Bonaccorsi et al., 2006); Austria (Leitner et al., 2007) or Germany (Kempkes and Pohl, 2006; Warning, 2004).

Research using micro data

As stated before, cross-country studies are difficult to perform due to problems with gathering comparable micro data on HEIs performance. Few analysis are based on data for institutions of higher education from more European countries (such as: Bonaccorsi and Daraio, 2007 covering universities from Italy, Spain, Portugal, Norway, Switzerland and the UK), but still they are limited in time dimension. A notable exception is a study by Agasisti and Johnes (2009) who compare technical efficiency of English and Italian universities in the period from 2002/2003 to 2004/2005. Finally, there is practically no evidence concerning HEIs from the New Member States thus no comparison is possible between units located in European countries with considerably different levels of economic development.

As far as specific studies on research performance are concerned, especially the theme of potential determinants of research productivity

Determinants of research productivity

has been discussed in the literature. Usually the starting point is the financial condition of HEI and the funds available to researchers. For example, Aghion et al. (2007) put research spending deficit as the main reason of the performance gap between European and American universities (measured by the Shanghai ranking and patents). In the following publication, Aghion et al. (2009) conclude that financial condition increase the research output of universities as long as are assured the autonomy of a unit and competitiveness in obtaining financial sources. The role of different funding sources (e.g public versus private, general versus project funds) for research productivity of an individual institution was emphasized by (among others) Lepori et al. (2007).

One of the other main topics focuses on the possible relationship between research output and the teaching load - its nature still remains rather disputable. Ideally, teaching effectiveness and research productivity would be complementary so that good researchers were also good academic teachers. However, a common view is that the two activities are substitutive in nature because more time devoted to teaching contracts the amount of time (and energy) an academic staff member can devote to research activity. Fox (1992) argued that research and teaching are rather conflicting that complementary. However, the review of various studies on teaching-research relationship in academia performed by Hattie and Marsh (1996) proves that all kind of relationships between the two activities are possible. A negative relationship emerges in 'scarcity model' (i.e. time on teaching and research are negatively correlated) or in models emphasising divergent personality qualities of teaching and research plus divergent rewards for the two types of obligations. On the other hand, one may also consider that research performance is an *a priori* condition for good teaching (so-called 'conventional wisdom model') or that research and teaching require similar qualities (high commitment, creativity, investigative mind and critical analysis – 'G model') – in such a case a positive relationship between teaching effectiveness and research productivity can be confirmed. In the conclusions of the review, Hattie and Marsh (1996) stated that the interplay of all the forces leads to a neutral link and, consequently, in their view the common belief that research and teaching are inextricably entwined is a myth. They confirm the finding on zero teaching-research relation in the subsequent publication: Marsh and Hattie (2002).

Even though it is extremely difficult to gather person-level data, there have even been attempts to test hypothesis on research determinants with the use of questionnaires. For example, relationship between research output versus teaching load and funding has been confirmed in

a study based on a survey of academic economists in Australia (Fox and Milbourne, 1999). It has been found that 10 per cent increase in the number of teaching hours may reduce research output by as much as 20 per cent, while a 10 per cent increase in the number of grants held per year may raise annual research output by as much as 15 per cent. A study based on the survey data concerning economists in the USA (Fender et al., 2005) confirms that teaching commitments, among other factors (i.e. research climate in the institution, cooperation with top co-authors, graduate background, years from PhD completion), play an important role in influencing the number of publications per academic staff member in top economic journals. In the same study quality research production has been found to be negatively related to time spend on teaching and academic service by single authors. Those departments that required less teaching and fewer service obligations increased the probability of high quality research productivity.

Among other most often analysed potential determinants of research productivity we can find: size, age and location of the units (Crespi, 2007; Bonaccorsi and Daraio, 2007).

Research efficiency of Polish HEIs has been assessed by Kierzek (2009) by means of comparing publication and citation records across institutions (universities, technical universities, research institutes of Polish Academy of Science in the years 1973-2008).[27] Olechnicka and Płoszaj (2008) applied bibliometric data coming from the same source as ours (ISI Web of Knowledge) to the study on regional patterns of research output and network effects concerning Polish HEIs. Szuwarzyński (2006) employs DEA (Data Envelopment Analysis) methodology to assess the didactic efficiency of Polish HEIs, but he refers to different types of HEIs as an aggregate, for example: universities versus technical universities and economic academies. Nevertheless, to the best of our knowledge, no published study based on microdata has quantified the role of various determinants of research performance in Polish academia versus European standards.

2.2. Specificity of universities' production function and related technical caveats

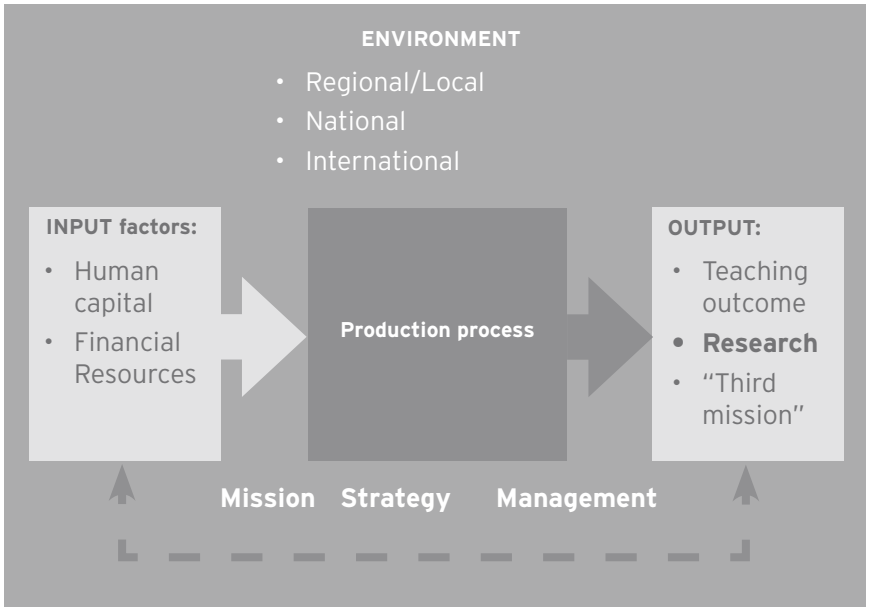
The analysis of the effectiveness and competitiveness of HE sector is usually conducted with the use of aggregated data, thus the whole process of research production is seen from the perspective of whole countries. Bonaccorsi and Daraio (2007 p. ix) state that aggregated indicators such as gross expenditure on higher education or R&D as per cent of GDP are "*clearly relevant information, but of little value to address more sophisticated policy issues*". In previous section, for

illustrative purpose, we have presented several country-level indicators related to our research topic. Undoubtedly, in order to learn more about the determinants of research productivity, there is a need to look at research output creation from the perspective of individual units and their characteristics.

The production process in HEIs

We assume that university can be described as a unit that obtains inputs and through the production process creates outputs. As inputs we can consider human resources (staff, students), as well as financial resources that a certain HEI disposes of. Differently from a standard firm, HEIs are characterised by multiple outputs: the results of teaching (graduates and the knowledge they have gained in the course of studies), the results of research and the results of joint work with the external surrounding (the engagement of universities in entrepreneurship and business-related activities – the so called 'third mission'). Hence, it is clear that the process of universities' 'production' differs substantially from other industries. Figure 4 presents in a synthetic way a nature of relations between HEIs' inputs and outputs.

Figure 4. Production process at higher education institution



Source: own elaboration based on Bonaccorsi and Daraio (2007) p.407

Specificity of HEIs production function becomes a challenge to the researcher willing to quantify and evaluate the efficiency of single units of higher education. The standard techniques of measuring efficiency (for example based on the indicators of economic analysis) are questionable, due to: complex input-output relation; difficulty in determining casual relationshipsdue to two-way effects; endogeneity;

and dependence on environmental factors. Measuring universities' productivity is very different from measuring businesses' behaviour as, especially, public HEIs, have other goals than profits maximisation - by definition, public institutions are non-profit.

In our study we focus on a restricted aspect of HEIs efficiency, namely the research productivity. Efficiency related to 'third mission' is analysed qualitatively in Section 4.3, while we do not assess the effectiveness and quality teaching. In particular, we aim at identifying sources of heterogeneity in research efficiency visible across Polish (and European) technical universities and universities.

Main difficulty linked with the empirical analysis of HEIs' research output (and productivity function in general) stems from the fact that it can only be based on micro statistics. That is why the first step in our research agenda is to collect micro data on the Polish universities and technical universities. The data on Polish HEIs are then matched with the statistics referring to HEI from other European countries. It allows us to perform comparative studies.

We now pass to the presentation of basic research questions (causal claims) that we intend to analyse.

2.3. Research questions

We propose five causal claims to be tested:

1. What is the elasticity between funding (its magnitude and sources) and the research output?

Undoubtedly, the scale of funding influences research opportunities (more resources mean better infrastructure, conditions for continuous education of research staff, possibility to participate in conferences and study visits, no need to search for another job because of poor salaries etc.) However, we are interested in the magnitude of this relation. Additionally, it is important to investigate whether the source of funding (public versus private) matters for the research outcome (as suggested by Aghion et al., 2009). The autonomy of the university is often expressed as the share of non-governmental funds in its total revenue (Bonaccorsi and Daraio, 2007). In addition, there should be a positive feedback between research output and revenues from research, since applied research activity can be one of the sources of HEIs' income (patents etc.).

2. Does an increase in the teaching load causes a drop in research output?

Impact of teaching load

We argue that because of, at least, dual function of university staff (teaching and research - we do not include in the quantitative analysis 'third mission' of universities), there is a negative relation between teaching load and research output. Possible trade-off between research productivity and teaching is mainly due to time constraints that academic staff members have to face. This effect can be strong in case of Polish HEIs where academic staff members have typically higher teaching load than their colleagues in other European countries. On the other hand, research activity allows universities to hire doctoral students who may act as teaching assistance, lowering the teaching load of senior staff (Bauerlein, 2009).

3. Does concentration of resources in large units lead to an increase in research productivity (economies of scale)?

Size of an institution and the research potential

What is the optimal size of an institution from the point of view of its research potential? The issue is of a great relevance from the point of view of governmental policy concerning HEIs, especially in the context of the vivid discourse relating to eventual concentration of funding in larger universities and/or eventual merges of smaller institutions. We test the relation between the size of research units and their research output (intuitively, bigger units are often perceived as stronger in the research field, due to major visibility of their performance than, that the smaller institutions, but is really research efficiency higher in case of big HEIs?). Economy of scale is understood as the reduction in average total cost of production due to the production expansion.[28] The previous empirical studies do not give a clear picture whether economies of scale exist in higher education sector (see for example Cohn et al., 1989 versus Felderer and Obersteiner, 1999). On the other hand, diseconomies of scale may also occur due to complicated bureaucracy procedures in big units and possible waste of resources.

4. Does heterogeneity of units lead to an increase in research productivity?

Influence of interdisciplinarity

Nowadays, interdisciplinary is often perceived to be one of the main determinants of successful research. However, it may also lead to an insufficient focus on specific issues and to a lack of ability to master in fewer fields of research (dispersion versus specialisation). This refers to the concept of economies of scope.[29] In the literature on higher education there are two approaches to the economies of scope.

The first one refers to the university's specialization i.e. whether the university is more research or student oriented (research and teaching are understood as separate outputs). The second approach refers to the thematic heterogeneity of institutions (more different faculties). We are going to utilize the second concept of economies of scope.

5. To what extent individual characteristics of single universities (such as: tradition – year of establishment, location, prestige etc.) influence research output?

The importance of individual characteristics of universities

Top universities ranked high in academic rankings are often those with longer tradition (e.g. University of Oxford or University of Cambridge). Does it necessarily mean that recently established units find themselves in a difficult position as far as research is concerned? It could also be the case that HEIs with shorter tradition have more flexible and modern structures, enabling efficient research activity. Another question is whether the location in (or close to) big cities, where usually more institutions of higher education and industry co-exist, play an important role (centre versus periphery relations)? Is the level of development of the surrounding area important (for example giving major stimulus to research if advanced industry is present nearby)? On the other hand, units located in poorer regions can benefit from the convergence process. There is no unambiguous prediction about the direction of the link between tradition or location on research efficiency.

We hope that the answers to the above research questions would give an important indication to the policy makers involved in the reform of higher education in Poland. Being aware that not all processes in HE can be easily and straightforwardly measured in a quantitative way, in addition to causal claims' testing we will present in a descriptive manner forms of third mission cooperation of HEIs with the external surrounding.

In the next section we present relevant methodology and the data which serve us to perform empirical analysis on research efficiency determinants.

3. University level investigation on research efficiency- methodology and data issues

3.1. How to measure the quality of research output?

Research output of a given higher education institution can be assessed in several ways. Bibliometric methods are based on analysis of publication (or citation) records. Absolute number of publications, by authors claiming affiliation with a given unit or in a given country (depending on the level of analysis), in high quality journals gives information on overall research output. Cross country comparisons of publication record are possible if one uses international publication/ citation database (such as Thomson Reuters' ISI Web of Knowledge used in our study).

Additionally, research orientation of a given university or the whole system of higher education can be measured by the ratio of PhD recipients to total number of students. It captures the relative importance of doctoral education in teaching output. It has to be pointed out that PhD students play a special role in research creation: being at the same time an input (conducting own research and publishing) and output (PhD degree as the result of education).

Next, the information on patents and licenses granted (or applied for) can be treated as an indicator of applied research efficiency. The main problem relies in the fact that very often patents are developed within consortiums composed of academic institutions and companies. It is often the case that jointly developed patents are then formally registered by patent offices as 'owned' by private companies and not universities, thus the statistics obtainable from patents databases[30] only partially reflect applied research performed in the academia.

Methods of HEIs evaluation

Consequently, at the level of individual institutions, research activities conducted by HEIs have been usually evaluated by the following methods:

- expert peer-review process (this approach, adopted for example by Research Assessment Exercise in the UK combines the number of indicators such as: academic staff, PhD students and different types of research outputs: publications, patents, software, exhibitions etc.);

- evaluation of research orientation of a given university (measured by the ratio of PhD recipients to total number of students as in: Bonaccorsi and Daraio, 2007);
- comparison of research funds (grants and contracts), especially those coming from the private sector;
- the use of bibliometric indicators (based on the analysis of publication records as in: Creamer, 1999; Dundar and Lewis, 1998; Porter and Toutkoushian, 2006; Tien and Blackburn, 1996; the case of Poland was analysed by Kierzek, 2008).

Each of these approaches has its virtues and drawbacks. The first approach (peer-review) is usually a tool to asses HEIs by founding bodies and is used to influence their decisions concerning the level of financing. Its main criticisms stress the high costs of the method and the lack of international comparability. Then, the information on doctoral students is rather a restricted measure of research orientation of a given unit and, additionally, PhD students can be considered both as input and output of research process. Next, data on research funds indicate how active a unit is in gathering sources for research but, unfortunately, such data is not easily obtainable and comparable across university units from different countries. Consequently, while comparing research performance within our sample of HEIs we concentrate on the bibliometric approach. It is based on comparisons of international scientific publications and thus has a great advantage over the remaining methods as being able to allow for objective cross-country and longitudinal comparisons of research output. Moreover, it is relatively easy to implement, low-cost and ensures quick updates if one wanted to extend the time dimension or HEIs sample covered by the study.

3.2. Our measures of research output

In order to be able to present the Polish case in a comparative setting, we computed the indicators that can be used to measure research output of single HEIs in Poland, allowing also for international comparisons of research performance.

All the bibliometric data in our study come from Thomson Reuters' ISI Web of Science database (being a part of ISI Web of Knowledge[31]) which lists publications from quality journals (with positive impact factor) in all scientific fields.[32] We adopt a 'top-down' approach, based on the attribution of a publication listed in ISI Web of Science to a given HEI, based on the identification of its name in the address specified by the author(s).[33] We are aware of the shortcomings of bibliometric methods for the purpose of universities' rankings and evaluation of their

research performance (see Kierzek, 2009 for a critical discussion)[34], but on the other hand publication is by far the most popular way of research dissemination that allows cross-units and cross-country comparisons of research output through time. Additionally, current strategy adopted by Polish MSHE recognizes publication record as one of the basic indicators of scientific proficiency within so-called 'parametric evaluation' (*ocena parametryczna*) of public HEIs in Poland.

We have counted all publications (scientific articles, proceedings papers, meeting abstracts, reviews, letters, notes etc.) published in a given year, with at least one author declaring as affiliation one of the HEIs being under consideration.[35] Given that original papers published in high quality journals are the most prestigious outcomes of research activity, we also computed a restricted measure of research output, counting only original scientific articles listed in Web of Knowledge and associated with author(s) affiliated with a given HEI.

Absolute number of publications (articles) gives information on overall research output of a given country/institution, but a more comparable measure is the average number of publications (articles) per academic staff member. Comparing these indices across institutions of higher education within a given country, as well as across countries, we obtain a very straightforward indicator on relative research productivity.[36]

3.3. Data

3.3.1. Initial remarks

Micro level evidence that would enable to assess the productivity and efficiency of HEIs not at the level of countries, but rather at the level of single universities, is rather limited. A notable exception is the activity of the Aquameth consortium[37] which aims at gathering comparable microdata for a sample of European universities from different countries. Indeed, Aquameth members state that nowadays, there is a paradox between the common understanding of the importance of knowledge creation and the lack of data about the main knowledge producers – universities (Bonaccorsi and Daraio, 2007). Unfortunately, data gathered by Aquameth consortium is not freely available to researchers.

As for the sample composition, countries, other than Poland (covered by our study) have been selected by the simple criteria of data availability. It should be underlined that the collection of micro data (at the level of single HEIs) is not a trivial issue. Only a few countries make publicly available their statistics concerning universities' personnel,

financial statistics, number of students or graduates, etc. The collection of such data concerning Polish HEIs is particularly difficult as there is no unique freely available source of statistics on single universities or technical universities and, consequently, various institutions (Ministry of Science and Higher Education, Central Statistical Office) have to be contacted. Moreover, a very restrictive policy on data dissemination in Poland practically gives the institutions possessing the data the right to reject to give access to the statistics concerning single units. Thus making the micro data on HEIs performance unavailable to the researcher willing to use it for research purposes.[38] It is rather stunning given that most important HEIs in Poland are public (and thus funded from public money).

Even though our data come from various sources and concern institutions from distinct countries, particular attention has been put on assuring maximum level of comparability of crucial variables across countries in accordance with Frascati manual (OECD, 2002) and UOE (Unesco-UIS/OECD/Eurostat) data collection manual (2004).

All the financial statistics (data concerning revenues) which were originally reported in national currencies have been recalculated into real (2005=100) Euros using exchange rates from Eurostat and country specific CPI (Consumer Price Index) from OECD. Additionally, in order to take into account considerable price differences between countries, we have used PPP indices from Eurostat (where EU27=100), reporting all financial data in purchasing power standard corrected values.

3.3.2. Sample composition

The main criterion of sample composition is the availability of the data and the presence of HEIs in our primary source of bibliometric indicators (ISI Web of Knowledge). The analysis is based on a university-level database, containing information on outputs and inputs of 34 Polish public higher education institutions (18 technical universities[39] and, for comparison, 16 universities – we follow the MSHE classification of HEIs into each of these two groups). Additionally, we have gathered micro statistics concerning HEIs from a set of EU (Austria, Finland, Germany, Italy and the United Kingdom) and non-EU (Switzerland) countries for which it is possible to collect comparable micro data. We draw on the unbalanced panel (not all the information is available for all countries through all years) containing the statistics at the level of single HEIs within the period: 1995-2008. For those countries which, as Poland, explicitly distinguish between universities and technical universities, we created a subsample containing technical

universities only (44 units). Table 7 contains the information on the number of HEIs from every country. To the best of our knowledge this is the most comprehensive micro dataset on European HEIs[40] (as far as the number of units, time and thematic coverage is considered) and the only one including Polish HEIs. Full list of 291 units included into our study is presented in the Appendix 2.

Table 7. Sample composition

country	Number of all HEIs	Number of Technical Universities
Poland	34	18
Austria	11	2
Finland	16	3
Germany	71	15
Italy	55	4
UK	92	0
Switzerland	12	2
Total	291	44

Source: own elaboration

Naturally, both public and private sectors differ in legal status, organization, funding system, strategy etc., thus micro statistics on private and public universities are not fully comparable. We argue that the analysis of their research performance should be conducted separately for these two sectors and we restrict our sample to public institutions only.

Additionally, we decided to focus only on the university sector, thus in case of binary higher education system we excluded from our sample applied science institutes/schools (such as German or Austrian Fachhohschule, some applied science HEIs in Finland and in Switzerland) which conduce research only marginally. Moreover, we excluded from our analysis special purpose units, which specialize in one discipline only (medicine, arts, sports etc.) as incomparable to multi-faculty units and distance learning universities. Finally, the units with most of missing observations concerning publication records or ambiguous affiliations[41] or units with for which the data was of exceptionally poor quality were not taken into consideration. In the end our full dataset contains 291 European HEIs.

3.3.3. Variables and data sources

Variables and data sources

Given double mission of higher education institutions (teaching and research)[42], as outputs we consider: teaching output (measured in terms of graduates), as well as research output.

In our case, research output is quantified by means of bibliometric indicators, based on the analysis of publication records in Thomson Reuters' ISI Web of Science database. In order to allow for cross-country and cross-units comparability of research performance, we compute two basic indicators: the number of all publication per academic staff member and the number of articles per academic staff member.

As for the input measures, our dataset contains information on: total number of students[43]; doctoral students, staff[44] (total, academic and non-academic[45]); ratio of professors to other academic staff members; and financial flows. Unfortunately, the data concerning the number of doctoral students is available only for Poland, Austria and Finland.

