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and early career performance of academic researchers****Anders Broström,**

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Academic breeding grounds:

Home department conditions and early career performance of academic researchers

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Abstract: This study investigates how research group characteristics relate to the early career success of PhD candidates who are trained in the group. In particular, we study how the citation impact of early-career PhDs is related to the staff composition and the funding of the group. Using data on a cohort of Swedish doctoral graduates in science, engineering, mathematics and medicine, two sets of findings are obtained. First, students who were trained in groups with a lower number of PhD students perform better in terms of academic productivity. From the perspective of research policy, this finding suggests a decreasing return to funding additional PhD student positions allocated to professors already maintaining larger research groups. Second, PhD students trained in groups whose funding for PhD research is conditioned by funder influence over the topic of thesis research are more likely to stay in academia. Controlling for career destination, however, PhDs from such groups have lower than average scientific productivity and citation impact. These results suggest that funders of PhD studies face a trade-off between the two different funding objectives of “getting what they want” in terms of research content and fostering successful scholars.

Keywords: academic careers; PhD studies; research funding; research group; research performance

JEL-codes: I23

1. Introduction

It is well established that there are large differences in productivity between scientists: a relatively small proportion of scientists contribute to the majority of the publications (Lotka, 1926; Kyvik, 1991). The skewness of productivity and citation distributions persist also when controlling for variables such as experience, academic position and scientific field. This raises the question of how performance differences arise.

Two leading explanations in early research on this topic were the “sacred spark” hypothesis, which relates performance differences to differences in innate ability and motivation for scientific research work, and the hypothesis of accumulative advantage or “Matthew effects” in science (Merton, 1968; Allisson & Stewart, 1974). Explanations of the latter type, which suggest that early-career differences in productivity and recognition between scholars may be reinforced over time, naturally lead to expectations on potentially far-reaching effects of differences in the quality of education and training received as a PhD student. Ensuring high quality graduate training is therefore a key concern for science policy. In view of this, it is somewhat discomforting that there is yet limited scientific study on what key factors of graduate training that are linked to early-career scientific productivity of PhDs.

In an important contribution to such study, Waldinger (2010) provided evidence on the widely assumed relationship between the scientific strength of the supervisor and the quality of PhD training. Studies have also shown that supervisors’ recruitment patterns of PhD students also predict students’ productivity, insofar as students’ nationality (Gaule & Piacentini, 2013) and their background in relationship to the supervisor’s scientific network (Baruffaldi et al., 2016) are concerned. From the perspective of science policy, these findings suggest some leverage for directed action – primarily in allocating funding for PhD student training to the most qualified supervisors.

In this study, we extend extant research on early-career research performance. Specifically, we investigate how the early-career success of STEMM (science, technology, engineering, mathematics and medicine) field PhDs is related to the characteristics of the local scientific environment in which they were trained.

In postulating that not only the supervisor, but the wider local academic context, shape academic careers, we draw on a comparatively large body of research which has established that local institutions shape (and are shaped by) research group members. The scope of the group’s reciprocal influence on the individual member may include issues such as what research problems to pursue, what research methods to use and how to disseminate research. In support of such expectations, empirical studies of research groups and departments have recorded that departmental prestige and group leader status (Long & McGinnis, 1981; McCormack et al., 2014; Agrawal et al., 2017), along with resource factors such as access to equipment and research assistance (Kyvik, 1993; Dundar & Lewis, 1998; Ramesh & Singh, 1998) seem to be correlated with the scientific performance of group members. Furthermore, leadership and funding composition of groups have been found to affect both individual research productivity (Fox, 1983; Ramsden, 1994) and the mental well-being (Levecque et al., 2017) of group members, including PhD students.

With the literature on research environments supporting the existence of an important formative effect of successful environments on participating academics, it follows naturally to expect that the local scientific environment has a particularly important role to play as breeding ground for academic careers. We suggest that PhD education better prepares students for scientific work when conducted in a group where the student has ample opportunity for high-quality interaction with other (primarily senior) scientists, and to participate in decision making across the full range of key research decisions. Such opportunity is likely to be linked to the prestige of the group. Furthermore, we argue that the quality of training is systematically linked to the group's composition of staff and funding.

Drawing on a unique combination of survey data, publication records and data on research funding collected from a cohort of Swedish doctoral graduates, the study reports evidence in line with these expectations. In particular, we find that PhD students from groups with a high concentration of PhD students and groups whose funding mix gives significant influence of external funders over the thesis topic choice of students have lower scientific productivity than other students.

The paper is structured as follows. Section 2 develops arguments about why and how the milieu where a researcher was trained may provide important keys to understanding differences in individual early-career success of researchers. In sections 3 and 4, an empirical study undertaken to test these arguments is reported. Section 5 summarises the findings and concludes the paper.

2. The research group and the graduate student

The research question of this study is which research groups that are most likely to spawn successful PhDs. In analysing this question, we are focusing on the following more specific question: What characterizes a group that maximizes its PhD students' opportunities to learn how to successfully pursue scientific research? In tackling the latter question, we move from a view of learning in graduate education as being driven by the quality and intensity of interaction with other scholars (Sinclair et al., 2014). We also postulate that the working conditions of the student, as shaped e.g. by local funding conditions, affect students' abilities to develop into fully proficient scholars.

There is probably no group of scientific staff for which the local milieu is more important than for PhD students. A new graduate student typically enters into the world of science through the projects and research programmes championed by the local research group. New personal networks in the world of science are to some extent built as extensions of networks where group members are already established. Through relationships characterised by asymmetric power between junior and senior members, PhD students are also socialised into adoption of existing norms and practices (Frickel & Moore, 2006; Walker et al., 2008). In particular, the main supervisor potentially exerts significant influence over the student's development of abilities and cognitive orientation (Platow, 2012; Buenstorf & Geissler, 2014). Such processes of enculturation are integral to the research training, enabling students to develop into independent researchers with abilities to pursue and disseminate research.

