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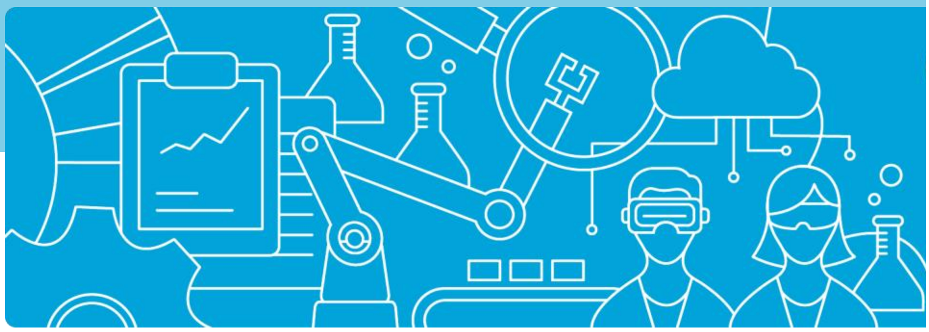

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# Researcher Mobility and Cooperation in the Science System

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# 1 Executive Summary

This work covers two tasks: (1) the analysis of international inventor mobility and cooperation, with the focus on Germany in the context of a number of selected comparison countries; (2) The analysis of researchers in critical career positions in the German research system.

**Inventor mobility** remains a less understood topic in the studies of the global mobility of the highly skilled, despite its significance in international knowledge flows. **Chapter 2** of this report achieves the following goals: 1) analyse Germany's position in inventor mobility flows over time and in relation to other relevant countries; 2) analyse Germany's international inventor co-operation structure in relation to other relevant countries; 3) provide insights into effects of inventor mobility and co-operation patterns on the German innovation system.

We conducted a literature review on international inventor mobility, with particular attention on evidence regarding mobility to Germany. We then analysed transnational patent applications available in the database PATSTAT in the period of 2000-2020. To improve the results, we developed a method for inventor disambiguation tailored specifically to the analysis of international mobility.

Our empirical analysis revealed that **more inventors leave Germany than come here**. However, Germany also experiences a **significant turnover** of mobile inventors and is the **key hub** in international cooperation network, especially among other European countries. This position provides Germany an advantage in international knowledge flows. Our findings also revealed that **internationally mobile inventors are a valuable source of talent in Germany**. They are more productive than immobile and are more likely to produce highly cited patents. A lion share of international inventor mobility takes place within multi-national enterprises.

The following recommendations were derived from the analysis:

- Inventor mobility to and from Germany should be further encouraged, especially temporary and shorter-term mobility within internationational offices of one organisation, in order to generate more links and knowledge exchange. This should lead to further cementing of Germany as the international inventor mobility and co-operation hub.
- Particular attention should be paid to encouraging inbound international inventor mobility in high-tech, emerging technologies, in which it is particularly valuable.
- Since researchers represent a significant source of internationally mobile inventors, knowledge exchange in the innovation system should encourage innovation activities by international academics;
- Research on international inventor mobility has several major gaps, including understanding the scale and scope of such mobility, its recent trends (especially since 2012), its causes, mechanisms and effects. The limited knowledge about this phenomenon

leads to the limited understanding about which aspects of international inventor mobility can be better supported by policy. We recommend funding a further in-depth study on international inventor mobility, with the specific focus on the organisational level factors and dynamics.

The impact of mobility on the country level has so far mainly been analysed by looking at the contribution of foreign-born inventors to innovation. However, these effects are not directly linked to mobility of inventors. A more robust link between invention and propensity for international migration could be established.

The need to analyse **researchers occupying critical positions in the German research system** stems from their current and future influence over the direction of scientific research in the country. An important policy question is whether the German system is able to attract prominent and high-potential international researchers to these positions. In **Chapter 3** of this report, we analysed the composition and characteristics of researchers belonging to the following groups: holders of the European Research Council (ERC) grants and Emmy-Noether fellowship awards, directors of German non-university research organisations and professors in German universities, including professors of German research-intensive universities.

The analysis covers the years 2005-2021 and achieves the following objectives: 1) analyse diversity of researchers in critical career positions, in terms of international experience and gender; 2) analyse mechanisms and determinants of international researchers' transitions to critical career positions.

We constructed a unique dataset in which researchers in critical career positions in Germany are matched with their Scopus publication records. Our results show that **researchers in critical career positions constitute a small, but important minority among Germany-based scientists**. Researchers in these critical groups significantly differ from each other in terms of their international exposure, their timing of transition to Germany, collaboration rates with Germany prior to transition and citation impact prior to transition. We distinguished three channels of international mobility to Germany: grant-linked mobility, elite researcher mobility, and 'ordinary' mobility. **International researchers (incomers and returnees) are more represented in critical career positions** than overall among researchers working in Germany. However, their share decreased in the latest time period and the **representation of female researchers is still low**. International researchers in critical groups tend to come to Germany at the early career stage Among them, **the majority have German or Austrian origin**. The findings indicate that the German research system may offer limited opportunities for career progression of mid-career and no-German speaking international researchers.