From the measurement point of view, the biggest difficulty is the lack of unified accounting system for universities' budgets. We possess data on total revenues and, if available, revenues by source of funding (in particular: proportion of funds coming from the public sources). Furthermore, we made an attempt to gather data on funding by destination, distinguishing between two main categories: research and teaching. Matching the information on available financial resources and size of the unit in terms of staff and students, we have computed relative indicators of financial possibilities of single HEIs, such as revenues per employee etc.

Additionally, we provide information on HEIs': year of foundation, faculty composition (number of faculties; dummies if there is a faculty of: medicine/pharmacy[46], economics/business), location and statistics related to the level of economic development (GDP per capita in constant PPS terms) of the region where a given HEI is located. Table 8 summarizes our variables coverage by country.

Table 8. Variables coverage in our dataset

Variables group	Variable name (name in database)	Countries covered						
		PL	AUT	FIN	GER	ITA	UK	CH
Identification	HEI name (HEI_ID)	x	x	x	x	x	x	x
	country name (countryISO)	x	x	x	x	x	x	x
	year	x	x	x	x	x	x	x
	Technical university identification (techuniv)	x	x	x	x	x	–	x
Research output	number of publications (publ)	x	x	x	x	x	x	x
	number of articles (articles)	x	x	x	x	x	x	x
	number of publications per academic staff member (publPerAcad)	x	x	x	x	x	x	x
	number of articles per academic staff member (articlesPerAcad)	x	x	x	x	x	x	x
Research orientation	Number of PhD students (students_doctoral)	x	x	x				
Size	Total staff - full time or fte (total_staff_full)	x	x	x	x	x	x	x
	Total academic staff - full time or fte (academic_staff_full)	x	x	x	x	x	x	x
	Total number of students (students_total)	x	x	x	x	x	x	x
Teaching load	Number of students per academic staff member (students_totalPerAcad)	x	x	x	x	x	x	x
Staff/ Employment structure	Academic staff- full time or fte (academic_staff)	x	x	x	x	x	x	x
	Professors to academic staff ratio (prof_acadStaff)	x	x	x	x	x	x	x
Finances:								
Overall financial indicator	Total revenues in real euro (PPS), 2005=100 (REALrevenues_total_PPP_eu27)	x	x	x	x	x	x	x
Revenues structure	Revenues from government as % of total revenues (revenues_gov)	x	x	x	x		x	x
	Teaching related revenues as % of total revenues (revenues_did)	x		x			x	x

Relative financial indicators	Total revenues per employee in real euro (PPS), 2005=100 (REALrevenuesPerEmployee_PPPeu27)	x	x	x	x	x	x	x
	Total revenues per student in real euro (PPS), 2005=100 (REALrevenuesPerEmployee_PPPeu27)	x	x	x	x	x	x	x
Additional:								
Faculty composition	Number of faculties (nofac)	x	x	x	x	x	x	x
	Medicine or pharmacy faculty (yes/no) (medfarm)	*	x	x	x	x	x	x
	Economics or business faculty (yes/no) (econ)	*	x	x	x	x	x	x
Tradition	Year of foundation (yearfound)	x	x	x	x	x	x	x
Location	Main location (location)	x	x	x	x	x	x	x
	GDP per capita of nuts-2 region (GDP)	x	x	x	x	x	x	x

Notes: *in Poland there are medical universities where medical and pharmaceutical faculties are present and universities usually do not have such faculties

Source: own elaboration.

As for the data sources (Table 9), countries differ in availability and coverage of university-level data. The most comprehensive databases concerning HEIs exist in Finland, the UK and Italy, with freely available online platforms giving access to all statistics which are not confidential. For Swiss, Austrian and German HEIs, the data was kindly provided by the staff of respective Central Statistical Offices. Part of the data (usually for the last year) can be accessed through the HEIs' web pages. In Poland, unfortunately, micro-data on HEIs (even public ones) practically does not exist for research purposes. There is no on-line platform containing the data; some statistics are available in paper version in various sources published by MSHE or Central Statistical Office. Consequently, the data on Polish HEIs we have managed to gather come from multiple sources, as shown in Table 10.

Table 9. European sources of data on individual HEIs

Country	Source	Online platform	Data publicly available
Finland	Finnish Ministry of Education	https://kotaplus.csc.fi/online/Haku.do	yes
Switzer-land	Swiss Federal Statistic Office	www.statistique.admin.ch	yes
Germany	Federal Statistical Office (Destatis)	www.destatis.de	yes
Austria	Austrian Federal Ministry of Science and Research	http://www.bmwf.gv.at/unidata	yes
UK	Higher Education Statistics Agency	http://www.heidi.ac.uk/	yes
Italy	Ministry of Science and Education (MIUR)	www.nuclei.cnvsu.it ; www.dalia.cineca.it	yes
Poland	Ministry of Science and Higher Education	www.nauka.gov.pl	no

Source: own elaboration

Table 10. Sources of data on Polish HEIs

Output data	**Data source**
Number of publications - all - articles only	ISI (Institute of Scientific Information) Web of Knowledge: Web of Science; Thom-son Reuters
Input data	**Data source**
Total staff	MNiSW. Szkolnictwo Wyższe, Dane podsta-wowe, variuos issues 1996-2009*
Academic staff (total, number of professors)	MNiSW. Szkolnictwo Wyższe, Dane podsta-wowe, variuos issues 1996-2009*
Number of students (full time ,PhD students)	MNiSW, Szkolnictwo Wyższe, Dane podsta-wowe, variuos issues 1996-2009*
Total revenues	Dziennik Ustaw, Monitor Polski B
Revenues related with teaching activity of which: - revenues from government allocation	MNiSW, Department of financing HEIs
Revenues from governments' grants and contracts	MNiSW, Department of financing HEIs
Other data	**Data source**
Year of foundation	Web pages of universities
Number and type of faculties	Web pages of universities
Location	Web pages of universities
GDP per capita of nuts-2 region	regional statistic of Eurostat

* data for 2008 from GUS

Source: own elaboration

4. Empirical analysis

First of all, in this section we show the evidence on research productivity of Polish technical universities vis-à-vis Polish universities and foreign HEIs. Then, we provide general description of the emerging relationships between the research output (in terms of publication record) and its possible determinants, summarized in the form of the five aforementioned causal claims (see Section 2.3). In the next step, we try to quantify the relevance of single determinants of research output by means of econometric model, with the number of publications per academic staff member (or articles per academic staff member) being a proxy of individual unit's research efficiency (dependent variable).

4.1. Research competitiveness of Polish HEIs – micro level descriptive evidence

Figure 5 and Figure 6 compare our two basic bibliometric measures of research output (publications and articles listed in ISI Web of Science per academic staff member employed in a given HEI) across HEIs in seven countries from our sample. The data refer to the year 2008 (the latest available observation). Along with within-country averages we also demonstrate the minimum and maximum values (referring to the worst and the best, in terms of publication record, HEI within each country present in our sample).

Number of publications per academic staff member

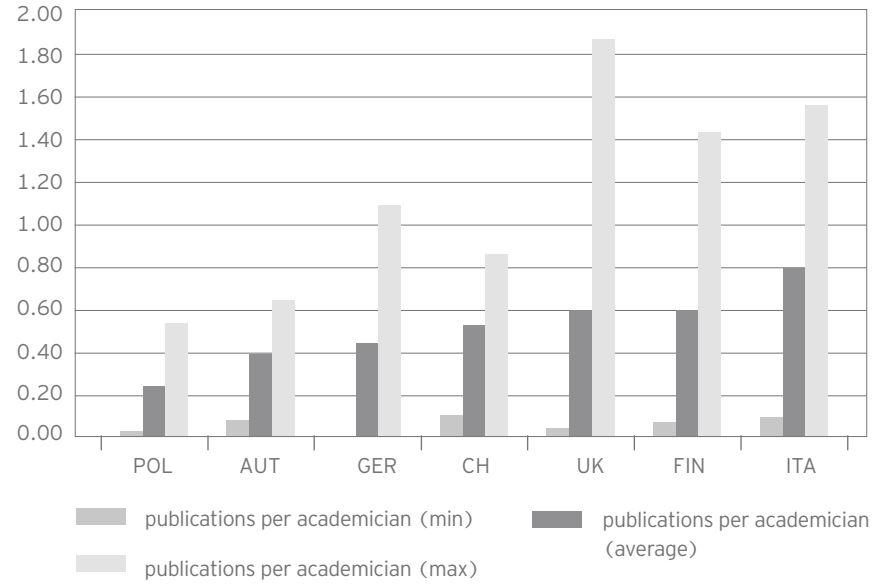
It is evident that the number of publications per academic staff member reflecting research done at Polish HEIs is extremely low. On average, in 2008 across all HEIs (universities and technical universities altogether) average indicator 'publications per academic staff member' is equal to 0.23 which means that on average an academic staff member based in Polish HEI has one publication in a journal listed in ISI Web of Knowledge in four years! Obviously, it is highly plausible that some researchers publish more, but at the same time some of them do not publish in high quality journals at all (Kierzek, 2008, p. 35 notes that in Poland "usually 3-5 scientist are responsible for around 75% of overall publication and citation record of a given HEI".). Maximum value was reached by Wroclaw University of Technology (0.54 publication per academic staff member annually); within universities – by University of Cracow (0.54). If we consider only the number of original articles (excluding from the publication record the conference proceedings, book reviews etc.) bibliometric indicator is even lower (here we rescale the values multiplying by 100): 14 original articles per 100 academic staff members affiliated at Polish HEI in 2008 (maximum at Wroclaw

University of Technology: 32 articles per 100 academic staff members employed and, within universities 38 articles per 100 academic staff members at University of Cracow).

Comparing these values to the European standards, it turns out that the average publication record at Polish HEI is very low – on average a member of academic staff employed at Polish HEI has two times less publications per year than Austrian or German academic staff member and five times less than academic staff members in the best performer – Italy (on average 0.8 publication per academic staff member in 2008.) The best scores within reference countries were reached by: Universität Innsbruck in Austria (0.64 publications per academic staff member), Universität Lübeck in Germany (1.1), University of Bern in Switzerland (0.87), University of York in the UK (1.9), University of Ancona in Italy (1.57) and University of Helsinki in Finland (1.4).

If we restrict the sample to technical universities only (Figure 7 and Figure 8) the picture of average publication record per academic staff member in Poland versus other countries is very similar to the one described above. The only difference is that on average staff employed at technical universities has a bit more publications or articles per year than academic staff members employed at universities, but this difference may be due to the fact that ISI Web of Knowledge lists more journals specialized in technical sciences than in humanities. Still, on average per each 100 academic staff members working at Polish technical universities in 2008 there appeared only 29 papers (among which 16 articles) in high quality journals – for comparison in case of foreign technical universities this indicator is equal to 39 in Germany, 48 in Finland, 51 in Austria, 74 in Switzerland, 97 in Italy. The best scores within these countries and within technical universities only were reached by: Technische Universität Graz (0.54 publications per academic staff member in 2008), Technische Universität Kaiserslautern (0.56), Federal Institute of Technology Lausanne (0.77), Politecnico di Torino (0.84)[47], Helsinki University of Technology (0.66). It means that only the standard of best performing Polish technical universities (such as Wroclaw University of Technology) is close to German, Finnish or Austrian one while many others lag behind and only in Poland we have many HEIs with practically null publication record in ISI Web of Knowledge.

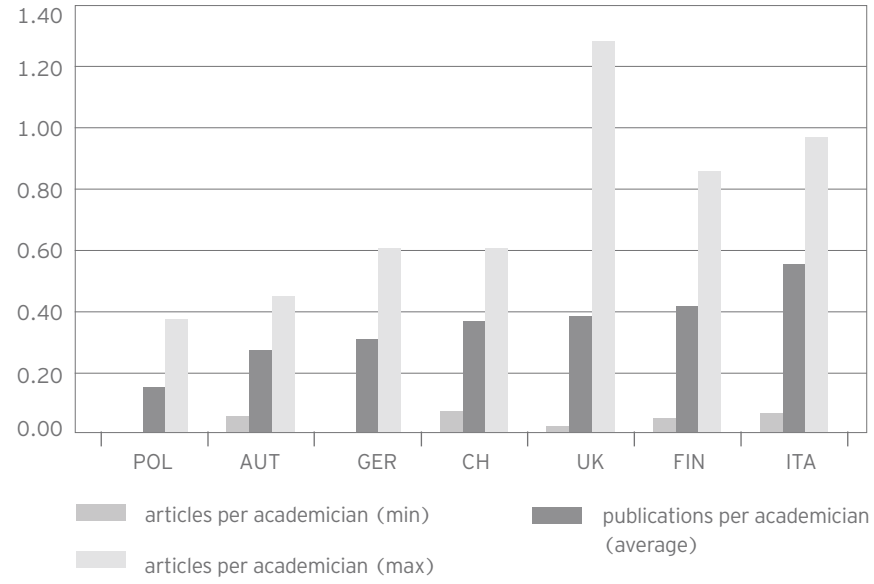
Figure 5. Research productivity (number of publications per academic staff member) – Poland versus six European countries (2008), all HEIs



Note: all HEIs: universities and technical universities.

Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from Sources indicated in Table 9.

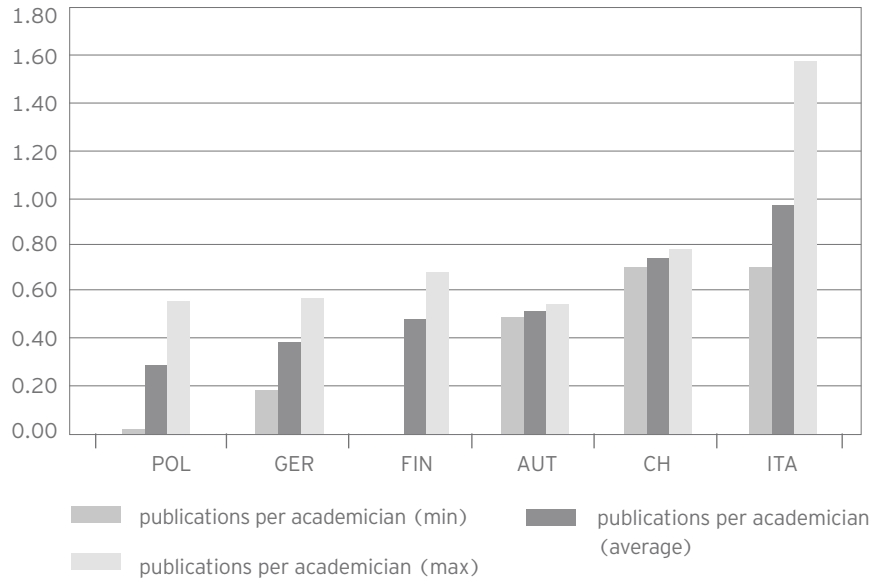
Figure 6. Research productivity (number of articles per academic staff member) – Poland versus six European countries (2008), all HEIs



Note: all HEIs: universities and technical universities

Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from Sources indicated in Table 9.

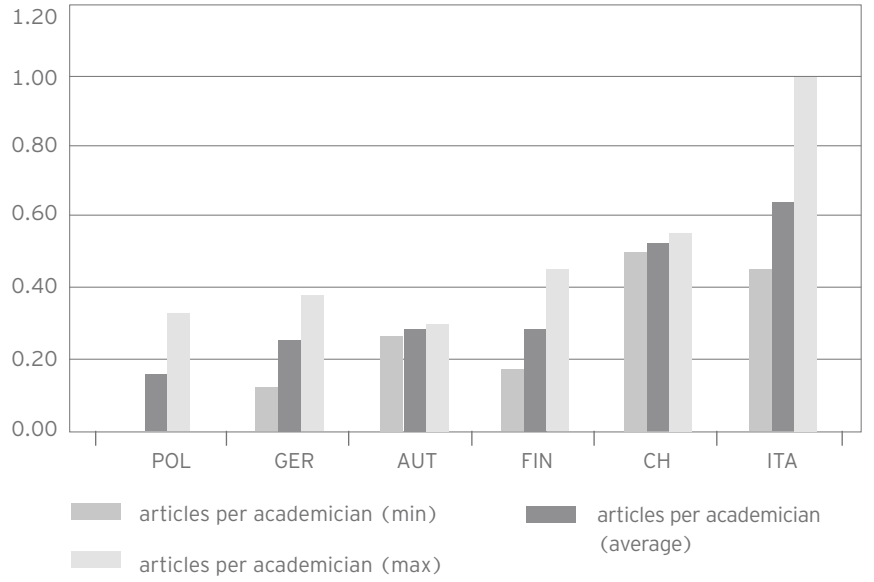
Figure 7. Research productivity (number of publications per academic staff member) – Poland versus five European countries (2008), technical universities



Note: technical universities only.

Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from Sources indicated in Table 9.

Figure 8. Research productivity (number of articles per academic staff member) – Poland versus five European countries (2008), technical universities



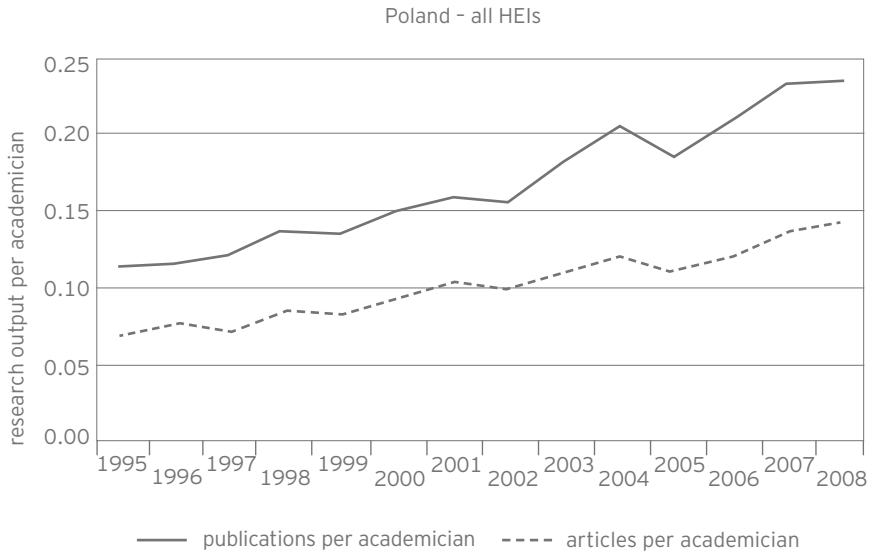
Note: technical universities only.

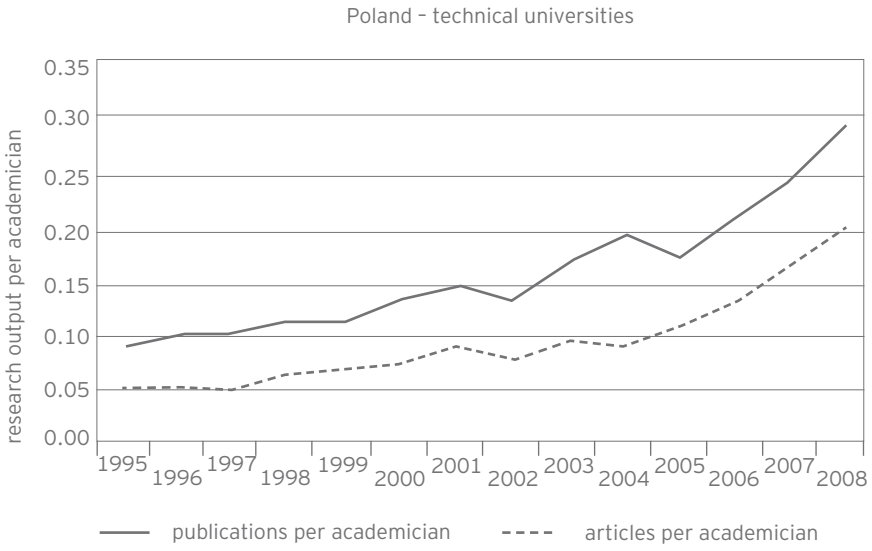
Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from Sources indicated in Table 9.

Figure 9 demonstrates the evolution of our two basic bibliometric indicators, concerning research output of Polish HEIs in our sample within the years 1995-2008. Upper plot refers to all HEIs while lower plot refers to technical universities only. Even though the levels of these two indicators of research productivity are still well below standards typical for more developed countries (see Figure 8) we clearly note the increasing trend. The positive thing is that between the years 1995-2008 the situation improved and the number of all publications and articles per academic staff member in Poland doubled.

Similar pattern is confirmed in the subsample of Polish technical universities (Figure 9 lower plot). Average number of publications per academic staff member in 2008 was slightly higher than in case of all HEIs, but the rising trend is confirmed. Typically, in 1995 there were, at Polish technical universities, only 9 publications in ranked journals per 100 academic staff members, in 2008 – already 29. An interesting thing is that research output productivity has risen more rapidly in case of technical universities than in the whole sample of Polish HEIs, particularly in the years 1999-2002 and after 2005. As a result, even though in 1995 typical values of publications per academic staff member and articles per academic staff member employed at Polish technical universities were below overall (all HEIs) averages, in 2008 the reverse holds true.

