IRTG 1792 Discussion Paper 2018-011

How to Measure a Performance of a Collaborative Research Centre

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This research was supported by the Deutsche Forschungsgemeinschaft through the International Research Training Group 1792 "High Dimensional Nonstationary Time Series".

http://irtg1792.hu-berlin.de
ISSN 2568-5619

International Research Training Group 1792

How to Measure a Performance of a Collaborative Research Centre

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New Public Management helps universities and research institutions to perform in a highly competitive research environment. Evaluating publicly financed research results improves transparency, helps in reflection and self-assessment, and provides information for strategic decision making. In this paper we provide empirical evidence using data from a Collaborative Research Centre (CRC) on financial inputs and research output from 2005 to 2016. After selecting performance indicators suitable for a CRC, we describe main properties of the data using visualization techniques. To study the relationship between the dimensions of research performance, we use a time fixed effects panel data model and fixed effects Poisson model. With the help of year dummy variables, we show how the pattern of research productivity changed over time after controlling for staff and travel costs. The joint depiction of the time fixed effects and the research project's life cycle allows a better understanding of the development of the number of discussion papers over time.

Key words: Research Performance, Time Fixed Effects Panel Data Model, Fixed Effects Poisson Model, Network, Collaborative Research Centre

1. Introduction

New Public Management (NPM) helps universities and research institutions to perform in a highly competitive research environment. It emerged in the 1980s (Hood 1991) with the goal of improving efficiency and overall performance of public sector institutions by using business management approaches and models. NPM places a strong focus on permanent monitoring and evaluation of performance. Measuring research performance allows an analysis of the structural issues in science. It can thus facilitate the development of a scientific system and strengthen excellence in research.

This paper discusses Collaborative Research Centers (CRC) – long-term university-based research institutions funded by the German Research Foundation (DFG 2018). Evaluating publicly financed research results improves transparency, helps in reflection and self-assessment, and provides information for strategic decision making. Periodic monitoring of resource use and interim results allows CRC management to keep the finger on the pulse and to react to unfavourable phenomena promptly or to develop options for improvement; thereby, supporting success of the CRC.

There are numerous studies that concentrate on the evaluation of university research or research institutions in general (Pastor et al. 2015, Van den Berghe et al. 1998). Lee (2010) and Bolli and Somogyi (2011) discuss performance measurements for departments and research units. Jansen et al. (2007) and Carayol and Matt (2004) further investigate performance indicators for research groups. However, a CRC differs from common research units or institutions, because of its interdisciplinary background. The performance indicators used for the evaluations of a CRC should be designed specifically for its needs and purposes in order to reflect the behaviour of involved research fields and other underlying characteristics.

In this paper we focus on a selection of performance indicators for intermediate and final evaluations suitable for broad applicability within CRCs and identifying a relationship between productivity and resource use of CRCs that may have implications for funding policy. The goals of this paper include: (i) Selecting performance indicators suitable for a CRC; (ii) Visualizing goals vs. results, societal impact and the interdisciplinarity structure of research results of a CRC; (iii) Analysis of a

dependence structure between financial inputs and research outputs of a CRC and development of research productivity over time.

To achieve these objectives, we use the twelve years (2006 – 2012) of data from a Collaborative Research Center 649 "Economic Risk" (CRC 649) on 32 sub-projects (SPs). For each SP we observe the yearly staff costs, travel costs, number of discussion papers (DPs) and the total number of citations per year. The life span of each SP varies, which results in an unbalanced panel.

Schröder et al. (2014) indicate that the proposal for funding determines objectives for the research activity. To examine the correspondence between objectives and research results of the CRC, we carry out a semantic analysis of proposals and abstracts from published DPs. As a result, we find that both use 50% of the same words.

Apart from research activity, a CRC has an impact on society through public events, transfer of knowledge or promotion of young researchers. For instance, young researchers usually perform specific theoretical or practical research that is also used for their Ph.D. thesis. Collecting data on their further career helps to better understand this impact. With the help of a mosaic plot, we visualize three important dimensions of young researchers careers after receiving their Ph.D. within the CRC: gender, location and the area of work. For example, we show that nearly 70% of individuals obtain a job in academia.

Through a network analysis, we illustrate the interdisciplinarity structure of the research results and find out that most DPs were published in the fields of mathematical and quantitative methods, followed by financial economics, macroeconomics and monetary economics.

To study the relationship between research outcomes and funding for the CRC, we regress the number of DPs on staff and travel costs using SP-level data. With the help of year dummy variables added to the model, we show how the pattern of the SPs' productivity changed from 2006 to 2016 after controlling for staff and travel costs. Since the level of spending from the previous year and the preceding number of DPs may influence the current number of DPs, we additionally control for the lagged variables. The productivity of each SP may differ due to some heterogeneity or individual

effects, such as the skills of a principal investigator (PI), average abilities or skills of researchers employed at the SP, or the specific behavior of a research field. For instance, working on a publication with one vs. more co-authors, writing in English vs. other languages, or publishing in books vs. articles may affect the research outcomes. Therefore, we allow for the possibility of individual SP effects. Considering the data structure, we apply a time fixed effects panel data (FE) model. Since the number of DPs is a count variable, we also apply a fixed effects Poisson (FEP) model.