The above arguments provide a rationale for why scientifically stronger research groups offer better learning opportunities for PhD students (Waldinger, 2010). Groups with strong academic reputation are likely to offer its' students better access to valuable external networks. Furthermore, students' opportunities for qualified localised learning are naturally dependent on the general quality of the scientific environment.

In what follows, we discuss what other observable characteristics of the local institutional environment that may be related to learning. Specifically, we elaborate on the role of staff composition, and funding of the group. We argue that these factors, which have been identified as important predictors of individual as well as collective scientific performance in previous studies (Agrawal et al., 2017; Conti and Liu, 2015), may also be related to students' opportunities to develop into capable researchers.

Group composition

The quality as well as intensity of interaction within a research group can be expected to vary with the size and composition of the group (Shibayama & Kobayashi, 2017). Senior researchers in postdoctoral career phases complement the supervisor as role models, advisors and collaborators. Senior group members may also through their established professional networks facilitate PhD students' contacts to other groups and environments, e.g. opening up opportunities to interact with leading scientific environments. While junior group members may be less relevant in these respects, they may still play important roles for localised interaction. The possibility to study together with and share experiences with other graduate students within the confines of the research group furthermore facilitates students' endeavour to cope with research training. In tasks related to experimental work and to formal coursework in particular, graduate students may well learn from and with their peers.

In view of these argument, small groups may provide inadequate opportunities for situated learning (Dundar and Lewis, 1998). However, it could also be argued that bigger is not always better. Students may well find that opportunities for collaboration and networking within the group declines, as the group becomes too large for members to maintain strong ties between each other. In particular, this would seem likely in an environment where the ratio of PhD students over senior (postdoctoral) staff is high. Students in such groups may experience inadequate attention and support from seniors. They can also be expected to receive less support from seniors in establishing their own external academic networks.

In summary, the intensity of localised interaction and support to establish a personal network beyond the local group may for the individual student increase with the number of seniors in the group (holding the number of PhD students constant), but decrease with the number of students in the group (holding the number of seniors constant).

Funding

Funding for research in some form is a prerequisite for PhD education to take place. More generally, the level of funding that a group has at its disposal will determine the staffing of the group. The total size of a research group, including research assistants and technicians, will therefore be a rather direct proxy for the total *level* of funding available to the group. Still, it may

be expected that the level of group funding affects the publication patterns of PhD students. In particular, groups lacking resources to supply the lab with appropriate equipment and material, and groups where funding issues restricts the opportunities to travel (conference fees, travel costs) may constitute sub-optimal environments for PhD education.

Conditional on a certain level of funding, the funding mix of a group can be expected to influence its research activities (Maxwell & Smyth, 2011). Groups whose funding is derived primarily from education will have less time for research activities, and may therefore offer a lower intensity of local research-oriented learning opportunities for its PhD students. Groups whose funding for research is largely free for the group to dispose as it sees fit may develop its research agenda more flexibly than groups whose research is organized around projects with external stakeholders (e.g. EU funding, industry funding, etc), to the extent that strong dependence on the latter type of funding reduces research productivity (Grimpe, 2012; Banal-Estanol et al., 2015). The latter factor would seem particularly important for PhD students and other junior staff (Gulbrandsen & Smeby, 2005), who are typically engaged with much of the actual lab work specified in research funding contracts. Furthermore, participating in the tasks of identifying, evaluating and choosing between possible research questions may be considered important learning activities for junior scholars (Overall et al., 2011). PhD students funded through an arrangement that narrows down (or ex-ante specifies) the research agenda for their thesis project may have less opportunity for such learning. In particular, students whose PhD was centred on delivering work designed and prioritised by actors outside the research group may not have the opportunity to grow into autonomous researchers able to set out and explore a research agenda of their own.

3. Methodology

The relationship between group-level factors and individual-level early career research performance is tested in the context of STEMM field PhD graduates in the Swedish research system. Field-normalised citations to works co-authored by the (former) PhD student are used as primary measure of research performance, as this measure is traditionally seen as being associated with the individual's standing in the international research community.

Operationalisation of key variables

As main tool for data collection, a non-anonymous survey was directed towards doctoral holders in Sweden. In what follows, we discuss how key variables were operationalised in this survey.

Scientific strength

As empirical proxies for the scientific strength of the local environment, we focus on two complementary measures. First, we collect data on the main supervisor's publications, and on citations to these publications, from the Web of Science. The variable storing this data is named *superv_cit*. Second, respondents were asked to provide an assessment of the group's scientific network (*group_sci*). The following statement was used: "The group had continuous exchange with scientifically leading environments". Responses were given using a 7-degree Likert scale, ranging between "Fully disagree" and "Fully agree". The neutral option in between these positions was anchored "Partly agree".

Group composition

The “research group” of the individual is operationalized as the individuals which the former research student identifies as belonging to his or her local research milieu during graduate studies. The respondents were asked to provide the average number of staff in the research group in the period of his or her studies. Information on four categories of staff was requested separately: 1-Full professors (*professors*); 2-Postdoctoral researchers at all levels (*postdocs*); 3-PhD students (*PhD_students*); 4-Research assistants and technical staff (*technicians*).

