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Science after Communism: Peers and Productivity in East German Science*

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Abstract

We analyze the role of complementarities in collaboration and academic productivity using a unique dataset on East German scientists' publications in fields of science, technology, engineering, and mathematics (STEM) after the German re-unification in 1990. We focus on East German scientists' connections to their peers, their scientific productivity and impact as measured by the number of publications, citation accumulation, and the quality of journals where they publish. East German scientists show a significant convergence to their West German peers in all productivity accounts. We use the similarity of research portfolio to West German research in 1980s as identification and find that the effect of losing a collaborator on the productivity and collaborations of East German scientists differs with respect to their complementarities. Moreover, we find East Germans who collaborated with Soviet scientists on non-Western research fields during the 1980s are significantly more likely to re-wire their collaboration networks towards Western Europe and the US in 1990s and 2000s. They are also more likely to switch their field of research and collaborate with West Germans who moved to an East German university or research institute after the re-unification.

JEL Classification: J61, O33

Key Words: Peer-Effects; Productivity; Institutions; Migration; East Germany

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1 Introduction

Technology and innovation are the main drivers of sustained economic growth as they provide a significant edge in international competitiveness (Verpagen, 2006) and it is crucial to understand their complex dynamics. Although it is hard to pin down every single factor that goes into the production of new ideas (Jones, 2005), it has been shown that collaborative interactions (Singh, 2005), team formation dynamics (Jones et al., 2008, Wuchty et al., 2007) and institutional environment (Heinze and Kuhlmann, 2008, Kim et al., 2009) play a significant role in innovation above and beyond what can be explained by qualities of individuals alone.

Academic research in natural sciences and engineering provides a solid fundament for new technologies and thus fuels innovation. Collaboration in academic research is important to overcome constraints of individual expertise or institutional capacities on the creation of impactful research as shown, for instance, by Jones (2009) using patent data from 1963 to 1999 and by Lariviére et al. (2015) using journal publication data covering 110 years from 1900 onwards. Despite the evidence on the growing importance of collaboration and research teams, the literature on peer effects delivers findings that look contradicting at first sight. On the one hand, Borjas and Doran (2012) show that the influx of Soviet mathematicians in the US after 1992 had negative productivity effects for US mathematicians, and Waldinger (2011) finds no effect of Jewish scientists' emigration in 1930s on their remaining colleagues at German universities during that time. On the other hand, Azoulay et al. (2010) shows that the loss of a very productive peer significantly reduces the productivity of their collaborators; Ductor (2015) finds statistically significant and positive productivity effects of research collaboration; Moser et al. (2014) show that the influx of Jewish emigres who fled the Nazi Germany to the US significantly increased the productivity of their peers in the US.

The above mentioned seemingly contradicting findings are put into context brilliantly by Borjas and Doran (2015b) where the interaction of peers is shown to give rise to two competing forces, namely, having to compete against peers (such as faculty positions, funding, journal space, or simply the attention of the scientific community) puts a downward pressure on one's productivity whereas spillover of ideas increases productivity. Hence the sign of the net peer

effect on productivity is determined by whichever of these two competing forces dominates the other. Borjas and Doran (2015b) show that spillover effects dominate competition effects if the lost collaborator has a very high productivity. In line with the idea of the above mentioned two competing forces being at play, Azoulay et al. (2019) show that the death of a star scientist affects the productivity of their peers adversely while the productivity of their non-collaborators increases.

In this paper, we investigate complementarities in collaboration and show these to be at least as important in driving productivity as collaboration with highly productive collaborators or stars. Collaboration with stars is not an option for most of the scientists, but a productive and beneficial collaboration can be an option for many scientists, if they can sufficiently and mutually benefit from their complementarities. We contribute to the literature on peer effects by showing how complementarities, as measured by research similarity, affect collaboration and productivity.

To analyze the role of complementarity in collaboration and scientific productivity, we make use of a large scale institutional shock in German academia during the re-unification of Germany in 1990. We analyze the productivity effects of sudden and unexpected changes brought about by the fall of the Berlin Wall and the German re-unification on East German scientists. The era from November 1989 until mid-1990s for East German scientists is best described by freedom of movement and communication as well as large scale institutional restructuring that brought new opportunities for collaboration but also job insecurity at the same time. A significant institutional re-structuring requires significant re-adjustment. Focusing on East German scientists who were active around this period, we investigate how East German scientists did adjust to western style academic structure, how this affected their productivity. Moreover, what impact was made by the sudden availability of potential peers and collaborators, not only as a result of East German scientists' freedom of movement and communication but also as a result of the large influx of West German scientists to East German universities and research institutes. East German scientists got the opportunity to freely collaborate with Western scientists, that is, West Germans, West Europeans, and scientists from the US, after the fall of the Berlin Wall in November 1989 and more so at an

institutional level after the German re-unification in October 1990. How did this affect the scientific productivity of East German scientists?

Archambault et al. (2017) analyze East and West German scientists' publication patterns from 1980 to 2000 and show a significant convergence (or rather catching up) of East German scientists with their West German peers. This is a significant achievement, especially considering Kozak et al. (2015) where members of the pre-1990 eastern block, except for East Germany, are shown to have experienced no significant improvement compared to their productivity and impact levels under the communist regime. An important revival in the scientific productivity of most of the East European countries is shown be linked to interactions and collaborations with the European Union (Jurajda et al., 2017).

We open up the black box of East German convergence process and use this natural experiment to establish causal relations between collaboration and productivity by focusing on East German scientists' connections to their peers, their scientific productivity and impact as measured by the number of publications, citation accumulation, and the quality of journals where they publish. East German scientists show a significant convergence to their West German peers in all productivity accounts after re-unification. East German scientists with higher similarity of research portfolio to West German research in 1980s publish in journals with high impact factors, but they do not diverge from their East German peers in terms of publication and citation counts. East Germans who collaborated with Soviet scientists on non-Western research fields during the 1980s are significantly more likely to re-wire their collaboration networks from USSR towards Western Europe and the US after 1990.

In addition, we investigate the cognitive mobility of East German scientists. Cognitive mobility is the switch of a researcher to a new subfield where they have not been active before. Borjas and Doran (2015a) show that US mathematicians who experienced a large influx of Soviet mathematicians into their specific research area in 1990s moved away from these areas to new research topics. Such mobility in the space of ideas can also be an optimal response by East German scientists to changes in the institutional setting after 1990. We document relations between East German scientists' expertise, qualities, collaborations, and their propensity to switch to a new subfield. Although East German scientists with a similar

portfolio to West Germans are less likely to switch their field, those who lost a previous collaborator are more likely to do so.

The remainder of this paper proceeds as follows. In Section 2, we describe the historical background of East and West German academic structures and the harmonization of the two German states' university systems post-Reunification. In Section 3, we describe the data, present descriptive findings on productivity differences of East and West German scientists, and we explain the identification strategy. We present our main analysis in Section 4 where we investigate East German scientists' productivity, collaborations, and field of activity. Section 5 focuses on a specific subset of East German scientists, namely those who hold a professorship in the East after 1990. Section 6 concludes.

2 Historical Context

Collaboration opportunities between East and West German scientists were very limited, which was primarily due to the political climate of the cold war. After the Berlin Wall was erected in 1961, East and West German scientists' collaborations came to a sudden halt (Sabel, 1993). East German scientists have been collaborating exclusively with scientists from their East European and Soviet allies from then on. An agreement that came to force in 1975 made it possible to collaborate with West German scientists, although under extremely restricted conditions. The bilateral agreement of scientific and technological collaboration (*wissenschaftlich-technologische Zusammenarbeit -WTZ*) of September 1987 between East Germany and West Germany aimed at easing some of the extreme restrictions of the 1975 agreement and make interactions between East and West German scientists on major research projects more of a practical possibility (Wissenschaftsrat, 1990). According to Wissenschaftsrat (1990) the WTZ agreement has given rise to collaborations on about 60 projects between East and West German scientists until July 1990. Considering that the intra-German border opened in November 1989, it is plausible to expect that a non-negligible portion of the above mentioned 60 collaborations as of July 1990 contains interactions after the opening of the border.

The WTZ agreement continued to provide the main guideline for collaborations between East and West German scientists until the official re-unification in October 1990 which brought about the heavy task of unifying academic systems of the two countries. This process caused great disruption in the scientific environment of East Germany as the process involved an enormous amount of reshaping and rescaling of East German science as well as a thorough re-evaluation of East German scientists.

The academic system in the post-war West Germany was based on that of the Weimar Republic before 1933 which was rooted in the *Humboldtian* ideal of the unity of higher education and academic research (Günther and Schmerbach, 2010). This structure was considered *essentially healthy*[1] and thus, apart from de-Nazification and infrastructural rebuilding, a return to the traditional federal education system was deemed appropriate where universities became the responsibility of *Bundesländer*, the German federal states. A science council that exists until today was formed in 1957, consisting of representatives from the federal states and the federal government. The following decades saw different dynamics of reconstruction, expansion, some reforms as a result of the 1970 student movement and, in the 1980s, rising student numbers and stagnant numbers of academic personnel (Kehm, 1999).

In contrast to West Germany's federally structured and *Humboldtian* academic system, the post-war East Germany replaced the traditional institutional autonomy of higher education with a central education system run by the state secretary office and introduced Marxism-Leninism as mandatory part of every higher education curriculum in 1960s (Kehm, 1999). East Germany followed the Soviet system to introduce a clear separation between higher education and research. Universities were primarily oriented towards training of students to accommodate the needs of the East German centralized economy. For this aim, the industry and universities worked closely together, the size of university programs was adapted to economic needs and alumni were centrally placed into the job market. The institutes of the *Academy of Sciences -Akademie der Wissenschaften (AdW)* were mainly responsible for research and development, including the administration of doctorate and *habilitation*

[1]The phrase *essentially healthy* is our own translation of *im Kern gesund*, a phrase coined by the Prussian minister of education Carl Heinrich Becker with respect to the university system after the First World War and widely re-used, e.g. by Kehm (1999), in describing the university system after the Second World War in West Germany.

processes and even (although not exclusively) the appointment of professors (Kocka, 1994, Wissenschaftsrat, 1990).

After the re-unification of the two German states in October 1990, the structure of West German university system was largely applied to East German universities. The division of subjects and disciplines of East German universities was adapted to West German standards and there was a substantial reform in the personnel structure. All university personell and personell of research institutes within *AdW* were reviewed and evaluated politically and scientifically (Kocka, 1994, Sabel, 1993). If the outcome of staff reviews were negative, as was the case in most subjects that were political or close to politics, the academic in question was dismissed. It is possible that the outcomes of political and scientific reviews were somewhat linked, since some of the ruling party (SED) members were appointed for their political loyalty instead of relevant qualifications. This link could also give a possible explanation as to why the share of SED members was 63% in university staff and only 13% in East Germany's total population (Schattenfroh, 1993). It must also be noted that East German scientists were held up to very different standards before the re-unification where competition and mobility was discouraged, publication opportunities in Western journals were either restricted or not possible at all, especially in case of social sciences (Günther and Schmerbach, 2010), meaning that a politically positive evaluated scientist might fail the scientific review simply because the measure of good quality is now much different than what it used to be just a couple of years ago.

The academic staff members that remained in the social science departments often had difficulties to adapt to the substantial changes in their disciplines and to the orientation towards the western academic paradigm. While adjustment in relatively ideology-neutral subjects like the natural sciences was not as difficult, East German academics in these subjects had different problems since they had largely been unable to publish their work in international journals and follow academic discourse outside of the Soviet Union. Especially older members of the academic staff therefore often could not adapt to the expected volume of publications and thus were left behind in international academic discourse (Günther and Schmerbach, 2010). In case of a positive outcome the academic could apply to open tenders for their old or similar positions. However, a significant downsizing of the former East Ger-

man academia was taking place at the same time (Kocka, 1994) and a positive evaluation was by no means sufficient to secure an academic position. This is the reason why many West German scientists were able to obtain academic positions in the former East German universities, re-structured or newly established research institutes despite downsizing in the East. This mobility of West German scientists brings East German scientists, who actually survived the political and scientific review as well as the downsizing, in close contact with new peers and potential collaborators.