Based on these findings, we offer the following recommendations:

- Grants are the mechanism for international researchers to enter the German system. Transitions from grant-based to permanent positions in the system could be better understood and supported. Further opportunities for mid-career and senior researchers could be created to facilitate transitions to permanent positions in universities.
- Create international mobility opportunities for researchers advancing through the ranks in the German higher education sector. If professors do not have international mobility experience, they are not likely to encourage international mobility of their staff and therefore, low rates of mobility will persist.
- Create opportunities for international researchers to transition to mid- and senior-career positions in the German research system. Since we did not find the 'double peak' of international professorial-level mobility, questions can be raised about why international professors move to Germany less and which aspects of recruitment and promotion processes should be targeted in reform.
- Continue to implement measures to advance gender equality in the German research system, with the focus on critical positions in the research system. Continue to implement measures to promote international mobility opportunities among women. This will likely also lead to increase in female researchers in critical positions in the research system.
- Need for further research on critical groups and the factors facilitating international researchers' advancement to these positions.

# 2 Lot 2: Inventor mobility and cooperation

## 2.1 Introduction

Knowledge exchange between innovation systems leads to an increase of effectiveness and quality in scientific outcomes. Here, international mobility of the highly skilled plays a crucial role. For R&D-performing companies and government authorities, understanding international talent mobility flows and harnessing their potential could advance knowledge production and economic growth.

Among the international mobility of the highly skilled, in particular inventor mobility remains less understood. In this chapter, we pursue three objectives: 1) analyse Germany's position in inventor mobility flows over time and in relation to other relevant countries; 2) analyse Germany's international inventor co-operation structure in relation to other relevant countries; 3) provide insights into effects of inventor mobility and co-operation patterns on the German innovation system.

To achieve these goals, in this chapter, we conducted desk-based analysis of current research on international inventor mobility, with particular attention on evidence regarding mobility to Germany. We then conducted analysis of transnational patent applications available in the database PATSTAT in the period of 2000-2020. To complete the analysis, we developed a method for inventor disambiguation tailored specifically to the analysis of international mobility.

This chapter is structured as follows: section 2.2 reviews lessons from the review of relevant literature. Section 2.3 outlines the methodology of the analyses, including dataset construction and the disambiguation method. Section 2.4 analyses Germany's position in international inventor mobility flows. Section 2.5 presents further in-depth analyses for Germany. Section 2.6 offers in-depth analysis of specific technology fields. International inventor cooperation is analysed in Section 2.7. Recommendations are offered in Section 2.8.

## 2.2 Literature Review: international inventor mobility

International inventor mobility has not been well studied in the literature so far. In order to gain an understanding of the main trends, driving factors and effects of inventor mobility, we conducted a review of scientific and grey literature. Searches were conducted in December 2022 and January 2023 using the Web of Science search engine. In the first instance, the keyword combination "inventor mobility" was used as the main search term. More nuanced searches were conducted based on the search terms “intra-firm mobility”+”inventor” or “extra-firm mobility”+”inventor” as well as “mobile inventors”. In total, about 45 scientific publications were identified. The analysis was supplemented by search on Google Scholar in order to identify grey literature such as project reports that deal with the topic of inventor mobility. An additional 10 studies were identified using this approach.

The literature was classified into thematic clusters: (1) literature describing mobility patterns, (2) literature analysing effects of inventor mobility at firm level (leaving and hiring firm), (3) literature analysing socio-economic effects of inventor mobility on regions or countries. Another topic cluster was (4) literature addressing factors influencing inventor mobility and firms’ reactions trying to prevent inventor mobility and impede knowledge transfer. During the analysis, attention was paid to the methods and data used in the respective studies, and in particular to the results reported for Germany.

### *2.2.1 Patterns, determinants and effects of inventor mobility*

The role of high skilled migration is well recognized in the academic literature (Miguélez & Fink 2013). First contributions stressed the adverse consequences of the loss of highly skilled specialists from developing countries who leave to work abroad (Bhagwati and Hamada, 1974; Bhagwati and Rodriguez, 1975). The loss of human capital, tax revenues, and innovative competence associated with the mobility of skilled human capital caused economists to stress the negative effects of outward migration for socio-economic development, described by the term “brain drain” (Miguélez and Fink 2013). Further research revealed that effects of talent mobility are not one-way: countries of origin benefit from remittances and reinvestment of resources by migrants back into their home countries (Grubel and Scott, 1966; Faini, 2007; Mountford, 1997, Beine et al., 2001). Some highly skilled people return to their countries of origin, bringing in skills, capital and networks (Rosenzweig, 2008, Mayr and Peri, 2009, Dos Santos and Postel-Vinay, 2004). Even if migrants do not return, overseas diaspora members play a role in knowledge transfer and skills between their home and host countries, positively influencing home country values, norms and institutions (Saxenian, 2002; Li and McHale, 2009; Spilimbergo, 2009).