Funding

First, we collect data that proxies for the balance of the group’s funding between education and research-oriented sources. For this purpose, we collect data on *grants* awarded directly to the main supervisor of each focal individual. We also ask the respondents of the survey to assess the funding situation of the group (variable *group_funding*). The key statement here was “the group had strong and continuous funding for its research”, to which respondents were asked to provide an answer on a 7-degree Likert scale anchored by the response alternatives “Fully disagree” (1), Partly agree (4) and “Fully agree” (7).¹

Second, we seek to study to what extent funding of the group’s research, and the research of the PhD student in particular, comes in a form that shapes the conditions for research. In order to capture these conditions, respondents are asked to assess two statements. The first of these is formulated as follows “My research was supported by external funders who had decisive influence over the choice of thesis topics”. The second goes one step further to claim “My research was conducted in dialogue with external funders who influenced the choice of methods and the choice of specific research questions”. For both these statements, respondents were asked to state their level of agreement on a 7-degree Likert scale. These responses are coded as *inf_fund* and *inf_fund_meth*, respectively. To frame the first of these responses, two control variables were introduced on the basis of parallel survey questions about the influence of the student her- or himself (*inf_self*) and of the supervisors (*inf_sup*) over the choice of thesis subject.

Our interest here is primarily in understanding how external influence over research through external funding affects the conditions for research training. The level of funder influence may, however, be correlated with the group’s orientation towards collaboration with external stakeholders. This factor may, in turn, affect researchers’ early career publication pattern. Research groups which are closer to practise, in that their research agenda is close to industrial or clinical problems, may foster its student to engage in more applied types of research. To disentangle such effects from the role of direct funder influence over the thesis project, we introduce a set of variables capturing the level of outreach in the group. These include 1) the response to a question where the respondent is asked to assess the statement “The group had good contact with research stakeholders (industry, public authorities, NGOs)” on a Likert scale (*group_ext*); 2) a dummy variable indicating whether the individual was admitted to PhD studies on the condition that the costs of education were born by his or her employer (*adm_employer*); and

¹ Including direct indications of research funding also allows us to disentangle any direct effects of funding on the quality of PhD education from group size (where more funding is used to hire additional staff) and scientific strength (where stronger supervisors are likely to obtain more research funding).

3) the share of the supervisor's publications that had at least one co-author with a non-academic address (*superv_copub*).

Control variables

Beyond measures of these constructs, the data collection procedure was designed to allow the incorporation of key controls related to individual's research productivity.

A range of individual level factors are known to influence research productivity. In particular, there is a broad congruence on age difference in scientific productivity – older individuals having lower incentives to invest heavily in academic publishing (Levin and Stephan, 1991). Across settings, STEMM fields and time, there is also a remarkably consistent pattern of gender differences in publication and citation impact (Xie and Schauman, 1998; Sabatier and Carrere, 2006; Beaudry and Lariviere, 2016; van den Besselaar and Sandström, 2016). Controls for *age* and gender have been therefore been constructed from register data.

In recognition of the possibility that students differ in their ability to develop networks that extend beyond the local research group, controls for the individual's inclusion in organised trans-group collaboration (*res_school*, *exchange*, *mobility*) were constructed.²

Finally, a number of control variables are included on the premise that they are expected to proxy for differences in the ability and ambition of individuals, beyond what is captured by the above variables. This is important, as the presence of any remaining unobserved heterogeneity of this kind that may also be correlated to group and supervisor characteristics threatens to introduce bias into our estimates. While no empirically observed factor may in itself perfectly account for differences in ability and motivation, we are able to collect information on a number of variables that, we would argue, together with the variables already presented above should be able to capture a substantial part of such differences. First, we control for the grade point average (*GPA*) achieved by the focal individuals while in high school. Second, we include a variable denoting the number of university-level *credits* that the individual had earned prior to commencing PhD studies, and a variable counting the number of disciplines that the candidate had spent at least one semester studying at university level (*study_scope*). Thirdly, a set of variables describing the students' admittance into PhD education are included.

Data collection

From official registers, information was collected on all individuals who in the year 2006 received a PhD degree in Science, Engineering Science, Medicine or Mathematics from a Swedish university.³ 1700 individuals were thus selected and a survey was sent out in December 2011. In the survey, respondents were asked to provide information about 1) their background before being accepted into PhD education; 2) conditions and activities during their education; 3) the milieu in which they were primarily active and 4) their professional status in 2011. In order to make it possible to combine survey data with data from other sources, respondents were asked to agree to provide their full name, as well as the name(s) of their supervisor(s). Furthermore, respondents were asked to approve that certain register data (age, location of work in 2011, name

² This refers to “research schools”; a form of network organization which typically receive national funding for both PhD recruitment and for training activities across universities.

³ Individuals who in the same year received a PhD in Economics, Business Administration, Psychology, Law, and Sociology were also included in the survey, but information on this group are not used in the present paper.

of university, grades from secondary education and gender) were provided to the researcher by Statistics Sweden.

After two rounds of reminders, 900 answers were collected. 35 of these had unit nonresponse issues, primarily pertaining to the permission to use personal names for further data collection. Utilising the personal name and complementary information provided in the survey, survey data was matched to our data on publications and citations. For 32 further responses, the name of either the respondent or the supervisor could not be identified with certainty in the publication database. After removing 99 responses from social science PhDs⁴, the usable sample therefore consists of 734 individuals.

Among other items, the survey asked respondents to identify the names of supervisors, keyword description of their area of research, and their 2011 institutional affiliations. Based on this data, additional publication data on publications and citations was collected for each individual and for their main supervisor. Publication records covering the period 2000-2011 was collected in the ISI Web of Science database through manual search.⁵ All citations to these publications up until 2016 were collected and normalized by scientific field.⁶ For the purpose of this paper, only citations to original research articles were included.⁷

Finally, data on all research grants awarded by the main Swedish research funding bodies in the period 2000-2006 was also collected.⁸ From this data, the amount of funding awarded to the main supervisor of the focal PhD student during the period were summarized into the variable *grants*.