Figure 9. Bibliometric indicators of research output in Poland (1995-2008)



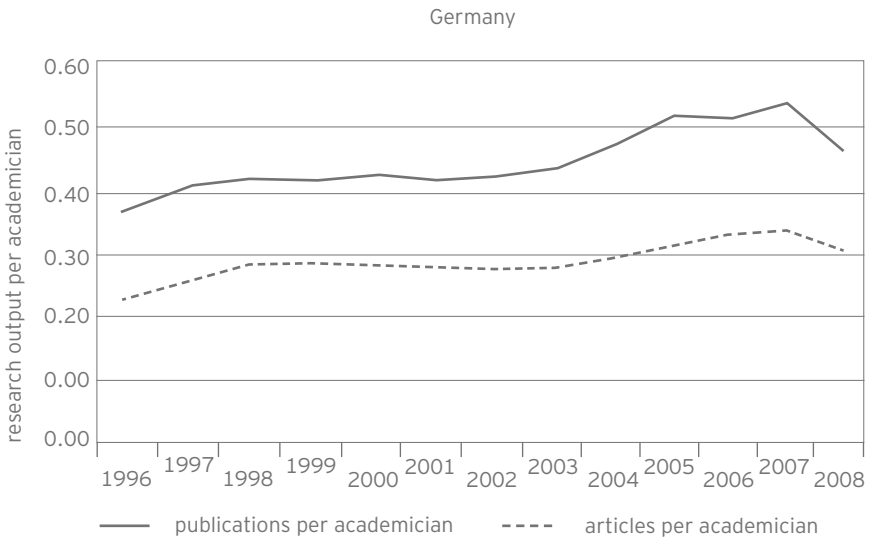


Note: number of publications and articles listed in Thomson Reuters' ISI Web of Science with at least one author claiming affiliation at one of the HEIs from a sample composed of 16 Polish universities and 18 technical universities.

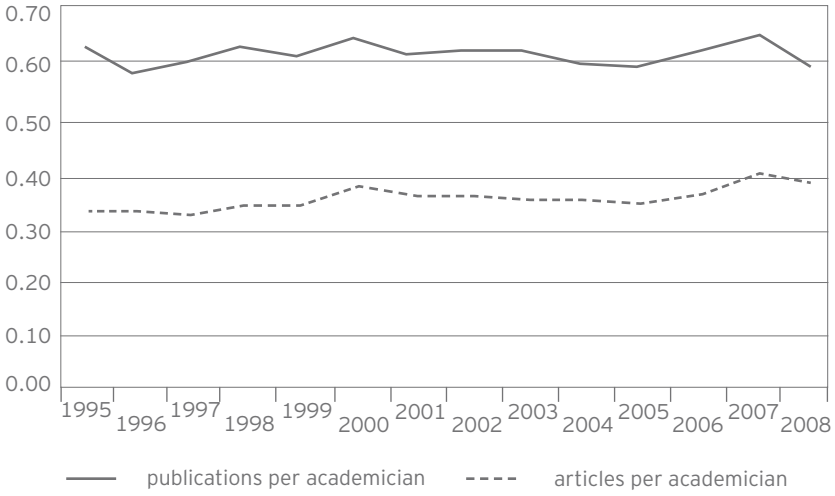
Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from MSHE.

For comparison in Figure 10 we demonstrate trends in research output in other European countries.[49] Taking into account the trends in research productivity, the number of publications per academic staff member and the number of articles per academic staff member rose particularly in Germany and Switzerland after 2003, in Italy in the whole analyzed period.

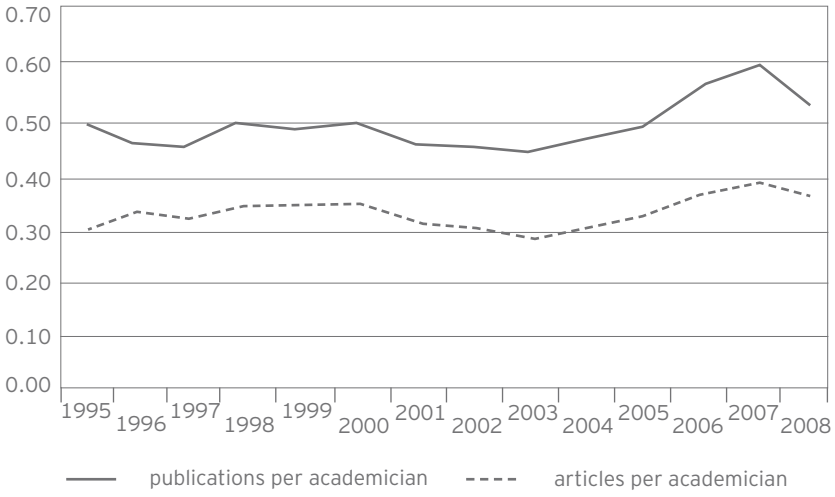
Figure 10. Bibliometric indicators of research output in European countries (1995-2008*)



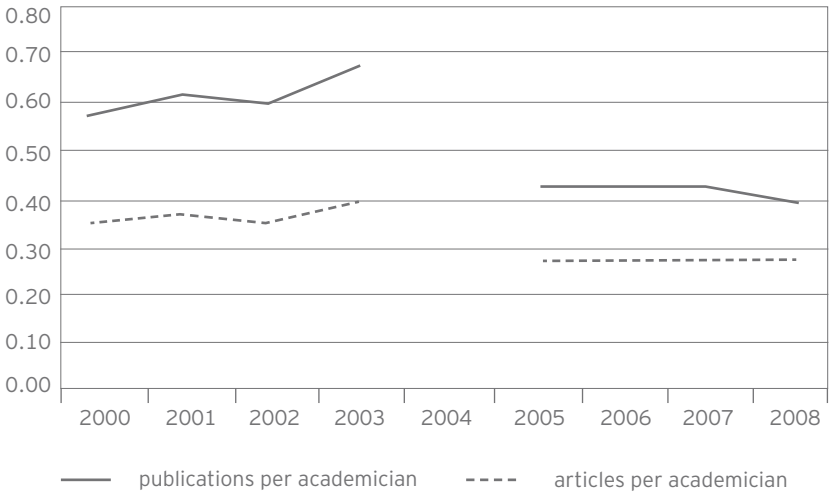
Great Britan



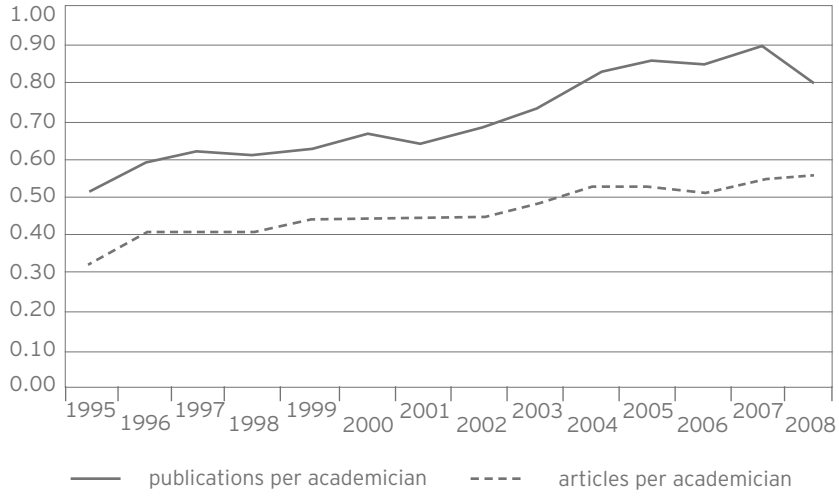
Switzerland



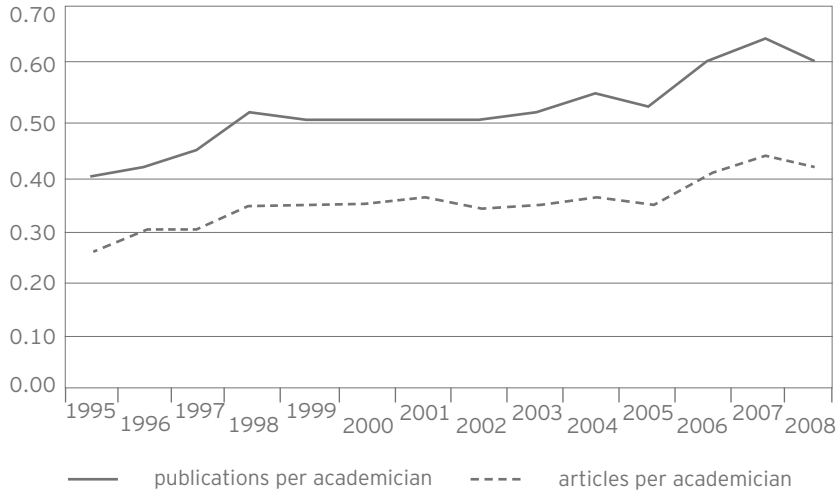
Austria



Italy



Finland



Note: number of publications and articles listed in Thomson Reuters' ISI Web of Science with at least one author claiming affiliation at one of the HEIs from our sample

*Germany: 1996-2008, Austria: 2000-2003 and 2005-2008 (break in series concerning staff statistics in 2004, the two subperiods should not be directly compared).

Source: own elaboration with bibliometric data from Thomson Reuters' ISI Web of Science and the number of academic staff members from sources indicated in Table 9.

As summary statistic hide a great deal of heterogeneity observable across academic units, Table 11 and Table 12 show bibliometric indicators along with some key statistics concerning single HEIs' in Poland, divided into technical universities and universities. We report the number of publications per academic staff members and articles per academic staff member in 2008, while other data refer to the preceding year (mainly due to data availability but it is also justified if one considers long publication process – hence it is better to compare research output in a given year with the

level of funding or the teaching load from the previous year). For comparison, in Table 13 we show analogical variables concerning foreign HEIs (along with Polish summary statistics) from our sample.

Within Polish technical universities (Table 11) in 2008, the research productivity, measured in terms of publications per academic staff member, was the highest in Wroclaw University of Technology (around 1 publication in a journal listed in ISI Web of Science per 2 academic staff members and 1 original article per 3 academic staff members). Top 5 technical universities with the highest number of publications per academic staff were the following: Wroclaw University of Technology, Gdansk University of Technology, Szczecin Technical University, AGH Cracow and Warsaw University of Technology. On the other end of the ranking there are five technical universities with less than 2 publications per 10 academic staff members annually: Koszalin University of Technology, Cracow University of Technology, Kielce University of Technology, Radom University of Technology and Bielsko Biala Academy.

Comparing technical universities in Poland to Polish universities, it turns out that in general HEIs with technical orientation are characterized by better research performance measured by bibliometric indicators (on average 0.29 publication per academic staff member employed at technical university and 0.19 publication per academic staff member employed at university in Poland in 2008). However, we should remember that the nature of publications varies across disciplines and while technical scientists publish mainly in scientific journals, researchers specializing in humanities and social sciences (thus employed mainly at Polish universities and not technical universities) publish more books and articles in journals not listed in Web of Knowledge. Also within universities we notice great heterogeneity in research efficiency with 54 publications per 100 academic staff members in University of Cracow and only 4 publications in high quality journals per 100 academic staff members in case of Szczecin University.

As far as potential determinants of research performance are considered, in general a better position in publications (articles) per academic staff member ranking is rather (it is not a strict rule) typical for Polish HEIs with lower teaching load (measured in terms of students to academic staff ratio) and higher revenues per employee.

Comparing values representative for Poland with the European standards (Table 13) it is clear, that Polish HEIs are characterized by publication record well below that typical for foreign HEIs. It does not mean that within each of the countries in our sample there are no HEIs with weak publication record but the general visibility in high quality

international journals of research done by academic staff members employed in Austrian, Finnish, German, Italian, Swiss or British is much higher than the one of their Polish colleagues.

HEIs differ greatly in size. On average, Polish HEIs from our sample have approximately 23,000 students – it indicates that Polish units are rather big. The biggest universities, in terms of the number of students, exist in Italy (on average 30,000 students, but also very big units of over 130,000 students such as University La Sapienza in Rome or University of Bologna). The smallest HEIs function in Switzerland and Finland.

Furthermore, the proportion of students per one academic staff member in Polish HEIs is more or less in the middle of the ratio typical for European HEIs (with only 8 students per one academic staff member in Switzerland and as many as over 34 students per one academic staff member in Italy). Taking into account the staff composition, in Poland on average little more than half of total employees working at HEIs perform academic duties (0.56) In other countries the proportion of a academic staff in total staff is similar, the lowest in UK (0.44) and the highest in Switzerland (0.67).

Polish HEIs confirm to have the lowest level of funding (around 40000 euro annually per one employee and 4000 euro annually per one student) – very low especially when compared with Italy or Switzerland (more than two times more money per employee annually than in Poland). Generally, while Poland is characterized by the lowest real revenues per student per year, Austria, Finland and Germany have similar values to each other (two time higher than in Poland) and Switzerland has very well-funded universities with almost seven times higher revenues per student than in Poland! At the same time the proportion of revenues related to didactic activity to total revenues in Polish HEIs is very high (on average 83% and at most almost 100% while in the UK on average 28% and at most 46%). These two pieces of information put together (low general level of funding plus focusing resources on didactics) mean that Polish HEIs dedicate considerably less money to research related activities than European universities, which are stronger in terms of publication productivity. Moreover, the proportion of funds coming from the public sources in Poland is relatively high (67%, compared to UK only 42% on average) but also in several other European countries it is high (e.g. Switzerland).

Table 11. Research output and key statistics for Polish technical Universities

Name	Polish name	Publications[1] per academic staff member (2008)	Articles[2] per academic staff member (2008)	Total number of students 2007	Students/ academic staff ratio (2007)	Academic staff / total staff ratio (2007)	Revenues per employee in euro PPS (2007)	Revenue from the public sources in total revenues in % (2007)	Revenue didactic/ revenue total in % (2007)
Bielsko Biala Academy	Akademia Techn.-Human-ist. w Bielsku Białej	0,01	0,00	8228	21,9	0,61	34911	63,5	87,3
Radom University of Technology	Politechnika Radomska	0,06	0,03	10972	21,6	0,53	35823	68,2	93,5
Kielce University of Technology	Politechnika Świętokrzyska w Kielcach	0,14	0,08	8021	21,3	0,48	35736	78,4	99,6
Cracow University of Technology	Politechnika Krakowska	0,14	0,09	14489	12,8	0,58	44013	67,0	74,9
Koszalin University of Technology	Politechnika Koszalińska	0,15	0,06	10660	22,3	0,58	b.d.	b.d.	b.d.
Czestochowa Univer-sity of Technology	Politechnika Częstochowska	0,22	0,09	14785	18,0	0,61	38948	72,2	83,2
Opole University of Technology	Politechnika Opolska	0,23	0,13	11113	23,9	0,53	39536	66,8	91,9
Lublin University of Technology	Politechnika Lubelska	0,24	10011	10011	17,4	0,51	33630	71,8	84,8
Bialystok University of Technology	Politechnika Białostocka	0,24	0,11	12156	17,2	0,56	36565	70,1	89,6
Gliwice University of Technology	Politechnika Śląska w Gliwicach	0,25	0,13	28964	15,3	0,54	44757	68,5	73,7

Rzeszow University of Technology	Politechnika Rzeszowska	0,28	0,19	11949	17,7	0,49	34160	73,7	84,0
Poznan University of Technology	Politechnika Poznańska	0,38	0,17	17740	15,2	0,63	51133	70,3	75,3
Lodz University of Technology	Politechnika Łódzka	0,38	0,24	19453	13,7	0,53	46352	68,3	69,4
Warsaw University of Technology	Politechnika Warszawska	0,44	0,22	29741	13,8	0,52	56087	62,1	69,6
AGH Cracow	Akademia Górniczo-Hutnicza w Krakowie	0,47	0,25	30614	14,4	0,55	48194	63,2	65,2
Szczecin Technical University	Politechnika Szczecińska	0,47	0,30	9880	14,1	0,50	38352	76,6	80,7
Gdansk University of Technology	Politechnika Gdańska	0,53	0,29	19343	17,6	0,47	47803	62,7	66,9
Wroclaw University of Technology	Politechnika Wrocławska	0,54	0,32	31951	17,1	0,51	50831	70,8	73,9
Average Tech.Univ.PL		**0,29**	**0,16**	**16671**	**17,5**	**0,54**	**42166**	**69,1**	**80,2**

Note: 1. All publications (articles, conference proceedings, book reviews) listed in ISI Web of Science. 2. Scientific articles listed in ISI Web of Science. n.a. denotes unavailable data. Source: own elaboration

Table 12. Research output and key statistics for Polish universities

Name	Polish name	Publications[1] per academic staff member (2008)	Articles[2] per academic staff member (2008)	Total number of students (2007)	Students/ academic staff ratio (2007)	Academic staff / total staff ratio (2007)	Revenues per employee in euro PPS (2007)	Revenue from the public sources in total revenues in % (2007)	Revenue didactic/ revenue total in % (2007)
Szczecin University	Uniwersytet Szczeciński	0,04	0,03	32149	27,6	0,58	34809	63,1	92,9
Bydgoszcz University-Bydgoszczy	Uniwersytet Kazimierza Wielkiego w Bydgoszczy	0,06	0,03	13989	21,2	0,63	34307	69,4	94,9
Rzeczow University	Uniwersytet Rzeszowski	0,09	0,07	19880	16,5	0,64	27346	71,7	96,5
Zielonogora University	Uniwersytet Zielonogórski	0,10	0,06	18314	17,8	0,56	31335	71,7	91,4
University of Bialystok	Uniwersytet w Białymstoku	0,11	0,08	14306	16,9	0,63	31079	65,0	91,4
Olsztyn University Olsztynie	Uniwersytet Warmińsko-Mazurski w Olsztynie	0,11	0,08	36511	19,3	0,61	40179	70,9	85,6
Opole University	Uniwersytet Opolski	0,14	0,10	15176	19,6	0,59	33962	68,2	92,4
University of Lodz	Uniwersytet Łódzki	0,14	0,11	38269	17,2	0,60	36132	66,3	91,3
Lublin University	Uniwersytet Marii Curie-Skłodowskiej w Lublinie	0,20	0,14	29818	15,9	0,57	32165	69,9	89,6
University of Gdańsk	Uniwersytet Gdański	0,21	0,15	28352	16,5	0,56	34379	67,1	89,6
Katowice Silesian University	Uniwersytet Śląski w Katowicach	0,23	0,16	35243	19,9	0,59	42545	67,9	91,9
University of Poznan	Uniwersytet im. Adama Mickiewicza w Poznaniu	0,26	0,20	49170	17,9	0,61	38540	71,1	84,6
Torun University	Uniwersytet Mikołaja Kopernika w Toruniu	0,28	0,19	27946	19,5	0,52	48984	50,8	65,3
University of Warsaw	Uniwersytet Warszawski	0,29	0,20	55515	17,4	0,53	50868	52,1	78,3
Wroclaw University	Uniwersytet Wrocławski	0,33	0,24	38059	20,7	0,56	42048	67,4	88,6
University of Cracow	Uniwersytet Jagielloński w Krakowie	0,54	0,38	38879	16,0	0,54	55524	49,4	61,3
Average.Univ.PL		**0,19**	**0,14**	**30723**	**18,7**	**0,58**	**38387,5**	**65,1**	**86,6**

Note: [1]. All publications (articles, conference proceedings, book reviews) listed in ISI Web of Science. [2]. Scientific articles listed in ISI Web of Science.
Source: own elaboration

Table 13. Research output and key statistics - summarize values by country, all sample

Country	Publications1 per academic staff member (2008)	Articles2 per academic staff member (2008)	Total number of students (2007)*	Students/ academic staff ratio (2007)*	Academic staff/ total staff ratio (2007)	Real revenues per employee per year in euro PPS (2007)**	Real revenues per student per year in euro PPS (2007)**	Revenue from the public sources in total revenues in % (2007)	Revenue didactic/ revenue total in % (2007)
Poland	0,23 (min 0,01, max 0,54)	0,15 (min 0,00, max 0,38)	23283	18,1	0,56	39968	4189	67,2	83,3
Austria	0,40 (min 0,08, max 0,64)	0,26 (min 0,06, max 0,44)	19424	15,1	0,65	71820	9261	75,1	b.d.
Finland	0,61 (min 0,07, max 1,43)	0,42 (min 0,06, max 0,86)	11317	13,7	0,48	56278	9105	65,1	38,8
Germany	0,45 (min 0,00, max 1,1)	0,31 (min 0,00, max 0,6)	17664	10,7	0,48	46117	9040	57,3	b.d.
Italy	0,79 (min 0,09, max 1,57)	0,55 (min 0,07, max 0,98)	30639	34,5	0,55	105890	6278	b.d.	b.d.
UK	0,59 (min 0,03, max 1,88)	0,39 (min 0,00, max 1,27)	18596	20,3	0,44	85379	11299	42,1	27,9
Switzerland	0,53 (min 0,1, max 0,87)	0,37 (min 0,06, max 0,6)	9724	7,7	0,67	84407	20436	82,3	77,8

Note: [1] All publications (articles, conference proceedings, book reviews) listed in ISI Web of Science. [2] Scientific articles listed in ISI Web of Science. n.a. denotes unavailable data. All sample – technical universities and universities.

* Italy: 2005; **Italy: 2005, Germany: 2006 due to data availability

Source: own elaboration

4.2. Testing causal claims

In this subsection we present quantitative evidence on the links between research output and possible determinants of scientific efficiency based on the microlevel database described previously. We demonstrate the case of Polish HEIs and trends typical for the HEIs in the European sample.

Table 14. The impact of different factors on research performance – summary of the results of the empirical study

Indicator of:	Variable	Effects on research performance (measured by publication per academic staff member)	
		All Polish HEIs	All European HEIs except Poland
Magnitude of funds	Revenues per employee	+	+
	Revenues per student	+	+
Structure of funds - financial autonomy	Government revenues as part of total	–	–
Structure of funds - destination	Didactic revenues as part of total	-	-
Size (Economies of scale)	Students total	+	+
	Staff total	+	+
	Academic staff	+	+
Teaching load	Students per academic staff member	-	-
Staff composition	Professors per academic staff	+	+
Research orientation	PhD students per total number of students	+	+
Location	GDP per capita (NUTS2)	+	?
Economies of scope/ size	Number of faculties	+	+
Tradition	Year of foundation	+	?
Technical orientation	Technical university	+	?
Faculty composition	Medical faculty	n.a.	+
	Economic faculty	n.a.	-

Notes:
"+" there is a positive association between a given variable and research output (publication per academic staff member)
"-" there is a negative association between a given variable and research output (publication per academic staff member)
"?" the relation between research output and a given variable is ambiguous.