Miguélez and Fink (2013) observe a rising trend particularly among migrant inventors. Based on a large-scale international study of PCT patents, they find that North America stands out as a destination for mobile inventors. These results are in line with those observed for highly skilled migration in generally, in which the US attracts the largest shares of immigrant workers, while European economies are lagging behind (see for example Bertoli et al. 2012, Docquier and Rapaport 2009). Germany is an 'intermediate' destination that experienced both an inflow and an outflow of international talent.

**Technological similarity between countries is found to be the main determinant for inventor migration** (Drivas et al. 2022). Cultural-linguistic and religious proximity play a minor role. Drivas et al. (2022) also report that although the role of geographic proximity is still significant, mobile inventors are less confined geographically than other labour migrants. Firm type and size were also found to be significant influencing factors: Hoisl (2007) found that an increase in firm size negatively influences inventors' likelihood to move. Inventors working for firms with 5,001 to 10,000 employees moved 17% less likely compared to the reference group of firms with less than 51 employees. This likely indicates that large firms have high R&D resource capacity, which is attractive to inventors. Academic inventors tend to be less mobile than inventors employed by companies (Crespi et al. 2006).

Inventors represent an important asset to firms. A share of the literature on inter-firm inventor mobility covers the topics on how firms protect their assets against inventor mobility, and efforts firms make to influence inventor mobility (retain, attract inventors). Firms try to prevent other firms from appropriating the value of their inventions. Both source and destination firms are more likely to extend the validity of patents held by mobile inventors than is the case for patents held by other, non-mobile inventors (Goosen and Carnabuci 2020). Meanwhile, a firm’s litigiousness significantly reduces spillovers otherwise anticipated from departures of employee inventors. Corporate reputation for toughness can be valuable to firms seeking to prevent unauthorized transfers of proprietary knowledge through employee exits (Agarwal et al. 2009). As restrictive non-competition laws seem to lower the likelihood of patent commercialization, positive effects of inventor mobility gradually decline when on-competition agreement enforcement increases in severity (Huang 2017).

Inventor mobility may also be influenced by other, more general characteristics: Bisset et al. (2020) for example find that political instability significantly increases the rate at which inventors leave the country.

With regard to the effects of inventor mobility, **effects on inventor productivity, firm-level effects and national-level effects** have been analysed. Hoisl (2007) studied the causal link between inventor mobility and productivity. Based on a sample of 3.048 German inventors representing 3.349 patents filed at the European Patent Office, the study finds that moving inventors are 14,5% more productive than non-movers and that mobility leads to an increase in inventor productivity. Thus, mobility can lead to a better match between employer and employee, which then results in a higher productivity. Huang's analysis of a survey among US inventors show that movers generated more patent applications than non-movers (Huang 2017). Trajtenberg (2005) found that the patents owned by mobile inventors were both more domain-specific and in general more valuable than patents owned by non-mobile inventors. Van der Wouden & Rigby (2020) support this finding, noting that inventor productivity increases for up to 15 years following a mobility event.

On the firm level, hiring more and higher skilled inventors is an important channel through which companies can achieve higher innovation output. Through the mobility of inventors, the transfer of tacit knowledge that is otherwise immobile is facilitated (Dosi 1988). Rahko (2007) finds that mobile patent inventors with many prior patents positively influence the future innovation performance of the hiring firm. Interestingly, inbound inventor mobility per se does not affect the firm's innovation output, which means that the rule of 'the more the better' may not be effective.

Further findings indicate that firms that hired workers from more productive firms experience significant productivity gains one year after the hiring (Stoyanov and Zubanov 2012). Moreover, hiring inventors who possess technological knowledge that differs from the firms' main field of technology had a positive effect on the hiring firm's productivity. Inventors with different technological expertise and inventors from technologically related but not too similar firms bring complementary skills and knowledge that seem to benefit firms' future innovation performance (Rahko 2007; Song et al., 2003). These findings are in line with other studies showing that hiring workers previously in R&D to one's non-R&D activities, boosts both productivity and profitability of the hiring firm (Maliranta et al. 2009). On the opposite side, firms that lose inventors experience decline in patenting performance (Rahko, 2007). However, company that loses the inventor can benefit from the flow of knowledge from the inventor's new employer, with some potential for reverse spillovers (Huang 2007).