We show that the increase of staff costs by 100% leads to an expected increase in the number of DPs by roughly 43% (FE) or 1.62 DPs (FEP). Travel costs have a diminishing effect on the number of DPs according to estimation results of the considered models. The previous level of both staff and travel costs negatively influence the number of DPs. We depict the estimates of coefficients of the dummy variables for years and find that the development trend corresponds with the stages of a project's life cycle. For instance, the most significant declines in the number of DPs take place during the stage of theoretical and empirical research, whereas the finalization stage corresponds with the growth in the number of published DPs.

The programmed R codes are available on the web-based repository hosting service and collaboration platform GitHub.

The remainder of the paper is structured as follows. Literature review on performance indicators is presented in Section 2. Section 3 describes the data and provides some preliminary descriptive analyses. Section 4 introduces the methodology and shows empirical results. Finally, Section 5 summarizes the results.

2. Literature Review

The combination of a peer-reviewed process and quantitative indicators is common practice in research performance assessment. The German Council of Science and Humanities (WR, germ. - Wissenschaftsrat) suggests evaluating the research institutions within three dimensions (research, promoting young researchers and knowledge transfer), which contain nine research performance criteria (WR 2004). We select five criteria relevant to a CRC and provide a literature review on suitable indicators that may reflect the performance of the CRC.

1. *Research quality* shows originality and novelty of research outputs, trustworthiness of methodology, impact and relevance for further research.

Indicator	Definition	Literature
Relative reception success		
C_{Pub}	Relation of total number of citations (NC_{Pub}) to the total number of publications (N_{Pub})	WR (2012), Diem and Wolter (2013), Donner and Aman (2015)
C_{Pub}/FC_m	Citations per publication in relation to the citation's average of the field	WR (2012), Abramo and D'Angelo (2011), Moed et al. (2011), Van den Berghe et al. (1998)
C_{Pub}/JC_m	Citations per publication in relation to the citation's average of the journal	Moed (2010), WR (2012)

Table 1: Research quality.

2. *Effectiveness* reflects the contribution of all SPs to the development of expertise in the research field within the CRC and beyond.

Indicator	Definition	Literature
Research activity		
N_{Costs}	Total amount of the third party expenses (TPE)	WR (2012), Schmoch and Schubert (2009)
N_{Staff}	Total number of staff financed from TPF	Carayol and Matt (2004), WR (2012)
RA_{unit}	Research activity of unit (SP) – multiplication of the total number of publications and the total number of citations of a unit with regard to the institutions-wide number of citations for the analyzed period ($RA_{SP}=N_{Pub_{SP}}*C_{Pub_{SP}}/C_{Pub_{CRC}}$)	Pastor et al. (2015)

Research productivity		
N_{Pub}	Total number of publications	WR (2012), Abramo and D'Angelo (2011), Diem and Wolter (2013), Moed et al. (2011), Hornbostel (1991)
NC_{Pub}	Total number of citations	WR (2012)
FN_{Pub}	Fractional productivity – total number of contributions to publications, where each contribution is a publication divided by the number of co-authors	Abramo et al. (2009), Abramo and D'Angelo (2011)
ScS_{Pub}	Scientific strength – weighted sum of publications authored by each person, where the weights for each publication is the number of citations per publication in relation to the citation's average of the field (C_{Pub}/FC_m)	Abramo and D'Angelo (2011), Abramo et al. (2009)
h	h-index	Hirsch (2005), Bornmann (2013)
Visibility of CRC		
$AbsC_{Pub}$	Absolute citation count in the light of maximum citation count of a single publication ($C_{Pub_{max}}$) and the number of non-cited publications (N_{ncPub})	WR (2012)
Reputation	List of scientific prizes and awards	Zheng and Liu (2015), WR (2012)
Professional activity	Editorships Review activities Editorial board memberships Academic functions Academic memberships Organized conferences and workshops	WR (2012)

Table 2: Effectiveness.

3. The *efficiency* criterion describes a quantity of research outputs in relation to a specific input, i.e. total costs, staff expenditures, number of staff, etc.

Indicator	Definition	Literature
N_{Pub}/N_{Staff}	Relation of the number of publications (N_{Pub}) to the number of research staff (N_{Staff})	Pastor and Serrano (2016), WR (2012), Abramo and D'Angelo (2011)
NC_{Pub}/N_{Staff}	Relation of the number of citations of publications (N_{Pub}) to the number of research staff (N_{Staff})	WR (2012), Lee (2010)
N_{Costs}/N_{Staff}	Relation of the TPE to the total number of research staff (N_{Staff})	WR (2012), Pastor and Serrano (2016), Barra and Zotti (2016)

Table 3: Efficiency.