Source: own elaboration based on econometric analysis (Appendix 3)

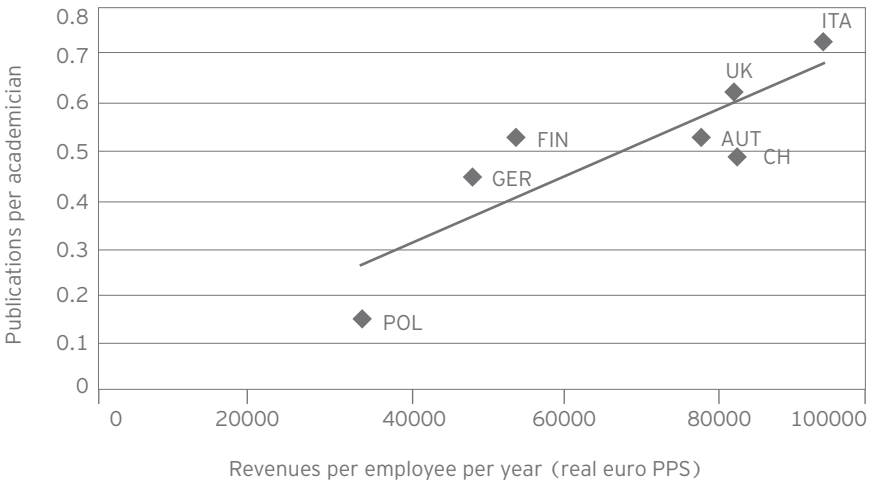
Table 14 contains summary of the results of the formal econometric empirical study (Appendix 3) where we investigate the relationships between research output (in terms of publications per academic staff member) and different variables of interest. Column (1) refers to the sample of Polish HEIs while column (2) to all European HEIs from our sample except the Polish ones. The positive/negative sign "+"/"-" indicates that there is a positive/negative association between a given variable and research efficiency (without determining strict causal relationship). In a few cases we have obtained ambiguous results (estimation is either statistically insignificant or the sign of the relationship is not robust) - such a situation is marked in Table 14 with question mark "?".Throughout the subsequent section we will one by one describe emerging results.

4.2.1. The role of funding – quantity and source

Sources of funding and number of scientific publications

Descriptive statistics from Table 13 prove that Polish HEIs are poorly funded when compared to the standards typical for European HEIs characterised by good research output. In order to test a common view that funds scarcity is one of the sources of Polish unsatisfactory scientific efficiency, we match information on HEIs' publication record with university level statistics on available financial resources (expressed in real 2005 prices) euro PPS per employee).

Figure 11. Relationship between research output and the magnitude of funding (country level evidence, averages 1995-2008)



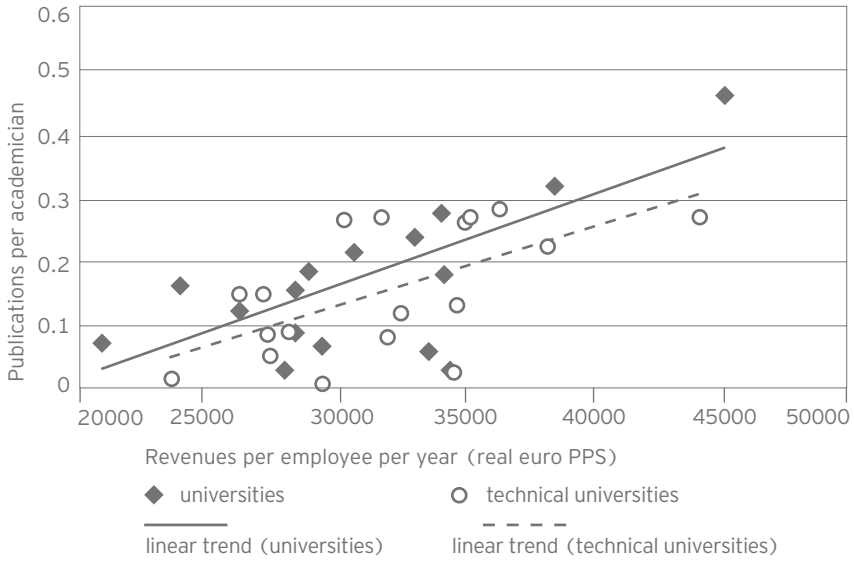
Note: points represent average values of publications per academic staff member and revenues per employee in a given country calculated as averages across HEIs from our sample within the years 1995-2008, line represents linear prediction (regression)

Source: own elaboration

Figure 11 indicates emerging positive relationship between revenues per employee (real euro PPS) and publication per academic staff member across HEIs from 7 European countries. Points at the graph represent average values of publications per academic staff member and revenues per employee in a given country calculated as averages across HEIs from our sample within the years 1995-2008. Poland is situated in the bottom left hand corner with the lowest revenues per academic staff member and the smallest publication record.

Interestingly, the relationship between funding and research output seems to be more pronounced in case of Polish HEIs than in other European countries. First of all, this is reflected in much higher value of correlation coefficient between revenues per employee and publication per academic staff member for Polish HEIs (compare Table A2 and Table A3 in the Appendix 3). Estimated elasticities (see Column (1) in Table A4 and A5 in the Appendix 3) between funding and research output are higher in Poland than in overall European sample. In case of Polish HEIs an increase in funding per HEI staff member by 1% could be associated with up to 4% rise in research efficiency.

Figure 12. Relationship between research output and the magnitude of funding in case of Polish HEIs



Note: points represent average values of publications per academic staff member and revenues per employee in a given HEI calculated as averages across time within the years 1995-2008, line represents linear prediction (regression)

Source: own elaboration

Figure 12 presents the relationship between research output and the magnitude of funding limited to the Polish HEIs. Points represent average values of publications per academic staff member and revenues per employee in a given HEI calculated as within-unit averages across time within the years 1995-2008. Both for universities and technical universities the positive relationship between revenues per employee and publication per academic staff member is confirmed. The best research performance is achieved by University of Cracow (point in the top right hand corner) characterised also by the highest magnitude of the revenues per employee.

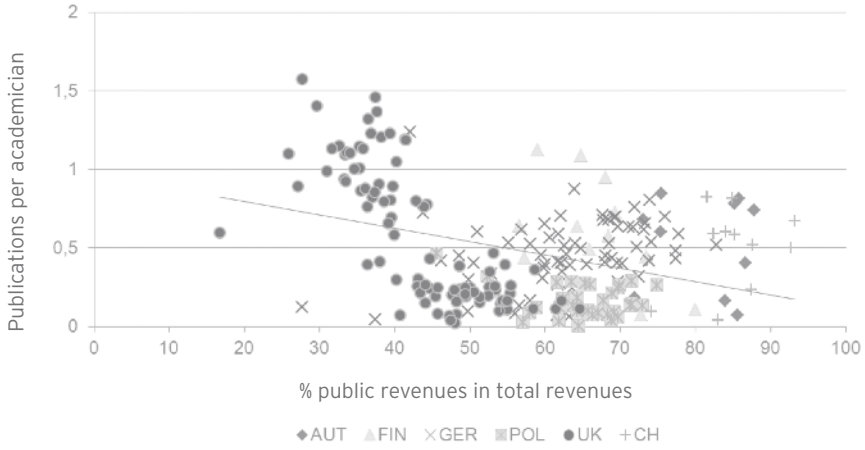
Source of funding vs productivity

However, the data on total revenues per employee do not indicate what is the source of the money (government versus private) and how the money is split between research and teaching tasks. In order to check whether not only the quantity of funding but also the source of funding is important for research productivity we distinguish between two variables: Rev_gov_{it} - % of budget coming from core governmental funding and Rev_did_{it} - % of budget dedicated to the didactic tasks. Figure 13 shows the relationship between the share of governmental funding and the research performance of all HEIs from our sample. We can see that countries with higher percentage of funding coming from governmental sources perform poorer in the light of bibliometric measures of research productivity. In particular, top (in terms of research indicators) UK institutions are characterised by relatively low percentage of funds coming from the public sources. This indicates that competitive research grants can be more productive than research financed with the public money. Nevertheless, we have to be aware that the variable indicating the share of government funding is partly associated with country's institutional environment. Additionally, the alternative sources of funding (private, competitive research grants) can strength the institution's autonomy (for a discussion of the role of autonomy and competition on university's research production see Aghion et al., 2009).

Figure 14 shows relationship between the research output and the type (destination) of funding. Despite data constraints (we posses data on the share of budget dedicated to the didactic tasks only for four countries), quite intuitive negative relationship is confirmed (major proportion of funds on didactics implies less resources for research and thus worse research outcome). Polish HEIs are characterised by the biggest share of budget dedicated to teaching activities (on average 83% and up to 99%) while UK with the lowest (on average 28%) which means than in case of Poland a very small proportion of funds is destined to research.

Negative relationships between the proportion of public funding or didactic related revenues on one side and publication per academic staff member on the other are confirmed in the regression analysis - both for Polish and European HEIs (Columns 3 and 4 from Table A4 and Table A5 in the Appendix 3).

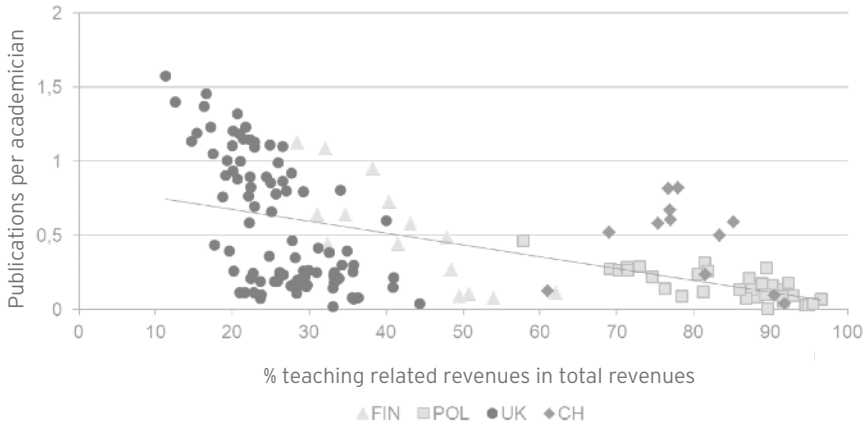
Figure 13. Relationship between research output and the source of funding (Poland and other European HEIs)



Note: points represent average values of publications per academic staff member and proportion of revenues from the public sources calculated as averages for single HEIs from our sample within the years 1995-2008, line represents linear prediction (regression)

Source: own elaboration

Figure 14. Relationship between research output and the type (destination) of funding (Poland and other European HEIs)



Note: points represent average values of publications per academic staff member and proportion of teaching related revenues calculated as averages for single HEIs from our sample within the years 1995-2008, line represents linear prediction (regression)

Source: own elaboration

4.2.2. Is there a trade off between research and teaching?

The responsibilities of academic staff

Due to at least double role of HEIs (didactic and research), in addition to teaching most of academic staff members (except instructors and lecturers) are expected to perform research and publish in, if possible, recognized journals. Working time at HEIs varies greatly depending on the type of post, the country etc. In Poland, teaching load varies across HEIs: the minimum teaching load for an academic staff (performing both teaching and research duties) is between 120 and 240 hours per year.[50] In the UK, there is a general division for academic staff of 40% teaching, 40% research and 20% administrative tasks. In practice the division between research and teaching differs greatly between and within institutions as is based on individual contracts.

Unfortunately, the data about average teaching load in terms of hours per academic staff member at the level of individual institutions are not available. That is why we proxy the magnitude of teaching load by the number of students per academic staff member. We assume that the higher the number of students per academic staff member the higher hers or his teaching load. Of course, it also depends on the number of students per class or course, but at least at the same country it should be similar.

In Figure 15 we demonstrate the relationship that emerges between our basic measure of teaching load and research output in case of Polish HEIs. There is a clear negative correlation between the number of students per academic staff member and the number of publications in ISI Web of Science per academic staff member – such a relationship is confirmed within a sample of Polish universities and technical universities (Figure 15), as well as in the overall sample composed of European HEIs from seven countries (Figure 16). Institutions where on average each academic staff member is 'responsible' (in terms of teaching and other duties) for a major number of students are characterised by lower research efficiency in terms of publication record than HEIs with a small number of students per every member of academic staff.

The negative relationship between teaching load and research output is confirmed by a negative correlation coefficient (around -0.3 in case of Polish HEIs) between the number of publications per academic staff member and the number of students per academic staff member shown in Table A2 in the Appendix 3. We can conclude that research activity and didactics are indeed rather competitive than complementary.
If we wanted to quantify more precisely the elasticity between teaching load and research efficiency (see Table A4 and A5 in the Appendix

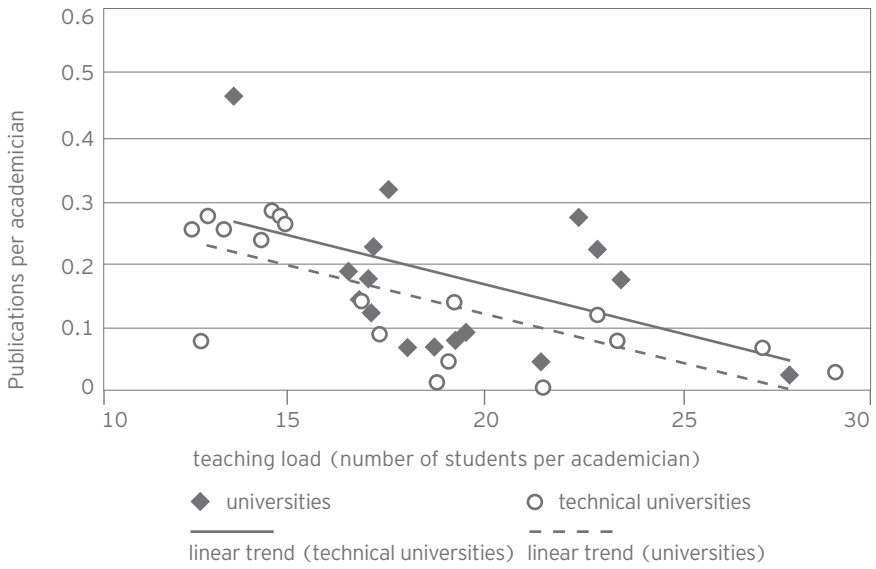
3) it turns out that, *ceteris paribus*, a decrease in the teaching load by 1% could be associated with as much as 0.8-1.6% rise in research productivity.

Note that our proxy measure of teaching load takes into account only teaching duties at the HEI with which an academic staff member is affiliated -we are not able to measure the magnitude of other teaching duties i in case of academic staff members teaching at two or more HEIs which is common for Polish academia.

The role of PhD students

Additionally, we checked the role of PhD students existence for the research output (there might appear positive links due to major research orientation of the unit). Both in case of Polish and European HEIs there is a positive correlation between the number of PhD students per total number of students and the number of publications per academic staff member. It can indicate the positive role of PhD students in research creation per se and/or the fact that institutions with higher number of PhD students are more research oriented. Similarly, units with major share of professors in academic staff also perform better in terms of research output. However, in case of Polish HEIs the magnitude of correlation coefficient is much smaller than in other European HEIs (compare results in Table A2 and Table A3).

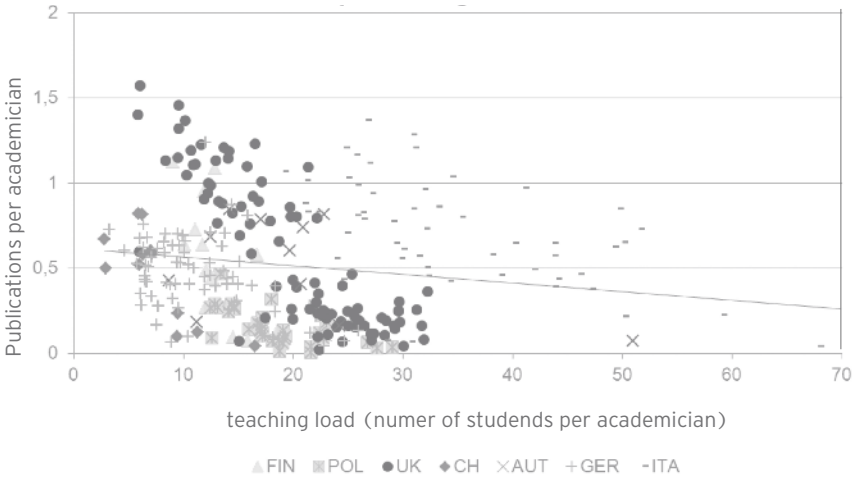
Figure 15. Relationship between research output and the teaching load in case of Polish HEIs



Note: points represent average values of publications per academic staff member and students per academic staff member in a given HEI calculated as averages across time within the years 1995-2008, line represents linear prediction (regression)

Source: own elaboration

Figure 16. Relationship between research output and the teaching load (Polish and other European HEIs)



Note: points represent average values of publications per academic staff member and teaching load (number of students per academic staff member) calculated as averages for single HEIs from our sample within the years 1995-2008, line represents linear prediction (regression)

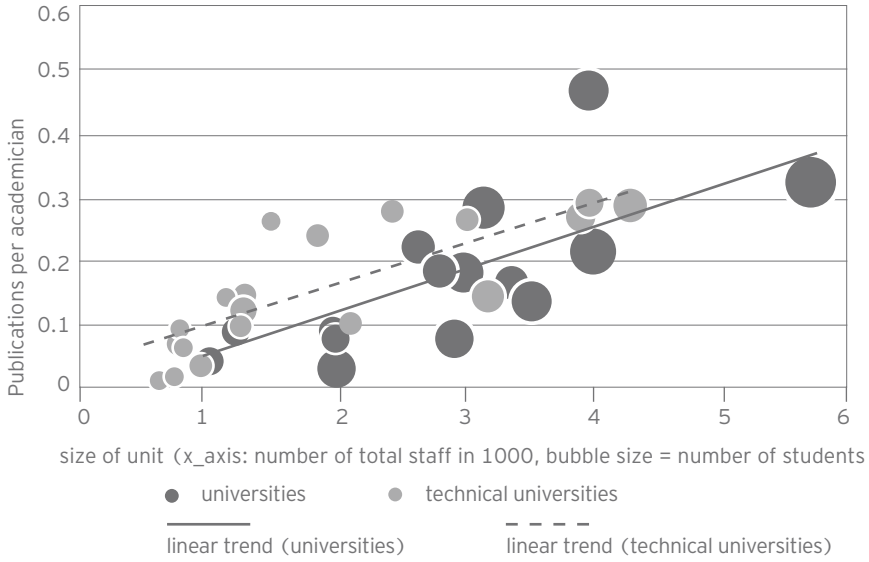
Source: own elaboration

4.2.3. Does concentration of resources in large units lead to an increase in research productivity?

Evidence from our sample of both Polish and other European HEIs confirms that there is a positive relationship between the size of the unit and its research performance. Figure 17 refers to the sample of Polish HEIs. The size of the institution is either measured by total number of staff (x axis) or total number of students (bubbles). Larger university units appear to be more productive in terms of publications per academic staff member which could suggest the appearance of the economies of scale. However, note that Polish system of financing HEIs' teaching tasks from the government (around 80% of total revenues - see Table 2) is to a large extent based on the size of the unit. Hence, major funds go to big universities and, as a result, apparent positive link between unit size and research productivity may in reality hide positive relationship between funding and research output.

The positive relationship between the size of the institution and its research performance is also present in our European sample (Figure 18). Finally, the relationship is confirmed in the regression analysis (Table A4 and Table A5).

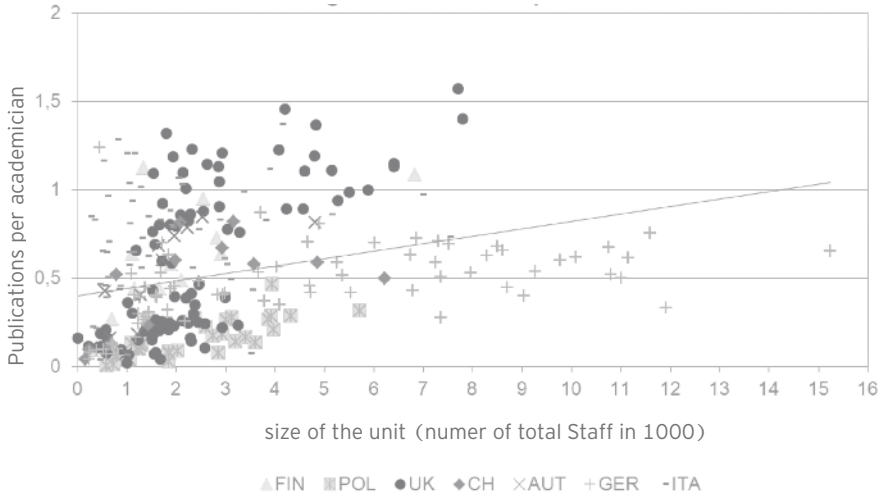
Figure 17. Relationship between research output and the size of the unit in case of Polish HEIs



Note: points represent average values of publications per academic staff member and size of the unit measured by the number of total staff (in 1000) calculated as averages for single HEIs from our sample within the years 1995-2008, line represents linear prediction (regression). Bubble size reflects the number of students.