On the regional and country level, the evidence regarding effects of inventor mobility comes from research on the role of the foreign-born in innovation. Since innovation is usually measured by patent output, these studies analyse impact of mobile inventors. Here, a steady stream of research has demonstrated that cultural and national diversity in companies is associated with higher innovativeness (Nathan and Lee 2013; Fujiwara; Rahko 2017). Finally, higher rates of skilled immigration are linked to higher innovation rates in the country overall (Kerr and Lincoln 2010; Hunt and Gauthier-Loiselle 2010; Audretsch et al. 2010; Crown et al. 2020; Fassio et al. 2019).

### *2.2.2 International inventor mobility in Germany*

A challenge in researching inventor mobility lies in the scarcity of reliable data. Unlike bibliometric databases, inventor mobility analysis faces the initial hurdle of handling name aggregation and disambiguation. Consequently, many studies on inventor mobility resort to using samples to glean insights into this phenomenon. In our investigation, we pinpointed two data sources that allowed for a country-level analysis of inventor mobility, with Germany also being included in the examination.

Probably the most comprehensive study of inventor mobility in Germany was carried out by Neuhäusler and Frietsch (2014) for the Experts Commission on Research and Innovation (EFI). Using the PATSTAT database, they examine the mobility of 28,503 German inventors who filed a patent in 2000. The mobility is analysed by following these inventors until the year 2009. Within the sample, 1,674 (5,9%) inventors gained an address outside Germany between 2000 and 2009. The USA (about 30%) and Switzerland (c.a. 27%) are the most attractive countries for mobile inventors from Germany, followed by Netherlands (8%) and Sweden (4%).

The analysis further shows that German inventors are especially mobile in the ICT-related fields and in fields related to medical instruments. In contrast, mobility among German inventors is lower in the fields of weapons, automobiles, engine and machine tools etc. The results suggest that outward mobility from Germany is comparatively low in fields where Germany has technological strengths (i.e. mechanical engineering). However, there are net outflows in fields, where Germany does not have particular technological strengths, for example in pharmaceuticals and biotechnology. The other source of data is the database of mobile inventors developed by the World Intellectual Property Organization (WIPO) with good coverage in 2000-2012 (Miguelez and Fink, 2013). In this data, inventor nationality was matched against their residence to identify their mobility status. Although this approach does not allow for the analysis of mobility trajectories, it allows to gauge prevalence of mobile inventors in countries and where they come from.

Several studies use this dataset to estimate the prevalence of mobile inventors in various countries in this time period. For example, Miguelez and Fink (2013) identify around 5.5% share of migrant inventors of and overall negative net immigration in Germany. Breschi et al (2014) estimate the share of foreigners among German inventors between 5% and 9%.

### *2.2.3 Implications and research gaps*

The current body of literature on inventor mobility is relatively scarce, especially when compared with the body of knowledge on researcher mobility. The main issues are the lack of data availability and access, but also the fact that inventor mobility is relatively uncommon compared to researcher mobility.

Inventor name disambiguation is a major impediment to international inventor mobility analyses. Since data providers do not offer standardised Inventor IDs, the disambiguation of inventor names needs to be performed by researchers. This is a data-intensive and methodologically complex task. WIPO cleaned a portion of USPTO data in the period of 2000-2012, however, this data is aged. Other analyses of inventor mobility had to rely on surveys and other sampled data (Hoisl, 2007; Crespi et al., 2006).

Given the lack of studies on international inventor mobility, we complemented our review with the insights from non-international inter-firm mobility, and with general studies of highly skilled migration. However, we have done so under the assumption that these phenomena are of a relatively similar nature. Our understanding of international mobility in Germany is also limited by the lack of available studies.

We conclude the review of literature by outlining the major gaps in the literature on international inventor mobility:

- Our understanding of scale and scope of international inventor mobility is lacking. The lack of data regarding recent trends (after 2012) is particularly concerning.
- Our understanding of causes and driving factors of inventor mobility could be advanced. We do not clearly understand how the determinants compound each other and which conditions are necessary to give impetus to international moves.
- The exact ways in which international inventor mobility is realised are not well understood. The literature has not paid much attention to mobility mechanisms in general among which especially the role of intra-company mobility is insufficiently understood.
- The impact of mobility on the country level has so far mainly been analysed by looking at the contribution of foreign-born inventors to innovation, mainly via patenting. However, these effects are not directly linked to mobility of inventors, because the immigrants are not necessary inventors at the time of move. A more robust link between invention and propensity for international migration could be established.