4. *Research enabling* relates to scientific activities that facilitate and support the research of young researchers.

Indicator	Definition	Literature
Promotion of young researchers		
N_{YR}	Total number of positions for young researchers	WR (2012)
$N_{Ph.D.}$	Total number of defended Ph.D.	WR (2012), Diem and Wolter (2013), Grözinger and Leusing (2006), Schmoch and Schubert (2009)
$D_{Ph.D.}$	Average duration of Ph.D. study	WR (2004)
$N_{Pub_{Ph.D.}}$	Total number of publications by young researchers	WR (2004)
	List of awards and prizes of young researchers	WR (2012)
	List of calls and appointments for young researchers	WR (2012)

Table 4: Research Enabling / Promotion of young researchers.

5. *Knowledge transfer* defines the transfer of research results and products or distribution of knowledge.

Indicator	Definition	Literature
N_{Pat}	Number of patents	WR (2011), Carayol and Matt (2004)
	List of Transfer projects	
	List of activities in public relations	WR (2012)
	List of research products and teaching materials	WR (2012)

Table 5: Knowledge Transfer.

3. Data

To provide empirical evidence, we use data from a Collaborative Research Center 649 "Economic Risk" (CRC) that was launched in 2005 for a four year term and extended twice, for a total life span of twelve years. As an interdisciplinary research center, it combined economics, mathematics and statistics and pursued research in three principal areas: financial markets and risk assessment, individual and contractual answers to risk, macroeconomic risks. For more information, we refer to the website of the CRC (CRC 649 2016).

Since the 32 sub-projects (SPs) of the CRC had different life periods, the dataset does not have the observations for all years that indicates an unbalanced panel, see Figure 1. The main reason for the panel being unbalanced is the attrition of SPs, as a result of research project's termination or the leave of principal investigators to other universities, and the establishment of new research projects during the prolongation phases.

We use data from annual financial reports, internal publications and DP's databases and CRC's newsletter. Additional insight is gathered from the texts of one proposal for a launch and two proposals for a prolongation of the CRC 649 (2005–2008, 2009–2012, 2013–2016) which were submitted to the DFG. On the one hand, one can see such proposals as goals that a CRC sets for each period.

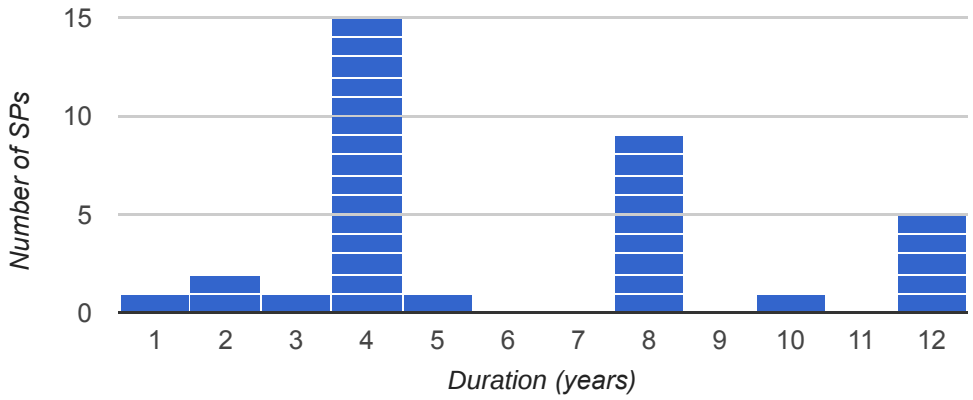

Figure 1 Distribution of SP life span in years.

On the other hand, the published DPs encompass the achieved results of the research activity. We undertake a semantic analysis on both informational sources, i.e. 61 summaries of SPs from three proposals and abstracts of 771 DPs. The two word clouds of the top 75 keywords are illustrated in Figure 2. We find that both use 50% of the same words. The different size of the same words, for instance the word "risk", indicates that the number of times the word is mentioned in the proposals and abstracts differs.