Source: own elaboration

Figure 18. Relationship between research and the size of the unit (Polish and other European HEIs)



Note: points represent average values of publications per academic staff member and size of the unit measured by the number of total staff (in 1000) calculated as averages for single HEIs from our sample within the years 1995-2008, line represents linear prediction (regression).

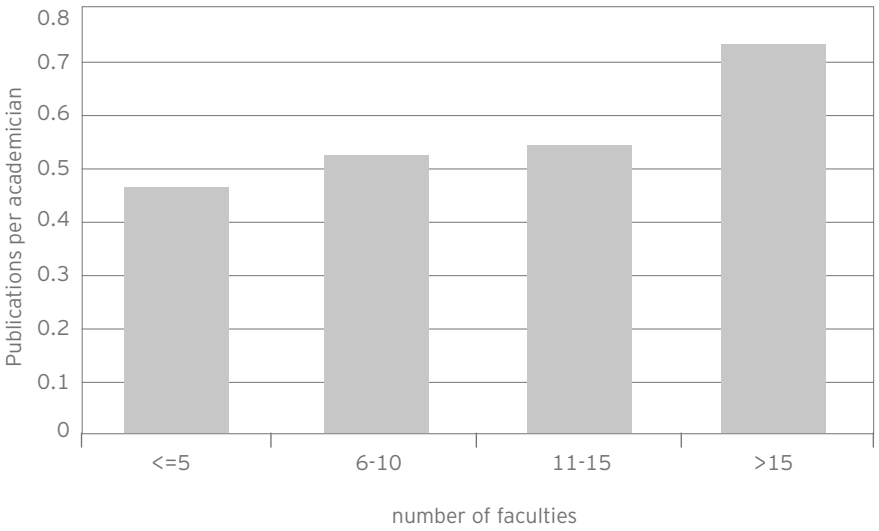
Source: own elaboration

4.2.4. What is the relationship between research output and interdisciplinarity of the unit?

Higher education institutions in our European sample vary considerable in the number of faculties – up to as many as 21 faculties.[51] In case of Poland, HEIs in our sample are composed of 4 to 20 different faculties. The argument linked to the emergence of economies of scope would suggest that interdisciplinarity of the unit, reflected in its composition and the number of didactic/research areas, could affect research output.

Figure 19 presents the relation between number of faculties and corresponding average number of publication per academic staff member. All institutions were divided into four groups starting with the units with the number of faculties not higher than 5; next group: with the number of faculties between 6-10; then 11-15; and final group with the highest number of faculties (more than 15). The height of the bars at the Figure 19 represents the average number of publications per academic staff member in a given group of HEIs. On average units with higher number of different faculties are characterised by higher publication records per academic staff member, but both middle groups (number of faculties between 6-10 and 11-15) do not differ substantially in the research output. Above result is confirmed by positive correlation coefficients between $nofac$ and publications per academic staff member both in case of Polish HEIs (Table A2 in the Appendix 3) and European HEIs (Table A3 in the Appendix 3). However, it should be noted that the number of faculties reflects not only the interdisciplinarity of a unit, but at the same time can be linked to the overall size of at least some of the HEIs (see the pairwise correlation between $nofac_i$ and variables indicating size: $Staff_{it}$, $stud_{it}$). Moreover, again in Poland this may reproduce indirectly the aforementioned impact of HEIs finances on research productivity (units with more faculties are typically big and thus receive major funds from the government).

Figure 19. Relationship between research output an the interdisciplinarity of the unit (number of different faculties)



Source: own elaboration

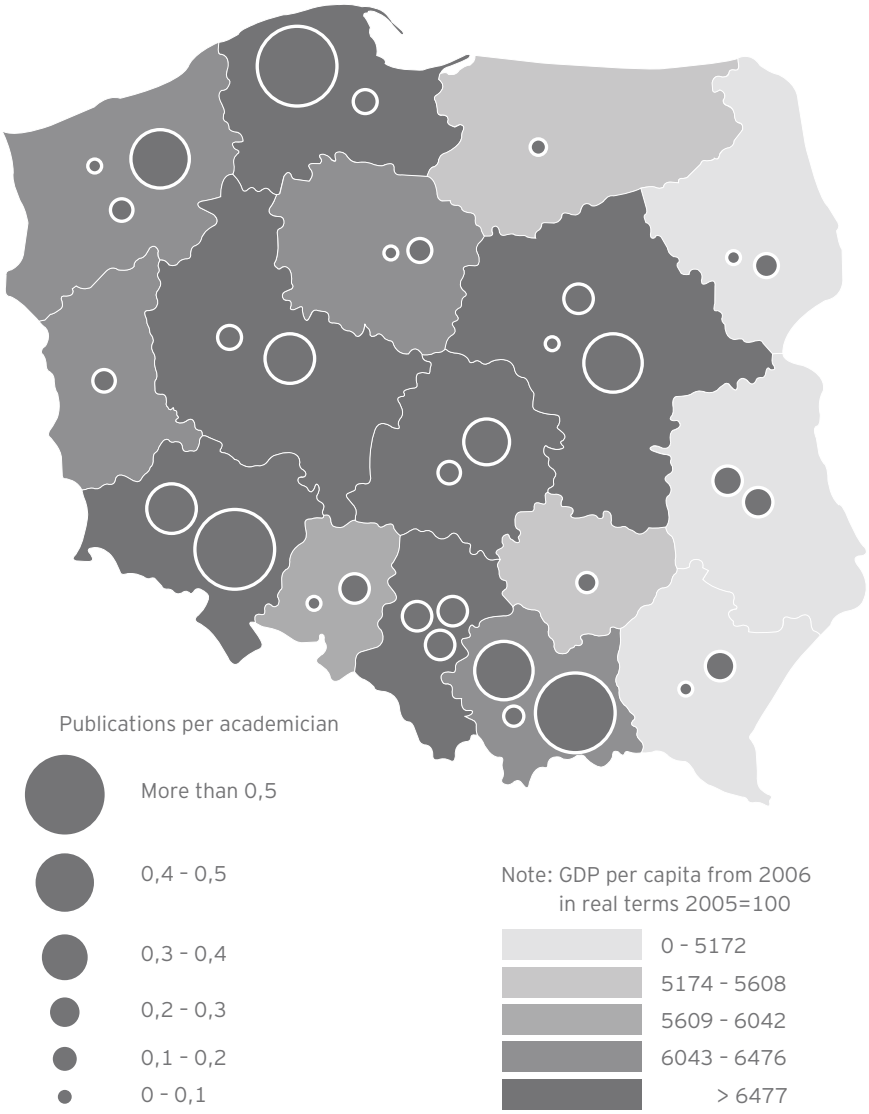
4.2.5. Individual characteristics of universities and their research output

We want to check whether university specific characteristics such as the year of foundation and location of the unit have an impact on its research performance. Indeed, there appears positive and significant coefficient of correlation between a dummy variable equalling 1 if an institution was founded at least 100 years ago and its research output for Polish HEIs (Table A2 in the Appendix 3). Older Polish HEIs can have some advantage in pursuing efficient research over newly established ones, probably because of longer tradition and major research networks establishes throughout the years of activity. Surprisingly, for foreign HEIs pairwise correlation coefficient between research output and tradition dummy is positive, but when we account for other characteristics such as size, funding, teaching load etc. in the multivariate regression analysis we obtained the negative parameter in front of dummy variable describing year of foundation. Consequently, we prefer not to draw strong conclusions concerning the link between the year of establishment and research output of a given unit in the European sample ("?"in Table 14 for European HEIs).[52]

As far as location patterns are concerned, in case of Poland we clearly see (Figure 20) that HEIs (both technical universities and universities) with best research performance are located in big cities/ agglomerations. Consequently, for the Polish sample the correlation

between the GDP per capita of the region where the unit is located and research performance is positive (Table A2). However, this is not a case for the whole European sample where the location seems to be less important for the research performance – statistically insignificant correlation coefficient (Table A3).

Figure 20. Map – publications per academic staff members in 2008 versus regional development level and location, Polish HEIs



Finally, through the regression analysis presented in the Appendix 3, we confirmed descriptive evidence showing that in case of Poland technical universities are on average characterised by higher research production (measured by the number of publication per academic staff member)

than universities – a positive parameter in front of variable in Column (2) of Table A4. For foreign HEIs analogous estimations are not robust, thus we conclude that in European sample there is no unambiguous relationship between the nature of the unit (technical university or not) and its publication record. Note that this may simply be referred to the fact that other European systems of higher education usually do not adopt such a strict distinction between technical universities and other types of universities. Finally, in foreign HEIs the presence of medical/pharmacy faculty can be associated with higher bibliometric score, while the contrary holds true for those with economics/business faculties.

4.3. Third mission – the case of selected Polish technical universities

„Third mission" of university

So called 'third mission' of a university in a broad sense is defined as all activities contributing to innovation, social and economic development carried by HEIs (Gulbrandsen and Slipersæter, 2007). This is strictly connected with terms such as "entrepreneurial university", "academic entrepreneurship", "knowledge commercialization" (see more in Clark, 1998; Etzkovitz and Leydesdorff, 1997). In a narrow sense, third mission refers to the cooperation of HEIs with external surrounding, in particular industry and government authorities.

Polish HEIs are obligated by law to cooperate with the economic environment, particularly through sale or free of charge transfer of R&D results. Among basic tasks of Polish HEIs except teaching and research we find dissemination of science and technology, as well as performance of different activitiesfor local and regional communities.[53]

Due to methodological problems (e.g. difficulties with definition and measurement of university-industry connections) we were not able to include indicators of HEIs' third mission activities in our quantitative analysis presented in section 4.2. However, being aware of third mission's importance, in this section we present forms and examples of university-economy cooperation on the basis of selected Polish technical universities. The technical universities usually have more strict links to the industry than Polish universities do, due to the nature of applied research that dominates in the technical sciences (Leja, 2009).

Forms of cooperation – Gdańsk University of Technology

In fact there can be numerous forms of university-environment connections. As an example we describe them on the basis of Gdańsk University of Technology (Table 15).

Table 15. Forms of cooperation with external surrounding – the case of Gdansk University of Technology (GUT)

Form of cooperation	examples	External partners
Participation in scientific networks and consortia	In 2008: 108 projects e.g: HOPU-S , AIRCLIM-NET2, MISTRA3, GRDE consortium4, The Center of Maritime Military Technologies5	industry, local/ regional authorities, other HEIs
Research & Development works commissioned by national and international companies and institutions (not including government grants)	In 2008: 183 (counted only those with the value higher than 10000PLN) e.g: works commissioned by LOTOS S.A, POLPHARMA S.A.	industry, local/ regional government, institutions
Long-term research cooperation agreements	In 2008: 40 agreements e.g: LOTOS Lab s z o.o., JS Hamilton Poland Ltd. Sp, Perlan Technologies Polska Sp. Z o.o., DORADCA Consultants Ltd. Sp. Z o.o, Nanoco sp. z o.o, MK AQUA Sp. z o.o., SAUR NEPTUN Gdańsk S.A, KOMPANIA PIWOWARSKA S.A.	industry
Students' internships	e.g: Delphi Poland S.A. , Soda Polska Ciech Sp. z o.o, Rafineria Gdańsk, Klimor	industry
Internships for GUT's employees	e.g WiComm Transfer program of the exchange of employees between GUT and ICT sector	industry
Promotion and educational actions aimed at popularization of technical sciences	e.g. Science Festival	other HEIs from the region, local and regional authorities, high schools
Educational actions aimed at gaining future students	e.g. preparatory courses for potential candidates/future students, open days	high schools
Partnership in Technology parks	- Pomeranian Science and Technology Park (PPNT[6]) - Gdańsk Science and Technology Park (GPNT7)	industry, local/ regional authorities, other HEIs from the region
Partnership in Clusters	- Pomeranian ICT cluster - The Baltic Center for Biotechnology and Innovative Diagnostics, BioBaltica [8]	industry, local/ regional authorities, other HEIs from the region
Special purpose foundations	Foundation of Energy Conservation[9]	Local suppliers of energy and gas
Clubs joining firms owned by former students	e.g. PKB+ - The Gdańsk University of Technology Business Club, The Alumni Association	Industry, alumni

Participation in international research programs	Joint realization of the EU projects (EU grants etc.), International Visegrad Fund	Industry, local/ regional authorities, other HEIs
Copyrights in the discipline of architecture, urban science and art.	in 2008: 38	industry
Implementation of research, license agreements, know-how	in 2008: 51	industry
Patents	in 2008: 35 applications and 17 patents assigned	industry

Notes:
Housing Praxis for Urban Sustainability
2Polish Thematic Network For Problems Of Air Pollution And Climate
3 Pathways of pollutants and mitigation strategies of their impact on the ecosystems
4 From Basic Oncology To Cancer Biotherapy: Understanding The Molecular Mechanisms Of Tumor Host Interactions To Develop New Therapeutic Tools
5 Centrum Morskich Technologii Militarnych
6 PPNT - Pomorski Park Naukowo-Technologiczny
7 GPNT - Gdański Park Naukowo Technologiczny
8 Bałtyckie Centrum Biotechnologii i Diagnostyki Innowacyjnej
9 Fundacja Poszanowania Energii

Source: own elaboration based on the Report on R&D activities and international activities in 2008, Gdańsk University of Technology (Raport z prac naukowo-badawczczych i współpracy międzynarodowej 2008) and information from the Office for Economic Cooperation at Gdansk University of Technology

One of the popular indicators of practical aspect of research performed at HEIs, comparable across units and countries, is the number of patent applications and patents granted (the last row of Table 15). For comparison, we also present the number of patents awarded to Polish technical universities in the period 1995-2006 (Table 16), divided into two subperiods. In the recent years for which the data is available (2000-2006), Technical University of Wroclaw managed to get the highest number of patents (417 in total, 22 per 100 academic staff members) – interestingly, this institution is also characterised by the highest number of publications per academic staff member among Polish technical universities (see Table 11). In the former subperiod (1995-1999) Warsaw University of Technology was the best performer in terms of international patent activity.

One of the main problems that HEIs point out as the difficulty in performing R&D is the low level of funds (see Table 13 and the comparison with the European standards). One of the external sources of significant financial resources, obviously conditioned on the HEI's ability to provide its own financial participation, are the EU funds. Table 17 presents the participation of Polish HEIs in the Seventh Research Framework Programme (FP7) – it is evident that the activity aimed at gaining sources from EU grants varies considerably across units. After 176 closed calls almost half of all 794 applications from Polish technical

universities came from 3 HEIs (Warsaw University of Technology, Wroclaw University of Technology and AGH Cracow) which are also on the top of the bibliometric and patent rankings (see Table 11 and Table 16). It suggests that at least in case of these technical universities the publication and patent activities, as well as searching for external financial resources seem to be rather complementary (for a discussion on the relationship between academic patenting and universities' research see Crespi et al., 2009). Obviously, these are also big units thus their capacity in preparing patent and grant applications could be greater than in case of smaller HEIs but the number of applications per 100 academic staff members also confirms that the aforementioned units are more active in preparing applications for EU funds.

Table 16. Number of patents in espacenet database granted to Polish technical universities as at least one of the applicants

Name of technical university	Number of patents (2000-2006)	Numer of patents per 100 academic staff members (2000-2006)	Number of patents (1995-1999)	Numer of patents per 100 academic staff members (1995-1999)
AGH Cracow	294	14,4	203	11,3
Bialystok University of Technology	8	2,2	*	*
Bielsko Biala Academy	21	2,9	34	5,8
Cracow University of Technology	46	5,7	57	9,5
Czestochowa University of Technology	90	8,0	44	3,9
Gdansk University of Technology	32	8,1	51	13,6
Gliwice University of Technology	21	4,1	14	3,5
Kielce University of Technology	86	7,5	73	7,0
Koszalin University of Technology	93	16,5	74	14,1
Lodz University of Technology	203	13,7	129	7,9
Lublin University of Technology	42	9,8	17	4,8
Opole University of Technology	45	3,9	44	4.2
Zielonogora Technical University	19	4,0	23	4,5
Poznan University of Technology	31	4,7	35	6,1
Radom University of Technology	189	10,8	173	11,4
Rzeszow University of Technology	337	15,6	329	14,2
Szczecin Technical University	417	22,2	262	13,9
Warsaw University of Technology	106	14,9	105	14,9
Wroclaw University of Technology	**	**	10	2,5

Note: number of patents based on the date of official patent publication, patents with a given HEI as applicant; academic staff calculated as the period mean

* Till 2000 functioned as a filiae of Lodz University of Technology

** Functioned as Zielonogora University of Technology till 2000, then since 1st Sept 2001 as a part of Zielonogora University

Source: own elaboration based on worldwide patent data from www.espacenet.com

Table 17. Participation of Polish HEIs in the 7th Research Framework Programme*

Name of technical university	No of applications	No of applications per 100 academic staff members	Accepted projects
Warsaw University of Technology	103	5,05	13
Wroclaw University of Technology	3	0,83	
AGH Cracow	10	1,38	1
Poznan University of Technology	15	1,87	
Lodz University of Technology	61	5,46	7
Gdansk University of Technology	1	0,25	
Gliwice Univesrity of Technology	6	1,18	1
Cracow University of Technology	37	3,23	6
Szczecin Technical University	9	1,60	
Czestochowa University of Technology	72	4,85	9
Rzeszow University of Technology	8	1,86	
Bialystok University of Technology	80	7,07	9
Lublin University of Technology	1	0,21	
Opole University of Technology	15	2,31	2
Koszalin University of Technology	61	3,49	5
Bielsko Biala Academy	176	8,13	24
Kielce University of Technology	105	5,58	16
Radom University of Technology	31	4,35	5
Technical University TOTAL	**794**		**98**

Note: *After 176 closed calls. Academic staff calculated as the period mean

Source: own elaboration based on the data kindly provided by Jerzy Supel (IPPT PAN)

In order to complete the picture of third mission realised at Polish technical universities, we present two specific cases of successful university-industry relations: the cooperation of Wroclaw University of Technology with companies from high-tech sector and the activity of Technology Transfer Center at AGH Cracow.

Wroclaw University of Technology

Frame 1. Cooperation of Wroclaw University of Technology with industry

Wroclaw University of Technology cooperates with more than 200 national and international companies. Among its industry partners there are: Google, Microsoft, IBM, EDF Polska, Siemens, Whirlpool, Dialog Telecom, KGHM Polska Miedź S.A., MAN, RAFAKO, Volvo.

Example: the cooperation of Wroclaw University of Technology and IBM

- an agreement about cooperation signed in 2007
- internships for students
- access to hardware, full-version software, professionally developed courseware, tools nad trainings
- participation in the IBM programme: IBM University Relations
- IBM Academic Day
- IBM Systems Technology Truck
- Establishment of Multipurpose Cloud Computing Centre
- major recent success: IBM and the Polish government signed an agreement to cooperate in the creation of a new IBM IT service delivery centre in Wroclaw. It involves cooperation with Wroclaw University of Technology to improve curricula of studies and better prepare students for opportunities in the information technology industry.

Source: http://www.ibm.com/university and Wroclaw University of Technology's Press Office

AGH University of Science and Technology

Frame 2. Technology Transfer Center at AGH Cracow

Technology Transfer Center at AGH Cracow (CTT AGH) (http://www.ctt.agh.edu.pl/) was established in March 2007. It deals with comprehensive technology transfer, including:

- Promoting research, technological and expert offer to business people and investors;
- Selling and making other forms of intellectual property accessible (patents, licenses, know-how);
- Patent protection;
- Obtaining financial means for supporting transfer of technologies;
- Providing information, consultation and trainings on transfer of technologies.

Activities in 2008:

- prepared 55 documentations in order to obtain patents, 1 for utility models and 11 for trademarks
- signed 24 license agreements, including 13 inventions, 10 know-hows, 3 computer programmes and 2 transfers of patent rights. Registered 3 new know-how solutions, conducted current formal-legal and accounting services for 30 implementation agreements and 130 license agreements
- prepared and coordinated 46 agreements and letters of intent including 24 contracts with companies, 13 with scientific institutions, 4 with regional units and 5 with consortia and clusters
- conducted a comprehensive service of 50 applications for Structural Funds
- organised thematic conferences

Source: own elaboration based on the Report on activities in 2008, CTT AGH available at: http://www.ctt.agh.edu.pl (Sprawozdanie z działalności w roku 2008, Centrum Transferu Technologii AGH)

Unfortunately, successful university-industry cooperation in Polish HES is rather an exception than the rule. According to the MSHE report (MNiSW, 2006) the majority (56%) of companies is not interested in cooperating with HEIs. The main indicated barriers are: the lack of law regulations designed to promote university-industry networking and the deficit of solid business offers on the part of universities. Furthermore, the recent report of Polish Agency for Enterprise Development[54] (Matusiak and Guliński, 2010) is very critical about the knowledge commercialisation and university-industry linkages. The entrepreneurship of HEIs is expressed by organizing additional teaching activities during weekends and making profit out of it, rather than by transferral of knowledge and innovation. This is due to: scarce regulations concerning intellectual property rights; low role of component linked to the commercialisation of knowledge during staff evaluation exercise; excessive bureaucracy; 'taxation' of inventors affiliated with the HEI (which causes the rise of shadow economy where the institution's assets are informally used in enterprises run by HEI's staff members); inefficient centres of technology transfers; and academic incubators often established for prestige but lacking competence.[55]

5. Conclusions and recommendations

Summary

Our project was motivated by the willingness to contribute to the actual debate on the necessary changes in Polish system of higher education. In particular, we were interested in pointing out the factors that can affect scientific efficiency measured in bibliometric terms, which is unfortunately low when compared to European standards. Moreover, our goal was to suggest potential improvements that could possibly lead to enhancing the competitiveness of research done in Polish HEIs.