## 2.3 Methodology

### *2.3.1 Dataset and definitions*

The analysis is based on the PATSTAT database of the European Patent Office. Data was collected on transnational patents, i.e. patents filed via the WIPOs PCT process or at the EPO directly, excluding double counts (Frietsch and Schmoch, 2010). Patents filed in the period of 2000-2020 were identified where at least one inventor had an address in one of the countries included in the analysis. These are Germany, France, Switzerland, The Netherlands, Denmark, Sweden, United Kingdom, Austria, South Korea, Japan, USA, and Canada. For the further processing of the data, harmonisation of applicant names by the KU Leuven was used.

*An international move* is defined as a change in the country of an inventor. Moves are calculated on an annual basis. If an inventor has multiple addresses in one year, the most reported country is counted as the main country for that year. An inventor's *country of origin* is defined as the first country the inventor reported in a patent application. So defined, country of origin may not match an inventor's nationality or ethnicity.

### *2.3.2 Inventor disambiguation*

We reconstruct inventors' mobility trajectories by establishing a link between different patents. By default, an inventor listed on a patent application in PATSTAT is assigned an ID. However, if some data about the inventor changes, a new ID is assigned. Therefore, the same inventor may have multiple IDs. The EPO aggregates some of these inventor IDs into a doc_std_name_id based on their own algorithm. However, an inventor still can have multiple doc_std_name_ids, so a further aggregation becomes necessary.

Therefore, we develop a novel, two-step name disambiguation method tailored to the analysis of inventor mobility. In doing so, we draw on previous efforts to perform name disambiguation, which typically encompass three steps: (i) clean the name data field; (ii) aggregate name data based on other available information available in the patent, such as location, technology class and co-inventors; (iii) run plausibility checks and disaggregate the data if needed. These various methods report good performance results, however, their limitation is that *inventor location* is often used as the main criteria to aggregate inventors. In other words, inventors located in different countries will be more likely to be assumed as namesakes rather than as one mobile person by these methods. For the purposes of this analysis, this is problematic.

In our approach, we develop a two-step process. In the first step, one year is taken as the unit of analysis, and inventor names are aggregated into clusters based on a number of criteria that indicate their likelihood to be the same person: same inventor ID, similar name, address within the same area, same applicant, and the same technological class. In the second step, these clusters are aggregated across the years into superclusters based on a different set of criteria: same inventor ID, citations to similar patents, similar co-inventors. Since the same applicant and distance are only relevant for the aggregation of cases within one year, but not for the aggregation of clusters across years, our method is better suited to identifying mobile inventors than most existing approaches.

The method was validated on a matched LinkedIn-patent dataset (Png, 2016) which contains data on 14,293 disambiguated inventor names and their patents. Of those inventors, 8,783 could be identified through matching in PATSTAT, subsequently forming our sample for the validation. Starting from the data where one patent is assigned to an individual inventor entity, our approach achieved 99.8% precision (quality of entities within the cluster) and 79.4% recall (aggregating separate clusters into superclusters), resulting in a 88.4% F-score.

## 2.4 Germany in international inventor mobility flows

In this section, we analyse Germany's position in international inventor mobility flows compared to other countries. For each country included in the analysis, we offer the analysis of inventor mobility balances in the period of 2000-2020 and also separated in 10-year periods: 2000-2010, 2011-2020. We calculate three types of mobility:

- immobile inventors: do not change country in the time period;
- inflows: inventors that moves to the country;
- outflows: inventors that leave the country.

Overall, there are around 2.7 mln inventors in the dataset, out of whom around 3.6% are mobile. The distribution of mobile inventors across countries varies significantly and is presented on Figure 1. In the UK, Australia, and Canada, the share of mobile inventors is above 10%. Japan and South Korea have large inventor populations, but very low mobility rates. Germany is on the lower end: 5.7% of inventors are mobile.

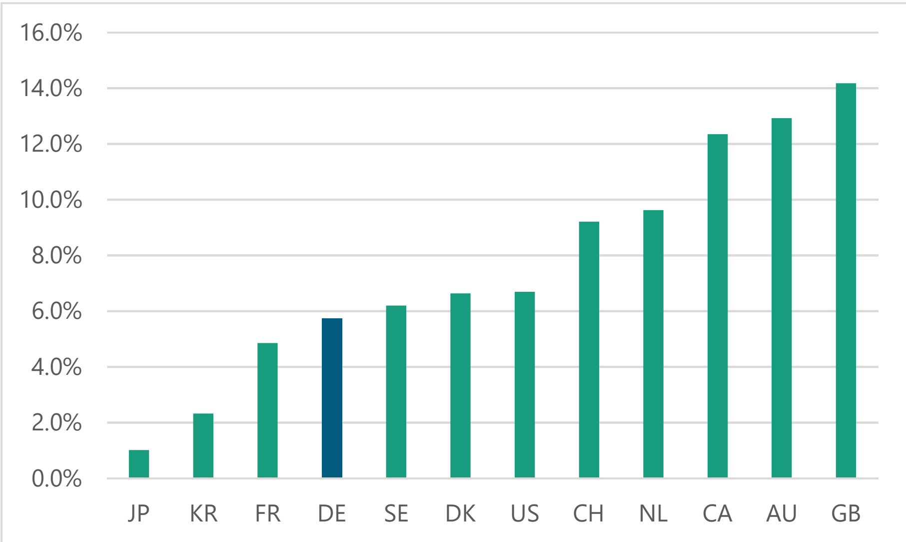


**Figure 1 Share of mobile inventors in selected countries, 2000-2020**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