Descriptive statistics

Through the combination of survey data with publication and funding information, variables corresponding to major factors identified as determinants of individuals' research impact in previous study (see above) have been made available as controls. Table 1 lists available variables, and Table A:1 in the Appendix provides correlation coefficients. Note that in variables based on respondents' answers to Likert scale questions, a higher value corresponds to a stronger positive position on a certain statement.

Table 1: Variable list

Variable	Description	mean	std. dev.	min	max
1. Background data					

⁴ In view of concerns that the concept of 'research group' as used in the survey may have a more ambiguous meaning in social science than in STEM subjects, we do not further analyse this sample.

⁵ Starting from a list of individuals provided through the survey, manual search of publications in the ISI Web of Science database were conducted. In cases of ambiguity due to naming conflicts or perceived miss-match between publication subject classification and main research area, available on-line material (CVs, biographies, etc) were consulted.

⁶ Through this sampling method, citations to all papers can be observed during a 5-year citation window. A substantial fraction of all papers in natural science, engineering and medicine receive all or close to all citations they will ever receive in this period (Wang, 2013). Highly cited papers may continue to accumulate citations for a long time period, but since we apply the logarithmic transformation to our citation measures, inter-individual variation in citation impact would likely only change very little if a longer citation window would have been applied.

⁷ In particular, publications of the type Letter/Note were not included.

⁸ These were the four major research bodies funded by the Swedish government (the Swedish Research Council, Formas, Fas, and Vinnova), in addition to four major foundations in the area of STEM research (the Swedish Foundation for Strategic Research, the Swedish Cancer Society, the Söderberg foundations, and the Swedish Heart-Lung Foundation).

male	male	.50	.50	0	1
gpa	grade point average from secondary education	16.3	2.0	10	20
credits	number of academic credits before PhD education	226	110	1.5	641
study_scope	number of disciplines studied before PhD education	1.12	0.41	1	4
age	age at graduation	37	8.4	27	66
mathematics	PhD in mathematics	0.03	0.16	0	1
science	PhD in natural science	0.32	0.47	0	1
engineering	PhD in engineering science	0.20	0.40	0	1
medicine	PhD in medicine	0.45	0.50	0	1
2. Admittance to PhD education					
adm_open	admitted in open competition	0.30	0.47	0	1
adm_internal	admitted after contact with department	0.52	0.50	0	1
adm_employer	admitted through agreement with non-academic employer	0.05	0.22	0	1
adm_other	admitted under other circumstances (base category)	0.13	0.30	0	1
3. Motives for undertaking PhD education					
mot_sci	to contribute to the advancement of science	5.4	1.6	1	7
mot_know	to increase own knowledge	6.2	1.1	1	7
mot_work	attractive working conditions (autonomy, flexible working hours)	4.9	1.9	1	7
mot_career	career opportunities after degree acquirement	5.6	1.6	1	7
experience	opportunities to exploit previous professional experience	3.1	2.5	1	7
4. Influence over thesis subject, methodology and research topics					
inf_self	individual had high influence over the choice of thesis subject	4.8	2.0	1	7
inf_sup	supervisor had high influence over the choice of thesis subject	4.9	1.9	1	7
inf_fund	external funders had high influence of the choice of thesis subject	2.4	1.9	1	7
inf_meth_fund	external funders had high influence over the choice of methodology and specific research topics	1.9	1.6	1	7
5. Conditions during PhD education					
exchange	individual made a shorter (two-six months) academic visit to another research environment	0.18	0.38	0	1
mobility	individual spent more than six month in another research environment	0.11	0.32	0	1
professors	number of full professors in group	1.6	1.2	0	8
postdocs	number of other postdoctoral staff in group	2.8	2.5	0	15
PhD_students	number of PhD students in group	5.3	5.1	1	50
technicians	number of technical / administrative support staff in group	1.2	1.9	0	20
group_funding	group had strong funding for research	4.9	1.9	1	7
group_sci	group had continuous exchange with leading scientific environments	5.0	1.7	1	7
group_ext	group had continuous exchange with stakeholders outside academia	4.2	2.0	1	7
res_school	individual was included in “research school”	0.17	0.38	0	1
grants	sum of external grants awarded to supervisor 2000-2006 (SEK)	3.2·10 ⁶	7.8·10 ⁶	0	7.2·10 ⁷
superv_cit	field normalised citations to the supervisor’s	48.8	67.9	0	773

	publications				
superv_pub	number of publications co-authored by the supervisor	36.0	37.9	1	383
superv_copub	share of supervisor's publications co-authored with non-academic co-authors	0.21	0.24	0	1
6. Situation after education					
academic	individual works in academia in 2011	0.38	0.49	0	1
citations	field-normalised citations to the focal individual's publications	8.23	15.0	0	205
publications	number of publications co-authored by the focal individual	6.9	7.5	0	95

Table 1 shows that the average group consisted of 1 or 2 full professors, 2 or 3 postdoctoral researchers (including associate or assistant professors), 5 PhD students and 1 technical support staff. The average student reports that the group had adequate funding and good scientific networks, and that research funders had limited influence over their thesis work. Further investigation shows that 27 % and 19 % state that research funder had relatively high (4-7 on a 7-grade scale) influence of the thesis topic and methods, respectively.⁹

The average individual furthermore had co-authored 7.6 full papers which jointly received 9.6 field-normalized citations from other papers in the Web of Science database. Further investigation reveals that 27 individuals, corresponding to 3.7% of the sample, had no publications listed in the Web of Science database. A further 32 individuals, corresponding to 4.4% of the sample, had not received any citations to their publications. Thus, the dependent variable is subject to a limited degree of censoring.

