Don't Talk to Strangers?
Cognitive Proximity, Social Proximity and the Productivity of Mobile Inventors

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Abstract: A British post-WW2-program to detain and interrogate German experts allows us to disentangle individual dimensions of proximity and to minimize self-selection bias. Our empirical analysis of post-detention patenting activities suggests that cognitive proximity is more important than social and institutional proximity in interactive learning.

1. Introduction

The past decades have witnessed radical changes in information technology and communication patterns. But even though long-distance communication has become easier, faster and drastically less expensive, there is little to suggest that geography has lost its economic relevance. Production activities are unevenly distributed across countries and regions (Ellison and Glaeser, 1997), and innovation activities likewise appear to be highly concentrated in space (Audretsch and Feldman, 1996). Economic agents incur vast amounts of costs to overcome geographic distance. In the United States alone, the number of passenger miles in air travel has increased by almost 20% from 2005 to 2014 (U.S. Department of Transportation).

Not only do persistent geographic imbalances and substantial travel costs suggest that the „death of distance“ (Cairncross, 2001) was announced prematurely. They also resonate with a long line of insights that date back at least to Alfred Marshall's (1920) notion of localized knowledge spillovers. Since then, countless studies in economics and geography have provided evidence that knowledge flows may be restricted by geographic distance. A straightforward explanation for the localized nature of knowledge is that not all knowledge is perfectly codified, and the transfer of non-codified knowledge requires face-to-face contact and interactive learning (Polanyi, 1967; Foray, 2004). Empirical evidence indicates that thus holds not only for knowledge flows between firms (Jaffe et al., 1993), but also for the diffusion of scientific knowledge (e.g., Helmers and Overman, 2015).

The localized nature of knowledge provides an economic rationale for mobility to overcome geographic distance. However, mobility alone may not be sufficient to allow for knowledge transfer, as learning also requires common prior contextual knowledge allowing for mutual understanding (Cohen and Levinthal, 1989). In addition, the willingness and ability to learn from each other may depend on trust and mutually shared values (Granovetter, 1985). Empirically disentangling cognitive and social factors from the role of geography in the transfer of knowledge has proven exceedingly difficult. One reason is that all the various dimensions of distance (or proximity) tend to be associated. For instance, replicating the seminal analysis of patent citations by Jaffe et al. (1993), Breschi and Lissoni (2005; 2009) have shown that a substantial fraction of localized knowledge flows reflect intra-regional labor mobility and localized social ties. Higher geographic proximity also tends to be associated with higher similarity in formal and informal institutions, and likewise in the curricula of education systems. A second complication in empirical identification is that geographic, cognitive and social proximity are often not exogenously given, but are actively shaped by the agents themselves in their attempts to learn from others. Mobility is as much influenced by deliberate choices as the formation of social ties and educational decisions conditioning an agent's ability to understand information about a given field of knowledge.

Against this backdrop, the purpose of this paper is to provide new evidence on the role of cognitive and social factors in shaping the effects of individual mobility. Our empirical analysis is based on unique historical evidence about post-World War 2 "intellectual reparations" (Gimbel, 1990b). In this empirical context, different dimensions of proximity can be distinguished in an unusually clear-cut way. In addition, mobility was unexpected and involuntary, which attenuates potential biases from self-selection. "Intellectual reparations" denote the post-WW 2 attempts by the Allied countries to acquire useful knowledge from the defeated countries, in particular Germany. During the final war years and following their victory in 1945, Allied forces secured large amounts of blueprints, samples etc. from corporate R&D laboratories in Germany. In addition, German scientists and engineers themselves became part of the intellectual reparations. In a variety of programs, highly educated Germans were brought to France, the Soviet Union, the United Kingdom or the United States to be interrogated about their fields of expertise.

Our empirical analysis focuses on this forced migration of German experts. Specifically, we study the invention activities of German experts (mostly industrial scientists and engineers) who were, under the auspices of the British BIOS ("British Intelligence Objectives Sub-Committee") program, detained in Britain and interrogated by British officials and company representatives. At the same time, rich knowledge exchanges and systematic teaching and learning activities among the detained German specialists have been documented. Our identification strategy exploits the fact that the detention of German experts in Britain, and their interviews at British firm sites, enforced geographic proximity on their interactions. Given the involuntary character of their detention, potential biases from self-selection into the mobility "treatment" are minimized. In addition, cognitive and social factors can be separated rather clearly in our empirical context. Cognitive proximity was high between German specialists and the British firm representatives by whom they were interviewed, but low within the group of detained Germans, who (as will be documented below) came from a variety of disciplinary and organizational backgrounds. In contrast, the degree of social proximity was high among the detained interned German experts, but low between the detained Germans and their British interrogators.