The net inflows of mobile inventors to the countries included in the analysis are visualised in Figure 2. Among the countries in the analysis, there are ones with consistently positive net inflows (Switzerland, Netherlands, South Korea) and consistently negative ones (France, Japan, UK, USA). A group of countries have around zero inventor inflows, meaning that approximately as many inventors leave as arrive (Denmark, Sweden).

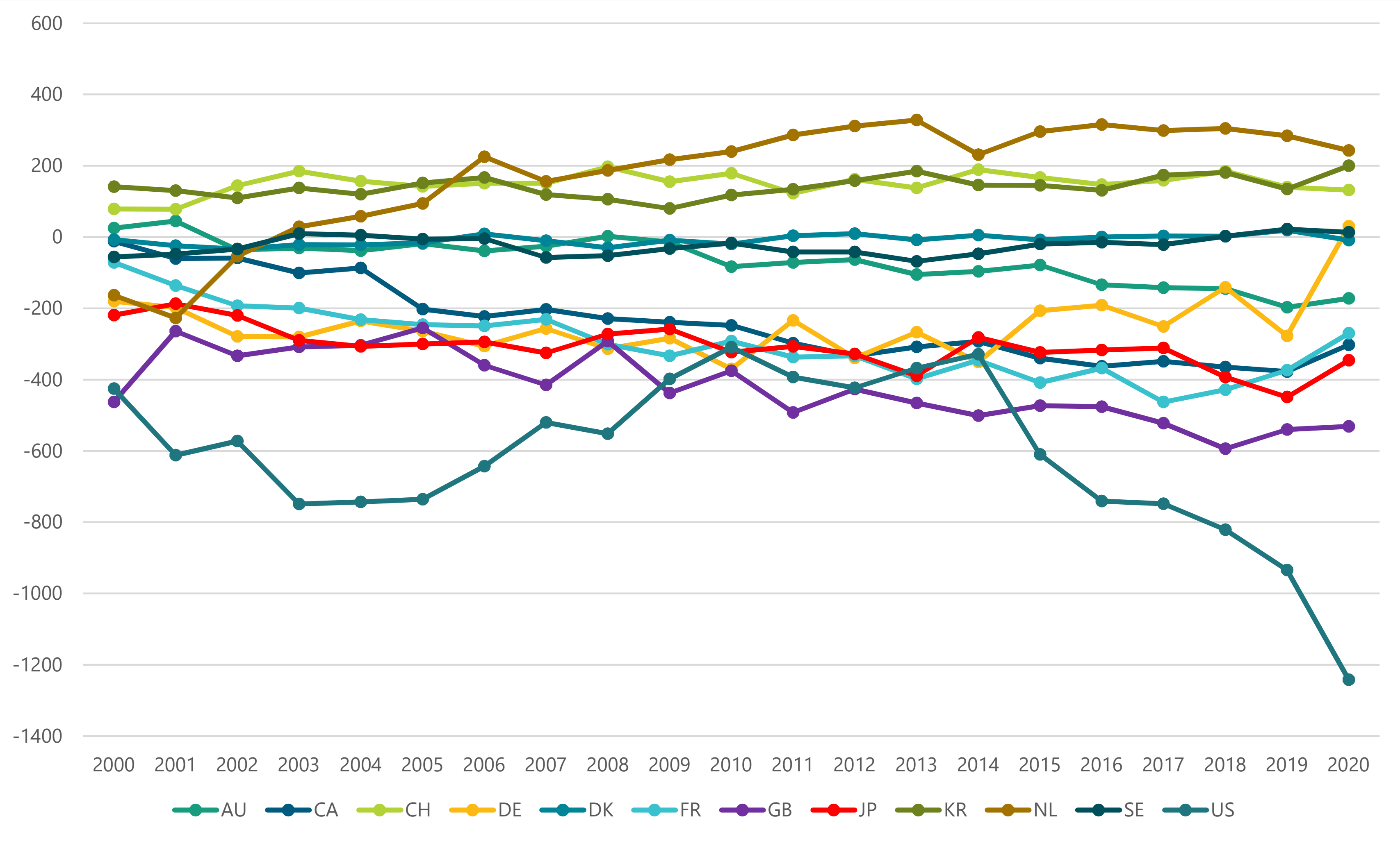


**Figure 2 Mobile inventor net inflows in selected countries, 2000-2020**
Source: Fraunhofer ISI analysis based on EPO PATSTAT.