Modelling

A field-normalised count of citations to publications authored by the individual is modelled as being logarithmically related to the variables listed in panels 1, 2, 4 and 5 of Table 1, as well as to the variable *academic* of panel 6. In view of the censored nature of the dependent variable, a tobit estimator is used.

An individuals' tendency to remain employed in academia after their PhD may be related to the quality of research training discussed in the key hypotheses, and as such, the variable *academic* is likely to be subject to endogeneity bias. We are not directly interested in the estimate on this variable per se, but in order to avoid any confounding impact on the estimates of key variables of interest, we choose to instrument it. For this purpose, we use the variables relating to the motives for undertaking PhD studies (panel 3 of Table 1), which were shown to be related to the career paths of PhDs by Mangematin (2000). These are only related to publication and citation outcomes through their influence on the individual's likelihood to remain employed in academia and as such suitable as instruments. Tests for underidentification and overidentification are

⁹ This figure matches well to results from a survey sent out to 2 400 PhD supervisors by Statistics Sweden in a time period matching that of our survey (ST, 2008). In this survey, roughly 40 % out of five STEM supervisors state that funders have non-trivial influence over the research topics of their students. Only 4 % indicate that funders influence the choice of methodology.

passed with a wide margin. We also conduct a weak identification test, which shows that the instruments pass the strictest Stock-Yogo critical value for testing against weak instruments.¹⁰

As the instrumented variable *academic* is dichotomous, we estimate our IV-tobit model in a 3-stage setting. We first regress *academic* on the full vector of independent variables, including the set of instruments, using a probit model. Results from this step are presented in the Appendix. Subsequently, we estimate a two-step tobit model where the predicted, continuous value of *academic* is included in the first stage equation.¹¹

4. Results

4.1 Selection into academic careers

While not a key focus of the present paper, our results on selection into and out of academic careers, as presented in the Appendix (Table A:2), deserves a quick summary here.

First, we note that PhDs stating that their entry into postgraduate studies was motivated by their interest in acquiring greater personal knowledge in the field of their studies (*mot_know*), and/or by the flexibility and independent nature of academia (*mot_work*), are more likely to be working in academia five years into their postdoctoral career.

Second, we find – in line with Hottenrott and Lawson (2017) – indications that group strength (*group_sci*) is associated with the likelihood of pursuing an academic career. The picture here is somewhat mixed, however, with some evidence of a negative relationship between supervisor strength (*superv_cit*) and the outcome *academic*=1.

Third, we also find that respondents who state that external funders had significant influence over their choice of thesis topic (*thesis_fund*) are more likely to stay in academia. We can only speculate as to the interpretation of this finding, but perhaps are such PhDs in a position to learn how to manage large multi-stakeholder research projects such as e.g. those funded through the European Commission’s Framework Programmes. As such, their skills may make them more attractive for postdoctoral employment in large projects, and better positioned to participate in applications for further such grants.

4.2 Main results

We next turn to our main results. Table 2 reports coefficient estimates from the second stage of the instrumented tobit model. These correspond to the marginal effect of the respective variable on the latent variable (i.e. the non-observed variable for which the positive realisations correspond to the number of observe citations). In our context, where less than one in ten observations are subject to censoring, these will be fairly close approximations to the marginal effect of the independent variables on the citation impact of each focal individual.

¹⁰ These tests are conducted using the *ivreg2* package for Stata. The main model is estimated with this module, using the full information maximum likelihood procedure. As the first-stage equation in our model is linear, the tests reported by *ivreg2* are valid also for our results, which are produced by the *ivtobit* module.

¹¹ Model residuals pass a test for being normally distributed.

Both indicators of the group's scientific strength (*superv_cit*, *group_sci*) are strongly related to the citation impact of the focal (former) PhD student. Furthermore, the citation impact decreases with the number of *PhD_students* in the research group where the individual was trained, all else equal. We find statistically weaker tendencies pointing towards that the presence of postdoctoral staff is positively associated with citation impact. This is in line with our argument that postdoctoral researchers may serve as role models, advisors and collaborators for PhD students in their group. We also find some evidence of a negative association between the presence of *technicians* in the group and PhD student citation impact. The number of full *professors* in the group is not found to have an effect on success in establishing an early-career publication track record.

Moving next to results regarding group funding, we do not find any indication that differences in the level of funding available to groups, beyond what is captured by differences in group composition, determines the citation impact of their PhD students. That is, neither the variable based on students' subjective assessment of funding (*group_funding*), nor the externally validated measure of grants obtained (*grants*) would seem to be related to the research performance of PhD students. However, students whose research was funded by an external arrangement that placed influence over the choice of thesis topic in the hands of funders performed worse than their peers for whom the choice of thesis subject was at the discretion of themselves and/or their supervisors.

Table 2: Determinants of research output for recent graduates. IV-tobit coefficients, second-stage results. Dependent variable: $\ln(\text{citations})$

	Dependent variable: $\ln(\text{citations})$
Scientific strength	
$\ln(\text{superv_cit})$.176*** (.035)
<i>group_sci</i>	.077*** (.026)
Group composition	
<i>professors</i>	.014 (.037)
<i>postdocs</i>	.037* (.020)
<i>PhD_students</i>	-.025** (.010)
<i>technicians</i>	-.038* (.023)
Funding	
$\ln(\text{grants})$.000 (.006)
<i>group_funding</i>	-.002 (.022)
<i>inf_fund</i>	-.057** (.026)
<i>inf_fund_meth</i>	.031 (.030)
Controls	
<i>inf_self</i>	-.023 (.022)
<i>inf_sup</i>	-.038 (.024)
<i>group_ext</i>	-.023 (.025)

superv_copub	.228 (.171)
academic	.813** (.331)
male	.234*** (.077)
gpa	.065*** (.020)
credits	.000 (.000)
study_scope	.079 (.088)
age	-.017*** (.006)
adm_open	-.129 (.097)
adm_internal	-.053 (.085)
adm_employer	.015 (.183)
exchange	.109 (.095)
mobility	.006 (.125)
res_school	-.141 (.102)
University fixed effects	YES
Discipline fixed effects	YES
Wald chi2(30) test statistic (test of model)	168.75***
Wald chi2(1) test statistic (test of exogeneity)	2.32