Our empirical results suggest that in spite of the involuntary nature of their mobility, and even though detention and interrogation aimed at "exploiting" (Gimbel, 1990b) German knowledge, participation in the BIOS program boosted the subsequent patent productivity of the involved German experts. We find strong evidence indicating that the German experts gained valuable knowledge from their interaction with British firm representatives. In contrast, there is no evidence suggesting that the mutual interaction among the detained

Germans exerted a relevant influence on their subsequent activities or their patent performance. These patterns are consistent with a substantial importance of cognitive proximity, while they do not suggest that social factors play an important role in the interpersonal transfer of knowledge.

The remainder of this paper is structured as follows. In Section 2 we discuss relevant prior work and develop testable hypotheses to guide the empirical analysis. Section 3 introduces the historical context of the analysis. Our data are presented in Section 4, while Section 5 discusses the empirical analysis and its results. Section 6 concludes.

2. What Factors Shape the Interpersonal Transfer of Knowledge?

Geography, Mobility and Learning

Countless studies show that not all economically relevant knowledge is a public good. Localized knowledge spillovers imply significant impediments to the transfer of knowledge across geographic space. Empirical work using a variety of data sources and methods indeed indicates that knowledge flows are stronger within than across geographically defined regions. Jaffe et al. (1993) first used patent citations as an indicator of knowledge flows and showed that a disproportionate number of citations refer to co-located patents (at various geographic scales). Using a variety of proxies, contexts, and methods, other authors have arrived at similar conclusions (e.g., Acs et al., 1992; Audretsch and Feldman, 1996).

The geographically sticky nature of knowledge is typically explained by the fact that not all relevant knowledge is perfectly codified, and that its interpersonal transfer requires face-to-face contact and interactive learning (Polanyi, 1967; Foray, 2004). Co-location increases the likelihood of chance encounters allowing for interactive learning. It also reduces the cost of deliberate interaction. To allow for face-to-face contact with distant partners, agents may permanently or temporarily move to where these partners are located. Powerful effects of mobility on the exchange and geographic transfer of knowledge have been demonstrated. Not only do mobile inventors learn new knowledge at their new location. Through their pre-existing personal relationships, they also become conduits of knowledge flows back to their home countries (Agrawal et al., 2006). In the context of academic research, it has been shown that the productivity of scientists increases post-migration (Franzoni et al., 2014). Even short term migration, such as scientists' research stays abroad, can lead to beneficial learning and long-lasting network extensions (Jöns, 2009).

Based on the prior evidence that imperfect codification causes knowledge to be localized and "geographically" sticky, and consistent with prior evidence suggesting that mobility allows agents to tap into new sources of knowledge, we predict the following effects of migration on agents' activities and innovation :

H1: Individual migration provides new opportunities for interactive learning, which migrating agents draw upon in their subsequent knowledge-creating activities.

H2: Individual migration provides new opportunities for interactive learning, which increases the post-migration productivity of knowledge-creating activities.

Cognitive Proximity, Social Proximity and Interactive Learning

Even though mobility allows agents to tap into new sources of relevant knowledge, it is not obvious that bridging geographic distance alone is sufficient to benefit from the opportunities that the new environment provides. Mutual understanding is an obvious first prerequisite of interactive learning (Boschma, 2005; Huber, 2012). Understanding requires a shared stock of background knowledge. The ability of agents to understand and evaluate the importance of information they newly encounter depends on how strongly it is related to their prior knowledge. The more related their prior knowledge is to the incoming information, the better their absorptive capacity for this new information tends to be, i.e. their "capacity to recognise, assimilate, and exploit" it (Cohen and Levinthal 1989, p. 593). Cognitive proximity, i.e. the similarity of what they know, can therefore be assumed as the most fundamental determinant of knowledge flows between individuals.

In principle, cognitive proximity may also have a downside (Boschma and Frenken, 2010). Very similar prior knowledge may also compromise the novelty of the newly accessed information for the agent. This is turn may limit her ability to derive useful insights from combining the new piece of knowledge with what she already knew before (Fleming, 2001; Nooteboom et al., 2007). In the context of mobile agents, this potential "trap" of excessive cognitive proximity in interactive learning may be a less salient concern, as mobility may often be motivated by the intention to access new sources of knowledge that differ those involved from prior interaction. As will emerge below, we have little reason to worry about the problem of "excessive" cognitive proximity in the setting of our empirical analysis.

In addition to cognitive proximity, other factors may condition the effectiveness of interactive learning. In this context, various authors have emphasized the importance of social proximity from personal ties, which may for instance be based on kinship, friendship, or shared prior workplace experience (e.g., Granovetter, 1985; Boschma, 2005; Broekel and

Boschma, 2012). Social ties may facilitate learning in a variety of ways. First, from the perspective of the learning agent, trust based on social ties may enhance the perceived relevance and trustworthiness of received information. Second, social proximity may also be an important prerequisite for agents' willingness to share information with others. Prior work has suggested that knowledge often has "club good" characteristics, with bi-directional knowledge flows between agents interacting on a basis of (expected) reciprocity (Breschi and Lissoni, 2001). It has moreover been shown that "clubs" of informal knowledge trading may even encompass members of competing firms (von Hippel, 1987; Schrader, 1990). As reciprocal knowledge sharing may be subject to free riding, authority relations and stronger control within a shared organizational context may further enhance the potential for interactive learning (Boschma, 2005).