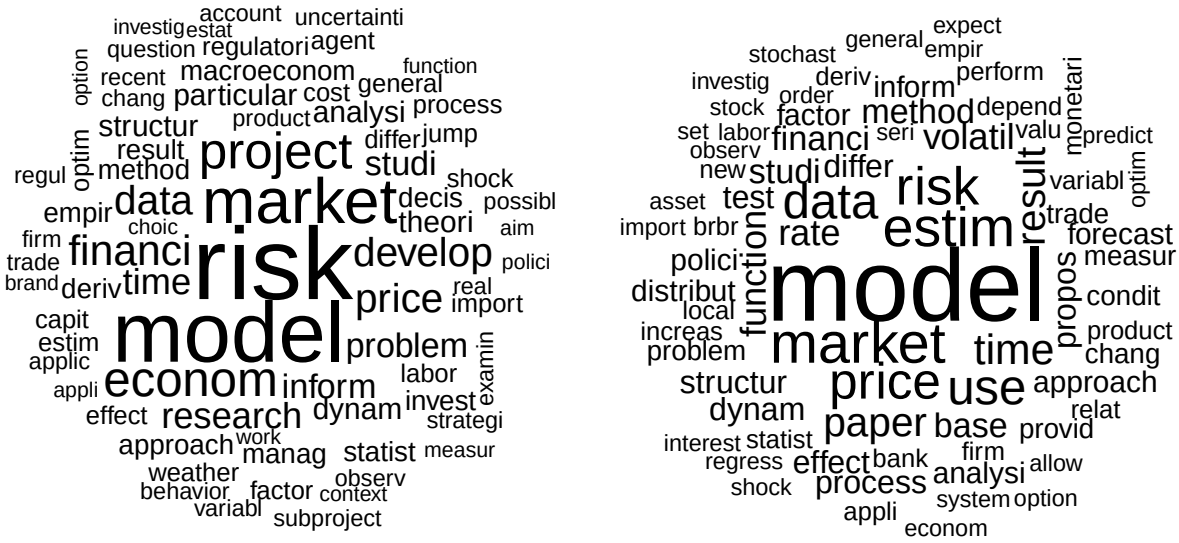

Figure 2 Semantic analysis of goals (left; 61 summaries from SP of three proposals for the CRC) vs. results (right; 771 abstracts from DP).

One of the primary goals of a CRC is the high-quality instruction, supervision and support of young researchers. The common result of this process is a Ph.D. defence. Collecting data on the further

career of the young researchers helps to better understand the impact on society. For instance, one may wonder how many females that worked and defended their Ph.D. thesis in CRC are afterward working in academia in Germany? To visualize such data we use a mosaic plot in Figure 3.

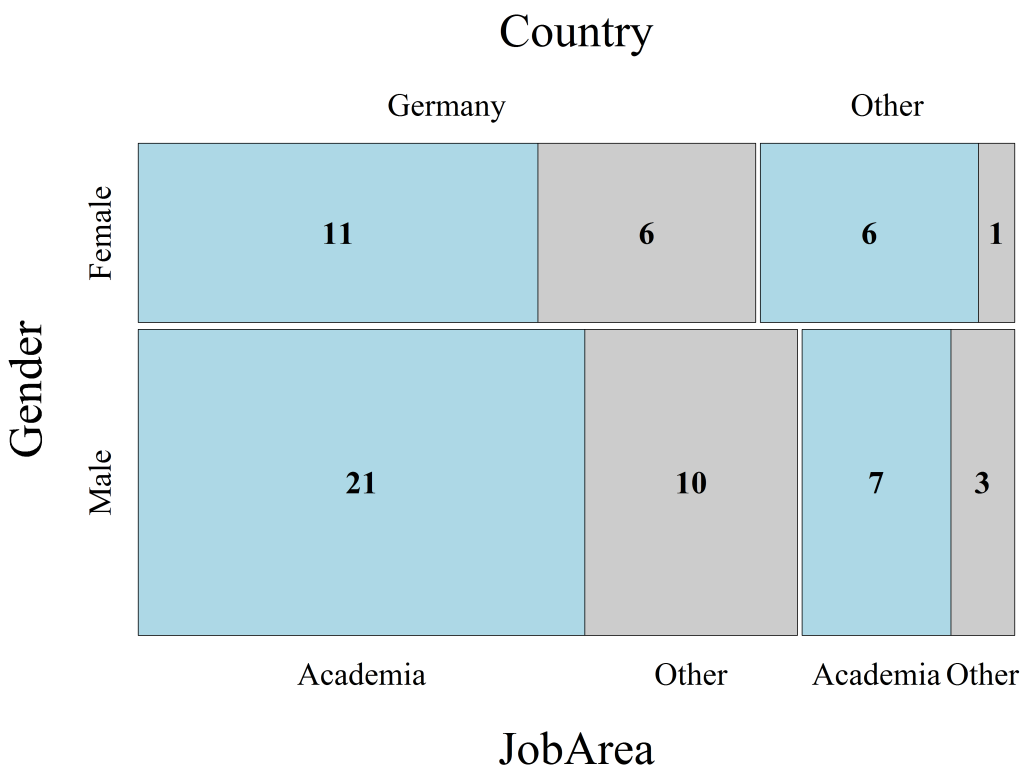

Figure 3 Mosaic plot of job type, location and gender of 65 CRC members who received their Ph.D. between 2005 and 2016 (as of Dec 2016)

The vertical axis splits the individuals according to their gender. The data are further divided into two groups on the upper horizontal axis according to the location of the job. The lower horizontal axis shows how many people received a contract in academia or other fields. The width and height of each segment represent the number of observations within each group. Consider the 65 members of the CRC that received their Ph.D. from 2005 to 2016. There are 11 female researchers that received jobs in academia in Germany and 6 in other countries. For males that stayed in academia, the number is 21 for Germany and 7 for other countries. This means that around 70% of young researchers employed by the CRC have found a job in a scholarly institution.