3 Data and Descriptive Findings on Scientific Output, Mobility, and Professorship

We obtain publication records of West German and East German scientists who publish in biology, physics, chemistry, mathematics, engineering, or medical sciences between 1979 and 2005 from Thomson Reuter's Web of Science (WoS). As scientists' nationalities are not recorded in the WoS (or any other similar database), we make use of affiliations to classify a scientist as an East or West German scientist. We take a scientist's main or dominant affiliation to be the one which is their most used affiliation within a given time period. Scientists whose main affiliation is located in East Germany during 1979-1989 count as East German, those with a West German main affiliation during the same period count as West German. We construct East and West German scientists' research portfolio from 1979 to 2005. We restrict our data to those who have at least two publications between 1979 and 1989 as well as between 1996 and 2006. Thus our dataset contains a total of $721,065$ peer-reviewed publications by $8,836$ West German and $1,187$ East German scientists.

We observe the mobility of scientists based on changes in their affiliations, however not every change in the affiliation is an official move. A scientist may be visiting a research institute without giving up their initial position at their home institute and yet publish using the affiliation of the host institute. When a scientist's main affiliation changes, we take it that this scientist has moved, which is in line with the methodology proposed by Robinson-Garcia et al. (2019). Based on changes in scientists' main affiliations after 1990, we tabulate their movement in Table 1. 893 of $1,187$ East German scientists remained in the region of former

Table 1: East German and West German Scientists' Mobility after 1990

	Total	After 1995 in Germany		Abroad
		East States	West States	
Active before 1990 in				
East Germany	*1,187*	893	209	85
West Germany	*8,836*	523	7,027	1,286

East Germany (East states/Länder) after 1995, 209 moved to the former West Germany, 85 moved abroad.

Publication data do not show scientists' academic rank which can be a useful dimension in the analysis of scientific productivity. For instance, professorship comes with job security and may lead to differences in research attitudes. We collect information on newly hired or re-hired (as explained in the previous section) professors in sixteen East German universities[2] between 1990 and 1999 using universities' online resources and records of the German National Library.

East German universities underwent significant restructuring following the German re-unification and a significant portion of academic re-structuring including the evaluation and either re-hiring or replacing of former East German professors was concluded mainly by 1995 (Burkhardt, 1997). Although professors make up a small share in our dataset of East and West German scientists, they provide useful insight into the academic re-unification process. In Table 2 we document the share of West German and East German scientists who were appointed as professors in natural sciences, engineering, and social sciences in the above mentioned sixteen East German universities between 1990 and 1995. Professors with a West German doctoral degree make up about half of all hired professors in East German universities in natural sciences and engineering, whereas this ratio is 86% when social sciences are considered. We suspect that the observed displacement of East German professorships in social sciences may have been also the case in other ranks, hence a meaningful analysis of East German social scientists' post re-unification productivity levels is challenging, hence our analysis in this paper is focused on scientists in natural sciences and engineering.

[2]BTU Cottbus-Senftenberg, Bauhaus U Weimar, Europa U Frankfurt, U Jena, Humboldt U, U Halle-Wittenberg, U Magdeburg TU Bergakademie Freiberg, TU Chemnitz, TU Dresden, TU Ilmenau, U Erfurt, U Greifswald, U Leipzig, U Potsdam, and U Rostock

Table 2: Hiring of Professors in East German Universities 1990-1995

	Hired Professors		Percentage of
	Total	from West Ger	West Ger hires
Natural Sci. & Eng.	*351*	*175*	*49.9%*
Biological Sciences	32	23	71.9%
Physics	74	46	62.2%
Computer Sciences	39	23	59%
Mechanical Eng.	44	22	50%
Civil Engineering	19	9	47.4%
Chemistry	53	21	39.6%
Biochemistry	8	3	37.5%
Mathematics	69	25	36.2%
Electronics	13	3	23.1%
Social Sciences	*236*	*203*	*86%*
Political Sci.	22	22	100%
Philosophy	17	17	100%
Economics	51	47	92.2%
Sociology	30	25	83.3%
History	52	43	82.7%
Management	39	30	76.9%
Psychology	25	19	76%

While professors who obtained their PhD in East Germany began their tenure at the universities on average 17.8 years after obtaining their PhDs, the average time span for professors who obtained their PhD in the former West Germany was at only 14.7 years. This difference could be caused by relatively young West German professors, reinforcing the theory that primarily inexperienced West German professors were hired at the East German universities. However, it could also be caused by the fact that those East German professors hired in the post-reunification period were usually the ones deemed ideologically untainted and perhaps were stuck as non-professorial staff for a longer time in East Germany as result of their ideological insubordination.

The re-unification process started with travel freedom between East and West Germany in November 1989 and East Germany officially ceased to exist in October 1990. The first years of the re-unified Germany witnessed a great deal of academic restructuring in the former East Germany. According to Burkhardt (1997), the initial evaluation of East German professorships was completed by 1995. The period between 1989 and 1995 is a period of large scale structural adjustments in the former East German academia. We focus on East and West German scientists who remained within the territory of former East and West Germany, respectively, after re-unification. Their productivity and impact trends from 1979 to 2005 are shown in Figure 1 where upper left panel depicts average publication numbers, upper right panel shows normalized citations, lower left panel shows normalized and annually variable impact factors of journals where their work got published in that year.

East German scientists produced less publications and received less citations per publication compared to their West German peers throughout 1980s. In 1980s, West German scientists published about three papers and East Germans about two papers per year. We observe a catch-up process in 1990s. After 1995, the annual average increases to four papers for West Germans and to three papers for East Germans. In terms of citations and journal quality (impact factor) the catch up of East Germans is clearly visible. East Germans' average citation count increases from below one to above 1.5 from mid 1990s on and to 2 by 2004 whereas West Germans' citations remain within 2 to 2.5 for the whole period. This indicates an increase in the impact of East German science during this period as it starts to receive significantly more citations than it did before. Another important catch-up process is wit-

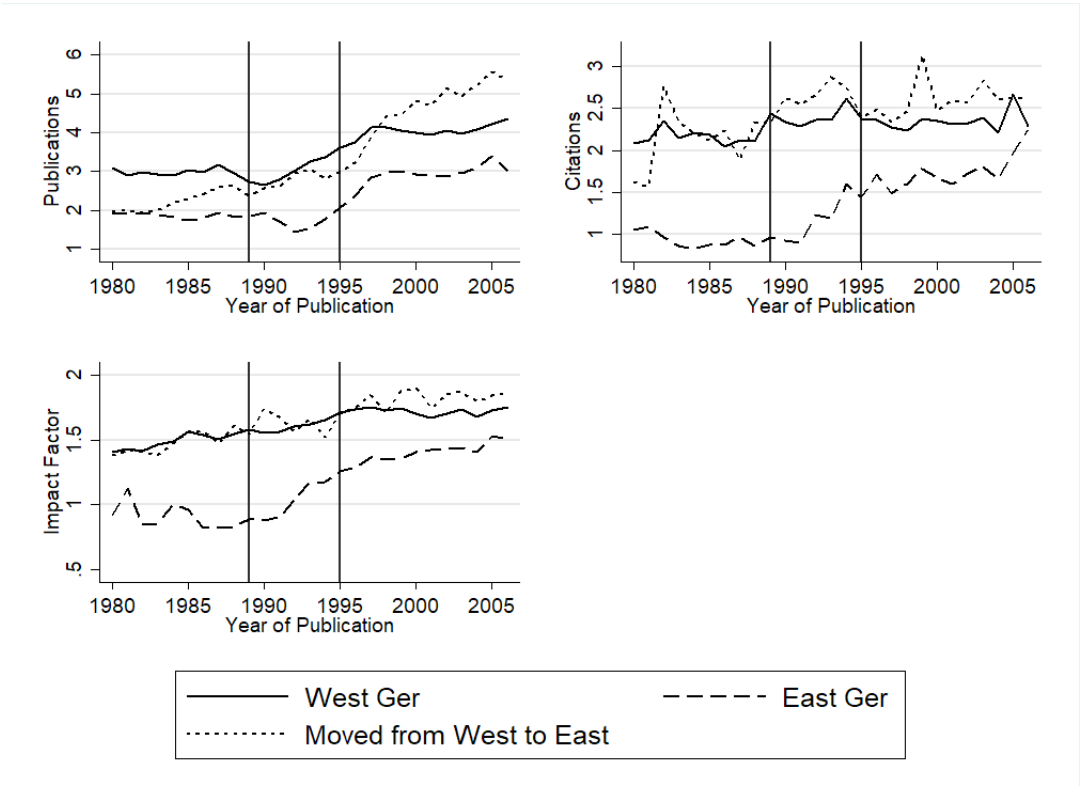

Figure 1: Productivity of Stayers in West and East Germany compared to In-migrants to East

nessed in the average impact factors of journals where East Germans publish. East Germans catching up with West Germans in terms of impact factor means that East Germans are publishing in better ranked journals starting from early 1990s on. This indicates a change in the publication culture of East Germans rather than a strict improvement in quality.

The dashed line in Figure 1 depicts the productivity of those West German scientists who moved from West Germany to East Germany during 1990-1995. In terms of publications, they lack behind the average of West German scientists in 1980s. A possible explanation would be that this group of migrant scientists (migrating from West to East Germany) is younger than their West German peers. We do not have data about the actual age of scientists, but we confirm that the first publication of migrant scientists appears on average later than their non-migrating peers. The publication productivity of West-to-East migrating scientists soon catches up and surpasses their West German peers. In terms of citations and impact factors, migrating West Germans are indistinguishable from the other West Germans in 1980s and they look even better in these accounts in 1990s and thereafter.

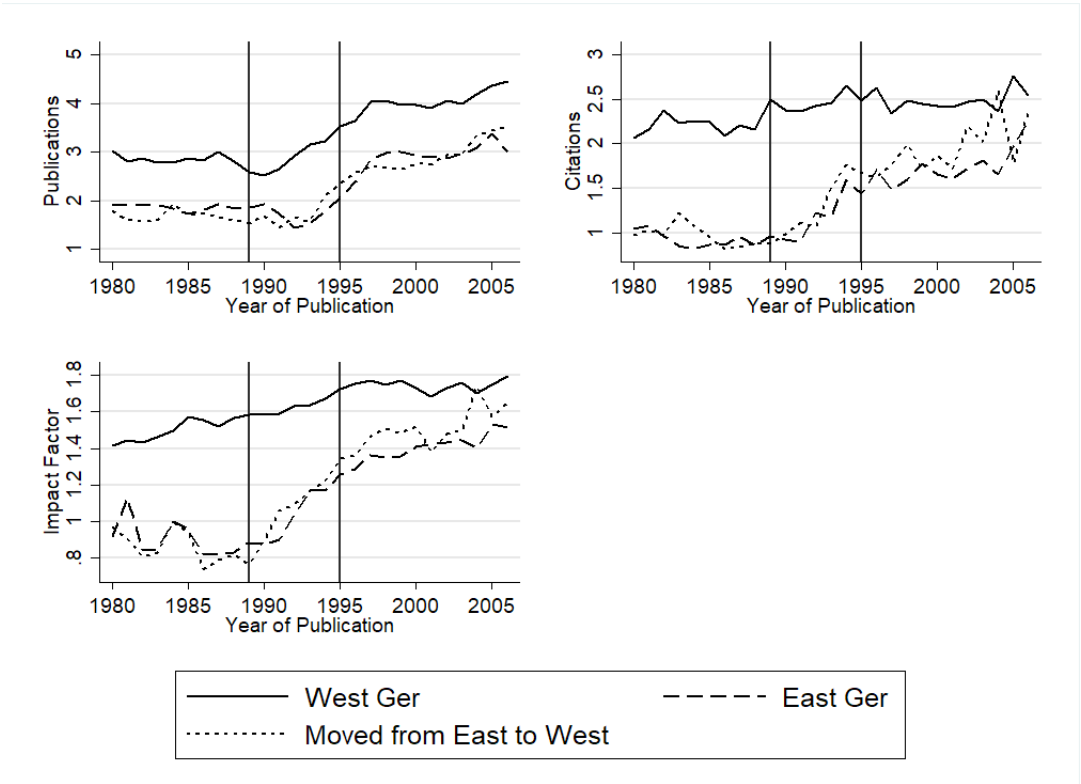

Figure 2: Productivity of Stayers in West and East Germany compared to Out-migrants from East

Figure 2 depicts the same East and West German stayers but the dashed line depicts of those who migrated from East to West. As shown in Table 1, about 18% of East German scientists who were active throughout 1980s moved to West German territory during or after re-unification and continued their scientific activity there.[3] In terms of annual number of publications, the East-to-West migrants are very similar to their non-migrating East German peers in 1980s and they remain so also afterwards. In terms of citations and journal quality, migrating and non-migrating East German scientists are fairly comparable in 1980s, but emigrating East Germans' annual average citations and journal quality remain consistently above non-migrating East German scientists from mid 1990s onwards. Hence both figures 1 and 2 reveal that migrants in either direction were fairly representative of their own group in

[3]The actual amount of movement is larger than what we observe in our data. Many East German scientists with an academic post in 1980s chose to move to the West to take industry jobs shortly after re-unification and did not wait for the result of their re-evalution of their initial academic post. Our data contain only those migrants who take up positions where they are expected to publish research, as they are the ones relevant for the aim of this paper. Inclusion of all East German scientists who migrated West and gave up research altogether after 1990 will necessarily lead to larger numbers of migrants.

terms of publication productivity and impact before re-unification. Although this is outside the scope of this paper, it is worth mentioning that both migrant groups perform consistently better than their initial peer groups after mid-1990s, indicating positive productivity effects of migration on migrants.