The relevance of social proximity in interactive learning is consistent with empirical evidence that localized patent citations are often based on labor mobility or social ties among inventors (Breschi and Lissoni, 2005; 2009). It may also help explain why competitive advantage in localized industry clusters is often limited to entrepreneurs who have previously worked for leading firms in the same industry (e.g., Wenting, 2008; Buenstorf and Klepper, 2009). Boschma (2005) proposes to further distinguish social proximity from institutional proximity, which derives from exposure to similar formal and informal institutions. The implied relevance of more "macroeconomic" factors for interactive resonates with findings indicating the importance of ethnic ties for inventors (Agrawal et al., 2006) as well as entrepreneurs (Alcacer and Chung, 2007).

In the context of individual mobility, the above considerations suggest that bridging geographic distance may be necessary but not sufficient to attain new knowledge. In addition to geographic proximity successful interactive learning may also require cognitive proximity allowing mobile agents to absorb and integrate the information that that access in their interactions in the new environment. We therefore hypothesize:

H3a: Cognitive proximity allows migrating agents to benefit from interactive learning in their post-migration knowledge-creating activities.

In addition, effective learning by mobile agents may also require social proximity to their interaction partners in the new environment. Social proximity may both be necessary for them to trust in what they are told, and for their partners to be willing to share any relevant information. This informs our final hypothesis:

H3b: Social and institutional proximity allow migrating agents to benefit from interactive learning in their post-migration knowledge-creating activities.

To some extent at least cognitive and social proximity may be established in the course of interaction itself. However, a common cognitive basis may be required at the outset of the interaction, as the interacting agents may otherwise be frustrated and give up in their endeavor to learn from their communication partner. Similarly, an initial lack of social proximity may compromise the quality of the interaction in irreparable ways. We accordingly focus on initial differences in cognitive and social proximity between interacting agents in our subsequent empirical analysis.

Empirical Identification Issues: Correlations in Proximity Dimensions and Self-Selection into Migration

The extant empirical evidence of effects of proximity and mobility is limited by two types of empirical identification issues. First, the various dimensions of proximity are not normally independent, but may correlate and possibly co-evolve in potentially complex ways (e.g., Huber, 2012). In addition, empirical measures of proximity often suffer from imprecise measurement. Accordingly, effects of individual types of proximity are difficult to separate using standard regression techniques. A second concern is that proximity need not be given exogenously. Agents can and typically will shape their own proximity to others. Geographic proximity can be reached by migrating to attractive interaction partners. Unless prior mobility can be observed, individual locations cannot there be assumed to be randomly distributed. The same holds for other dimensions of proximity, which may be sought deliberately by the respective agents.

To deal with concerns of self-selection into mobility, a number of recent studies have analyzed effects of historical migration events that was induced by "push" rather than "pull" factors, and where political risks and/or economic hardships left individuals little choice but to escape from their current location. More specifically, several studies have analyzed the effects of the Jewish emigration from Germany after 1933 on German and U.S. science and innovation (Waldinger, 2010, 2012; Moser et al., 2014). In a similar spirit but drawing on more recent history, Borjas and Doran (2012; 2015) have studied the emigration of Soviet mathematicians after the collapse of the Soviet Union. Analyzing such "forced" mobility events helps to isolate the effects of specific types of proximity. At the same time, it minimizes the potential bias of non-random selection into the mobility "treatment". In what follows, we will adopt the same basic approach and exploit a facet of European 20th century history that, to the best of our knowledge, has so far escaped the attention of economists: the involuntary mobility of German experts as part of "intellectual reparation" schemes at the end of World War. 2.

3. Post-WW2 Intellectual Reparations and the BIOS Program

Prior to World War 2, Germany's science and technology were highly developed. Before the Nazi government dismissed and frequently killed a large number of Jewish and "politically unreliable" scientists, German universities were world leaders in a variety of science and engineering disciplines (Waldinger, 2012). In spite of the subsequent brain drain, the Nazi war efforts provided German researchers with ample resources and good working conditions in fields such as aeronautics and missile technology that were deemed of pivotal military importance. German industrial research and development likewise benefitted from a long-standing commitment to research (cf. Murmann, 2003, for the chemical industry) as well as from the preparations for the war. For instance, the Nazi government's focus on decreasing Germany's dependence of foreign raw materials boosted research efforts in the field of synthetic fuels and materials.