In order to understand if the intended interdisciplinarity occurred, we analyze DPs that serve as an outcome of the CRC research activity. Almost each DP has codes indicating subject fields according to the Journal of Economic Literature (JEL) classification in the economic sciences (see JEL 2018).

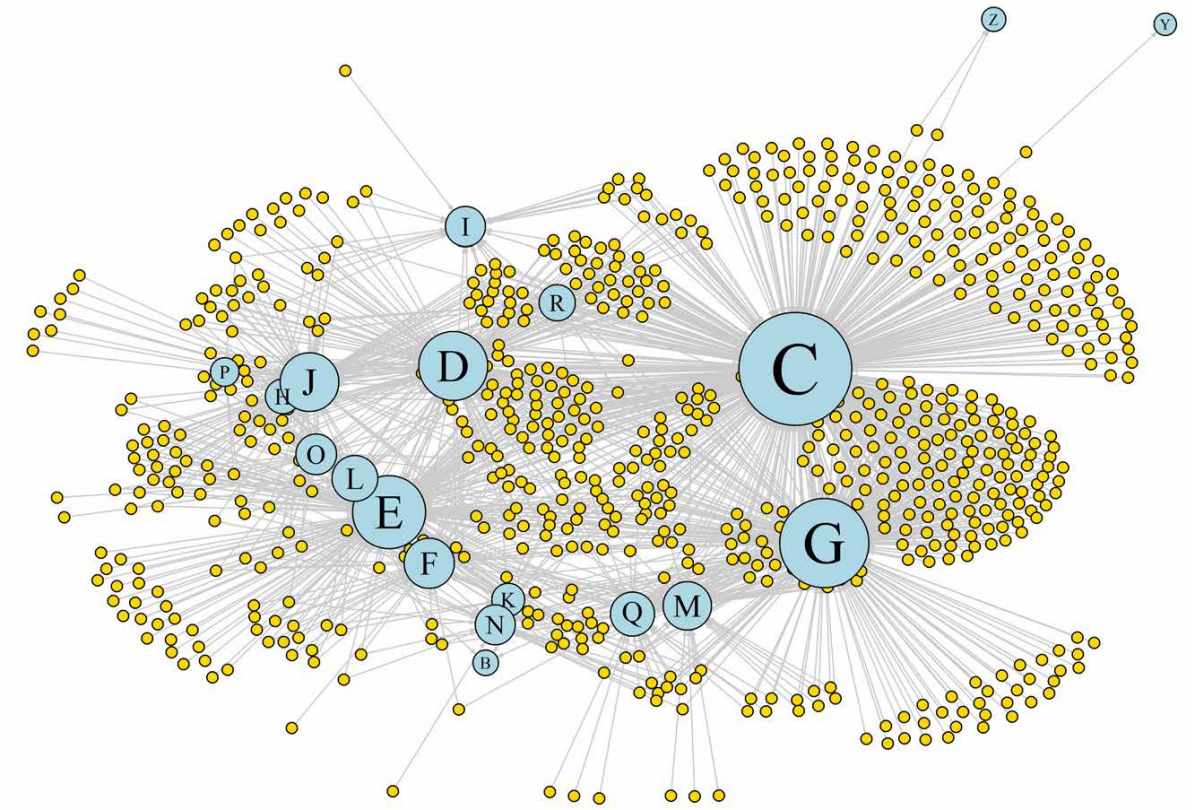

Figure 4 Network of 760 discussion papers (yellow) and 20 JEL codes (blue) published from 2005 to 2016.

We show the network of collaborating disciplines in Figure 4. The small gold circles introduce the DPs, whereas the nodes leading to the bigger blue circles indicate the JEL code of the corresponding research area. The size of each blue circle reflects the relative number of references to DPs. The explanation of JEL codes is given in Table 6. For instance, most of the DPs were published in the C area, i.e. mathematical and quantitative methods. They are followed by G, financial economics, and E, macroeconomics and monetary economics.

Code	Research field
A	General Economics and Teaching
B	History of Economic Thought, Methodology, and Heterodox Approaches
C	Mathematical and Quantitative Methods
D	Microeconomics
E	Macroeconomics and Monetary Economics
F	International Economics
G	Financial Economics
H	Public Economics
I	Health, Education, and Welfare
J	Labor and Demographic Economics
K	Law and Economics
L	Industrial Organization
M	Business Administration and Business Economics / Marketing / Accounting / Personnel Economics
N	Economic History
O	Economic Development, Innovation, Technological Change, and Growth
P	Economic Systems
Q	Agricultural and Natural Resource Economics / Environmental and Ecological Economics
R	Urban, Rural, Regional, Real Estate, and Transportation Economics
Y	Miscellaneous Categories
Z	Other Special Topics

Table 6: JEL Classification System

4. Analysis of Research Productivity

The observed time series across the same SPs indicate the longitudinal or panel structure of the data. To investigate the relationship between the input and the output variables, we use the methods designed for panels.