These balances stay consistent for all countries over the whole observation period, with the exception of the UK and the US that experience a deepening negative trend. Germany's mobility balance remained negative for the entire observation period, with a upward trend in the latest years. In 2020, Germany experienced net inflow of inventors for the first time.

Looking at inflows over the whole time period (Figure 3), certain selected countries experienced mobility surplus, while others experienced a mobility deficit. For example, 22.7% more inventors came to Switzerland in 2000-2020 than left. However, the overall number of inventors moving to and from Switzerland is not large, with only around 700 more inventors coming there than leaving in 2000-2020. The Netherlands and South Korea also experienced mobility surplus in the observation period. On the other end are Japan, France and Canada who experienced net outflow of inventors. Overall, very few inventors in Japan are mobile, but 24% more inventors left the country in 2000-2020 than arrived here. The US has the largest inventor turnover among the selected countries, followed by the UK and Germany. Overall, 5.6% fewer inventors came to Germany in 2000-2020 than left.

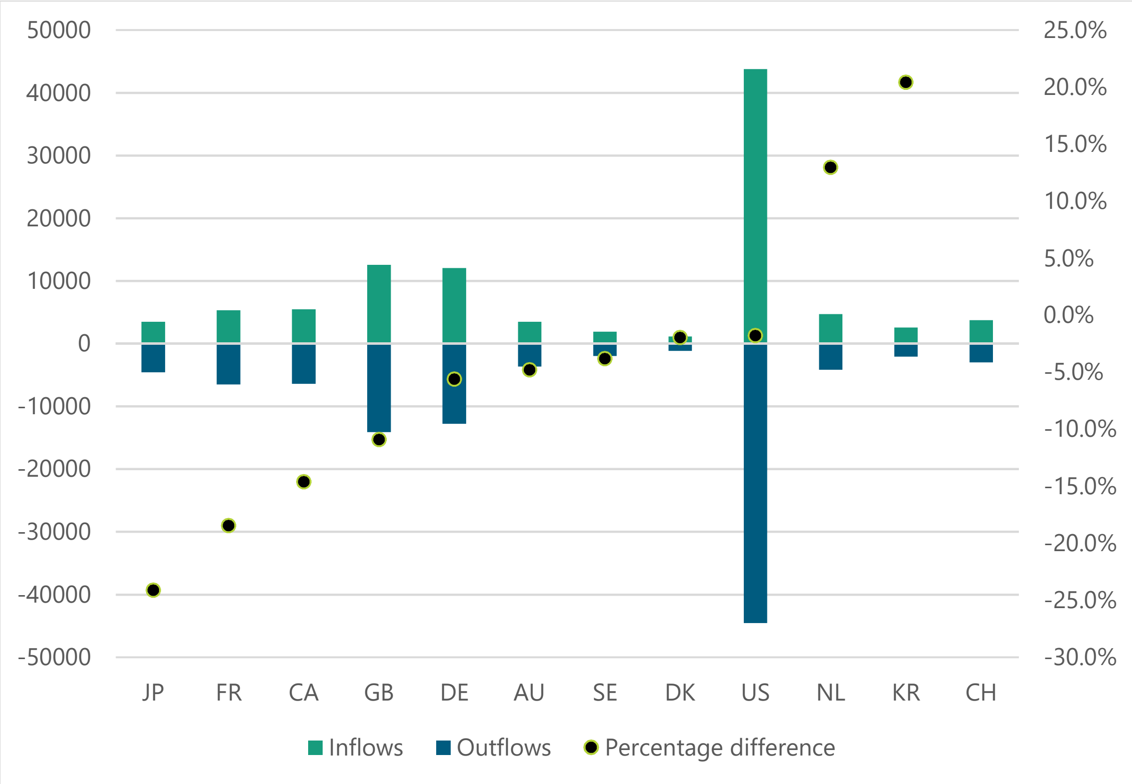


**Figure 3 Mobility balances in selected countries, 2000-2020**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

Over the two ten-year time periods, countries that had net negative mobility trend in 2000-2010 (UK, France, Japan, Canada) experienced deeper negative trends in 2011-2020, while countries that had net positive mobility trend in 2000-2010 (Netherlands, Switzerland) experiences higher net inflows in 2011-2020 (Figure 4). Germany, the US and South Korea are exceptions. Germany and the US still experienced net outflow of inventors in 2011-2020, but the gap between inflows and outflows was smaller than in the previous decade. South Korea's net inflow of inventors became smaller in 2011-2020 than in 2000-2011.