Already in 1944, months before the war was over, the Allied forces started a variety of programs to get a hold of German knowledge. These programs quickly evolved and grew increasingly more sizeable over time. Originally, both the U.S. and U.K. governments hoped to acquire useful German knowledge for military purposes, which was justified with the need for advanced technology to win the war against Japan. Soon, however, military considerations gave way to an overt willingness to extract "intellectual reparations" (Gimbel, 1990b) from Germany to support the competitiveness of U.S. and U.K. industries. German production and R&D sites of interest were identified, secured and systematically searched by Allied specialists. Many of the documents captured were not self-explanatory, and German experts had to be questioned to understand them. In the aftermath of WW2, German scientists and technicians were held captive in special camps in the occupied zones in Germany. This also helped the U.S. and U.K. governments to keep these Germans from falling into Soviet hands.

"Whether they liked it or not" (Gimbel, 1990b), many German experts who proved to be useful were taken from Germany to reveal their expertise in the Allied countries. The research group of Wernher von Braun that was flown to the USA shortly after the war had ended is only the most prominent example (Lasby, 1971; Jacobsen, 2014). The military documents keeping record of these programs were only recently and gradually declassified. To our best knowledge, this study is the first empirical analysis conducted on the basis of this data.

In this study, we focus on the "BIOS" program (British Intelligence Objectives Sub-Committee), which was set up by the U.K. government in order to get as much information as possible out of selected German experts. These were brought to the U.K. and held captive in a detention center. According to one of the German experts who experienced the internment, they spent most of their time interacting with the other Germans, only to be questioned from time to time by British officials or company representatives. In some cases, they were even taken to other parts of the U.K. by the request of companies to be questioned there.

For most of the experts, this treatment came unexpected. Before being brought to the U.K., they had been told they would be "guests of the British Empire" and they had been promised a short stay. Instead, they spent weeks or even months in a camp secured by barbed wire. To pass the time, the detained German experts started giving each other lectures about their areas of expertise. Some had pre-existing contacts to British firms, which they believed they could renew during their stay in Britain. However, this was mostly prohibited by British officials, who fully controlled the schedule of meetings and interrogations. The German experts had no say in whom to meet (Gimbel, 1990a). Expert talks between the Germans and employees of U.K. firms thus established new contacts.

In the meetings with their British counterparts, the Germans talked to experts from their fields trying to tap into their expertise to solve practical problems. Thus, even though the rationale of the detention was to "exploit" (Gimbel, 1990b) the German expertise, the detained Germans also learned about technological interests, approaches and problems on the British side. This necessarily bi-directional flow of knowledge actually was a relevant concern of the British officials involved with the program (ibid.). We will focus on the effects of the BIOS program on the subsequent patenting activities of the German experts in our empirical analysis.

4. Data

The primary dataset used to study the effects of the BIOS program is a set of lists with names of German scientists and engineers who were brought to Great Britain between October 1946 and August 1947 to be questioned and to be denied to the (Soviet) enemy. These lists were made publicly available by the British Ministry of Supply in 2006. They encompass three distinct projects, "BIOS", the "Darwin Panel Scheme" and the "DCOS Scheme". We focus on BIOS, which was the most sizeable of the three programs. BIOS was special in that it brought German experts to the U.K. for short periods of time to be questioned by public officials and by representatives of U.K. firms.

After retrieving the scientists' names and the duration of their stay from the lists, we searched for their names on patents in DEPATISnet (the online database of the German patent office). In total we counted 249 experts who stayed in the UK for at least one week (mean duration: 6 weeks). 169 were involved in patenting activities. 40 of those matched to several inventors sharing the same name. Because we do not have any further criteria (except the name) we could not clearly distinguish which of the matched inventors is the one on our list. Thus we decided to exclude them from the sample. Of the 129 experts left, we found 74 to have patenting activities both before and after 1947, which is the year during which the treatment occurred. Between them, they are listed as inventors on 4,206 unique patent documents. We examined all documents manually to identify the country of residence of the experts as well as their applicants and co-inventors. In addition we tracked all foreign citations to these patents using the PATSTAT database (version April 2009). We matched our list to PATSTAT via the publication number.[1]

In order to measure causal effects that the treatment had on our German experts, we needed a control group. For two reasons, we decided against using German inventors for the control group: first, we cannot rule out that inventors not in the BIOS program were not in another similar program, and second it is to be expected that the treated experts were chosen by the British for a reason, so there should be systematic differences between the treated and not-treated Germans. To deal with these issues, we decided to look for Swiss inventors. Switzerland provides a suitable control group for several reasons. It directly neighbors on Germany and is relatively similar in term of culture and (at the time) industrial structure. In addition, Switzerland was neutral in World War 2, which should make it a better match than any of the Allied countries.

In constructing our control group, for each German patentee we tried to find the most similar Swiss counterpart based on their patenting activities prior to 1947. We picked our "twins" based on several criteria: First of all, we searched for patentees active in the same patent classes as the German inventors. At the most detailed IPC level, we found potential matches for 43 of the German experts. We went through the list of potential matches and compared the inventors' productivity (measured by patent output) before 1947 selecting the most similar one for each German. We only included Swiss inventors who were also active after 1947 which ensures a reasonable comparison in the post 1947 period. For the remaining 31 Germans we repeated the same procedure using the four-digit IPC level.