4.1. Methodology

The basic framework for the panel data analysis shows the model (Wooldridge 2002):

$$y_i = \beta X_i + u_i, \quad i = 1, \ldots, K, \tag{1}$$

where $y_i = (y_{i1}, \ldots, y_{iT})^\top$ is a $(1 \times T)$ vector of observations for $t = 1, 2, \ldots, T$, $X_i = (x_{i1}^\top, \ldots, x_{iT}^\top)^\top$ is a $(K \times T)$ matrix of observations, β is a $(K \times 1)$ vector of coefficients and u_i is a $(1 \times T)$ vector of unobservables.

The unobserved SP effect may contain such factors as publishing behavior in a research field, average researchers' abilities or skills of principal investigators of SPs that should be roughly constant over time.

We allow for arbitrary correlation between the unobserved SP heterogeneity or fixed effects c_i and the observed explanatory variables x_{it} and, therefore, use the fixed effects model for each i (Wooldridge 2016):

$$y_{it} = \beta_1 x_{it1} + \ldots + \beta_k x_{itk} + c_i + u_{it}, \quad t = 1, 2, \ldots, T, \quad i = 1, 2, \ldots, K, \tag{2}$$

where y_{it} includes dependent variables and x_{it} independent variables for individual i at time t, $\beta_1, \ldots, \beta_k$ are the unknown coefficients, c_i is individual effect or individual heterogeneity and u_{it} are idiosyncratic errors that change across individuals i and time t.

The fixed effects estimator (or the within estimator) is obtained as the pooled OLS estimator on the time-demeaned variables. The strict exogeneity assumption on explanatory variables, $\mathrm{E}(u_{it} | \mathbf{X}_i, c_i) = 0$, provides that the fixed effects estimator is unbiased (Wooldridge 2016). As the number of SPs

(clusters) is large, statistical inference after OLS should be based on cluster-robust standard errors to account for heteroscedasticity and within-panel serial correlation (Cameron and Miller 2015).

Next, we are interested in the pattern of SPs' productivity, i.e. number of produced discussion papers, in different time periods. For this purpose we use time fixed effects that change over time but are constant across SPs. We include the dummy variables for $T-1$ years to avoid the multicollinearity. Usually the first year is selected as a base year. The time fixed effects model (FE) is (Stock and Watson 2003):

$$y_{it} = \beta_1 x_{it1} + \ldots + \beta_k x_{itk} + \delta_1 + \delta_2 D_2 + \ldots + \delta_T D_T + c_i + u_{it}, \tag{3}$$

where $D_2, \ldots, D_T$ are time effects and $\delta_1, \ldots, \delta_T$ are the parameters to estimate.

When the dependent variable involves count data, it has a Poisson distribution instead of a normal distribution. Hausman et al. (1984) introduce a fixed effects Poisson model (FEP) as:

$$\mathrm{E}(y_{it}|x_i, a_i) = a_i \mu(x_{it}, \beta_0), \quad t = 1, 2, \ldots, T, \tag{4}$$

where β_0 is a $(1 \times K)$ vector of unknown parameters to be estimated and μ is the conditional mean. Wooldridge (1999) further derives a consistent estimator for FEP using a quasi-conditional maximum likelihood estimator (QCMLE).

4.2. Empirical Results

Before presenting the estimates, we explain some specifications of the model. Since the yearly staff and travel costs are in nominal Euros, a slight increase may happen due to inflation. One possibility to deal with this is an adjustment using a Consumer Price Index (CPI). Another way to track the effect of real spendings is the use of a logarithmic form. The interpretation of the estimation results is then done using the level-log model.

Table 7 presents the results of FE (1) and (2), and FEP (3) and (4) models for the number of DP as a dependent variable. The parameters of interest are staff costs $\beta_{logStaffCosts}$, travel costs $\beta_{logTravelCosts}$ and year-specific influence δ_{year}. We also include lagged variables into the models (2)

and (4), since the current number of research outputs may be affected by the previous number of publication and invested funds in economic sciences and mathematics. The models (2) and (4) encompass the number of DPs $\beta_{nDP_{t-1}}$, staff costs $\beta_{logStaffCosts}$ and travel costs $\beta_{logTravelCosts}$ in the time $t-1$. The intercept *const* is the average of individual effects c_i across all SPs that is reported by Stata. We use cluster-robust standard errors to account for heteroscedasticity. The significance level of all estimates decreases as a result of standard error adjustment (Wooldridge 2016).