Although the issue of higher education reform in Poland has resulted in a lively discussion in the scientific and non-scientific environments, surprisingly little effort has been put into quantifying the relationship between the research efficiency of higher education institutions in Poland and its determinants. Such a fact can be (partly) justified by the practical unavailability of university-level statistics in Poland, preventing researchers from performing a quantitative analysis of research productivity at the micro level.

One of the main tangible contributions of our project is the creation a unique micro dataset on Polish HEIs, covering 16 universities and 18 technical universities within the period 1995-2008. The database contains variables describing HEIs' multiple inputs and outputs, characterising both the teaching mission and knowledge creation (research). We have decided to focus on research efficiency measured through the publication record in internationally recognized journals. This is a powerful signaling mechanism, which influences the visibility and perceived quality of a given academic unit. Moreover, such a measurement of research achievements is entirely in line with the way of quantifying research efficiency of Polish public HEIs adopted by the Ministry of Science and Higher Education. Our dataset on Polish universities is compatible to existing European databases (e.g., Finnish KOTA, English HESA), which allows for comparative studies. Consequently, we were able to match observations on Polish HEIs with analogical ones concerning higher education institutions from a set of EU (Austria, Finland, Germany, Italy, and the United Kingdom) and non-EU (Switzerland) countries. We were initially interested in technical universities, but for comparison purposes we finally included also universities into our broad sample. In the end, we consider 291 HEIs from 7 countries.

Of course, we are aware of the shortcomings of the database we have constructed: not all public HEIs are covered; the data on finance is restricted; and different data sources might result in biases. Unfortunately, Poland still adopts a very restrictive data dissemination strategy concerning statistics on single units, even such banal ones as those concerning the number of staff or students. Our basic recommendation concerning the possibilities of research on the education system in Poland would be the following: a common micro database covering all public HEIs should be created and made publicly available, for example, on the web page of the MSHE. In our opinion, especially, the data concerning financial issues of public HEIs (revenues, expenditures, etc.) should be freely available to all taxpayers (as in other EU countries) and should not be treated as 'confidential'. The problem concerning a general lack of microdata of HEIs is not only present in the case of Polish institutions. The European and world statistical agencies (such as Eurostat and OECD) refer to HEIs as an aggregate while only some of the national agencies (like from these six countries that we explored in our study, apart from Poland) provide micro-level information on HEIs performance. Surely there is a need to build an integrated dataset of HEIs at the European level and we have attempted to do so.

At the beginning of the report, we have presented the description of the heterogeneity of national higher education systems in seven European countries (Poland, United Kingdom, Germany, Austria, Finland, Italy, and Switzerland). We have taken into consideration the key differences that are principally important: funding system, university governance, student tuition fees, and wage level of academic staff. The gap between an average wage level of academic staff in Poland and Western European counterparts causes very high opportunity costs for Polish scientists (especially young, ambitious, and research productive). Additionally, the lack of strategic management in the case of many Polish HEIs is also a serious drawback. Altogether, these factors result in many formal and informal barriers to a quick and fruitful academic career.

Within this background, the major aim of our project was to provide a comparative quantitative study on research productivity and its determinants, explaining relationships emerging in public "economics of research". In order to reach our goal and analyze why Polish HEIs find it so hard to meet international standards of research productivity, we have tested five specific causal claims. Contemporarily, we have estimated research production function for Polish HEIs and for the sample of European HEIs separately. To the best of our knowledge this is the first study attempting to quantify the relations between research

productivity and its possible determinants (a thing often perceived as 'immeasurable') based on the case of Polish HEIs presented in a broader context.

The main answers that we obtained for our five basic research questions are as follows:

1. *What is the elasticity between funding (magnitude and sources) and the research output?*

The impact of financial resources on the average research output is not trivial: we have found that, *ceteris paribus*, a 10% increase in funding could be linked to a rise in research productivity done at Polish HEIs by around 40%. This is not surprising if we take into account that the average funding per staff member typical for Polish HEIs is two times lower than that in countries like Italy or Switzerland. Additionally, in Polish HEIs, the vast majority of funds (more than 80%) go to financing didactic-related activities; thus, few resources remain for financing research activity. Additionally, we have found that the greater the proportion of financial resources coming from the government, the lower the research efficiency, which suggests that public funds are used less effectively than those coming from the private sources. UK is an example of a country where public funds cover only approximately 40% of HEIs financial needs (in Poland on average almost 70%) but the research output is highly competitive.

2. *Does an increase in the teaching load causes a drop in research output?*

Unsurprisingly, we have confirmed a negative relationship between teaching load and research output. Specifically, *ceteris paribus*, a decrease in teaching load by 10% could be associated with as much as 8-16% improvement in research efficiency. The negative impact of excessive teaching load on research output is confirmed also in case of foreign university units. Hence, we argue that indeed there exist substitution relations between teaching obligations and research productivity.

3. *Does a concentration of resources in large units lead to an increase in research productivity?*

Large schools are more research effective

Our results indicate that larger HEIs in Poland appear to be more productive in terms of publication record per academic staff member which may be a sign of emerging economies of scale. However, this also reflects the fact that Polish system of financing HEIs' teaching tasks

from the government is, to a large extent, based on the size of the unit. Thus, an apparently positive link between university size and its research productivity may in reality hide a positive relationship between funding and research output. Then, the structure of academic staff is related to research output in the same manner in Poland as in other European HEIs. In particular, a greater proportion of professors in total academic staff can be associated with better scientific productivity but this relationship is stronger abroad than in Poland.

4. *Does heterogeneity of units lead to an increase in research productivity (economies of scope)?*

We have found that the more heterogeneous Polish HEIs (those with more faculties) appear to perform better in terms of research efficiency. Such a tendency is also confirmed in the sample of European HEIs. However, in case of Poland this effect can again be linked to the size impact– bigger universities are typically composed of more faculties – and thus indirectly it reflects stimulating effect of major finance resources obtained by big HEIs from the Polish government.

5. *To what extent do individual characteristics of single universities (such as: tradition - year of establishment, location, prestige, technical orientation etc.) influence research output?*

In Poland older university units with longer tradition, stronger positions in academic networks and major experience (for example: in gaining funds), appear to perform better in terms of research productivity. In the European sample the relationship between year of establishment and research efficiency is more ambiguous. As far as location patterns are concerned, in the case of Polish HEIs we have found that the most effective ones are located in the core regions/cities, while for the European HEIs location in economically strong places is not an unambiguous determinant of research efficiency.

During all stages of our analysis we have been taking into account the differences between the Polish universities and technical universities. Indeed, we have found some specific features. In general, Polish technical universities perform better in the light of bibliometric indicators of research productivity than the universities (this, however, can be connected to the properties of the publication database we were using - there are more ranked journals in the field of technical sciences than in the humanities). However, we would like to stress the rising trend concerning research productivity observed at least within the years 1995-2008, especially visible in case of technical institutions. Technical universities have a bigger proportion of revenues coming

from research activities, which is regrettably still low if compared to the European standards. We have also analysed some specific case studies of Polish technical universities that have managed to establish strong and productive links with the external environment, especially with the industry. Such links enhance research productivity, which is proved by good publishing results and higher scores in patent activity. The possibility to cooperate with industry in applied research distinguishes technical universities from other HEIs in Poland.

Recommendations

We hope that the conclusions that can be drawn from our analysis will serve as an important, quantifiable input into the discussion on the reform of the Polish system of higher education and the competitiveness of Polish scientific research. We want to stress that the purpose of our project was neither the creation of a new institution ranking, nor recommendations concerning funding formula for the public resources. We rather aimed at defining and measuring, through as detailed empirical analysis as possible, of some general relationships describing Polish higher education sector and its research efficiency. Some immediate policy recommendations have emerged from our study.

Comparison between Polish and foreign research productivity reveal that Poland still lags behind in terms of research output and visibility of Polish researchers in high quality publications. Currently, despite some attempts to introduce reforms, Polish HEIs lack of constant staff evaluation and thus there is scarce pressure on academic staff to do high quality research. We strongly believe that continuous staff evaluation (conditioning promotion) based on publication record or other indicators of research productivity, as for example in the UK, should become a standard in Polish academic world. Additionally, we strongly believe that MSHE should adopt much more transparent policy of data dissemination. Statistics on individual HEIs, containing also research indicators and effectiveness scores referring to every public HEI, should be freely and publicly available, for example in a form of open on-line platform similar to KOTA in Finland. This should improve transparency in evaluation of academic units and facilitate creation of a natural competition among Polish HEIs.

Increased funding

The arguments related to the necessity of increase in funds available to Polish HEIs, especially on research purposes, do not have to be justified. Unambiguous relationship between the magnitude of funding an research output is confirmed not only in case of Polish HEIs but also in case of other European systems of higher education. It may be perceived to be banal but we cannot expect academic staff members to perform top quality research without giving them the best infrastructure, data sources and the opportunities to participate

in international conferences, training courses, study visits, summer schools, etc. Moreover, we would like to emphasise that not only the magnitude of funding is important, but also its sources. Major share of public funds in total revenues appears to be associated negatively with research output, which may indicate that money gained from private sources are more productive. Public money -granted in the base of algorithms or formulas and typically less oriented on proving the efficiency of their use than sources from the private sources-, are likely to be at least partially wasted. Our recommendation would go in the direction of promoting open competitions for research grants, also those coming from the government. We also believe that in case of restricted financial resources (as in Poland), putting major emphasis on real effectiveness of funds spending is of a crucial importance.

Increasing the participation of competing forms of financing

Another important recommendation here concerns the teaching load. Obviously, all academic staff members would be glad to hear that the average amount of teaching-related activities was reduced, but this does not guarantee a rise in research efforts of all academic staff members (some could spend more time on teaching in private HEIs, etc.). However, our results indicate strong negative relationship between the amount of teaching obligations and research output, not only in Poland but also in Western European HEIS. Hence, we would suggest a progressive lowering of the teaching load for those members of Polish academic staff whose duties concern both teaching and research and who obtain good research output (here we come back to the necessity of constant evaluation of academic staff). Another solution is to divide academic staff into two categories (according to research output) - those more devoted to research (with lower teaching load) and those more devoted to teaching (with major teaching load, but no strong pressure on publications). This could boost the research efficiency as well the quality of didactics. Of course, this should be in line with the accurate restrictions on how much outside activity academic staff is allowed to have and how much people earn in academia.

At this stage it seems rather risky to recommend concrete proposals concerning the optimal size and thematic range of the institutions. In Poland on average big units seem to be more research productive and this can be the argument in favour of funds concentration in line with MSHE current proposals. Location seems to be an important factor of academic units research performance, but the relationship can be two-way: HEI can serve as a significant determinant of region vitalisation. In case of foreign HEIS big units also appear to be more research productive, but there is no straightforward link concerning location and publication record. Hence, going into the direction of promoting

big, already strong units located in Polish metropolies we would risk strengthening already existing core-periphery relations in Polish system of higher education.

Commercialization of knowledge

Finally, concerning third mission of HEIs and their links with external surrounding, particularly with industry and business, major efforts should take place in order to remove barriers to knowledge commercialisation. The most important aspect is connected with the law regulations concerning the status of academic staff engagement in industry activities. Further, the professionalisation of technology transfer centres and provision of high quality support for academic staff members in preparation of applications, fulfilling bureaucratic procedures etc. is needed. Moreover, activity aimed at practical application of research should become an even more important component of staff and HEIs' evaluation, especially in case of technical universities.

Our study focused mainly on quantitative evidence on research productivity and surely does not exhaust the theme. It should be underlined that because of very specific character of research production in HEIs, the soft factors such as: governance, formulation and realization of strategy, institutional setting etc. may also play an important role. Hence, further complementary studies are needed. In particular, such aspects could be analysed: innovation potential at HEIs; institutional support for knowledge commercialisation; the role of technical universities in rationalizing science and technology policy; the character of relations within the EU schemes of funding; the use of international contacts and exploration of broad scientific networks; and the ways of promoting contacts between producers with leading foreign partners where Polish HEIs can act as a link.

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Appendix 1 Descriptions of National Education Systems in Poland, UK, Germany, Austria, Finland, Italy and Switzerland

		Poland	UK	Germany	Austria	Finland	Italy	Switzerland
Sector structure (Public/ private University/non-university)		Public (131) and private (325)[56] institutions (2008)	Government-dependent private organisations: 166 higher education institutions, 116 universities. [57]	385 state-maintained and state-recognised institutions of higher education: 124 universities, 55 Colleges of art and music, 204 Fachhochschulen, 110 private or run by Churches(2007)[58]	22 public universities and 18 private universities of applied science[59]	Two parallel sectors: universities (20) and polytechnics (29).[60]	95 universities: 56 state universities, 3 state polytechnics 16 non-state universities that are legally recognised, 3 universities for foreigners, 6 higher schools/institutes, called 'special system high schools' and 11 on-line universities. Additionally non-university tertiary education sector: The High Level Art and Music Education system [61]	10 public Cantonal Universities and 2 Federal Institutes of Technology (FIT), 7 public and 2 private Universities of Applied Sciences, teaching training institutions. Additional professional education sector. [62]
University governance[63]	Executive Head	Rector: head, representative and manager of HEI, supervises teaching and research activities	Vice-Chancellor	Rector or president, plus chancellor who is the senior administrative officer and responsible for the budget.	Rector (elected by the governing board) university council	Rector	Rector	President or Rector with different competencies and tasks depending on single university[64]
	Academic Body	Senate – adopts HEI statutes, study regulations, admission	Post-1992 institutions-Academic Board	University Board	Senate	Senate	Senate and Board of Governors that manages and monitors economic and financial resources, defines	University council (board of trustees or collegium) different task,

		Poland	UK	Germany	Austria	Finland	Italy	Switzerland
University governance[63]		rules; adopts activity-and-finance plan, approves HEI's financial report, approves rector's reports and assesses rector's performance.	Pre-1992 institutions: Senate				administrative,	structure and responsibilities depending on financial and accounting regulations.
	Decision making Body	Rector: head, representative and manager of HEI, supervises teaching and research activities	Vice-Chancellor	Rector or president, plus chancellor who is the senior administrative officer and responsible for the budget.	Rector	Rector. The governance structure of polytechnics depends on the ownership nature.	Rector	President and university council, different task, structure and responsibilities depending on individual university.
	Grant for teaching and operational activities	Number of full-time students, number of fulltime doctoral students, number of academic staff members,	Mainly student related factors, measured by number of students who complete their year of study (and North	Bund and Land funding system: mixture of historical input and output criteria, varies	Universities: 20% based on performance indicators, 80% on contract (requirement of strategic plan and intellectual capital report). Mixture	Universities: Number of degrees that universities are supposed to award over the period multiplied by	For 75 % of overall budget: criteria of past costs. Differentiation for field of study : cost per student in various fields of study and number of students enrolled.	National and regional funding system, allocation input and output .

		Poland	GB	Germany	Austria	Finland	Italy	Switzerland
Criteria used for public grants awarded[65]		considered in conjunction with the cost indexes for the different fields of study concerned. Consideration of past costs.	England) Number of credit values completed by students (Wales) Student enrolment Scotland) institution-related factors: number of students recruited from areas of social deprivation, higher costs for institution from London		tof performance criteria: number of students, degree awarded, titles given, the amount of income obtained from research and development projects, Universities of Applied Science: Standard cost for each student enrolled, which varies depending on the year and programme of study	the unit cost which reflects differences between study fields as well as policy priorities. Polytechnics: Number of students in different study fields. Average number of awarded basic and postgraduate degrees in the previous two years.		
	Grant for research	Development of academic staff, right to confer scientific titles, quality certificates received, number of publications and research projects undertaken, lecturers activities of academic staff, awards and distinctions received for excellence in research, use of research results (licences, services provided, copyright, etc.).	According to the quality rank awarded by Research Assessment Exercise (RAE). Volume is measured by the number of research-active staff submitted to the RAE	Competitive grants from research council			Number of people actively employed in research, number of doctoral research courses plus output measure (number of research projects undertaken and academic publications).	Bardzo duża rada badawcza.

	Poland	GB	Germany	Austria	Finland	Italy	Switzerland
Tuition Fee[66]	No tuition fees in case of public sector and full-time day courses. Registration fees when students first start tertiary education.	England, Wales and Northern Ireland – tuition fee set by individual institutions. Scotland: No tuition fees for full-time studies leading to a first qualification.	Until 2005, no fees for the first academic degree Now depending on Landers	Tuition fees determined by the central education authorities: Austrian and EU citizens, 363.36 EUR per semester.[67]	Public sector: students pay an annual contribution to their own organisations.	Annual tuition fees established by the board of directors of each university (and possible administrative fees and/or contributions to student organisations). A minimum fee for enrolment is foreseen by law	Annual tuition fees
Financial support to students[68]	Student grants: (social, scholarships for board and housing, performance-based scholarship, scholarship for handicapped students) and loans. The scholarships can be given jointly.	Grants and loans	Grants and loans financial assistance under the terms of the Federal Training Assistance Act	Study grants (depending on parents's income), tuition fee grants and the performance-based scholarships	Study grant, a housing supplement and state guarantee for a student loan.	Grants support	Grants
Reform of HE sector and main changes	In the process of introducing a new strategic policy	In 1992 polytechnics were given university status, 2004 legislation about maximum tuition fee.	2001- new career curriculum, decentralisation of system towards regional governance: Lands.	1993 - universities of applied science introduced, 2002 University Law – full autonomy to universities, act as a 'full' legal entity.	Early 90s : agreement between HEI and Ministry, and new internal evaluative procedures were introduced. An autonomy of	1989 law to increase the autonomy of universities, the 1999 curriculum reform, Law of 9 January 2009, no. 1 which introduced amendments to uni	1995-1997 creation of applied science universities.

	Poland	GB	Germany	Austria	Finland	Italy	Switzerland
					HEI was strengthened. 1 Jan 2010 - Finnish Universities become independent corporations under public law or foundations under private law	versity professors and researchers recruitment procedures.	
Average wage level for an academic staff €/month Base, gross salary Full-time employees	Assistant (without PhD) 511. Adiunct (with PhD): 814 Associated Professor (habilitated doctor) 1045 Full Professor: 1395[69]	Researchers 3341 Lecture 3989 Senior lecturers 4849 Professor 7315 [70]	Junior professors 3 405 Professor 3 890 W3 professors a basic salary of 4 723 Performance bonuses may be added to W2 and W3 basic salaries.[71]	n.a.	Research Assistant 1 772 Postdoc/ Senior Assistant 3.220 Lecturer 3 420 Professor 5.218 [72]	Researcher 1 685 - 4622 Associate Professor 3004 - 6232 Full Professor - 3969 - 8522[73]	Assistant Professor 5013 Associate Professor 57600 Full professor 6505[74]
Barriers to academic development[75]	Low level of salary and unhealthy relations between top professors and young scholars, resulting in many formal and informal barriers to academic career.	Low security of the position. Wide use of temporary fixed-term contracts versus a permanent position	Informal processes play an important role to obtain an academic position with relevant role of supervisor.	Limited number of professorship, contract of Assistant Professor expires after a maximum of six years.	Not enough posts for post docs.	Highly closed system, not meritocratic	An informal age limit of 35 to obtain habilitation to individuate those having substantial chances of success in moving on in the system.