For the Swiss control group, we then repeated the patent scanning procedure we had already undertaken for the German experts. For six German inventors no appropriate twin could be found, leading to 68 Swiss inventors on the list (the respective German inventors were dropped). Not for all patents all required bibliographic information was accessible.

[1] Some of the patents retrieved from DEPATISnet could not be found in PATSTAT. Other documents were not digitally available in DEPATISnet. The 4206 documents mentioned are priority patents (of DOCDB patent families) which could be found in both databases. Originally we obtained 5510 patents from DEPATISnet (including all patent family members). Furthermore, citation reports were only available for patents published at the German patent office. This limited us in the possibilities for citation analyses.

For some patents, none of the information required for our analysis could be found. We decided to exclude all patents lacking full information. This, however, further reduced our sample by 10 German inventors (and their Swiss counterparts) who then had no patents left in either the pre- or post-1947 period. Thus, we were left with a sample of 58 German and 58 Swiss patentees.

Descriptive statistics of our sample are presented in Table 1. In addition to the number of patents filed before and after 1947, Table 1 also shows the incidence of U.K. affiliations (which we set to 1 if a patentee's address was British) and the average number of U.K. applicants and U.K. co-inventors. The table shows that the Swiss control group matches the BIOS sample well, as there are no significant differences between the average statistics before 1947 and there are no significant differences between the time spans during which Germans and Swiss were active.

	full sample	German inventors	Swiss inventors	
n	116	56	56	
patents pre	1658	909	749	
patents post	2933	2427	506	
average (median in breakets)				p-value mean difference
patents pre	14.29 (8)	15.67 (8)	12.91 (8)	0.42
patents post	25.28 (6)	41.84 (11)	8.72 (11)	0.02
year first patent filed	1928.34 (1929)	1929.84 (1931)	1926.84 (1931)	0.09
years active	31.53 (32)	31.19 (32)	31.88 (32)	0.74
UK affiliation pre	0.01 (0)	0.02 (0)	0.00 (0)	0.32
UK affiliation post	0.07 (0)	0.12 (0)	0.02 (0)	0.03
UK applicants pre	0.00 (0)	0.00 (0)	0.00 (0)	
UK applicants post	0.13 (0)	0.26 (0)	0.00 (0)	0.01
UK co-inventors pre	0.01 (0)	0.02 (0)	0.00 (0)	0.01
UK co-inventors post	0.06 (0)	0.12 (0)	0.00 (0)	0.00

Table 1: descriptive statistics.

However, for the post 1947 period, significant differences can be found between the two groups. The number of post-treatment patents is significantly higher for German inventors, which seems to support Hypothesis 2. We can also observe that 11% of the German inventors actually stated their residency to be in the U.K. after 1947. Here, the difference between the German and the Swiss group also becomes significant after the treatment. The number of U.K. applicants affiliated to patents increases for Germans as well and becomes significantly different to that of inventors in the control group. Though an increase in the average number of co-inventors from the UK is observable (from 0.02 to 0.11), the difference between treatment and control group is not significant.

5. Empirical Analysis

Using the dataset on German and Swiss inventors described above, we first study whether there are observable traces of the U.K. detention experience in the patenting activities of the German experts (as predicted by Hypothesis 1). We then compare the development of patenting output over time for the two group of German and Swiss inventors (Hypothesis 2). Finally, we begin to disentangle potential effects of cognitive and social proximity that might account for the observable differences (Hypotheses 3a and 3b).

To trace potential effects of the detention treatment on German inventors, a simple univariate difference-in-difference estimation of three observable outcomes is conducted first (Table 2). We employ three different indicators of interaction with the U.K.. The first variable, "U.K. address" measures whether or not an inventor moved his residency to the U.K. The second one, "total number of U.K. co-inventors", measures the number of co-inventors from the UK listed for the inventors in our two groups. The third variable, "total number of UK applicants", does the same for applicants from the U.K.. For the means of these variables, we look at the differences between treatment and control groups. The diff-in-diff estimator shows the difference of this difference between the two time periods (before and after the treatment in 1947). To test whether the difference in the differences of the means deviates from zero, we calculated the distribution by random resampling. The quantile cutting zero received by the bootstrapping is presented in the last column of Table 2. The quantiles point to a low chance of receiving similar results by random. Furthermore, only two of our German experts seem to have shifted all their activities to the U.K. (with their residency, co-inventors and applicants all being listed as U.K.), others seem to have kept in contact with German inventors and applicants while also moving some activity (residency and/or co-inventors/applicants) to the U.K.. All of this is in line with Hypothesis 1, which states that migrating inventors draw upon new opportunities of interactive learning in their subsequent knowledge-creating activities.

number of inventors with:	German		Swiss		diff-in-diff estimator	quantile cutting zero*
	pre	post	pre	post		
UK address	1	7	0	1	0.09	0.05
UK co-inventors	1	4	0	0	0.05	0.12
(UK co-inventors total number)	1	7	0	0	0.10	0.08
UK applicants	0	9	0	0	0.16	0.00
(UK applicants total number)	0	15	0	0	0.26	0.00
any kind of UK interaction	2	10	0	1	0.14	0.00

* bootstrapped with 1000 iterations

Table 2: U.K. interaction - Diff-In-Diff estimates.