3.1 East German Activity in West German Fields

Since there was no or very little academic interaction between East and West during cold war, Eastern and Western science developed in separate areas. Similarly, there was very little academic interaction between East and West Germany before 1989 so that the two countries' scientific communities developed their research agenda and expertise without much interaction with one another. An East German scientist could not have imagined collaborating with West German or in general Western peers before the end of 1980s except under very extraordinary circumstances, so they could not have developed a research agenda with an explicit career plan to collaborate with Western scientists. In Table 3 we document the share of top specialized fields (*specialization* in the WoS database) in all publications of West German and East German scientists between 1979 and 1989. Although *general chemistry* and *biochemistry and molecular biology* is ranked high in both camps' research activity, there is little overlap in most of the fields listed in Table 3, for instance nearly 5% of West German publications is on *cardiovascular system* yet this field is not among the top fields in East German publications. *Veterinary medicine* receives a lot of attention in the East German science but this field has no comparable share in West German science.

When the political obstacles that prevent interaction and collaboration with the West were lifted, a reasonable expectation is that those East German scientists whose research is close to West German research, in the sense that it covers areas where West German scientists are working on as well, may found themselves with better opportunities to get in touch with Western scientists. The unpredictability of the fall of the Berlin Wall, lifting of the iron curtain, and re-unification of Germany support our claim that an East German scientist could not have developed a research portfolio in 1980s with the hope of having sustained collaboration with Western scientists in the next decade, or surviving an overtake of East German academia by West German structures for that matter. Similarity of an East German

Table 3: Most Popular Research Fields in West and East Germany 1979-1989

Field (within Main Discipline)	Share of Field in All Publications
West German Scientists	
Biochemistry & Molecular Biology (Biomedical Research)	7.8%
General & Internal Medicine (Clinical Medicine)	5.13%
General Chemistry (Chemistry)	5.1%
General Physics (Physics)	4.9%
Cardiovascular System (Clinical Medicine)	4.7%
Nuclear & Particle Physics (Physics)	4.6%
Immunology (Clinical Medicine)	3.11%
Neurology & Neurosurgery (Clinical Medicine)	3.05%
Gastroenterology (Clinical Medicine)	2.7%
East German Scientists	
General Chemistry (Chemistry)	12.2%
Physical Chemistry (Chemistry)	8.5%
Biochemistry & Molecular Biology (Biomedical Research)	8.3%
Veterinary Medicine (Clinical Medicine)	3.7%
Applied Physics (Physics)	3.6%
General & Internal Medicine (Clinical Medicine)	3.5%
Solid State Physics (Physics)	3.22%
Endocrinology (Clinical Medicine)	3.19%
Pharmacy (Clinical Medicine)	3.16%
General Physics (Physics)	3.1%
Inorganic & Nuclear Chemistry (Chemistry)	2.9%
Dairy & Animal Science (Biology)	2.7%

scientist's research portfolio to West German science of 1980s is the main identification that we employ in our analysis.

We capture the above mentioned closeness or similarity to West German scientific agenda of 1980s using various measures that have been well established in the literature. Similarity based on the correlation coefficient of fields' shares is a textbook measure of similarity (Newman, 2010) and was also employed in the analysis of Borjas and Doran (2012). The *correlation coefficient* between field shares of publications of any scientist s and West German scientists is defined by

$$C_s = \frac{\sum a_{sf} w_f}{\sum a_{sf}^2 \sum w_f^2} \tag{1}$$

where a_{sf} is the share of field f in all publications of scientist s between 1979 and 1989; w_f is the share (not total number as opposed to above) of field f in West Germans' publications between 1979 and 1989. This measure takes values from zero to one and a greater correlation between fields of activity will yield a larger correlation coefficient.

Two other alternative measures to capture research similarity are based on *intensity* and *distance*. *Intensity* of research similarity was employed by Borjas and Doran (2012) and it is defined by

$$I_s = \frac{\sum a_{sf} W_f}{\max W_f} \tag{2}$$

where a_{sf} is defined as above, W_f is West German scientists' total number of publications in field f between 1979 and 1989. If a scientist s published only in fields where there has been no West German publications at all, then the intensity similarity will be zero. If s published in the field where West German scientists published most, then the intensity similarity will be one.

Similarity based on vector distance of field activity vectors is another alternative that has been used by Cutler and Glaeser (1997) and Borjas and Doran (2012) and it is defined by

$$D_s = 1 - \frac{1}{2} \sum |a_{sf} - w_f| \tag{3}$$

In Figure 3, we divide East German scientists into two groups, those who are working in the most similar fields to West Germans, and those who are working in the least similar

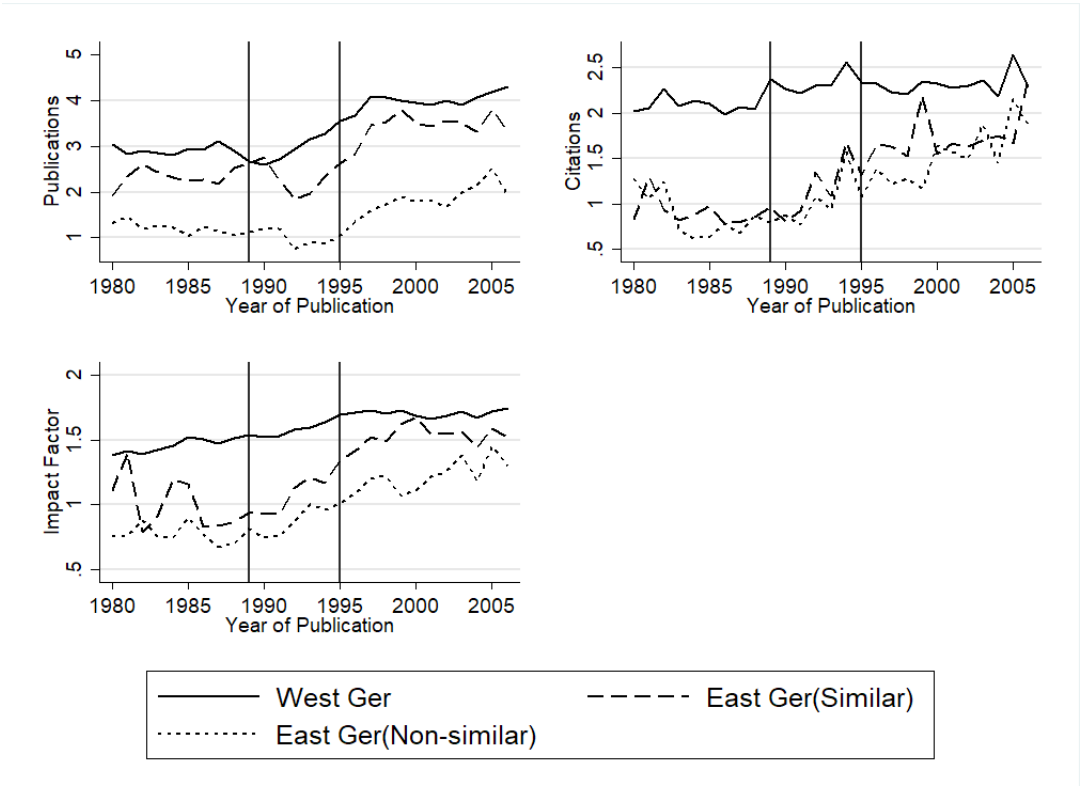

Figure 3: Productivity of More Similar and Less Similar East Germans to West Germans

fields (in terms of intensity) to West Germans. Scientists with most and least similar fields are determined using the individual similarity index of these scientists. Those with an index value in the first quartile are deemed as most similar and those with an index value in the fourth quartile are deemed scientists with least similar agenda to West Germans. West-similar East German scientists used to publish more than their non-similar peers also before 1990. In terms of citations and impact factor, the gap between West-similar and nonsimilar East German scientists is less obvious before 1990, the gap widens rather obviously after 1990 when impact factor is concerned. This indicated that West-similar East German scientists find their way into high impact Western journals relatively easier than their peers after the structural haul over of the East German academia.

4 Productivity and Collaborations of East German Scientists

We run difference-in-difference estimations to find out if and how east Germans' output is catching up with that of the West German scientists and what role is played by peers in this process. We regress the scientific output of scientist s in year t on standard controls, quartic life cycle controls, and similarity to 1980s West German scientific activity. Years from 1990 to 1994 are left out of the analysis because these were years of stark transition. We estimate

$$Output_{st} = \beta X_{st} + \gamma(Post1990 \times Similarity_s) + \phi_s + \phi_t + \epsilon_{st} \tag{4}$$

where ϕ_s and ϕ_t are individual and year fixed effects, respectively, and γ is the coefficient of main interest. Scientific output is measured in three different ways: number of publications, count of field-normalized citations, and annually variable field-normalized journal impact factor. Any statistically significant difference in scientific output after the German re-unification between similar and non-similar East German scientists to West German research topics will reveal itself as a significant and positive point estimate for the coefficient γ. A non significant estimation of γ would mean that there is no significant change in how similar and non-similar scientists differ before and after the re-unification, although the absolute productivity of both groups may be increasing or decreasing together. The first three columns of Table A.2 lists coefficient estimates for γ. Panels B, C, and D of Table A.2 three alternative measures for research topic similarity to West Germans. Those East German scientists whose research topics were similar to West Germans' topics publish significantly less than their East German peers who have been working on non-similar topics to West Germans. Their papers, however, are published in journals that have significantly higher impact factors. We find no statistically significant divergence between citation counts of East German scientists based on their similarities to West German research. These findings are consistent across all three similarity measures we employ in our analysis, except for the number of publications when intensity is used.

Table 4: Differences in the Productivity of East German Scientists after 1990

	East and West Germans			East Germans		
	Papers	Cites	IF	Papers	Cites	IF
[Panel A:Similarity=Correlation]						
Post1990*East	0.161^a	0.161^a	0.240^a			
	[0.0359]	[0.0189]	[0.0269]			
Post1990*Similarity	-0.492^a	-0.171^a	-0.305^a	-0.405^a	-0.00729	0.514^a
	[0.0427]	[0.0294]	[0.0321]	[0.133]	[0.0696]	[0.111]
Post1990*East*Similarity	0.361^a	0.274^a	0.792^a			
	[0.137]	[0.0746]	[0.110]			
[Panel B:Similarity=Intensity]						
Post1990*East	0.152^a	0.176^a	0.241^a			
	[0.0352]	[0.0188]	[0.0273]			
Post1990*Similarity	-0.256^a	-0.0793^a	-0.148^a	-0.0855	0.0119	0.386^a
	[0.0284]	[0.0195]	[0.0212]	[0.0847]	[0.0439]	[0.0733]
Post1990*East*Similarity	0.291^a	0.142^a	0.535^a			
	[0.0906]	[0.0481]	[0.0751]			
[Panel C:Similarity=Distance]						
Post1990*East	-0.255	-0.363^c	-0.989^a			
	[0.361]	[0.219]	[0.290]			
Post1990*Similarity	-2.086^a	-0.499^a	-1.044^a	-3.057^a	-0.288	1.834^a
	[0.216]	[0.149]	[0.160]	[0.698]	[0.408]	[0.571]
Post1990*East*Similarity	0.911	1.081^a	2.596^a			
	[0.665]	[0.409]	[0.539]			
Observations	136500	107871	107714	14793	10780	10761

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity is based on West German fields of strength.

Regs include age and quality controls, individual and year FE.

When the sample is restricted to East Germans only, as in the first three columns of Table A.2, we obtain significance only in case of impact factor weighted publication numbers. That is, there is no statistically significant divergence or convergence between more similar and less similar East German scientists on accounts of total publication numbers and citations after the re-unification. More similar East German scientists publish significantly less compared to less similar East Germans but outperform them on the account of outlet quality as they are publishing in journals with higher impact factor.