Source: own compilation based on sources indicated in the footnotes

Appendix 2. List of all HEIs in the sample

ISW_ID	Państwo
Montanuniversität Leoben	AUSTRIA
Technische Universität Graz	AUSTRIA
Technische Universität Wien	AUSTRIA
Universität Graz	AUSTRIA
Universität Innsbruck	AUSTRIA
Universität Klagenfurt	AUSTRIA
Universität Linz	AUSTRIA
Universität Salzburg	AUSTRIA
Universität Wien	AUSTRIA
Universität für Bodenkultur Wien	AUSTRIA
Wirtschaftsuniversität Wien	AUSTRIA
Abo Akademi	FINLAND
Helsingin kauppakorkeakoulu	FINLAND
Helsingin yliopisto	FINLAND
Joensuun yliopisto	FINLAND
Jyväskylän yliopisto	FINLAND
Kuopion yliopisto	FINLAND
Lapin yliopisto	FINLAND
Lappeenrannan teknillinen yliopisto	FINLAND
Oulun yliopisto	FINLAND
Svenska handelshögskolan	FINLAND
Tampereen teknillinen yliopisto	FINLAND
Tampereen yliopisto	FINLAND
Teknillinen korkeakoulu	FINLAND
Turun kauppakorkeakoulu	FINLAND
Turun yliopisto	FINLAND
Vaasan yliopisto	FINLAND
Bauhaus-U Weimar	GERMANY
Brandenburgische TU Cottbus	GERMANY
FU Berlin	GERMANY
H Vechta	GERMANY
Humboldt-Universität Berlin	GERMANY
TH Aachen	GERMANY
TU Bergakademie Freiberg	GERMANY
TU Berlin	GERMANY
TU Braunschweig	GERMANY
TU Chemnitz	GERMANY
TU Clausthal	GERMANY
TU Darmstadt	GERMANY
TU Dresden	GERMANY

TU Hamburg-Harburg	GERMANY
TU Ilmenau	GERMANY
TU Kaiserslautern	GERMANY
TU München	GERMANY
U Augsburg	GERMANY
U Bamberg	GERMANY
U Bayreuth	GERMANY
U Bielefeld	GERMANY
U Bochum	GERMANY
U Bonn	GERMANY
U Bremen	GERMANY
U Dortmund	GERMANY
U Duisburg-Essen	GERMANY
U Düsseldorf	GERMANY
U Erfurt	GERMANY
U Erlangen-Nürnberg	GERMANY
U Flensburg	GERMANY
U Frankfurt a.M.	GERMANY
U Gießen	GERMANY
U Greifswald	GERMANY
U Göttingen	GERMANY
U Halle	GERMANY
U Hamburg	GERMANY
U Hannover	GERMANY
U Heidelberg	GERMANY
U Hildesheim	GERMANY
U Hohenheim	GERMANY
U Jena	GERMANY
U Karlsruhe	GERMANY
U Kassel	GERMANY
U Kiel	GERMANY
U Koblenz-Landau	GERMANY
U Konstanz	GERMANY
U Köln	GERMANY
U Leipzig	GERMANY
U Lübeck	GERMANY
U Lüneburg	GERMANY
U Magdeburg	GERMANY
U Mainz	GERMANY
U Mannheim	GERMANY
U Marburg	GERMANY
U München	GERMANY
U Münster	GERMANY

U Oldenburg	GERMANY
U Osnabrück	GERMANY
U Paderborn	GERMANY
U Passau	GERMANY
U Potsdam	GERMANY
U Regensburg	GERMANY
U Rostock	GERMANY
U Siegen	GERMANY
U Stuttgart	GERMANY
U Trier	GERMANY
U Tübingen	GERMANY
U Ulm	GERMANY
U Wuppertal	GERMANY
U Würzburg	GERMANY
U des Saarlandes Saarbrücken	GERMANY
ANCONA Politecnica delle Marche	ITALY
Universita' degli studi di Bari	ITALY
BARI Politecnico	ITALY
Universita' degli studi di Basilicata	ITALY
Universita' degli studi di Bergamo	ITALY
Universita' degli studi di Bologna	ITALY
Universita' degli studi di Brescia	ITALY
Universita' degli studi di Cagliari	ITALY
Universita' degli studi di Calabria	ITALY
Universita' degli studi di Camerino	ITALY
Universita' degli studi di Cassino	ITALY
Universita' degli studi di Catania	ITALY
Universita' degli studi di Catanzaro	ITALY
Universita' degli studi di Chieti G. D`annunzio	ITALY
Universita' degli studi di Ferrara	ITALY
Universita' degli studi di Firenze	ITALY
Universita' degli studi di Foggia	ITALY
Universita' degli studi di Genova	ITALY
Universita' degli studi di Insubria	ITALY
Universita' degli studi di Lecce	ITALY
Universita' degli studi di L`aquila	ITALY
Universita' degli studi di Macerata	ITALY
Universita' degli studi di Messina	ITALY
Universita' degli studi di Milano	ITALY
Universita' degli studi di Milano Bicocca	ITALY
Milano Politecnico	ITALY
Universita' degli studi di Modena	ITALY
Universita' degli studi di Molise (CB)	ITALY

Universita' degli studi di Napoli Federico II	ITALY
Napoli II Universita'	ITALY
Universita' degli studi di Padova	ITALY
Universita' degli studi di Palermo	ITALY
Universita' degli studi di Parma	ITALY
Universita' degli studi di Pavia	ITALY
Universita' degli studi di Perugia	ITALY
Universita' degli studi di Piemonte Orientale	ITALY
Universita' degli studi di Pisa	ITALY
Universita' degli studi di Reggio Calabria	ITALY
Universita' degli studi di Roma la Sapienza	ITALY
Universita' degli studi di Roma Tre	ITALY
Universita' degli studi di Roma Tor Vergata	ITALY
Universita' degli studi di Salerno	ITALY
Universita' degli studi di Sannio	ITALY
Universita' degli studi di Sassari	ITALY
Universita' degli studi di Siena	ITALY
Universita' degli studi di Teramo	ITALY
Universita' degli studi di Torino	ITALY
Torino Politecnico	ITALY
Universita' degli studi di Trento	ITALY
Universita' degli studi di Trieste	ITALY
Universita' degli studi di Tuscia (VT)	ITALY
Universita' degli studi di Udine	ITALY
Universita' degli studi di Urbino	ITALY
Universita' degli studi di Venezia Ca' Foscari	ITALY
Universita' degli studi di Verona	ITALY
AGH Cracow	POLAND
Bialystok University of Technology	POLAND
Bielsko Biala Academy	POLAND
Bydgoszcz University	POLAND
Cracow University of Technology	POLAND
Czestochowa University of Technology	POLAND
Gdansk University of Technology	POLAND
Gliwice Univesrity of Technology	POLAND
Katowice Silesian University	POLAND
Kielce University of Technology	POLAND
Koszalin University of Technology	POLAND
Lodz University of Technology	POLAND
Lublin University	POLAND
Lublin University of Technology	POLAND
Olsztyn University	POLAND
Opole University	POLAND

Opole University of Technology	POLAND
Poznan University of Technology	POLAND
Radom University of Technology	POLAND
Rzeczow University	POLAND
Rzeszow University of Technology	POLAND
Szczecin Technical University	POLAND
Szczecin University	POLAND
Torun University	POLAND
University of Bialystok	POLAND
University of Cracow	POLAND
University of Gdańsk	POLAND
University of Lodz	POLAND
University of Poznan	POLAND
University of Warsaw	POLAND
Warsaw University of Technology	POLAND
Wroclaw University	POLAND
Wroclaw University of Technology	POLAND
Zielonogora University	POLAND
Federal Institute of Technology Lausanne	SWITZERLAND
Federal Institute of Technology Zurich	SWITZERLAND
University of Basel	SWITZERLAND
University of Bern	SWITZERLAND
University of Fribourg	SWITZERLAND
University of Geneva	SWITZERLAND
University of Lausanne	SWITZERLAND
University of Lucerne	SWITZERLAND
University of Lugano	SWITZERLAND
University of Neuchatel	SWITZERLAND
University of St. Gallen	SWITZERLAND
University of Zurich	SWITZERLAND
Aberystwyth University	UK
Anglia Ruskin University	UK
Aston University	UK
Bangor University	UK
Bath Spa University	UK
Bournemouth University	UK
Brunel University	UK
Cardiff University	UK
Coventry University	UK
Cranfield University	UK
De Montfort University	UK
Edinburgh Napier University	UK
Glasgow Caledonian University	UK

Heriot-Watt University	UK
Kingston University	UK
Leeds Metropolitan University	UK
Liverpool John Moores University	UK
London Guildhall University	UK
London Metropolitan University	UK
London South Bank University	UK
Loughborough University	UK
Middlesex University	UK
Newman University College	UK
Oxford Brookes University	UK
Queen Margaret University, Edinburgh	UK
Sheffield Hallam University	UK
Southampton Solent University	UK
Staffordshire University	UK
Swansea University	UK
Thames Valley University	UK
The Manchester Metropolitan University	UK
The Nottingham Trent University	UK
The Queen's University of Belfast	UK
The University of Aberdeen	UK
The University of Bath	UK
The University of Birmingham	UK
The University of Bolton	UK
The University of Bradford	UK
The University of Brighton	UK
The University of Bristol	UK
The University of Cambridge	UK
The University of Central Lancashire	UK
The University of Chichester	UK
The University of Dundee	UK
The University of East Anglia	UK
The University of Edinburgh	UK
The University of Essex	UK
The University of Exeter	UK
The University of Glasgow	UK
The University of Greenwich	UK
The University of Huddersfield	UK
The University of Hull	UK
The University of Keele	UK
The University of Kent	UK
The University of Lancaster	UK
The University of Leeds	UK

The University of Leicester	UK
The University of Lincoln	UK
The University of Liverpool	UK
The University of Newcastle-upon-Tyne	UK
The University of Northampton	UK
The University of Nottingham	UK
The University of Oxford	UK
The University of Plymouth	UK
The University of Portsmouth	UK
The University of Reading	UK
The University of Salford	UK
The University of Sheffield	UK
The University of Southampton	UK
The University of St Andrews	UK
The University of Stirling	UK
The University of Strathclyde	UK
The University of Sunderland	UK
The University of Surrey	UK
The University of Sussex	UK
The University of Teesside	UK
The University of Warwick	UK
The University of Westminster	UK
The University of Winchester	UK
The University of Wolverhampton	UK
The University of Worcester	UK
The University of York	UK
University of Abertay Dundee	UK
University of Chester	UK
University of Derby	UK
University of Durham	UK
University of Glamorgan	UK
University of Gloucestershire	UK
University of Hertfordshire	UK
University of Manchester	UK
University of Ulster	UK
University of the West of England, Bristol	UK

Appendix 3. Quantifying determinants of research efficiency - econometric estimation

We aim at providing quantitative evidence on the direction and strength of links between research efficiency (assessed at the level of single institutions) and HEIs' individual characteristics. Econometric modelling, employed in empirical economic studies, provides us with very useful tools that permits us to do so. In particular, specific formulation of the empirical model to be tested gives us the possibility to quantify the elasticities between research output and its potential determinants.[76]

Production function and empirical specification

Our empirical strategy is based on specifying a research production function for HEIs. A research production function describes how an institution combines resources (inputs) to generate outputs:

$$Output_{it} = Input_{it} + X_{it} + \varepsilon_{it} \qquad (1)$$

where: i denotes an institution, t refers to time period, X_i is a matrix of controlled variables (other potential determinants of output) and ε_{it} is the standard error term.

The basic specification of the research production function takes into account two inputs (capital and labour) and can be expressed by the following regression equation[77]:

$$ln\, y_{it} = \alpha_0 + \beta_1\, ln\, k_{it} + \beta_2\, ln\, L_{it} + \varepsilon_{it} \qquad (2)$$

where:

y_{it} - research output per worker measured as: publication per academic staff member ($Publ\_acad_{it}$)

k_{it} - capital per worker measured by total real revenues (in euro, PPS) per employee

L_{it} - labour input measured by the number of academic staff

ε_{it} - error term

The parameter β_1 measures the elasticity between research output per worker and capital per worker while the parameter β_2 indicates the elasticity between labour input and research output.[78]

The basic specification (2) is enriched by other potential determinants of research output. In particular, in order to address quantitatively the interplay between research output and a set of inputs we fit the following econometric model:

$$ln\,(Publ\_acad_{it}) = \alpha + \beta_1\, ln\,(Rev\_staff_{it-1}) + \beta_2\, ln\,(AcadStaff_{it}) +$$

$$\beta_3\, ln\,(Stud\_acad_{it}) + \beta_4\, ln(PhD\_stud_{it}) + \beta_5\, ln\,(Prof\_acad_{it}) + \beta_6$$

$$yearfound_i + \beta_7\, nofac_i + \beta_8\, techuniv_i + \lambda_1 + \varepsilon_{it} \qquad (3)$$

where: i refers to single HEI and t denotes the time period

Rev_staff_{it-1} - total real revenues (in euro, PPS) per employee from the previous year

$AcadStaff_{it}$ - total number of academic staff

$Stud\_acad_{it}$ - the number of students per academic staff member

PhD_stud_{it} - number of doctoral students per total number of students

$Prof\_acad_{it}$ - the share of professors in the academic staff

$yearfound_i$ - dummy variable, equals 1 if a university was founded at least 100 years ago, 0 otherwise

$nofac_i$ - number of different faculties

$techuniv_i$ - dummy variable, equals 1 for technical universities, 0 otherwise

λ_1 - time dummies

ε_{it} - error term

Additionally, in case of foreign HEIs we add dummy variables describing faculties' set:

$econ_1$ - dummy variable, equals 1 if institution has economics or business faculty, 0 otherwise

$medfarm_i$ - dummy variable, equals 1 if institution has medicine or pharmacy faculty, 0 otherwise. Polish units are not heterogeneous in this aspect.

Research production function allows us to test specific research questions that have been described (Section 3.2) and preliminarily investigated. Log-log specification is extremely useful as estimated coefficients associated with each of the right hand side variables will be equal to elasticities between output per academic staff and each of the per worker inputs[79].

Table A1 summarizes explanatory variables' definitions together with their role played in the research production function of HEIs.

Table A 1. Explanatory variables in the model of research production function

Variable	Definition	Description of
$Publ\_acad_{it}$	Total number of publications (indexed in ISI Web of Knowledge) per academic staff member	Research output
Rev_staff_{it-1}	Total real revenues (in euro PPS 2005 prices) per employee from the previous period	Financial resources
Rev_gov_{it-1}	Percentage ratio of government funding to total revenues from the previous period	Governmental financial support
Rev_did_{it-1}	Percentage ratio of teaching funding to total revenues from the previous period	Financial support for teaching
$AcadStaff_{it}$	Academic staff (full time equivalent or full time job)	Labor input and institution's size
$Stud\_acad_{it}$	Total number of students per academic staff member	Teaching load
PhD_stud_{it}	Number of PhD students per total students	Research orientation
$Prof\_acad_{it}$	Number of professors per academic staff	Staff qualification
$yearfound_{i}$	Dummy variables, equals 1 if institution was founded at least 100 years ago	Tradition
$nofac_{i}$	Number of different faculties	Interdisciplinarity and/ or institution's size
$techuniv_{i}$	Dummy variable, equals 1 for technical universities	Institution's orientation
$medfarm_{i}$	Dummy variable, equals 1if institution has medicine or pharmacy faculty, 0 otherwise	Faculty composition
$econ_{i}$	Dummy variable, equals 1if institution has economics or business faculty, 0 otherwise	Faculty composition

Source: own compilation

Regarding the measurement of capital per capita (k_{ti}), we utilize the data on past revenues per employee (Rev_staff_{it-1}). Research process is time consuming that is why current revenues may not have an effect on measured current research outputs. Alternatively (not jointly with overall magnitude of funding, due to collinearity problems) we

introduce into the eq. (3) the share of government revenues in total revenues (Rev_gov_{it-1}) and the share of teaching related revenues as per cent of total (Rev_did_{it-1}). also in the form of lagged values. They will let us know whether not only the level of funding is important for the research output but also its sources.

As a measure of labor input, we use total academic staff ($AcadStaff_{it}$) - this variable reflects also the size of the institution.

We proxy teaching load with the ratio of students per academic staff member ($Stud\_acad_{it}$) – see Section 4.2.2 for a discussion.

Furthermore, we account for: the research orientation of a university (measured by the number of doctoral students per total number of students PhD_stud_{it}) and the qualifications of staff (the ratio of professors to all academic staff members $Prof\_acad_{it}$). The coefficient associated with the latter variable would indicate if a major share of professors in the academic body is associated with a major research efficiency, thus which group of academic staff is more productive (professors or junior academic staff such as adjuncts - PhD holders and assistants - without PhD).

The interdisciplinarity of a unit is measured by the number of different faculties ($nofac_i$).

Finally, we introduce some dummy variables. We proxy tradition by the variable $yearfound_i$, equalling 1 if institution was founded at least 100 years ago. Technical universities are distinguished with the dummy: $techuniv_i$. Furthermore, in case of European HEIs we introduce dummies on faculty types: $medfarm_i$ if a university has medicine or pharmacy faculty and $econ_i$ if a university has economics or business faculty.

All the variables (except dummies) are expressed in their natural logarithms.[80] The first step in the econometric analysis is to check for unit roots in the panel. We conducted Fisher test for panel unit root using Phillips-Perron specification (chosen because it does not require a balanced panel). The null hypothesis of unit root was rejected in all cases at standard levels of confidence.[81]

As for the estimation strategy, all the specifications have been estimated with Generalized Method of Moment (system GMM, one-step). In order to avoid potential endogeneity problems in case of financial variables[82], they were instrumented by their lags[83]. Time dummies (controlling for changes in technology of research production

and/or for the change in the number of publication that are indexed in ISI database) are included and statistically significant (not reported here due to space constraints).

Table A2 contains pairwise correlation coefficients between all the variables (expressed in logs) for Polish HEIs. Table A3 refers to the European sample. Some of the independent variables are highly correlated, so in these cases we cannot estimate the regression including them simultaneously into the model.

Estimation results – Polish sample

The next step is the estimation of the empirical model of research production function (3), starting with the sample of Polish HEIs. Table A4 presents the different versions of estimations referring to Polish HEIs. Variables are expressed in logs which allows for a convenient interpretation of the coefficients as elasticities between research productivity and its potential determinants.

Column (1) shows the basic specification that takes into account only two basic factors of production without any other potential determinants of research productivity namely capital (financial resources) and labor input (staff) as in equation (2). Positive relationship between the number of publications per academic staff member and revenues per employee is confirmed: ceteris paribus the rise of revenues per employee in previous period by 1% is associated with the increase in research efficiency by 4% in a current period. There is also a positive relationship between the size of the institution (proxied here by total number of academic staff) and research productivity of HEI.

Column (2) presents the augmented specification with additional variables that can have an effect on research performance. We confirm positive elasticities of research productivity with respect to total revenues per employee from the previous year and the parameter measuring size of the institution. The negative parameter in front of $Stud\_acad_{it}$ indicates that the higher the number of students per academic staff member, the lower research productivity of the unit, thus we conclude that that there is indeed a trade-off between research and teaching. Ceteris paribus, a rise in the number of students per academic staff member by 1% can lower the research productivity by around 0.8% (up to 1.6% if we take into account the structure of funds). Next, research productivity is positively related to the variable (PhD_stud_{it}) – (the ratio of doctoral students to all students). It can indicate the positive role of PhD students in research creation per se

and/or the fact that institutions with higher number of PhD students are more research oriented. Then we check a role of advanced academic staff members (measured by the share of professors in total number of academic staff $Prof\_acad_{it}$). The parameter is positive and statistically significant - units with major share of professors in academic staff are more productive. Similarly, in line with descriptive statistics, estimation results confirm that technical universities on average have higher research efficiency than Polish universities (a positive parameter in front of a dummy variable $techuniv_i$). Finally, dummy reflecting the year of foundation is positively associated with research output thus tradition can be a factor positively influencing research productivity of Polish HEIs.[84]

Finally, in Column (3) of Table A4 we show regression results including the revenues from government as a percentage of total revenues (Rev_gov_{it-1}). and in Column (4) - teaching related revenues as a percentage of total revenues (Rev_did_{it-1}). In both cases, we found a negative relationship between these variables and research productivity: an increase in the share of government and, similarly, and increasing in teaching related funding in total revenues are negatively associated with HEI's research efficiency.

Estimation results – European sample

It is interesting to compare the results of model (3) estimated for Polish HEIs with the results based on the sample of HEIs from other European countries from our sample (listed in Appendix 2).
The results of regression estimations of 'European model' are presented in Table A5. We are in the possession of data on PhD students only in case of: Austria and Switzerland, that is why we estimate most of the specifications without this variable. The positive role of PhD students for these two countries is confirmed, but note a considerable drop in the number of observations (Column 2 in Table A5).

There are a couple of noteworthy differences between the emerging evidence on research efficiency determinants in Polish and European HEIs. First of all, in case of Western European HEIs the elasticity associated with the financial resources is positive, but the size is significantly smaller than in case of Poland (compare the parameter in front of Rev_staff_{it-1} Column (1) from Table A5 and Table A6).
We can assume that Polish HEIs are much more underfinanced than foreign institutions (see data in Table 13), thus equiproportional rise in revenues could provoke major rise in research productivity of Polish HEIs than in case of richer foreign institutions. Then, when we account for universities size, resources, teaching load etc., year of foundation is not a key factor of universities research productivity in case of foreign

HEIs. Moreover, the relationship between the nature of a unit (technical university or not) and research productivity is not so straightforward as in case of Polish HEIs.

Similarly to Polish HEIs, foreign university units are characterised by a positive relationship between the research efficiency and: total number of academic staff; or the share of professors in academic staff. The negative association between the proportion of revenues from government and teaching related revenues with research productivity was confirmed (Column (3) and (4)), as in case of Poland.107.

Additionally, introduced dummies on faculty types reveal that there is a positive effect on productivity if medical or pharmacy faculty are present in a given HEI (the contrary holds true for the economics/ business faculty). However, it has to be noted that this is probably associated with the fact that in the Web of Knowledge there are more journals concerning medical science than economics.

In conclusions, we find that both in case of Polish and European HEIs there is a set of factors associated positively and negatively with the research productivity (see summary Table 14 in the main text of the report).

Robustness checks[85]

We assessed the robustness of the estimations results in several ways. First, we employed a more restricted measure of research output: the number of original articles per academic staff member, and did not obtain any significant alteration of the results. Similarly, when using revenues per student as a capital measure instead of revenues per employee, PhD per academic staff member instead of PhD per student and the exact year of foundation instead of a dummy variable – the results remain robust.

Additionally, we estimated the regression correcting for the presence of potential outliers with different cut-off rules (outliers detected in multivariate data using the method of Hadi, 1994). The results do not differ significantly. The same conclusions can be drawn when the European model was estimated without Italian HEIs, that differ significantly in size and financial indicators from other European HEIs.

Finally, to ensure the stability of our conclusions we employed an alternative specification of research production function without imposing log-linearization.[86]

Table A 2. Pairwise correlation coefficients between variables for Polish HEIs

	$Publ\_acad_{it}$	Rev_staff_{it}	Rev_stud_{it}	Rev_gov_{it}	Rev_did_{it}	$Stud_{it}$	$Staff_{it}$	$AcadStaff_{it}$	$Stud\_acad_{it}$	$Prof\_acad_{it}$	PhD_stud_{it}	GDP_{nt}	$nofac_{i}$	$yearfound_{i}$
$Publ\_acad_{it}$	1,00													
Rev_staff_{it}	0,56	1,00												
Rev_stud_{it}	0,63	0,53	1,00											
Rev_gov_{it}	-0,03	-0,21	0,09	1,00										
Rev_did_{it}	-0,61	-0,64	-0,79	0,30	1,00									
$Stud_{it}$	0,49	0,47	0,07	-0,40	-0,21	1,00								
$Staff_{it}$	0,65	0,38	0,49	-0,22	-0,47	0,84	1,00							
$AcadStaff_{it}$	0,63	0,40	0,44	-0,24	-0,41	0,87	0,99	1,00						
$Stud\_acad_{it}$	-0,29	0,12	-0,75	-0,28	0,56	0,23	-0,31	-0,28	1,00					
$Prof\_acad_{it}$	0,02	0,21	-0,35	-0,33	0,26	0,38	0,06	0,09	0,56	1,00				
PhD_stud_{it}	0,62	0,49	0,49	-0,15	-0,52	0,50	0,62	0,62	-0,23	0,01	1,00			
GDP_{nt}	0,24	0,54	0,24	-0,16	-0,16	0,44	0,36	0,36	0,13	0,27	0,45	1,00		
$nofac_{i}$	0,50	0,38	0,39	-0,36	-0,40	0,74	0,84	0,83	-0,19	0,30	0,47	0,39	1,00	
$yearfound_{i}$	0,43	0,26	0,24	-0,37	-0,32	0,39	0,43	0,42	-0,07	0,24	0,37	0,28	0,33	1,00

Note: sample without outliers detected in multivariate data using the method of Hadi (1994), with 5% significance level for outlier cutoff .All variables expressed in logs.