*N=734. Legend: *, ** and *** denotes 10%, 5% and 1% level of significance, respectively.*

In terms of magnitude, the effects on group composition and funding would seem to compare relatively well to the effect of group strength. We note that the effect of a one standard deviation increase in *PhD_students* is estimated to be equivalent to an increase in *superv_cit* by 0.8 standard deviations.¹² The corresponding relationship for funder influence is that a one standard deviation increase in *inf_fund* is equivalent to a 0.7 standard deviation increase in *superv_cit*.¹³ We conclude that our results point towards the existence of non-trivial trade-offs, where a student for example may face better training prospect in a slightly less prestigious group with a low student-staff ratio, than in a more prestigious group where they have to share senior attention with a large group of fellow PhD students.

As regards results on our control variables, we note that university employed (*academic=1*) have substantially more citations than those working in a non-academic job. This is hardly surprising, considering this group has had up to five more years of work in a positions where academic publishing is considered a key activity. The individual's gender (*male=1*) and *age* are also related to citation impact. This reflects the persistent gender gap in science, and the relatively lower incentive of PhDs who graduate well into their 40s or above to focus on academic publishing. It is also interesting to note that academic results from secondary-level education (*gpa*) have predictive power on results from graduate studies. A one-standard deviation increase in grade

¹² A one standard deviation increase in *PhD_students* is associated with roughly 13 % fewer citations.

¹³ A one standard deviation increase in *inf_fund* is associated with roughly 11 % fewer citations.

point average in a type of education normally finalised at the age of 18-19 is associated with roughly 14% more incoming citations to research co-authored by the individual.

4.3 Robustness tests

We conduct five sets of analysis to ensure the robustness of our results. In the first of these, we investigate alternative outcome measures. These include publication counts, fractionalised publication counts, and fractionalised (field-normalised) citations.¹⁴ Publication counts are less skewed than publication quality measures (Stephan and Levin, 1991). While our field-normalised citation counts measure is thought to convey more information, publication counts may therefore provide a more robust indicator of successful graduate training. Fractionalised measures, where the underlying bibliometric measure is distributed equally across all co-authors of a publication, provide useful alternative performance measures, where individuals who only co-author in large groups are attributed relatively less weight. Across these specifications all results remain similar to those reported in Table 2.

Our second set of robustness analysis concerns how estimates on our key i.v.s respond to the use of different estimators. Results from the IV-tobit estimator are contrasted to results from estimation using 1-OLS, 2-ordinary tobit and 3-2SLS models. Results, which are available on request, shows that the estimate on *academic* varies substantially between the first two models and the models where this variable is instrumented. Coefficient estimates also differ between the models in the order of 25-33 percent, but the signs and significance levels remain the same.

Thirdly, we subject the sample to variable trimming. In this set of robustness analysis, we first drop the 28 observations where respondents have reported having belonged to research groups with more than 30 members. We do this in view of these observations being potentially misleading, as the respondent may have provided information about an organisational unit (department, center, etc) rather than their immediate environment. Furthermore, we windzorize the dependent variable at 100 field-normalised citations. Finally, we replace all variables created from 7-grade Likert scale questions into dichotomous variables indicating whether the individual has provided a strong affirmative response (6 or 7) to statements about funder influence, etc. Again, all key results remain similar to Table 2.

Fourthly, we include three further control variables documenting the post-graduation career trajectories of our focal individuals. These include a variable indicating to what extent the individual's current professional activities is related to work done during the PhD, along with two variables describing post-graduation mobility. Mobility is associated with ambition and scientific ability (Horta et al., 2010), but can also occur as a response to limited success rather than as an expression of ability. Either way, mobility can be expected to be associated with adjustments costs for the individual (Cruz-Castro & Sanz-Menéndez, 2010). As suggested by evidence presented by Fernandez-Zubieta et al. (2013), these effects may well cancel each other out also over the long run. Consistent with such an expectation, we find that individuals who have conducted a postdoc abroad are not significantly more productive than other individuals, and that individuals who in 2011 were located in the same city as where they finished their PhD are

¹⁴ Covariates remain the same as in our main model, with the exception that the measure of supervisor publication performance is changed to match that used as independent variable.

16% more cited than their mobile peers. More importantly, however, estimates on our key variables are not affected by the inclusion of these variables.

Fifthly, we explore whether our results are driven by students from lab-intensive contexts. In subjects where PhD work is primarily carried out in team-based laboratory work, the relationships between group composition, funder influence and the quality of training can be suspected to differ from the main patterns that were established above. To test for such differences, we introduce a dummy variable for students in lab-intensive subjects and interact this variable with our key independent variables. The coefficient estimates of these interactions are found to be insignificant (p : 0.538, 0.610), which suggests that the effects of group composition and funder influence are not driven by specificities of lab-based PhD studies.

4.4 Additional analysis

The analysis of this paper is focused on the idea that there are important differences between research groups in the quality of training offered to PhD students in the group, and that such differences are systematically related to not only the academic standing of the group, but also to the group's composition of funding and staff. Our empirical analysis has verified that such patterns exist. But can we be sure that these patterns are driven by differences in the quality of training? In this section, we discuss two possible competing mechanisms: systematic differences in pre-education ability and motivation and temporary publication advantage. We also exploit publication data to directly test the corollary that group composition affects students' ability to build their personal academic networks.