In order to capture the catch-up process of East German scientists with their West Germans peers, we pool East and West German scientists to estimate the following specification

$$Output_{st} = \beta X_{st} + \gamma(Post1990 \times Similarity_s) + \theta(Post1990 \times East_s \times Similarity_s) + \phi_s + \phi_t + \epsilon_{st} \tag{5}$$

where $Similarity_s$ applies to all scientists in this sample. Similarity to West Germans for a West German scientist means whether this West German is active in a West Germany-dominated field or not. We expect to observe no difference in productivity trends of non-West similar West German scientists after 1990 so the coefficient γ is of no interest except for econometric integrity in this specification. A positive and significant θ, however, would reveal possible source of the descriptively observed catch-up between East and West German scientists and this coefficient is reported in the last three columns of Table A.2. In panel A, we list the estimated α coefficient from the following regression

$$Output_{st} = \beta X_{st} + \alpha(Post1990 \times East_s) + \phi_s + \phi_t + \epsilon_{st} \tag{6}$$

where both East and West German scientists are pooled together. This specification aims to capture the statistical significance of the catch-up process between non-migrating East and West German scientists shown in Figure 1. As a matter of fact, East German scientists catch up with their West German peers on a statistically significant basis in all three productivity accounts, namely total number of publications, citations, and impact factor weighted publications.

The last three columns of Table A.2 is based on pooled regression results using East and West Germans. Positive and statistically significant point estimates for θ show that East Germans that are more similar to West Germans catch up faster with their West German peers after re-unification on all three accounts. More West-similar East Germans don't significantly outperform their East German peers on accounts of publication counts and citations, but they catch up on all accounts with their West German peers who work in the West German dominant fields.

In Table A.1 in the Appendix, we use field fixed effects as many scientists publish in more than only one subfield (although they publish in the same discipline) so that individual fixed effects do not make field fixed effects all redundant. Results are qualitatively very similar to those displayed in Table A.2.

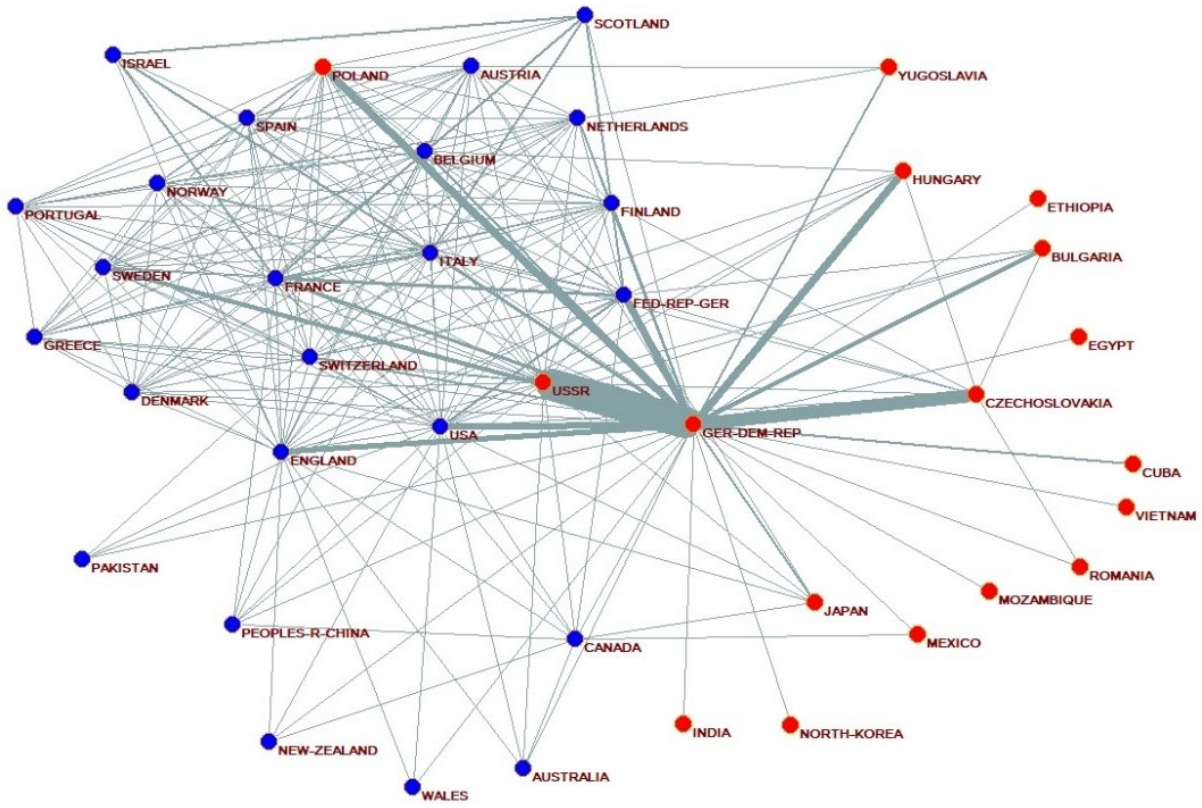

Figure 4: Collaboration Networks of East German Scientists 1979-1989 (More frequent collaborations are shown by thicker links; collaborating countries are found to form two communities according to Louvain partitioning which are marked red and blue)

Figure 4 shows international collaborations of East German scientists. Each link represents at least one collaboration of an East German scientist with scientists from the respective country on a published article. The more the number of collaborations the thicker are links. The Soviet Union stands out as the most heavily collaborated partner during 1979 to 1989. Connections between countries other than East Germany in Figure 4 show that East German

scientists collaborated with a team of scientists from those countries in the same publication. A rather complete network between West European countries is observed in Figure 4, which indicates that East German scientists have worked with international teams formed with scientists from West European countries. Collaborations with East European countries do not seem to create such a clique, most likely because such collaboration could be formed at will whereas collaborations with West Europeans required more formalities and could be justified only if East German scientists are part of large international projects.

Using a simple community detection such as the Louvain partition method, we identify two communities that can be separated to maximize the modularity of the network shown in Figure 4. Red and blue nodes belong to these two separate communities. It is important to note that these two communities may or may not be statistically significantly different subnetworks, as the aim of the community detection is simply to maximize the modularity of the collaboration network. For instance, USA, England, and West Germany are among *blue* countries whereas USSR, Hungary, Poland, and Cuba are among *red* countries in Figure 4. Some of these countries may end up in the other camp if we were to re-wire this network at random while preserving linking probabilities constant. Nevertheless, even using a very simple community detection algorithm, international collaboration network of East German scientists reveals an interesting division that lines up with the political background of 1980s.

Figure 5 captures East German scientists' international collaboration networks between 1995 and 2005. As collaborations become increasingly important, we observe a larger and denser collaboration network this time. Similar to Figure 4, we observe a densely webbed collaboration structure among most European countries, however the divide between East and West European countries is not as clear during 1995-2005 as it is during 1979-1989. Using Louvain partitioning, we detect two communities that maximize the modularity, identified by blue and red nodes. There is, however, no obvious and easy explanation for this division except for technical reasons. Poland is in the same community as England and France, whereas East German scientists are now put into the same community as the USA. The aim of this brief and descriptive documentation is to draw attention to overall patterns and macro-level traits of East German scientists' international collaboration.

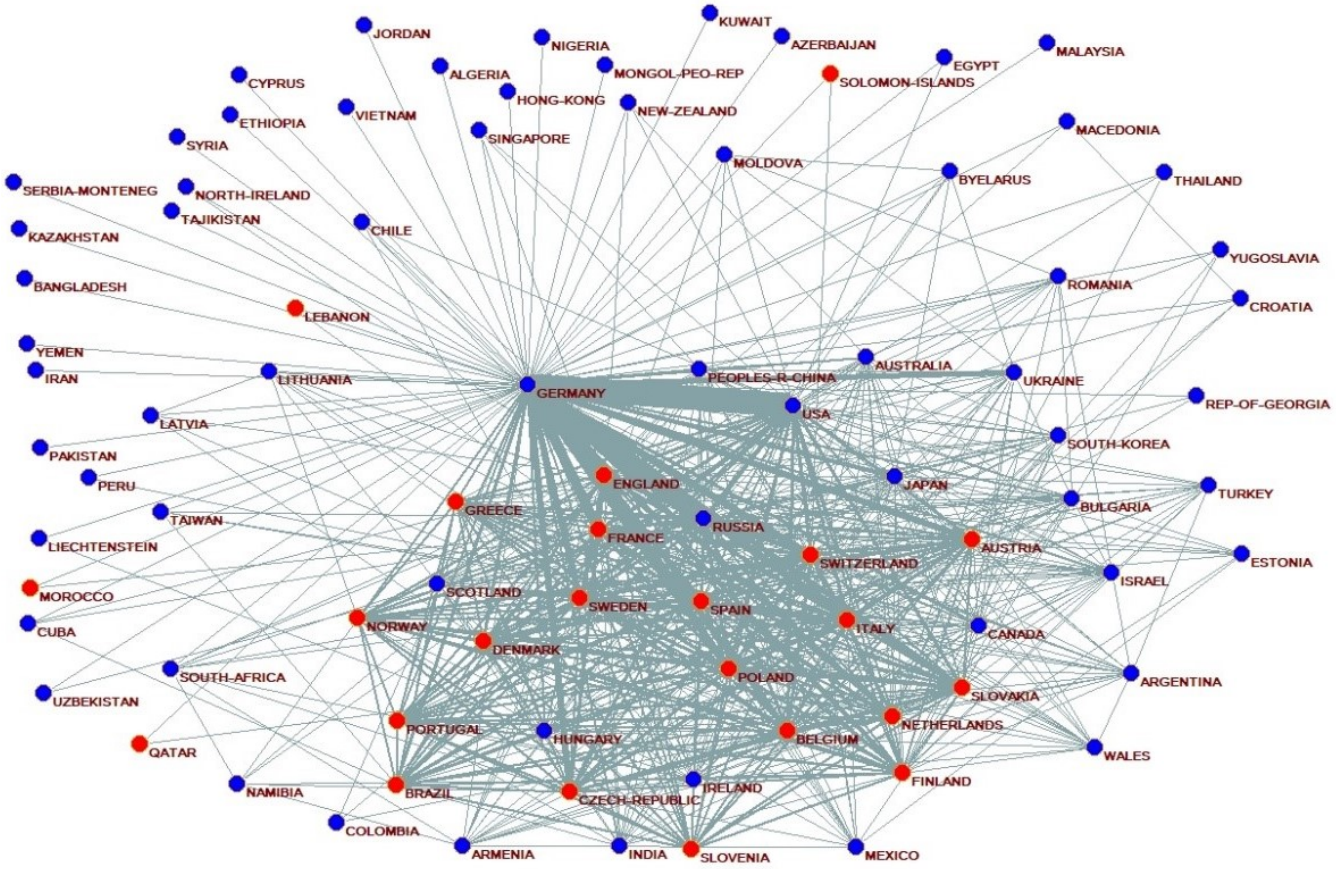

Figure 5: Collaboration Networks of East German Scientists 1995-2005 (*Germany* in this figure refers to scientists who remained in the former East German territory after reunification. More frequent collaborations are shown by thicker links; collaborating countries are found to form two communities according to Louvain partitioning which are marked red and blue)

Next we provide a more detailed analysis of East German scientists' micro-level collaborations where we investigate associations between collaboration patterns and productivity. We employ a linear probability model of collaboration with West German scientists who remained in West Germany through the German re-unification, West Germans who migrated from the former West to the former East Germany after re-unification (denoted *Inmigrants*), East Germans who migrated from the former East to the former West Germany after re-unification (denoted *Outmigrants*), West European or US scientists, and with USSR or former USSR[4]

[4]All countries that were once within the USSR prior to 1990 and became independent thereafter are considered to be the former USSR for purposes of this analysis.

scientists. In the first three columns of Table 5, we focus on the collaboration patterns of East German scientists. East German scientists who work in a West German-dominated (or *similar*) field are more likely to engage in collaboration with West German scientists after 1990 whether they are located in the former West Germany or actually moved to East to take up academic positions there, they are less likely to collaborate with outmigrating East German scientists as well as with scientists from the former USSR.

When the sample is expanded to include West and East German scientists together (last two columns in Table 5) then the likelihood of East Germans to collaborate with West-European or US scientists is significantly larger than their peers who may be West German or East German and in dissimilar fields. Moreover, East Germans in West German-dominated fields are significantly less likely to collaborate with (former) USSR scientists after 1990. This analysis documents a significant change in collaboration patterns of East German scientists. All three similarity measures yield qualitatively very similar results. Those that are active in West German-dominated fields switch to increased collaborations with West Germans and divert from their collaborations with scientists from the USSR. They also tend to collaborate significantly more with relocating scientists from West Germany to East Germany. There is, however, no statistically significant difference regarding establishing connections to West European or US scientists between East Germans that have similar and less similar research topics to those of West Germans. Those East Germans with similar topics to West Germans tend to collaborate significantly less with outmigrating East Germans compared to other East Germans do.