Next, individual counts of patent applications are studied to test Hypothesis 2 predicting inventor migration to have productivity-enhancing effects. For our sample, this would suggest an increase in productivity for the treated German experts after their stay in the UK. We employ a multivariate diff-in-diff framework, which identifies the effect of treatment by estimating the difference between the number of pre-1947 and post-1947 patent applications differs between members of the treatment and the control groups. Suitability of the diff-in-diff framework is suggested by Figure 1, which graphs the moving average of patent applications over time for the two groups. It indicates that pre-1947 patent applications are very similar in Germany and Switzerland, i.e. the common trends assumption critical for the validity of diff-in-diff results is fulfilled. Since patent counts are non-negative integers, we use a negative binomial model.Pooling the data of both time periods leads to a total of 232 observations (116 pre and 116 post).

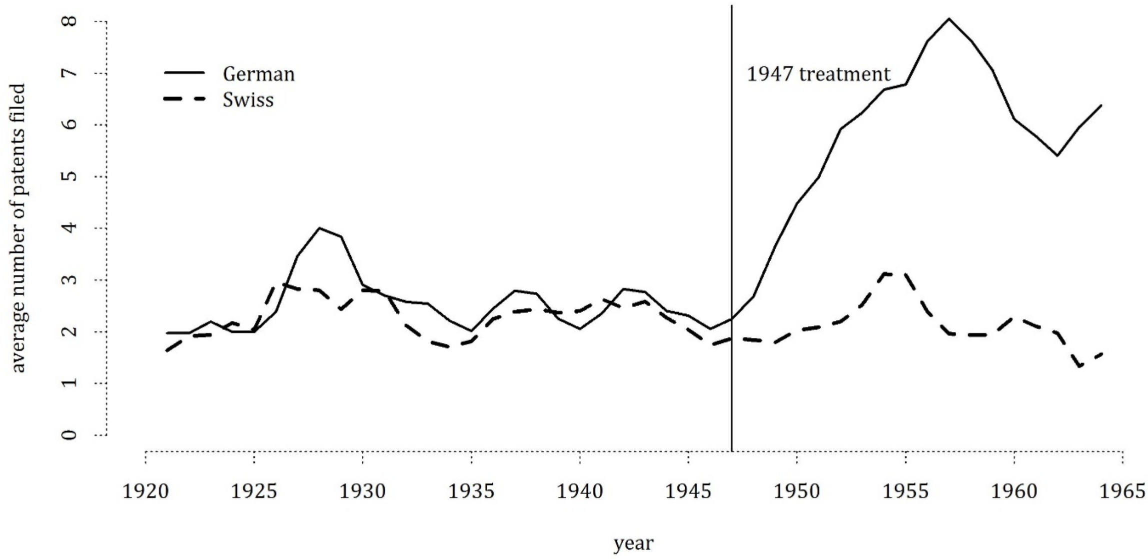

Figure 1: Average number of patents filed per year and group

To obtain the treatment effect, in Model 1 we include a dummy variable for the post- and pre-treatment periods (post, taking the value 1 for post 1947 activities) as well as for the treatment group (German, taking the value 1 for the treated Germans). The interaction term takes the value one if the observation belongs to a German inventor in the post 1947 period. Alternatively, in Model 2 the time period under observation is subdivided into 10 time categories (eight five-year intervals from 1922 to 1961 plus the time periods before and after these intervals). In Model 3, we return to the specification of Model 1 but include a full set of inventor-specific indicators of the treatment period.

$$y_{it} \sim \alpha + treat * post1947 + \; treat + post1947 + \sum_{j=1}^{10} period_{jt} + \sum_{k=1}^{116} (inventor_{ki} * t) + controls + e_{it}$$

To control for age effects, we further include a variable for the year the first patent was filed, as well as a variable for the year of the last patent filing. We also include the number of co-inventors to control for group effects. Industry-specific differences in patent activities, which might further bias our results, are controlled with IPC level (A-H) dummies.

Regression results are presented in Table 3. The key finding is that in all three models the interaction term post1947*treat is significantly positive (in Model 2, at the 10% level only).