4.4.2 Lower quality training or selection?

Thus far into our analysis we have relied on our rich set of controls to take care of any individual heterogeneity in terms of ability and motivation which is not related to experiences during PhD studies (treatment), but rather to innate inter-personal differences.¹⁵ However, if these controls do not pick up the full extent of differences, and such remaining differences are systematically related to group characteristics, our estimates may be subject to bias. This may be the case, in particular, for our variables on group strength. It does not seem unlikely that supervisors with superior academic status are able to attract PhD students of greater ability and motivation. Estimates on group strength in table 2 are therefore likely to reflect a combination of selection effects and treatment effects. We would argue that such concerns are not likely to affect our estimates on group composition and the composition of group funding, since neither factor in their own right is likely to play important roles in the matching between students and supervisor.

Judging by free text responses from our survey about the path to the PhD position, very few of the PhD students in our sample had been 'shopping around' to find the best possible group and supervisor. Overall, impressions from our survey come close to those of Azoulay et al. (2017), who investigated PhDs' choice of postdoc mentor: the process of matching is one characterised by "local search in delimited scientific and geographic spaces, coupled with the intervention of

¹⁵ Regressing the variables *PhD_students* and *inf_fund* on all group-level covariates at our disposal gives R²-statistics of 0.54 and 0.18, respectively. The remaining variation in students and funder influence are group idiosyncrasies, reflecting different preferences and research settings. This variation is the basis for our main identification strategy

chance encounters”¹⁶. In view of this, we find it unlikely that students would to any significant extent base their decision about accepting a PhD student position on factors such as research group composition or the nature of the group’s funding.

In further efforts to make sure that our results are nonetheless driven by individuals actively searching and choosing between different potential research groups, we remove all individuals who stated in the survey that they were admitted in open search and did not have previous connection to the research group into which they were eventually admitted. These constitute 24 percent of the sample. Our results are confirmed to hold with great precision also after this reduction.

4.4.2 Lower quality training or temporary disadvantage?

It would be possible to obtain our main results if group composition and funding would be related to temporary disadvantages to students’ publication activities, even if these disadvantages were not directly tied to inferior opportunities for learning. To investigate this issue, we exploit time-variation in our data. We split our measure of academic performance up into periods, by constructing measures of citations to publications published 1) during or just after the PhD (up until 2006), and 2) between 2007 and 2011.

Temporary disadvantage should only affect period 1, whereas a learning disadvantage of the forms discussed in section 2 affects both periods. If the main (negative) effects discussed above are driven by temporary disadvantage (less opportunity to publish during PhD), we should observe 'catch-up' in the second period. That is, conditional on publication performance in period 1, the individual from groups with many students and with funder influence should be more productive than the average individual in period 2. If, on the other hand, the main effect also contains an important element of learning disadvantage, students from such groups should do no better - possibly even worse - than the average student (conditional on period one performance).

The theory of accumulated advantage in science (Merton, 1968) suggests that period 1 performance should be an important predictor of period 2 performance. Period 1 performance is tied to condition during and before PhD studies, and the time-invariant demographic factors. We hence construct a two-stage model, where period 1 is modelled as a function of the full set of covariates used in Table 2, and period 2 performance is modelled as a function of period 1 performance along with variables describing the group’s composition of staff and funding.¹⁷ Results for the second stage of this regression are shown in Table 3. The coefficients reported in this table may be interpreted as reflecting potential associations between conditions during PhD studies and deviations from the trend of expected performance in period 2, given period 1 performance.

¹⁶ Regarding geographical mobility, we are also able to conduct some further investigation on the register data from which our survey population was drawn. We find that a full two thirds of all PhD students who graduated in 2006 were in 1997 already living in the same region as that of their graduating university, or moved there from an adjacent region where PhD level education was not offered.

¹⁷ Note: We run this analysis only for the set of individuals who pursue an academic career throughout period 2 in order to avoid conflating the (endogenous) choice of career path with academic performance.

We do not find clear indications that the composition of the research group where the individual studied would affect between-period performance changes. Neither do we find indications that funder influence over the choice of thesis topic would be associated with catch-up. This suggests that we cannot attribute our main results to temporary disadvantage.

Table 3: Key covariates as potential moderators between performance in the pre- and post-graduation periods. Second-stage results.

	Dependent variable: ln(citations to publications published 2007-2011)
ln(citations to publications published before 2007)	.987*** (.168)
ln(superv_cit)	.122* (.063)
professors	.054 (.064)
postdocs	.036 (.029)
PhD students	-.006 (.016)
technicians	-.033 (.032)
inf_fund	-.011 (.040)
inf_fund_meth	.066 (.050)
inf_self	-.045 (.036)
inf_sup	-.143*** (.040)
constant	.600* (.364)

*N=270. Legend: *, ** and *** denotes 10%, 5% and 1% level of significance, respectively.*

Table 3 also shows that conditional on period 1 performance, supervisory influence over the thesis is negatively related to period 2 performance. A possible interpretation is that while supervisory influence may orient the students towards ‘solvable’ problems during the PhD, it may also hamper the development of autonomy. Being allowed to participate in decision making about key objectives during the PhD studies would indeed seem to (also) offer above-average opportunities to learn the tricks of the trade needed to establish a successful early-career research program.

Finally, we find signs that the overall positive influence of supervisor scientific performance is further enhanced over time, beyond the predictions of accumulative advantage theory. This finding supports an interpretation of a supervisor effect going beyond a one-off increase in visibility accruing to the students of prominent supervisors (Waldinger, 2010).