When East and West German scientists are pooled together to analyze their differences in the last two columns of Table 5, we find that East Germans with similar research portfolio to West Germans do not get significantly more connected to West European or American co-authors. Interestingly, they are losing their connections to the USSR scientists fast so that their connection to the former Soviet Union significantly lacks behind their peers in former West Germany. This can be explained by the freedom to establish connections to parts of the world that used to be out of reach to either side of Germany prior to 1990. The connection of West Germans to USSR researchers much faster than East Germans is thus plausible. The

Table 5: Differences in Collaborations of East German Scientists after 1990

	East/West Ger with		East German with				
	West/US	USSR	West Ger	Inmig.	Outmig.	West/US	USSR
[Panel A:Similarity=Correlation]							
Post1990*East	0.0461^{a}	0.0279^{a}					
	[0.0127]	[0.00956]					
Post1990*Similarity	-0.0158	0.121^{a}	0.165^{a}	0.124^{a}	-0.127^{a}	-0.0362	-0.144^{a}
	[0.0200]	[0.00907]	[0.0372]	[0.0294]	[0.0299]	[0.0521]	[0.0415]
Post1990*East*Similarity	0.0836	-0.232^{a}					
	[0.0542]	[0.0411]					
[Panel B:Similarity=Intensity]							
Post1990*East	0.0428^{a}	0.0285^{a}					
	[0.0126]	[0.00971]					
Post1990*Similarity	-0.00514	0.109^{a}	0.0823^{a}	0.0999^{a}	-0.0862^{a}	0.0173	-0.0597^{b}
	[0.0135]	[0.00623]	[0.0231]	[0.0203]	[0.0215]	[0.0329]	[0.0276]
Post1990*East*Similarity	0.0668^{c}	-0.157^{a}					
	[0.0352]	[0.0278]					
[Panel C:Similarity=Distance]							
Post1990*East	-0.263^{c}	0.403^{a}					
	[0.156]	[0.114]					
Post1990*Similarity	-0.107	0.0724	0.883^{a}	0.649^{a}	-0.555^{a}	-0.321	-1.001^{a}
	[0.100]	[0.0453]	[0.222]	[0.166]	[0.171]	[0.298]	[0.229]
Post1990*East*Similarity	0.607^{b}	-0.791^{a}					
	[0.292]	[0.213]					
Observations	107871	107871	10780	10780	10780	10780	10780

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity is based on West German fields of strength. Regs include age and quality controls, individual and year FE.

same effect is, however, not found as a mirror image between East German scientists and West European and American scientists.

4.1 Emigrating Collaborators and former USSR Collaborations

In this section, we focus on two particular collaborations of East German scientists between 1979 and 1989, namely their collaborations with peers who emigrate from the former East Germany after re-unification, and with USSR scientists. Losing a co-author is a significant challenge for scientists as collaborations affect scientists' productivity highly significantly (Azoulay et al., 2019, Ductor et al., 2014). There are some East German scientists who emigrated elsewhere after the German re-unification, may it be former West Germany, Western Europe, or anywhere else in the world. As a result many East German scientists who chose to remain in former East Germany after re-unification may have seen several of their collaborators from 1980s move further away. Thus these East German scientists cannot be analyzed as if their situation did not change after re-unification and we need to pay attention how they were forced to cope up with emigrating collaborators.

Another group of East German scientists are those who have been collaborating with USSR scientists before the re-unification. Although collaboration with the USSR was not restricted like collaboration with the Western world was back then, an international collaboration is always costly and its benefits must justify its costs, meaning that a collaboration with USSR scientists may be taken as a signal of frontier research and involved scientists may well be expected to be outstanding scientists. Hence one may expect to find positive selection in case of collaborations between East German scientists and USSR scientists.Nevertheless, in both cases we have a subset of high quality researchers and the interaction of their collaboration patterns with their topics similarity to that of West Germany is illuminating that it shows how relatively strong academic labor force evolved after the re-unification following the academic re-structuring of the East.

Table 6 shows the above mentioned numbers. 537 East German scientists have neither an emigrating collaborator from their publication prior to the re-unification nor did they collaborate with any USSR scientist back then. 115 East German scientists do not have an emigrant East German collaborator and they did have collaborations with USSR scientists.

Table 6: East German Scientists who remained in East Germany after reunification and who collaborated with emigrant or Soviet scientists during 1979-1989

Number of East German Scientists who have		
	No USSR collab.	At least one USSR collab.
No emigrant collaborator	537	115
At least one emigrant collaborator	96	94 (24)*

*24 East German scientists have an emigrant East German scientist in their collaboration with the USSR.

96 East German scientists did not have an USSR collaboration but they have emigrating co-authors. 94 East German scientists have at least one USSR collaboration and also at least one emigrating co-author. In case emigrating co-authors, it is possible that an emigrant East German co-author was actually in the same paper that embodies a USSR collaboration. This can mean that the scientist may have lost their connection to the USSR scientist due to the emigration of this one East German co-author. There are 24 East German scientists who have been collaborating with USSR scientists on a paper where an East German co-author ended up emigrating elsewhere after the re-unification. We will treat these two group of USSR collaborators differently in our analysis for robustness purposes.

In addition, we also consider those East German scientists who have been collaborated with West European or US scientists before 1989. Such collaborations were not allowed freely and they were restricted greatly, yet collaborations with Western Europe and the US took place. East German scientists who participated in such collaborations were most likely scientists that have high research quality or other related intrinsic qualities. This goes for collaborators of the USSR scientists as well, but the official hurdle was not nearly as high as in case of collaborations with Western Europe or the US. Nevertheless, any collaboration is a relevation of a scientist's research quality, and no collaboration is random as there is mutual consent and selection is involved in the process of collaboration.

Figure 6 shows citations of East German scientists who have an emigrant co-author before re-unification in panel a; citations of East German scientists who have been collaborating with USSR scientists in panel b; citations of East German scientists who have been collaborating with scientists from Western Europe or the US in panel c. They are compared against East Germans who did not have any emigrant co-authors (panel a), or did not collaborate with

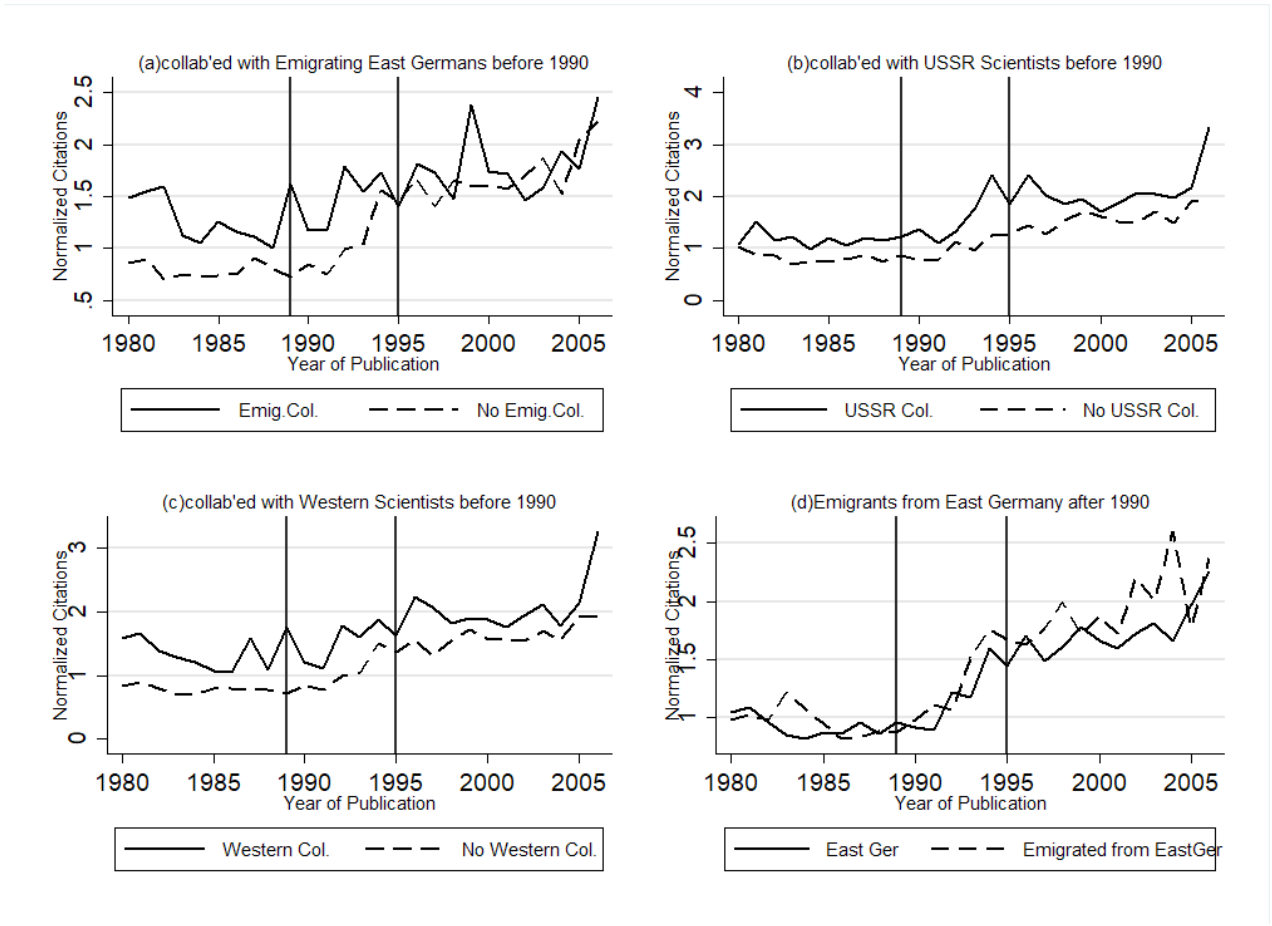

Figure 6: Citations of East German Scientists based on their pre-unification Collaborations

Soviet (panel b) or Western European/US scientists (panelc). As can be seen, all three groups were more productive in terms of citations than their comparison group. Those who have emigrating co-authors and those with Western European and US collaborations lose their edge after 1995, whereas those with USSR collaborations maintain their position against their comparison group. In panel d of Figure 6 we compare citations of emigrant East Germans against non-migrating East Germans and find that emigrating East German scientists are fairly comparable to stayers as far as citations are concerned, especially during late 1980s and early 1990s.

We repeat the analysis of Table 5 with special focus on these two groups of East German scientists in Table 7. We find that those East German scientists who have an emigrating co-author get significantly less citations for their work compared to other East Germans who did not have an emigrating collaborator upon re-unification. They tend to connect

Table 7: Differences in Collaboration and Productivity of East German Scientists after 1990 based on Past Collaboration with Emigrating East Germans and Soviet Scientists (Similarity is measured by *correlation coefficient*)

	Collaboration					Production		
[Panel A]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Emigrant share	0.173^{a}	0.0134	-0.772^{a}	0.238^{a}	0.0710	0.204	-0.351^{a}	-0.311
	[0.0640]	[0.0553]	[0.110]	[0.0892]	[0.0826]	[0.280]	[0.123]	[0.201]
Post1990*Similarity*Emigrant sh.	-0.598^{a}	0.0775	-0.533	-0.650^{b}	-0.381	-0.631	0.584	0.857
	[0.200]	[0.194]	[0.343]	[0.307]	[0.248]	[0.862]	[0.377]	[0.737]
Post1990*USSR share	0.00760	0.154^{b}	0.0425	0.449^{a}	-0.749^{a}	1.303^{a}	0.738^{a}	0.578^{b}
	[0.0887]	[0.0720]	[0.0582]	[0.145]	[0.172]	[0.320]	[0.195]	[0.261]
Post1990*Similarity*USSR sh.	0.270	-0.620^{a}	0.0121	-0.334	-0.0348	-1.427	-1.523^{b}	-1.832^{c}
	[0.313]	[0.240]	[0.196]	[0.500]	[0.591]	[1.070]	[0.642]	[0.968]
[Panel B]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*USSR share (without Emigrants)	-0.0466	0.172^{b}	0.0504	0.440^{a}	-0.818^{a}	1.172^{a}	0.824^{a}	0.437
	[0.0894]	[0.0747]	[0.0532]	[0.150]	[0.177]	[0.326]	[0.201]	[0.267]
Post1990*Similarity*USSR share (without Emigrants)	0.326	-0.627^{b}	-0.0220	-0.241	0.199	-0.867	-1.539^{b}	-1.274
	[0.320]	[0.247]	[0.173]	[0.515]	[0.606]	[1.081]	[0.656]	[0.984]
[Panel C]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Western share	-0.0441	0.0743	-0.00722	-0.290^{b}	-0.122^{a}	-0.207	-0.174	-0.157
	[0.0436]	[0.0508]	[0.0357]	[0.118]	[0.0421]	[0.242]	[0.118]	[0.150]
Post1990*Similarity*Western share	-0.141	-0.205	-0.223	-2.957^{a}	0.972^{a}	-0.541	-1.144^{c}	-2.901^{a}
	[0.349]	[0.260]	[0.331]	[0.505]	[0.284]	[1.012]	[0.585]	[0.777]
Observations	10542	10542	10542	10542	10542	14378	10542	10525

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity (correlation) is based on West German fields of strength. Regs include age and quality controls, individual and year FE.

to West Germans who are located in former West Germany as well as to West European and American scientists significantly more than their peers who have had an emigrating co-author. When interacted with scientists' similarity to pre-1990 West German research portfolio, the significant loss of citations is dampened. That means, East Germans who have had an emigrating co-author suffer loss in their citations after re-unification but those who have similar research to pre-1990 West Germans do not have significantly less citations. They, however, have a significantly less tendency to connect to West Germans, West Europeans, or Americans.