Source: own compilation

Table A 3. Pairwise correlation coefficients between variables for all HEIs except Polish

	$Publ\_acad_{it}$	Rev_staff_{it}	Rev_stud_{it}	Rev_gov_{it}	Rev_did_{it}	$Stud_{it}$	$Staff_{it}$	$AcadStaff_{it}$	$Stud\_acad_{it}$	$Prof\_acad_{it}$	PhD_stud_{it}	GDP_{nt}	$nofac_{i}$	$yearfound_{i}$
$Publ\_acad_{it}$	1,00													
Rev_staff_{it}	0,02	1,00												
Rev_stud_{it}	0,37	0,17	1,00											
Rev_gov_{it}	-0,27	-0,31	-0,17	1,00										
Rev_did_{it}	-0,35	-0,13	0,06	0,67	1,00									
$Stud_{it}$	0,38	0,09	-0,14	-0,16	-0,37	1,00								
$Staff_{it}$	0,46	-0,31	0,40	-0,03	-0,26	0,71	1,00							
$AcadStaff_{it}$	0,48	-0,20	0,46	-0,01	-0,16	0,72	0,98	1,00						
$Stud\_acad_{it}$	-0,28	0,38	-0,82	-0,19	-0,23	0,21	-0,48	-0,53	1,00					
$Prof\_acad_{it}$	0,29	0,14	-0,24	0,14	0,16	0,03	-0,24	-0,12	0,23	1,00				
PhD_stud_{it}	0,24	0,68	0,26	0,38	-0,73	0,26	0,37	0,29	0,01	-0,23	1,00			
GDP_{nt}	-0,02	0,17	0,19	0,05	0,23	0,05	0,14	0,12	-0,10	-0,21	0,43	1,00		
$nofac_{i}$	0,24	-0,08	0,05	0,07	-0,20	0,40	0,51	0,45	-0,11	0,12	0,48	0,12	1,00	
$yearfound_{i}$	0,14	0,08	0,29	0,04	-0,08	0,29	0,44	0,42	-0,23	-0,11	0,71	0,10	0,21	1,00

Note: sample without outliers detected in multivariate data using the method of Hadi (1994), with 5% significance level for outlier cutoff. All variables expressed in logs. Dummies relating to faculty composition not included.
Source: own compilation

Table A 4. Research production function – estimation results for Polish HEIs

	dependent variable: log of publications per academic staff member			
	(1)	(2)	(3)	(4)
Rev_staff_{it-1}	4,224***	0,754***		
	[0,195]	[0,097]		
$AcadStaff_{it}$	0,125***	0,089***	-0,027	-0,058
	[0,038]	[0,028]	[0,033]	[0,044]
$Stud\_acad_{it}$		-0,829***	-1,566***	-1,577***
		[0,069]	[0,124]	[0,187]
PhD_stud_{it}		0,248***	0,341***	0,325***
		[0,015]	[0,018]	[0,021]
$Prof\_acad_{it}$		0,322***	0,468***	0,688***
		[0,057]	[0,085]	[0,112]
$techuniv_{i}$		0,153***	0,357***	0,186***
		[0,029]	[0,031]	[0,045]
$yearfound_{i}$		0,387***	0,429***	0,404***
		[0,024]	[0,032]	[0,042]
Rev_gov_{it-1}			-1,111***	
			[0,160]	
Rev_did_{it-1}				-1,174***
				[0,216]
AR(1)	0,00	0,00	0,60	0,62
AR(2)	0,77	0,33	0,04	0,46
N	375	327	228	177
Zero-jedynkowe czasowe	YES	YES	YES	YES

Notes: all sample without outliers, detected in multivariate data using the method of Hadi (1994), with 5% significance level for outlier cutoff .All computations made using XTABOND2 for StataSE 9.0.Constant not reported. Standard errors in parentheses. Statistically significant at ***1, ** 5, * 10 percent level. Results are reported for one-step GMM estimator. The figures reported for Arellano-Bond tests are the p-values.

Table A 5. Research production function – estimation results for Western European HEIs

	dependent variable: log of publications per academic staff member			
	(1)	(2)	(3)	(4)
Rev_staff_{it-1}	0,283***	0,746***		
	[0,082]	[0,198]		
$AcadStaff_{it}$	0,654***	0,812***	0,661***	0,573***
	[0,007]	[0,024]	[0,017]	[0,020]
$Stud\_acad_{it}$		-0,809***	-0,437***	-0,576***
		[0,069]	[0,054]	[0,066]
PhD_stud_{it}		0,840***		
		[0,071]		
$Prof\_acad_{it}$		1,333***	0,543***	0,489***
		[0,107]	[0,013]	[0,016]
$techuniv_{i}$		0,189***	0,044*	-0,108***
		[0,038]	[0,024]	[0,038]
$yearfound_{i}$		-0,413***	-0,109***	-0,188***
		[0,063]	[0,012]	[0,015]
$econ_{i}$		-0,053	-0,130***	-0,208***
		[0,038]	[0,015]	[0,017]
$medfarm_{i}$		0,034	0,112***	0,191***
		[0,034]	[0,014]	[0,015]
Rev_gov_{it-1}			-0,316***	
			[0,065]	
Rev_did_{it}				-0,384***
				[0,069]
AR(1)	0,00	0,07	0,00	0,00
AR(2)	0,00	0,34	0,23	0,75
N	1347	134	1323	947
Time dummies	YES	YES	YES	YES
Country dummies	YES	YES	YES	YES

Notes: all sample without outliers, detected in multivariate data using the method of Hadi (1994), with 5% significance level for outlier cutoff. All computations made using XTABOND2 for StataSE 9.0.Constant not reported. Standard errors in parentheses. Statistically significant at ***1, ** 5, * 10 percent level. Results are reported for one-step GMM estimator .The figures reported for Arellano-Bond tests are the p-value

Endnotes

1 Data refer to 34 Polish public HEIs (universities and technical universities) taken into account in our study.

2 Statistics from SCImago 2007 JCR.

3 According to UOE manual (2004) public HE institutions are defined as institutions that are directly or indirectly administered by a public education authority. Private government-dependent HE institutions: institutions that are directly or indirectly administered by a non-governmental organisation (church, trade union, a private business concern, or other body) and which receive over 50% of their core funding from the public authorities. Private independent HE institutions are the institutions that are directly or indirectly administered by a non-governmental organisation and which receive less than 50% of their core funding from the public authorities.

4 An interesting case is the UK, where in 1992 the so-called 'polytechnics' have been transformed into universities with a new goal of conducting research and not only providing technical and professional training.

5 ISCED 5 programmes are divided into 5A, programmes that are largely theoretically based and are intended to provide sufficient qualifications for gaining entry into advanced research programmes and professions with high skills requirements, and into 5B, programmes that are generally more practical/technical/occupationally specific than ISCED 5A programmes (more about ISCED programmes, definitions and classification criteria see UOE, 2004, p.98-133).

6 For example, in the UK (except Scotland) instead of the number of enrolled students, the student related factor is measured by the number of students who complete their year of study (North England) or by the number of credits completed by students (Wales). In Finland teaching grants awarded to single universities depend on the number of degrees that universities are supposed to award over the period in compliance with its performance contract.

7 The academic body (Senate) is composed of academic and non-academic staff members employed at the institution and student representatives (minimum 20%) with the proportion depending on the individual university statute.

8 Dziennik Ustaw No.164, poz.1365.

9 The rules are set by the Polish law: Dz. U. Nr 164, poz. 1365, z późn. zm. Prawo o Szkolnictwie wyższym art. 130.

10 See for example the Open Social Debate launched by Polish Ministry of Science and Higher Education www.nauka.gov.pl

11 MNiSW (2009), Założenia do nowelizacji ustawy – Prawo o szkolnictwie wyższym oraz ustawy o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki.

12 See for example: Wyższa Szkoła Wstydu – The Higher Education of Shame – a series of articles published in 2009 and 2010 in the daily newspaper *Gazeta Wyborcza* (www.gazeta.pl)

13 Instytut Badań nad Gospodarką Rynkową (The Gdansk Institute for Market Economics).
14 Full text of the strategy, along with accompanying documents (such as the diagnosis of Polish higher education sector) in Polish can be assessed at www.uczelnie2020.pl).
15 "Strategia rozwoju szkolnictwa wyższego 2010 – 2020". The document (in Polish) can be assessed at www.krasp.org.pl .
16 The recent proposals of the reform put forward by Polish MHE (2010) include the facilitation and shortage of the habilitation procedure - the idea to abolish habilitation has been abandoned mainly due to strong objections of conservative Polish academic environment.
17 In this section we present aggregate data on the scientific efficiency of Polish higher education sector, while the evidence emerging from the micro data on separate HEIs is presented in Section 4.1.
18 www.arwu.org
19 For comparison, ARWU 2010 lists among Top 500 39 universities from Germany.
20 http://ranking.heeact.edu.tw
21 For comparison, taking into account European institutions 2009 Top 500 list includes 5 universities from Austria, 7 from Belgium, 1 from the Czech Republic, 4 from Denmark, 6 from Finland, 20 from France, 45 from Germany, 5 from Greece, 2 from Hungary, 3 from Ireland, 29 from Italy, 12 from the Netherlands, 4 from Norway, 3 from Portugal, 1 from Slovenia, 10 from Spain, 11 from Sweden, 8 from Switzerland and 36 from the UK.
22 There are also other alternative rankings (such as: Times Higher Education – QS World University Rankings of "The Times", Webometrics, Professional Ranking of World Universities performed by Ecole Nationale Superieure des Mines de Paris or CHE Ranking of Centrum fur Hochschulentwicklung) which also confirm poor international visibility and competitiveness of Polish HEIs.
23 http://www.scimagojr.com
24 Impact factor is a measure of the frequency with which the "average article" in a journal has been cited in a given period of time. The impact factor for a given journal is calculated based on a three-year period and can be considered to be the average number of times published papers are cited up to two years after publication.
25 Gryglewski R. (Jagiellonian University Medical College, discipline: pharmacology) and Grynkiewicz G. (Pharmaceutical Research Institute, discipline: biology and biochemistry).
26 European Patent Organisation (www.epo.org)
27 Related statistics are available at: www.ibch.poznan.pl
28 Formally, this is the situation when increasing all factors of production in a given proportion causes rise of the output more than proportionally (thus average cost per unit falls as scale of production is increased).
29 Economies of scope are formally defined as a situation when average total costs of production decreases as a result of increasing the variety of goods produced.
30 Such as esp@cenet service available at www.epo.org.
31 www.apps.isiknowledge.com

32 In 2009 Web of Science covered over 10000 of the highest impact journals worldwide and over 110000 conference proceedings.

33 Similar strategy has been adopted for example by: Abramo et al. (2009), Bonaccorsi and Daraio (2003) or Kierzek, 2008 (in Polish). On the contrary, Abramo et.al (2008) adopt to the Italian case so-called 'bottom-up' approach (publications are first associated with authors employed in a given HEI and only then bibliometric values are aggregated by university). However, 'bottom-up' method can be used practically only in case of relatively restricted sample of HEIs (in our case it would have meant the individuation – by name - of all staff employed in almost 300 HEI from 7 different countries across multiple time periods).

34 Bibliometric method is clearly selective and does not take into account other than publications results of scientific activity. Moreover, due to the very characteristics of the database we use (ISI Web of Knowledge) which lists more technical journals than those belonging to humanities; technical scientists' and technical universities' performance can be overvaluated with respect to HEIs with mainly humanities and social science faculties. Publications in English are overrepresented with respect to those in other national languages (even though high quality research has became dominated by journals published in English, some exceptions can refer to books or the research on country-specific issues published in journals with no international impact). Finally, the same importance is given to publications in journals with very high and low impact factor.

35 Note that papers co-authored by persons affiliated at the same institution are counted once.

36 Note that we do not aim at valuating the quality of publications. Research output quality could be assessed by the so-called Hirsh index (Hirsch, 2005) based on the citation record . The index h is defined as the number of publications associated with a given HEI that have been cited at least h times each. For example the value of such index typical for the University of Cambridge within the years 2000-2008 is close to 200 which means that within that period 200 papers published by authors affiliated with Cambridge have been cited at least 200 times each. Among Polish HEIs (universities and technical universities) analysed by Kierzek (2008) the highest value of Hirsch index was obtained by the University of Warsaw (h=77). However, the number of publications and citations is typically higher for big units thus a corrected Hirsh index was proposed by Molinari and Molinari (2008). It is defined as hm = h/N0.4 where h is Hirsch index and N denotes the number of publications (hm for the University of Cambridge is equal to 2.76 while for the University of Warsaw 2.09; time covered: 2000-2008). Among technical universities in Poland Technical University of Warsaw obtained the highest score (h=47 and hm =1.68; 2000-2008).

37 Advanced Quantitative Methods for the Evaluation of the performance of public sector research.

38 Central Statistical Office of Poland (GUS) in various publications shows aggregate statistics concerning HEIs, so we assume that in order to calculate the aggregates they must be in possession of disaggregated data

(at the level of individual institution). Unfortunately, our request to obtain the statistics on staff and revenues of Polish HEIs was rejected. According to the letter we received on March the 26th 2009 from the CSO: "*the data concerning employed staff and finances of Polish HEIs are accessible only at the aggregated level, due to the statistical confidentiality policy of CSO the data on individual HEIs are not publically available*".

39 Zielonogora Technical University existed only till the year 2000 so the data reported in some tables for the latest year of observation (2008) does not take this unit into account. Bielsko-Biala Academy started to exist in the year 2001.

40 Aquameth dataset is composed of 272 European units but limited time dimension. Access is restricted to the consortium members.

41 For example we excluded from our analysis University of London which as a confederal organization is composed of several colleges. It was not possible to identify publication record because we cannot be sure whether academic staff of University of London as her/his affiliation gives the name of the college or "University of London".

42 Additionally, so-called 'third mission' (links of HEIs with industrial and business surrounding) could be considered but it is hardly measurable. We deal with this issue in a descriptive manner in Section 4.3.

43 In line with UOE manual (2004, p.22) as students we consider any individual participating in tertiary education service in the reference period. We perform the analysis on the basis of total number of students, because only in case of some countries (Poland, UK) we could distinguish between full time and part time enrolments.

44 The data referring to the staff are presented as full time equivalent (UK, Finland, Switzerland, Austria) or as full time employment (Poland, Germany, Italy).

45 In line with UOE manual (2004, p.34) as academic staff we consider: "*personnel whose primary assignment is instruction, research or public service; personnel who hold an academic rank with such titles as professor, associate professor, assistant professor, instructor, lecturer, or the equivalent of any of these academic ranks; personnel with other titles if their principal activity is instruction or research.*" Note that academic staff contains persons that have double obligations (teaching and research, in different proportions according to the position held, lecturers typically teach more, professors have lower teaching load). For example, in some countries (e.g. in Italy) there exists a separate category of so-called 'researchers' that perform mainly research activity, but have some teaching obligations too, thus they are incorporated into 'academic staff' group.

46 Case of Poland is specific: almost all universities have economic/management faculties, while almost no universities (apart from, for example, University of Cracow) has medicine/pharmacy faculty, because they form so-called Medical Academies (Medical Universities). Hence, in case of Poland the use of these dummies in our sample is pointless.

47 1.4 at Universita Politecnica delle Marche which transformed from university into technical university in 2003.

48 Note that along with increasing research efficiency is can also reflect the increasing number of journals listed in the Web of Science. However, we treat it as an exogenous factor common to all countries.
49 A drop observable in 2008 can be due to temporarily incomplete listing of 2008 publications by Web of Science (we accessed the data in the summer 2009).
50 Dz. U. Nr 164, poz. 1365, z późn. zm. Prawo o Szkolnictwie wyższym art. 130.
51 Not taking into account special universities such as Cambridge University or Oxford university, where each college contains of several faculties.
52 Note that in case of HEIs merging with other academic units it is difficult to establish which year should be taken into account as the year of foundation.
53 Dz. U. Nr 164, poz. 1365, z późn. zm. Prawo o Szkolnictwie wyższym art. 13.
54 Polska Agencja Rozwoju Przedsiębiorczości.
55 For comparison, leading UK Universities have entrusted their technology commercialisation activities to separate professional legal entities – e.g. Oxford University to ISIS Innovation Ltd., Imperial College to Imperial Innovations Group plc. and Cambridge University to Cambridge Enterprise Ltd. These entities are either owned by the University or – as in the case of Imperial Innovations – are public with the University holding a minority interest.
56 GUS (2009a)
57 as at August 2009, The table excludes foreign and private higher education institutions operating in the UK., Source: Higher education in facts and figures - Summer 2009 available at www.UniversitiesUK.ac.uk
58 Eurydice (2007/2008)
59 as at September 2009, Austrian Federal Ministry of Science and Research: http://www.bmwf.gv.at
60 as at December 2009, Finnish Ministry of Education: http://www.minedu.fi/
61 Eurydice (2008/2009b)
62 as at September 2009, Swiss Federal Statistical Office: http://www.bfs.admin.ch/bfs/portal
63 Source: Eurydice (2008) and De Boer and File (2009)
64 Fumasoli (2007)
65 Main mechanisms for direct public funding, public and government-dependent private higher education as at 2006/07, source: Eurydice (2008) Higher Education Governance in Europe – policies, structure, funding and academic staff.
66 Eurydice (2007)
67 Eurydice (2008/2009a)
68 Eurydice (2007)
69 average salary at the Gdansk University of Technology, Poland, source: Department of Finance. Gross average salary with all bonuses and additional income (e.g research grants): Assistant 605 €/month, Adiunct 1116 €/month, Associated Professor 1709 €/month, Full Professor 2203 €/month according to GUS (2009b)

70 as at 2007/2008, Data come from the Higher Education Statistics Agency and were obtained through http://www.timeshighereducation.co.uk/Journals/THE/THE/19_March_2009/attachments/Tables_01.pdf

71 http://www.academics.com/science/salaries_30543.html?unpaged=true

72 as at 2007, source: Academic Career Observatory, http://www.eui.eu/ProgrammesAndFellowships/AcademicCareersObservatory

73 source: Academic Career Observatory, http://www.eui.eu/ProgrammesAndFellowships/AcademicCareersObservatory

74 net salary, see Berkhout et al. (2007)

75 based on the opinions expressed by young post docs at the Academic Career Observatory, see: http://www.eui.eu/ProgrammesAndFellowships/AcademicCareersObservatory/

76 Elasticity is formally defined as follows: if the elasticity between y and x is equal to e, then ceteris paribus 1% rise in x is associated with e% rise in y.

77 The specification (2) is derived from the standard Cobb-Douglas research production function which for a single unit has the form: $Y_{it} = \alpha_0 K_{it}^{\alpha} L_{it}^{\beta}$ where: i refers to the unit and t denotes the time period, Y_{it} is the output, K_{it} symbolizes the capital and L_{it} - labour. We do not assume a priori constant returns to scale thus $\alpha + \beta \neq 1$. Then per worker production function has the form: $Y/L = \alpha_0 (K/L)^{\alpha} L_{it}^{\beta+\alpha-1}$. Taking the logs at the both sides of the equation we obtain the expression (2) where: $y = Y/L$ i $k = K/L$; $\beta_1 = \alpha\beta$ $\beta_2 = (\beta+\beta\alpha-1)$.

78 $$Ey(k) = \frac{d \ln y}{d \ln k} = \frac{dy/y}{dk/k} = \frac{\Delta y/y}{\Delta k/k} = \beta_1 \; ; \; Ey(L) = \frac{d \ln y}{d \ln L} = \frac{dy/y}{dL/L} = \frac{\Delta y/y}{\Delta L/L} = \beta_1$$

79 As a robustness check we also performed the estimation of research production function with linear specification (without log-linearization). The results are available from authors upon request.

80 Summary statistics are available upon request.

81 Due to the space constraints we do not report the parameters of unit root tests, but all results are available from authors upon requests.

82 Endogeneity implies two way relationships between left hand side and right hand side variables. For example revenues have an impact on research output but also research output influences the magnitude and source of revenues. Estimations not taking this into account would be biased.

83 Unfortunately due to data constraints we were not able to employ other instruments (for a discussion of possible instruments used in a research production function see Aghion et al., 2009).

84 In the regression analysis we have also checked the importance of the number of different faculties for research performance, obtaining the positive parameter in the estimation. However, as $nofac_i$ reflects not only the interdisciplinary of a unit, but also is related to the size of the university (see the pairwise correlation between $nofac_i$ and variables indicating size: $Staff_{it}$, $AcadStaff_{it}$, $Stud_{it}$ w Tabeli A2), we decided to perform the regression with only one variable indicating size of the institution.

85 Due to space constraints, detailed results referred to this section are available from the authors upon request.

86 We thank Piotr Cizkowicz for pointing out this alternative specification.

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