4.4.3 Access to scientific networks

We have argued that one of the key benefits that PhD students accrue from members of their local research group is access to external networks. Exploiting publication data, we are able to directly test how this argument relates to our key variables. Specifically, we investigate how group composition and funder influence relate to the breadth of co-publication networks of our early career scholars. For this analysis we construct two new measures: 1) the average number of

authors per publication, and 2) the number of nationalities represented by authors of the average publication. Table A:3 in the Appendix presents results from this analysis. The average number of co-authors and the international scope of the focal individual's co-author network both increase in the number of postdoctoral staff in the groups, and decreases by the number of PhD students. Estimates fall in the range of 1-2.5 percentage points change per additional group member. Group strength (*group_sci*) and, interestingly, high-school *GPA* are also positively associated with both measures of co-author breadth.¹⁸ We do not find strong associations between funder influence over the thesis topics, and the breadth of co-authorship networks. We do, however, pick up a negative association between students' own influence over their thesis topic (*inf_self*) and the number of co-authors.

Since our models include a separate (strongly significant) control for the scientific network of the group (*group_sci*), our findings would seem to suggest that while the group's networks are indeed affecting the co-authorship patterns of junior group members, students trained in groups with many other PhD students have less opportunity to benefit from these networks. This is fully in line with our argument that students in 'unbalanced' groups may suffer from reduced attention and support from senior scholars.

5. Conclusions

Early career success in scientific publication is a strong predictor of a researcher's ability to establish herself and to contribute recognized research in later career stages (Petersen et al., 2012; Horta and Santos, 2016). For decision makers at all levels of academia and in funding bodies as well as in the authorities that regulate the funding of universities, it is therefore vitally important to understand how to provide the best possible premises for PhD student training and education. In this study, we study how early career research performance are shaped by the research group to which PhD students belong during their studies. Specifically, the study addresses a key concern for university leaders and research funding bodies seeking to allocate funding for PhD education across various research groups: By what criteria may we assess the potential of a research group as breeding ground for early-career success of PhD students?

Drawing on data on a cohort of STEMM field PhD graduates from Sweden, group-level characteristics are correlated to the citation impact and research productivity of the students five years after they successfully defended their thesis. Whereas previous studies have focused exclusively on how scientific strength and status are inherited between supervisors and their students, this study sets two further sets of factors in focus: the composition of funding, and the composition of staff.

We report evidence suggesting that PhD students whose thesis work is shaped by the nature of the (external) funding for the thesis, in the sense that the choice of thesis subject is decisively shaped by the conditions for funding, are more likely than other PhD students to remain within academia. Conditional on the employment situation, however, their performance is significantly lower than that of PhDs whose thesis subject is exclusively shaped by themselves and/or their supervisors. Furthermore, we find that the composition of the research group plays a significant

¹⁸ For the international breadth of co-authors, we also find negative associations to strength of group external networks (*group_ext*), and positive associations to supervisor strength (*superv_cit*), *age* and *grants*.

role in explaining the research performance of PhD students. Our results suggest that all else equal, groups with many PhD students are less potent training grounds for aspiring researchers.

This paper is among the first to study how micro-level institutional characteristics correlates with early career performance of PhD students trained in those groups. As such, it offers novel evidence on the formative years of scholars. In particular, the analysis offers two contributions to extant literature on scientific careers.

First, it shows that research group composition plays a role for the outcomes of PhD training - specifically in terms of early-career research performance. This finding suggests the need for further work investigating how research groups operate, and what elements of local interaction that are most important for successful PhD student training.

Secondly, the paper offers novel evidence which extends previous results on how funding conditions affect scientific performance. Azoulay et al. (2011) demonstrate that scientists enjoying grants allowing them considerable freedom to experiment and change course are more likely to publish high-impact articles. This paper shows that PhD students whose funding situation does not tie their work to specific research questions on average become more highly cited.

Our analysis offers two major insights of value to higher education policy. Decision makers tasked with assigning PhD student funding to supervisors would be well-advised to consider both the scientific merit and the present third cycle teaching load of available supervisors. A star scientist already advising a large number of students may be a less useful supervisor than a somewhat less prominent but less overburdened professor. For funders of PhD research, our findings suggest that there exists a trade-off between two potential objectives: to “get what they want” in terms of research content and to foster academically successful PhDs. Together, our results suggest that there is significant room for improvement of graduate training by redistributing resources and PhD students within the academic system, and by re-considering the conditions of certain funding arrangements.

However, the analysis also comes with inherent limitations regarding our ability to show beyond doubt that our results are not affected by selection. The latter mechanism is related to any differences in personal ambition and innate ability that exist before individuals are enrolled into graduate studies. In the analysis of individuals’ citation impact and research productivity, we are able to include a rich set of control variables which are likely to be correlated with unobserved differences in innate ability. Such variables include achievements in secondary and tertiary education, supervisor and group status, and university fixed effects. These variables are jointly significant across specifications, and do as such pick up a significant portion of the total selection effect on citation impact and research productivity. In further analysis, we do not find clear signs of selection as affecting our results on group composition and funding. We must nonetheless remain somewhat cautious about our ability to interpret our results as causal effects in the sense that they should be seen as representing the average treatment effect of the treated (ATT). In other words: while our results can certainly be argued to reflect a difference in outcome that a research funder may expect from funding a PhD project in research group, taking into account that the two groups may recruit different candidates, further research is needed to validate that they also reflect the difference in outcome that a prospective student would experience by being

trained in group A rather than in group B. To achieve this aim, scholars interested in understanding the quality of PhD education should seek to invent and apply novel identification techniques, e.g. allowing to recover the process of matching between student and research group (c.f. Azoulay et al., 2017).

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