East German scientists who have been collaborating with USSR scientists before the re-unification produce significantly less papers yet they get significantly higher citations after re-unification. They get connected to in-migrating West Germans as well as to West European and US scientists, at the same time they are being less connected to former USSR scientists compared to their East German peers. It is plausible to think that those who collaborate with USSR might have done so because they worked on hot topics on which western scientists were also working, so that these East Germans are actually good researchers and have been working on western topics so that they have a huge advantage over their East German peers after re-unification. When USSR collaboration is interacted with research similarity to West Germans' pre-1990 research portfolio, we actually find the opposite, namely these subset of East German scientists publish less, receive significantly less citations, and publish in less prestigious journals.

Panel B of Table 7 shows the last two rows of panel A above replacing USSR collaboration with only those USSR collaborations that do not include an East German co-author who emigrated after the re-unification. Results are qualitatively similar to those in panel A. We provide results using two alternative measures, namely intensity and distance, to capture similarity in the Appendix in Tables A.3 and A.4, respectively. When alternative measures are used, coefficients' significance and signs turn out fairly comparable to those shown in Table 7.

Estimations for interactions with western collaborations are shown in panel C of Table 7. We find no significant change in the difference of those East Germans who were able (or *allowed*) to collaborate with Western scientists before 1989 and their other East German peers

after re-unification in terms of annual publication numbers, citations, and journal quality. Those collaborators of Western scientists who have been working on West German topics turn out even worse, as they lack behind their peers in terms of citations and journal quality after re-unification.

4.2 Cognitive Mobility of East German Scientists

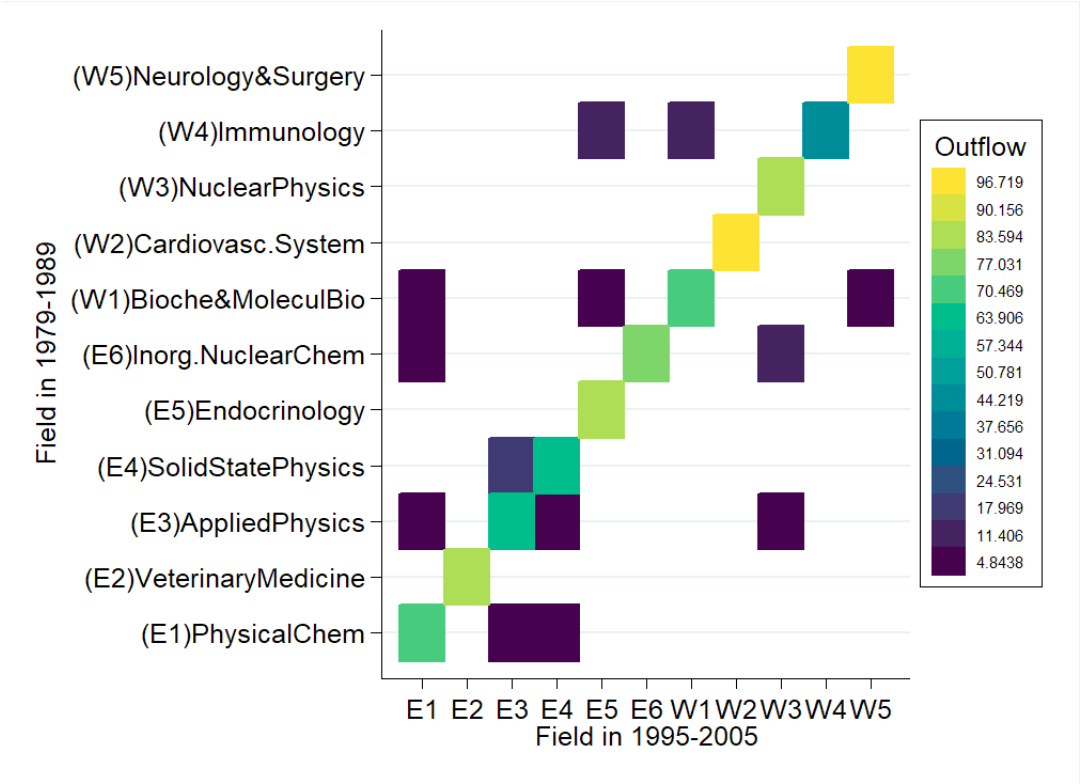

Figure 7: Cognitive Mobility of East German Scientists across Top Fields of East and West German Science from 1979-1989 to 1995-2005

We investigate East German scientists' mobility across different research fields. Scientists can respond to changing conditions in the academic environment by changing the field of their activity, which is referred to as cognitive migration (Borjas and Doran, 2015a). Figure 7 shows the movement of East German scientists between top research fields of East and West German scientific agenda from 1979-1989 to 1995-2005. We pick a total of eleven fields from Table 3 and rank them based on their share in East or West German total publication between 1979 and 1989. E1 to E6 are predominantly East German fields and W1 to W5 are

predominantly West German fields. We define the main field of an individual scientist in a given period to be the field where they publish most during that period. If everyone whose main field is physical chemistry during 1979-1989 keep the same research interest during 1995-2005, then we would observe that 100% of scientists with physical chemistry in 1979-1989 remained in that field during 1995-2005. If this was the case for every field, then we would observe markers on the 45-degree line from the origin color-coded to signal 100% in Figure 7.Nevertheless, we observe mobility across fields.

One can see in Table 3 that 8.5% of all peer-reviewed science and engineering publications was in physical chemistry in East Germany during 1979-1989. Figure 7 reveals that about 70% of scientists whose main field is physical chemistry during 1979-1989 still have their most publication in that field during 1995-2005. However, more than 10% of physical chemists ended up publishing more either in the field of applied physics or in solid state physics during 1995-2005 compared to how much they publish in physical chemistry during the same period. Similarly, endocrinology has been an important field for East German scientists during 1979-1989 as shown in Table 3. We see in Figure 7 that about 80% of all scientists with endocrinology as their main field remained in that field and about 20% published more extensively in another field during 1995-2005, which is not included among the eleven selected fields shown in Figure 7. Those East German scientists who published in a West German top field tend to remain in that field. For instance, more than 90% of East German scientists who published mainly on cardiovascular systems during 1979-1989continued publishing mainly in that field during 1995-2005. The same applies also to East Germans whose main field is neurology and neurosurgery during 1979-1989, as more than 90% of them kept this as their main field during 1995-2005.

Definition of a main field is a vague concept and we lose significant amount of information when aggregating data in that way. As a result, we prefer to document more micro-level changes in individual scientists' fields of publications. In Figure 8, we graph the probability that an East German scientist publishes in a new field in a given year. This new field does not need to dominate this scientist's research agenda or it does not need to embody a permanent shift in the research focus of this scientist. In panel (a) of Figure 8, we compare the share of new fields in East German scientists' publications whose research portfolio corresponds

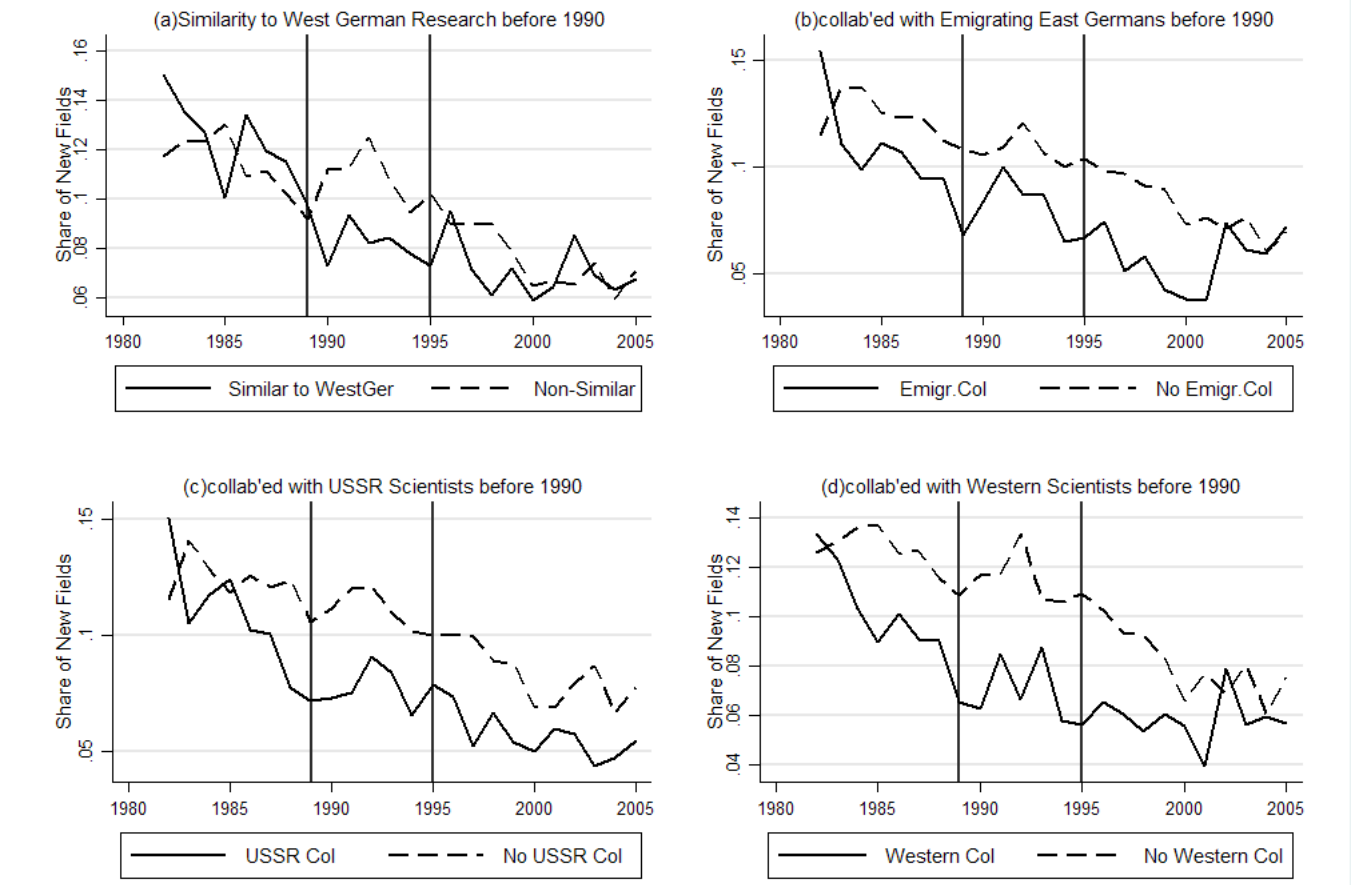

Figure 8: Share of New Field in East German Scientists' Publications

more similary and less similarly, respectively, to West German research during 1979-1989. Similarity is defined as the coefficient of correlation between field activity of a scientist and the overall West German publication portfolio during 1979-1989. Although this yields a continuous measure for similarity, we label those scientists with a similarity measure in the first quartile as *similar* and scientists in the fourth quartile as *non-similar*. Both show a decreasing trend and East German scientists with a non-similar research agenda to West Germans show a larger tendency to switch to a new field after 1989 compared to their peers whose research is more similar to the West German agenda. East Germans who had publications with another peer who emigrated after re-unification have a less likelihood to switch to a new field compared to other East German scientists who didn't have an emigrant co-author, as shown in panel (b) of Figure 8. Interestingly, East Germans who had at least

one publication where they collaborated with a scientist from the USSR during 1979-1989 are less likely to publish in a new field; similarly, East Germans with a Western (West Europe or the US) collaboration during 1979-1989 are less likely to embark into a new field.