Accordingly, in line with the prediction of Hypothesis 2, the German experts detained in the BIOS program experienced a stronger increase in their post-1947 patenting than did their Swiss counterparts. We also obtain the expected patterns for both age controls, as well as a generally increasing productivity differential between the German and the Swiss inventors (treat*period interaction). In unreported variants of Model 1, we excluded the three German inventors who had more than 180 patent publications (equal to the mean plus two times the standard deviation) to make sure that our results are not driven by outliers (highly productive inventors). In another model, we include a further dummy to control for those inventors that moved to the UK. Results were robust to both these modifications.

negative binominal regression
dependent variable: number of patents applied (in period t)

	model 1			model 2			model 3		
(Intercept)	-107.36	(24.10	***	-4.94	(17.72		461.31	(36.62	***
post1947*treat	1.11	(0.28)	***	0.66	(0.39)	*	0.93	(0.31)	***
post1947	-0.57	(0.20)	***	0	(0.31)		1.85	(1.29)	
treat	0.12	(0.20)		-0.35	(0.29)		0.36	(0.27)	
year first patent filed	-0.03	(0.01)	***	-0.04	(0.01)	***	-0.16	(0.01)	***
year last patent filed	0.09	(0.01)	***	0.04	(0.01)	***	-0.08	(0.02)	***
treat*period				0.12	(0.07)	*			
IPC dummies	TRUE			TRUE			TRUE		
period effects				TRUE			TRUE		
individual period effects							TRUE		
n	232			1160			1160		
AIC	1700.38			4496.19			4274.66		
logLik	-1670.38			-4448.19			-3998.66		
(p > chi2)	0			0			0		
pR2 (McFadden)	0.08			0.09			0.18		

*: p < 0.1 regression coefficient (standard errors in brackets)
**: p < 0.05
***: p > 0.01

Table 3: Regression results on the productivity of inventors.

Hypotheses 3a and 3b make prediction about the effects of cognitive and social/institutional proximity on interactive learning. Our sample allows us to test these hypotheses separately, which prior studies so far failed to do. The beauty of our sample is that the German experts brought to the U.K. essentially received a double treatment and were subjected to interactions starkly different in the degree of cognitive vs. social and institutional proximity. Being questioned by British officials and industry experts, they interacted with individuals active in the same industrial field but from a country that had been a war enemy until shortly before, and whose government had forcibly brought them to the detention center. Meanwhile, when they were not being questioned, the German experts spent their time together at the internment camp. Here, experts from different fields but the same national background interacted with each other.

Applying Hypothesis 3a to our sample, we expect that the German experts' interaction with British experts resulted in a broadening of their knowledge base (i.e., because they became familiar with new technologies), which could then, among the extension of knowledge networks, explain the rise in productivity observed in Models 1-3 above. To test this prediction, we construct measures of direct interaction with the U.K. (U.K. applicants and co-inventors) in the set of patent applications studied above and study how this interaction is related to the individual increase in patenting output after 1947. OLS is used for estimation because the increase (ratio of post- vs. pre-1947 patents) is continuous.

In Model 4 (Table 4), we first reproduce the main finding from above, i.e. that the German experts experienced a stronger increase that the members of the Swiss control group. Model 5 adds the total number of (unique) applicants in the post-1947 period, as well as the number of U.K. and U.S. applications, to the model. We find that the number of U.K. applicants is positive and marginally significant, whereas more U.S. applicants are associated with a lower increase (or even decrease) in post-1947 patent output. The difference between German and Swiss inventors is diminished by about 20% but remains significant. In Model 6, co-inventors instead of applicants are used as a proxy of international interaction. Here we find that all measures of co-inventors are directly associated with the increase of patenting activities after 1947. However, the (significant) coefficient of the number of British co-inventors is more than twice as sizeable as the (insignificant) one for U.S. co-inventors. In addition, controlling for the number of co-inventors drastically reduces the difference between German and Swiss inventors. This indicates that consistent with Hypothesis 3a, the interaction with U.K. co-inventors substantially boosted the post-WW2 productivity increase of the German experts.

The final Model 7 adds another piece of explanation. It differs from Model 6 in only one additional variable: the number of patents per inventor in subjectively new (four-digit) IPC classes. Adding this variable further reduces the (already insignificant) coefficient for the

German inventors, suggesting that new IPCs tend to be associated with higher patent output. The (insignificant) coefficient of U.S. co-inventors now becomes negative. In contrast, the coefficient for U.K. co-inventors is hardly affected. This suggests that the productivity-enhancing collaboration with U.K. co-inventors was mostly related to technology that the German experts already were knowledgeable before the war. In other words, it appears that the Germans learned new things about their fields of expertise rather than venturing into entirely new (for them) fields of technology. This interpretation finds further support in an analysis of the backward citations contained in the post-1947 patents filed by the German experts. Specifically, we find that the average number of citations to patents from the U.K. is about twice as large for patents that share at least one IPC class with the pre-1947 patents by the same inventor, than it is for patents that entirely fall into new IPC classes (from the inventor perspective). In contrast, no differences between "old" and "new" patents are obtained as regards the (more frequent) citation of German or U.S. patents.

Again, these findings are robust to excluding outliers in terms of patent applications (results are available upon request).