Dependent variable: nDP	FE model		FEP model	
	(1)	(2)	(3)	(4)
$\beta_{logStaffCosts}$	1.38^{**}	1.62^{*}	0.47^{***}	0.43^{**}
	(0.61)	(0.88)	(0.12)	(0.19)
$\beta_{logTravelCosts}$	-0.94^{*}	-0.34	-0.22^{**}	-0.04
	(0.55)	(0.47)	(0.10)	(0.09)
δ_{2006}	1.61	1.92	0.25	0
	(1.36)	(1.61)	(0.26)	(*omit.*)
δ_{2007}	-1.20	-2.55	-0.30	-0.98^{***}
	(1.38)	(2.46)	(0.31)	(0.25)
δ_{2008}	-0.95	-2.03	-0.23	-0.97^{***}
	(1.30)	(2.10)	(0.32)	(0.36)
δ_{2009}	-2.05^{*}	-3.16	-0.54^{*}	-1.20^{***}
	(1.13)	(1.98)	(0.33)	(0.23)
δ_{2010}	-1.93^{*}	-2.13	-0.51^{*}	-1.03^{***}
	(1.14)	(2.68)	(0.30)	(0.31)
δ_{2011}	1.10	0	0.33^{*}	0
	(0.70)	(*omit.*)	(0.20)	(*omit.*)
δ_{2012}	-2.79^{*}	-3.60^{*}	-0.71^{**}	-1.90^{***}
	(1.46)	(1.78)	(0.34)	(0.20)
δ_{2013}	-2.98^{**}	-3.18	-0.80^{**}	-1.32^{***}
	(1.30)	(2.52)	(0.32)	(0.41)
δ_{2014}	-1.36	-1.73	-0.44	-0.99^{***}
	(0.95)	(1.61)	(0.27)	(0.37)
δ_{2015}	-2.55^{**}	-1.90	-0.74^{**}	-1.02^{***}
	(1.17)	(1.77)	(0.33)	(0.31)
δ_{2016}	-0.30	0	-0.31	-0.69^{*}
	(1.79)	(*omit.*)	(0.36)	(0.41)
const	-2.37	0.05		
	(5.29)	(10.09)		
$\beta_{nDP_{t-1}}$		0.02		-0.01^{*}
		(0.16)		(0.03)
$\beta_{logStaffCosts_{t-1}}$		-0.66		-0.25
		(0.59)		(0.23)
$\beta_{logTravelCosts_{t-1}}$		-0.21		-0.02
		(0.58)		(0.13)
R^2	0.20	0.21		
AIC	706	437	463	253
BIC	742	469	501	258

Table 7 Estimation results for time fixed effects (within) regression (models (1) and (2)) and fixed effects Poisson regression (models (3) and (4)) with number of DP (nDP) as the dependent variable and with robust standard errors adjusted for clusters in SP.

In (2) and (4) two years were omitted because of collinearity. In (3) five observations were dropped out of the analysis because there was only one observation per group. Performing analysis on unbalanced data slightly increases the estimated effects of considered variables, but the general idea remains unchanged (Wooldridge 2016).

In the model (1) we see the positive, significant effect of staff costs on the number of DPs. 1.38/100 is the unit change in nDP when staff expenses increase by 1%. In other words, a 100% increase in staff costs leads to an increase in the number of DPs by 1.38. Similarly, the model (2) shows that a 100% increase in staff costs increases the number of DPs by 1.62, holding other variables constant. The fit of the FE models in (1) and (2) in Table 7 with nDP as the dependent variable is almost the same, indicating that including lagged variables does not significantly improve the model.

The FEP estimates have a different interpretation. For instance, the coefficient on $\beta_{logStaffCosts}$ shows that a rise of staff costs by 100% leads to an increase of the number of DPs by 47% and 43% for models (3) and (4) correspondingly. The coefficients on staff costs estimates for four models in Table 7 are significant at 1% to 10% level. The influence of previous values of staff costs on the number of DPs is negative and insignificant.

Travel costs have a diminishing effects on the number of DPs according to estimation results of considered models. The coefficient on $\beta_{logTravelCosts}$ implies that, if we increase the travel costs by 100%, we expect the number of DP to decrease by 0.94 DP due to FE model (1). The Poisson coefficient in (3) means that an increase in $logTravelCosts$ by 10% decreases nDP by 2% (0.22×0.10).

The coefficients on the year dummy variables reveal how the average productivity of SPs changes over time. As 2005 is selected as the base year, it is not reported with a coefficient. The coefficient on δ_{2006} in model (1) shows that, on average, 1.6 DPs are attributed to the year effect of 2006 holding other factors fixed. In Poisson case (3) one suggests that the expected number of DPs in 2006 is 25% higher than on average. The coefficients on δ_{2006} and δ_{2011} indicate a positive increase in the number of DPs even without changing expenses. The omission of year dummies would lead to the attribution of this positive effects to the effects of costs change.