In order to test whether differences between East Germans with different levels of research similarity to West Germans and different collaboration patterns significantly change after the re-unification, we run difference-in-difference estimations including standard controls for research quality, academic age as well as individual and year fixed effects. We estimate

$$\begin{aligned} NewField_{st} = \beta X_{st} + \gamma_1(Post1990 \times Similarity_s) + \\ \gamma_2(Post1990 \times Similarity_s \times Emigrants_s) + \\ \gamma_3(Post1990 \times Similarity_s \times USSR_{st}) + \phi_s + \phi_t + \epsilon_{st} \end{aligned} \tag{7}$$

where the vector X_{st} includes quality and age controls. We investigate interactions of East German scientists' past and initial collaborations with USSR scientists and report estimated coefficients of alternative specifications in Table 8.

Similarity to West German research is negatively and significantly related to post re-unification difference between East German scientists' propensity to embark on a new research field. Other collaboration characteristics such as previous collaborations with emigrant East German scientists or with Soviet scientists turn out insignificant, hence no difference in how subsets of East German scientists differ among each other before and after the re-unification when similarity is measured using the correlation coefficient between research portfolio vectors of individual scientists and the West German research portfolio (column (1) in Table 8). When intensity is used as similarity measure, we find statistically significant and negative relation between previous collaboration with emigrating peers and propensity to switch to a new field. This difference turns positive if the scientist has similar research to West Germans.

In order to shed light on collaborations with Soviet scientists, we control for the (former) USSR co-authorship in published papers. In any given year, a non-similar East German scientist is more likely to switch to a new field. In case of an East German scientist with a similar portfolio to the West German research, however, a USSR coauthor in any given year after re-unification significantly lowers this scientist's probability to publish in a new field

Table 8: Research and Collaboration Characteristics and the Propensity to Switch to a New Field by East German Scientists

	[Sim.=Corr.Coeff.]			[Sim.=Intensity]		[Sim.= Distance]
	(1)	(2)	(3)	(4)	(5)	(6)
Post90*Similarity	-0.184^{a}	-0.160^{a}	-0.189^{a}	-0.0185	-0.0202	-1.574^{a}
	[0.0410]	[0.0351]	[0.0414]	[0.0283]	[0.0286]	[0.188]
Post90*Emigrant share	0.0288		0.0365	-0.116^{c}	-0.109	0.103
	[0.0666]		[0.0668]	[0.0667]	[0.0668]	[0.488]
Post90*Similarity*Emigrant sh.	0.0727		0.0504	0.364^{b}	0.350^{b}	-0.0453
	[0.231]		[0.231]	[0.156]	[0.157]	[0.885]
Post90*USSR share	-0.0609		-0.227^{b}	-0.0657	-0.227^{b}	-0.592
	[0.0919]		[0.113]	[0.0943]	[0.115]	[1.227]
Post90*Sim.*USSR sh.	0.0756		0.568	0.0418	0.356	0.923
	[0.315]		[0.379]	[0.201]	[0.246]	[2.256]
Post90*USSR Coauthor		0.0729^{b}	-0.0230		-0.0155	-0.364
		[0.0330]	[0.0541]		[0.0578]	[0.461]
Post90*Similarity*USSR Coau		-0.238^{c}	0.0515		-0.00800	0.662
		[0.123]	[0.180]		[0.132]	[0.843]
Post90*USSR Coau*USSR share			0.574^{b}		0.559^{b}	4.370^{c}
			[0.247]		[0.255]	[2.647]
Post90*Sim.*USSR Coau*USSR sh.			-1.638^{b}		-0.952^{c}	-7.797
			[0.806]		[0.511]	[4.875]
Observations	33701	34129	33701	33701	33701	33701

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Dependent variable is one if publication is in a new field for the scientist, zero otherwise.

Similarity is based on West German fields of strength.

Regs include age and quality controls, individual and year FE.

as shown in column (2) of Table 8. In column (3), we interact past USSR collaborations with USSR co-authorship in a particular publication in a particular year. We find that East Germans who have been collaborating with USSR scientists during 1979-1989 are significantly less likely to publish in a new field in a paper after re-unification where they co-author with an USSR scientist. Hence East Germans who did not publish with any USSR scientist before 1990, have non-similar research to West Germans and have a co-author from the USSR in a paper after re-unification are very likely to publish that paper in a new field. Results based on distance definition of research similarity yield a qualitatively similar results as shown in column (6) in Table 8.

This findings shed more light onto our findings from Section 4.1. According to results shown in Table 7. East Germans who crafted many papers with USSR scientists prior to re-unification tend to collaborate less with (former) USSR scientists after re-unification compared to their peers and they publish higher impact papers compared to their peers. Such productivity are not obtained for West-German-similar East Germans who collaborate with USSR scientists. Table 8 reveals that East Germans who published a lot with USSR scientists have less probability to publish in a new field. If they have had a similar research agenda to West Germans, this probability decreases further so that they are significantly less likely to switch to a new field compared to their peers who do neither have a West-German-similar research portfolio nor did collaborate with USSR scientists before 1990. As shown in columns (3), (5), and (6) in Table 8, those East Germans who collaborated with USSR scientists before 1990 have a larger propensity to embark a new field if they coauthor with a (former) USSR scientist after re-unification. We know from Table 7 in Section **??** that those East Germans with many USSR collaborations before 1990 are less likely to engage in such a collaboration, but when they do, it is published as a new field, if they are not West-German-similar.

5 Productivity and Collaborations of Professors in East German Universities

In this subsection we focus on a specific subset of East German scientists, namely those who have held a chaired professorship in a former East German university after the re-unification. Appointment of a professor is a long and tedious procedure in the German university system and winner of such a process will have many academic merits. Moreover, tenured appointment brings life long job security, which can allow scientists to engage in more long term yet productive and promising projects. Hence, we provide a close glimpse into collaboration and productivity patterns of this specific group.

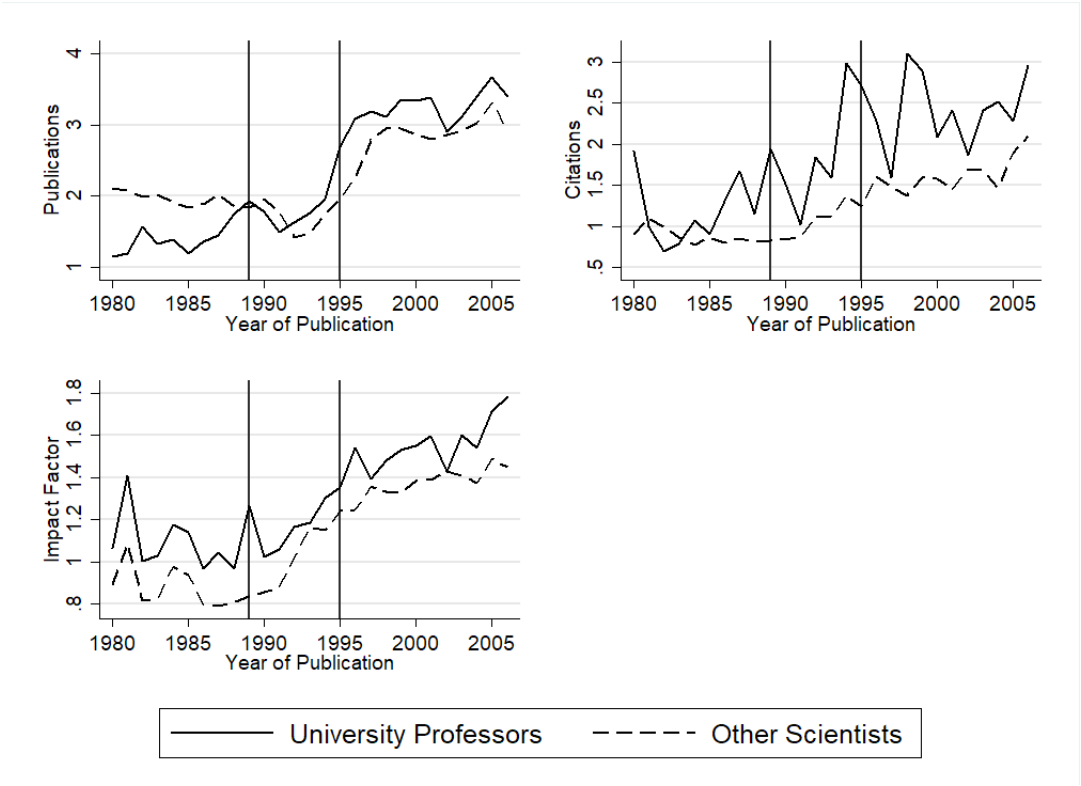

Figure 9: Productivity of East German professors and other scientists

In Figure 9, we show East German professors' publication numbers, citations, and impact factors of their outlets against the rest of the pool of East German scientists. Professors constitute a productive group in all productivity measures, with the exception of publication numbers in 1980s. This can be due to the fact that most professors are young and it is their

first time appointment so that their publication volume was very unripe, especially during the first half of the 1980s.

In Table 9, we re-run the analysis that has been presented in Tables 5 and 7 based solely on this specific subset of East German scientists, namely professors. Professors that have similar research to West Germans get connected to West Germans better than other professors whose research is not that similar to West Germans. They get better citations. When similarity is interacted with having an emigrating co-author, however, those professors have a significantly less number of publications, less citations, and publish in less prestigious journals compared to their peers. Intensity measure of similarity does not yield such dramatic results for citations and journal outlet, but correlation coefficient and vector distance based similarity measures agree on the above mentioned findings.

According to estimated coefficients in Table 9, there is no positive or negative change in professors' productivity trends if they have had an USSR collaboration before re-unification. Regarding their collaboration connections after re-unification, however they tend to connect to West European and American scientists more than their peers do, and they connect to USSR scientists less than their peers do. The reason why we do not find similar effects for USSR collaboration in case of professors can be that their numbers are very low so that the effects are estimated only with a lot of noise. Actually, not only professors with USSR collaborations are few, the overall number of professors in our analysis about 140, which is very low. This is the reason why estimated coefficients in Table 9 come with very large standard errors.

6 Conclusion

Re-unification of East and West Germany brought a lot of structural reforms for the academia in former East Germany, and this provides a unique opportunity to investigate the role of complementarities as well as the institutional setting in academic productivity. We use a unique dataset on West and East German scientists' publications in STEM fields during 1979-1989 and 1995-2005. Making use of the 1990 German re-unification's direct effects on German citizens' mobility and on the (former) East German academic structure, we

Table 9: Differences in Collaboration and Productivity of Professors in East German Universities after 1990