OLS regression
dependent variable: increase patenting activity (patens pre / patents post)

	model 4			model 5			model 6			model 7		
(Intercept)	-442.63	(303.92)		-312.43	(324.00)		101.04	(271.45)		-145.07	(104.51)	
German (treat)	5.29	(1.85)	***	4.23	(1.93)	**	0.88	(1.70)		0.41	(0.65)	
# patents pre1947 period	0.1	(0.10)		-0.13	(0.06)	**	-0.12	(0.05)	**	-0.04	(0.02)	*
year first patent filed				0.09	(0.10)		-0.01	(0.09)		0.05	(0.03)	
year last patent filed	0.12	(0.13)		0.07	(0.14)		-0.04	(0.11)		0.02	(0.04)	
# applicants post1947				0.68	(0.72)							
# UK applicants post1947				2.77	(1.62)	*						
# US applicants post1947				-4.31	(6.61)							
# co-inventors post1947							0.69	(0.12)	***	0.07	(0.05)	
# UK co-inventors post1947							5.99	(1.89)	***	6.02	(0.72)	***
# US co-inventors post1947							2.6	(1.84)		-0.42	(0.72)	
# patents with new IPC										0.19	(0.01)	***
IPC dummies	TRUE			TRUE			TRUE			TRUE		
n	232			232			232			232		
R2	0.25			0.28			0.48			0.92		
adjR2	0.16			0.18			0.40			0.91		

*: p < 0.1 regression coefficient (standard errors in brackets)
**: p < 0.05
***: p > 0.01

Table 4: Regression results explaining post 1947 patent output of Germans.

Ideally, we would further analyze the effects of knowledge flows indicated by backward citations to U.K. patents as a measure of using British technology. Doing so is frustrated by a lack of consistent information about patent documents from patent offices outside Germany (including the Swiss office). Search reports from other patent offices were not accessible, neither in PATSTAT nor directly at the national patent offices' websites. Since Swiss inventors filed their patents mostly at the Swiss patent office, we can only look at the citations of the German experts. In unreported analyses (available upon request) we looked at the role of citations to U.K. patents in this sample. Again consistent with Hypothesis 3a, the share of U.K. citations was directly related to the productivity of inventors.

In Hypothesis 3b, we predicted that high social proximity supports interactive learning. In our case, this would mean that the German experts interned in the UK profit from interactions with each other. To see whether the increase in productivity was driven by interactions among the German experts during their detention, we searched for mutual patent citations. We found one citation from a pre-1947 patent to a patent from the same period, 10 citations from the post-1947 period to the pre-1947 period, and 26 citations from the post-1947 period to a patent from the same period. All of these citations were identified as self-citations. Accordingly, there is no evidence of any relevant knowledge transfer between the German experts that stayed together in the U.K.. Also, no co-authorship was found between any of our experts. Thus, Hypothesis 3b is not supported by our data.

Overall, we thus conclude that, in comparison to social and institutional proximity, cognitive proximity is a far more important factor for the productivity-enhancing effects of inventor migration and interactive learning.

6. Concluding Remarks

Exploiting a "natural" experiment that took place after World War 2, we contribute to the literature on proximity and knowledge diffusion by providing new evidence on the antecedents of interactive learning. Our unique sample of German inventors who were brought to the U.K. for interrogation in 1947 enables us to distinguish between two treatments taking place at the same time. On the one hand, the German experts were questioned by British officials and industry experts from the same field. Underlying these encounters was a high degree of cognitive proximity, but a low degree of social and institutional proximity. Meanwhile, during their detention the German experts interacted among themselves. In this interaction, the level of social and institutional proximity was high whereas cognitive proximity was low.

In line with prior literature, we find support for our first two hypotheses predicting that migrating agents exploit the opportunities for interactive learning that migration provides them, and that this then also leads to an increase in their productivity. Our data clearly show that their stays in the U.K. led to network extensions focused on the U.K. for our German inventors, as compared to the Swiss counterparts in the control group. We also found the treatment to have a positive impact on the German inventors' productivity, as measured in patent publication count.

As for the reason of this migration-based increase in productivity, we expected cognitive proximity as well as social and institutional proximity to be of importance. The empirical evidence indeed suggests a substantial effect of cognitive proximity. That the German experts appear to have learned from their interactions with British officials and firm representatives is noteworthy also because this learning is the opposite of what the U.K. government wanted to achieve. The clearly stated objective of the BIOS program was to drain knowledge from the Germans, and not to trade knowledge with them. Our study suggests that such one-way "exploitation" of knowledge may be extremely difficult to achieve, supporting the view that knowledge exchange is always bi-directional.

In contrast, our evidence does not suggest that social and institutional proximity plays an equally important role as cognitive proximity. We could not find any kind of post-treatment links among the German experts who were interned together. This is all the more surprising since the rare historical literature on the subject suggests that the interned Germans spent most of their time together and even gave lectures about their respective work.

We thus conclude that social proximity alone does not suffice to induce interactive learning that then leads to productivity enhancement. Cognitive proximity, however, seems to play a much more important role, and seems to be a key driver of interactive learning.

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