One can see that the year effects have a negative impact on the number of DPs in the majority of years for all models. The project's life cycle could explain this. Research projects generally have five main stages: proposal development, funding review, project start-up, performing research and finalization of the project. We map the estimates of coefficients of the models and fit the stages of life cycles in Figures **??** and **??**. Proposal development and funding review take place before 2005 and are not depicted in these Figures.

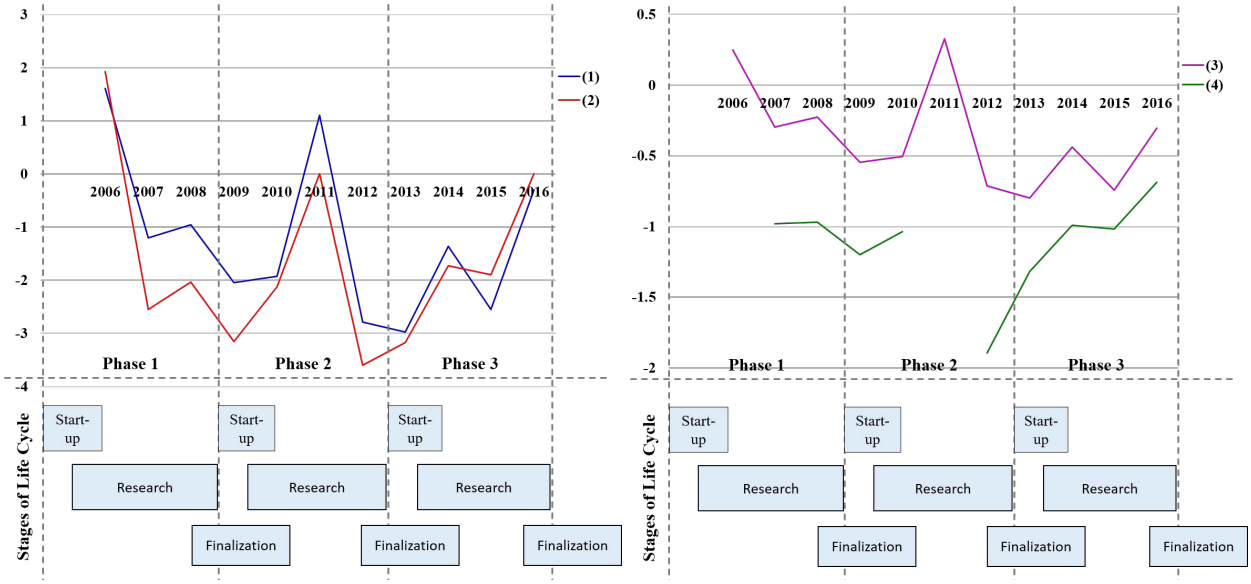

Figure 5 Estimates of coefficients on the year dummy variables for FE models (left) and FEP models (right). The lower part of the figure shows the corresponding stage of the research project life cycle.

A highly demanding application for a CRC requires extensive preliminary research. The results of this preliminary research are published as DPs in the first year 2005, thus, creating a specific bias towards later research outputs produced during the CRC's life time. The three following increases in the number of DPs take place in the finalization stage caused by the publishing of research results at the final stage of projects. The research outputs of the last phase in 2016 show part of the positive trend. In fact, 28 DPs were published in 2017, after the CRC was officially finished and financing ended. Three major declines could be explained by a theoretical and empirical stage of the research in the middle of each project life cycle. In summary, the joint depiction of the time fixed effects and

the research project's life cycle could allow a better understanding of the development of the number of DPs over time.

5. Conclusions

Our findings show that the performance indicators suitable for the intermediate or final evaluation of a CRC help create a better understanding of the dependence structure between research productivity and financial inputs, and provide relevant information for successful decision and policy making.

Using time fixed effects panel data model and fixed effects Poisson model, we show that increasing staff costs by 100% raises the number of DPs by 1.62 or 43% according to the estimates of FE and FEP models correspondingly. Travel costs have diminishing effects on the number of DPs according to our estimation results. We analyse the change in productivity of CRC over time for reasons not captured by the other independent variables using the dummy variables for years. We depict the estimates of coefficients for years and show that the development trend could correspond to the stages of a project's life cycle. For instance, the major declines in the number of DPs take place during the stage of theoretical and empirical research, whereas the finalization stage may correspond to the growth in the number of published DPs.

6. Acknowledgement

Financial support from the German Research Foundation (DFG) via Collaborative Research Center 649 "Economic Risk" and International Research Training Group 1792 "High Dimensional Nonstationary Time Series", Humboldt-Universität zu Berlin, is gratefully acknowledged. We are thankful for the assistance provided by Nicole Hermann und Dominik Prugger.

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This research was supported by the Deutsche Forschungsgemeinschaft through the IRTG 1792.