	Collaboration				Production		
	West Ger	Inmig.	West/US	USSR	Pubs.	Cites	IF
[Panel A: Similarity=Correlation]							
Post1990*Similarity	0.432^{a}	0.0813	0.295	-0.109	-0.512	0.646^{b}	0.496
	[0.157]	[0.103]	[0.190]	[0.161]	[0.418]	[0.299]	[0.369]
Post1990*Simil.*Emigr.sh.	-4.155^{c}	-1.462	-9.898^{a}	-4.520	-17.12^{a}	-8.842^{b}	-10.57^{b}
	[2.454]	[1.498]	[2.596]	[2.807]	[5.276]	[3.649]	[4.752]
Post1990*USSR share	-0.401	-0.231	0.967^{b}	-1.402^{a}	0.185	0.796	1.111
	[0.333]	[0.191]	[0.423]	[0.541]	[1.071]	[0.717]	[1.057]
Post1990*Western share	0.0359	0.577^{c}	-0.755^{c}	-0.244	-3.343^{b}	-0.657	-0.380
	[0.208]	[0.305]	[0.425]	[0.189]	[1.322]	[0.426]	[0.763]
[Panel B: Similarity=Intensity]							
Post1990*Similarity	0.164^{c}	0.0520	0.00365	-0.155^{c}	-0.592^{b}	0.103	0.259
	[0.0889]	[0.0658]	[0.110]	[0.0862]	[0.268]	[0.164]	[0.220]
Post1990*Simil.*Emigr.sh.	-3.434^{b}	-2.641^{b}	-0.561	0.215	-6.249	0.711	-1.568
	[1.331]	[1.134]	[1.682]	[2.124]	[3.805]	[2.512]	[3.658]
Post1990*USSR share	-0.569	-0.383^{c}	0.424	-1.492^{a}	-0.280	0.573	0.681
	[0.354]	[0.223]	[0.459]	[0.537]	[1.120]	[0.727]	[1.066]
Post1990*Western share	-0.0434	0.602^{c}	-1.233^{b}	-0.651^{b}	-1.647^{c}	-1.033^{b}	-0.584
	[0.223]	[0.308]	[0.601]	[0.326]	[0.994]	[0.502]	[0.893]
[Panel C: Similarity=Distance]							
Post1990*Similarity	1.427^{c}	-0.152	1.605^{c}	0.0224	-4.813^{a}	2.809^{c}	2.099
	[0.862]	[0.496]	[0.921]	[0.714]	[1.460]	[1.620]	[1.577]
Post1990*Simil.*Emigr.sh.	-9.298	-0.281	-44.04^{a}	-24.24^{a}	-13.83	-38.01^{b}	-41.63^{b}
	[13.01]	[4.420]	[11.01]	[8.885]	[20.16]	[15.33]	[16.62]
Post1990*USSR share	6.657	-11.41^{a}	31.12^{a}	4.823	3.572	-0.775	21.76
	[6.336]	[4.139]	[7.158]	[8.451]	[16.56]	[11.42]	[14.86]
Post1990*Western share	6.256^{b}	5.274^{c}	11.26^{a}	1.774	-25.33^{b}	9.711	0.838
	[3.080]	[3.103]	[3.977]	[3.096]	[10.84]	[5.969]	[7.157]
Observations	1449	1449	1449	1449	2222	1449	1446

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity is based on West German fields of strength. Regs include age and quality controls, individual and year FE.

investigate causal effects of scientists' complementarities and the newly established structure of the academic labor market on scientists' collaborations and research productivity.

A difference-in-difference analysis of East German scientists' connections to their peers, their scientific productivity and impact as measured by the number of publications, citation accumulation, and the quality of journals where they publish reveal intriguing findings. East German scientists who remained in former East Germany after re-unification show a significant convergence to their West German peers in all productivity accounts. East German scientists' complementarities with the newly established institutional structure of East German academia has a detrimental effect on their productivity. Although similarity of research to West German research prior to the re-unification may bring an edge for the survival during the restructuring of the East German academia, we find that the main leap forward came from those East German scientists who have been working with Soviet scientists on topics that were not necessarily a significant part of the West German research agenda before the re-unification.

Cognitive mobility is when researchers switch their field of academic activity, and this is also an important strategy to cope with shocks in the academic labor market (Borjas and Doran, 2015a). Cognitive mobility allows scientists to sustain their productivity by channeling their intellectual input to fields that they have not published in previously but may yield a higher marginal return under current circumstances. We find that East German scientists who collaborated with Soviet scientists on non-Western research fields during the 1980s are not only more likely to collaborate with West European and US scientists after the re-unification but they are also more likely to switch their field of research. Although East German scientists with a similar portfolio to West Germans are less likely to switch their field, those who lost a previous collaborator are more likely to do so.

These findings contribute to peer effects literature as they show that complementarities of research expertise between scientists or between scientists and governing structures and institutions of science policy, such as the academic labor market structure or structures of incentive and promotion, are significant drivers of scientific productivity or even academic survival. Although loss of collaborators has adverse effects on scientists' productivity, forma-

tion of new collaborations and cognitive mobility may make up for this loss if scientists are able to complement the process of knowledge production in some plausible way.

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Table A.1: Differences in the Productivity of East German Scientists after 1990 (including Field FE)

	East Germans			East and West Germans		
	Papers	Cites	IF	Papers	Cites	IF
[Panel A]						
Post1990*East				0.246^{a}	0.220^{a}	0.413^{a}
				[0.0184]	[0.0105]	[0.0147]
[Panel B:Similarity=Correlation]						
Post1990*Similarity	-0.517^{a}	-0.0395	0.496^{a}			
	[0.138]	[0.0739]	[0.113]			
Post1990*East*Similarity				0.345^{b}	0.265^{a}	0.800^{a}
				[0.137]	[0.0752]	[0.110]
[Panel C:Similarity=Intensity]						
Post1990*Similarity	-0.0941	0.00833	0.390^{a}			
	[0.0867]	[0.0456]	[0.0738]			
Post1990*East*Similarity				0.263^{a}	0.135^{a}	0.536^{a}
				[0.0906]	[0.0483]	[0.0749]
[Panel D:Similarity=Distance]						
Post1990*Similarity	-3.574^{a}	-0.509	1.632^{a}			
	[0.720]	[0.433]	[0.591]			
Post1990*East*Similarity				0.901	1.075^{a}	2.683^{a}
				[0.669]	[0.415]	[0.542]
Observations	136499	107869	107712	136499	107869	107712

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity is based on West German fields of strength.

Regs include age and quality controls, individual, year, and FIELD FE.

Table A.2: Differences in the Productivity of East German Scientists after 1990 (SIMILARITY BASED ON CITES)

	East and West Germans			East Germans		
	Papers	Cites	IF	Papers	Cites	IF
[Panel A:Similarity=Correlation]						
Post1990*East	0.135^{a}	0.101^{a}	0.292^{a}			
	[0.0316]	[0.0173]	[0.0252]			
Post1990*Similarity	0.145^{a}	-0.283^{a}	-0.491^{a}	0.0664	0.129^{c}	0.00913
	[0.0335]	[0.0239]	[0.0251]	[0.119]	[0.0699]	[0.101]
Post1990*East*Similarity	0.235^{c}	0.512^{a}	0.496^{a}			
	[0.120]	[0.0718]	[0.0996]			
[Panel B:Similarity=Intensity]						
Post1990*East	0.123^{a}	0.117^{a}	0.286^{a}			
	[0.0315]	[0.0171]	[0.0252]			
Post1990*Similarity	0.174^{a}	-0.145^{a}	-0.253^{a}	0.240^{a}	0.0718^{c}	0.0546
	[0.0198]	[0.0144]	[0.0150]	[0.0712]	[0.0406]	[0.0598]
Post1990*East*Similarity	0.196^{a}	0.263^{a}	0.317^{a}			
	[0.0745]	[0.0426]	[0.0608]			
[Panel C:Similarity=Distance]						
Post1990*East	0.628^{a}	0.0215	0.339^{c}			
	[0.236]	[0.120]	[0.186]			
Post1990*Similarity	1.108^{a}	0.0776	-0.702^{a}	-0.541	0.228	-0.571^{c}
	[0.136]	[0.0795]	[0.109]	[0.423]	[0.223]	[0.329]
Post1990*East*Similarity	-0.831^{c}	0.348	0.106			
	[0.442]	[0.225]	[0.348]			
Observations	136500	107871	107714	14793	10780	10761

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity is based on West German fields of strength.

Regs include age and quality controls, individual and year FE.

Table A.3: Differences in Collaboration and Productivity of East German Scientists after 1990 based on Past Collaboration with Emigrating East Germans and Soviet Scientists (Similarity is measured by *intensity*)

	Collaboration					Production		
[Panel A]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Emigrant share	0.173^{a}	-0.00581	-0.809^{a}	0.0366	-0.0500	-0.355	-0.338^{a}	-0.213
	[0.0630]	[0.0538]	[0.104]	[0.0842]	[0.0832]	[0.250]	[0.118]	[0.192]
Post1990*Similarity*Emigrant sh.	-0.384^{a}	0.0859	-0.261	0.0574	0.0397	0.985^{b}	0.346	0.283
	[0.105]	[0.124]	[0.205]	[0.186]	[0.171]	[0.495]	[0.216]	[0.438]
Post1990*USSR share	0.126	0.135^{c}	0.0442	0.374^{a}	-0.945^{a}	0.899^{a}	0.600^{a}	0.521^{c}
	[0.0914]	[0.0746]	[0.0672]	[0.140]	[0.171]	[0.321]	[0.199]	[0.267]
Post1990*Similarity*USSR sh.	-0.125	-0.356^{b}	0.00488	-0.00898	0.472	0.168	-0.620	-1.074^{c}
	[0.186]	[0.152]	[0.144]	[0.299]	[0.372]	[0.700]	[0.416]	[0.617]
[Panel B]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*USSR share (without Emigrants)	0.0514	0.169^{b}	0.0667	0.384^{b}	-1.022^{a}	0.839^{b}	0.706^{a}	0.346
	[0.0919]	[0.0786]	[0.0583]	[0.150]	[0.180]	[0.336]	[0.211]	[0.277]
Post1990*Similarity*USSR share (without Emigrants)	-0.0362	-0.398^{b}	-0.0551	-0.00531	0.629	0.309	-0.676	-0.636
	[0.193]	[0.159]	[0.123]	[0.315]	[0.390]	[0.722]	[0.440]	[0.635]
[Panel C]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Western share	-0.0462	0.00141	-0.0180	-0.305^{b}	-0.173^{a}	-0.416^{c}	-0.206	-0.143
	[0.0478]	[0.0577]	[0.0406]	[0.130]	[0.0476]	[0.251]	[0.127]	[0.161]
Post1990*Similarity*Western sh.	-0.0783	0.140	-0.121	-1.892^{a}	0.784^{a}	0.119	-0.607	-1.874^{a}
	[0.235]	[0.209]	[0.231]	[0.397]	[0.214]	[0.715]	[0.432]	[0.557]
Observations	10542	10542	10542	10542	10542	14378	10542	10525

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity (intensity) is based on West German fields of strength. Regs include age and quality controls, individual and year FE.

Table A.4: Differences in Collaboration and Productivity of East German Scientists after 1990 based on Past Collaboration with Emigrating East Germans and Soviet Scientists (Similarity is measured by *distance*)

	Collaboration					Production		
[Panel A]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Emigrant share	0.540	-0.291	-0.0675	2.731^{a}	2.683^{a}	-2.433	-3.136^{b}	-3.886^{b}
	[0.701]	[0.556]	[0.977]	[0.853]	[0.753]	[2.261]	[1.258]	[1.707]
Post1990*Similarity*Emigrant sh.	-0.968	0.610	-1.557	-4.894^{a}	-4.970^{a}	4.584	5.436^{b}	7.072^{b}
	[1.315]	[1.036]	[1.788]	[1.576]	[1.383]	[4.121]	[2.333]	[3.147]
Post1990*USSR share	-1.575	2.549^{a}	-0.325	2.766	3.341	16.45^{a}	6.076^{b}	7.990^{b}
	[1.220]	[0.855]	[1.025]	[1.741]	[2.104]	[3.785]	[2.359]	[3.162]
Post1990*Similarity*USSR sh.	3.082	-4.718^{a}	0.694	-4.440	-7.590^{c}	-28.54^{a}	-10.60^{b}	-14.54^{b}
	[2.275]	[1.587]	[1.913]	[3.227]	[3.878]	[6.952]	[4.366]	[5.865]
[Panel B]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*USSR share (without Emigrants)	-0.536	2.000^{b}	-0.460	1.619	2.239	13.22^{a}	5.440^{b}	7.286^{b}
	[1.236]	[0.868]	[0.962]	[1.815]	[2.179]	[3.836]	[2.454]	[3.301]
Post1990*Similarity*USSR share (without Emigrants)	1.085	-3.673^{b}	0.942	-2.299	-5.579	-22.64^{a}	-9.282^{b}	-13.24^{b}
	[2.302]	[1.614]	[1.794]	[3.371]	[4.023]	[7.064]	[4.548]	[6.134]
[Panel C]	West Ger	Inmig.	Outmig.	West/US	USSR	Pubs.	Cites	IF
Post1990*Western share	0.216	1.355^{b}	0.931	8.241^{a}	-2.322^{a}	3.207	3.007^{c}	7.282^{a}
	[0.871]	[0.629]	[0.786]	[1.315]	[0.786]	[2.756]	[1.544]	[1.963]
Post1990*Similarity*Western sh.	-0.549	-2.488^{b}	-1.853	-17.09^{a}	4.499^{a}	-6.548	-6.392^{b}	-15.00^{a}
	[1.694]	[1.197]	[1.535]	[2.479]	[1.530]	[5.165]	[2.942]	[3.742]
Observations	10542	10542	10542	10542	10542	14378	10542	10525

Standard errors in brackets. ^{c} $p < 0.10$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Similarity (distance) is based on West German fields of strength. Regs include age and quality controls, individual and year FE.