**Figure 4 Mobility balances in selected countries, net inflow in 2000-10 vs 2011-20**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

Figure 5 depicts the network that shows the importance of countries included in the analysis as source and destination of mobile inventors relative to each other. The USA is both a major source and destination for mobile inventors. The UK is its main mobility partner, followed by Germany and Canada. Germany emerges as the mobility hub in central and Northern Europe: it has strong mobility channel linking it to the Netherlands, France and the UK, but also to Denmark and Sweden. Mobility channels between these other countries are smaller than their personnel exchanges with Germany.

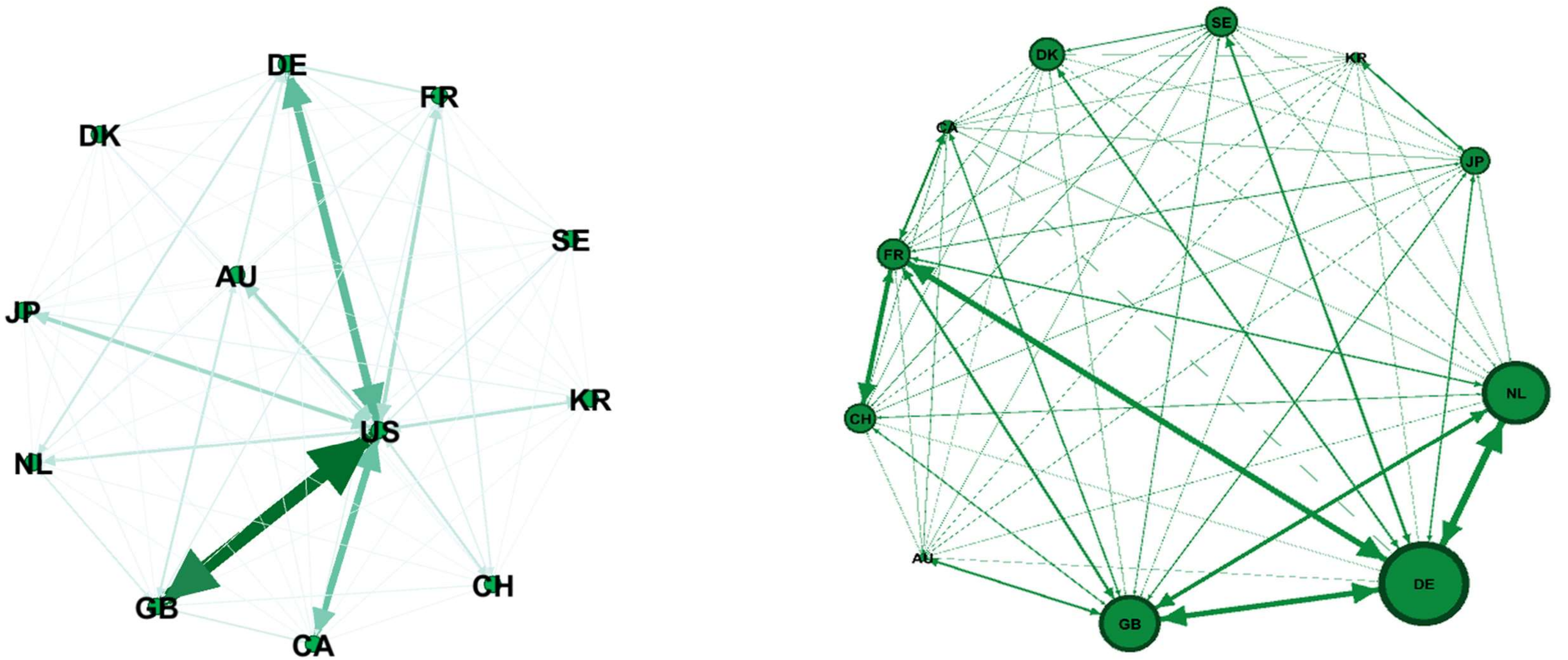


**Figure 5 Mobility balances in selected countries, social network view of the full dataset on the left hand side and the dataset without the USA on the right hand side**

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Nodes represent the selected countries and the edges reflect inflows and outflows of inventors between each pair of countries. Node size represents the scale of turnover of mobile inventors in the country. Yifan Hu layout.

### *2.4.1 Mobility balances in technology classes*

We now move on to the analysis of inventor mobility in technological classes. We start with the WIPO-5 classification of patents, which distinguishes the following classes: instruments, chemistry, mechanical engineering, and electrical engineering. Electrical engineering is the most populous field with 1.21 mln inventors, followed by chemistry (1.09 mln inventors) and mechanical engineering (1.03 mln) (Figure 6). The share of immobile inventors varies across these fields only within 1% - between 92.5% in 'other fields' and 94.8% in mechanical engineering.

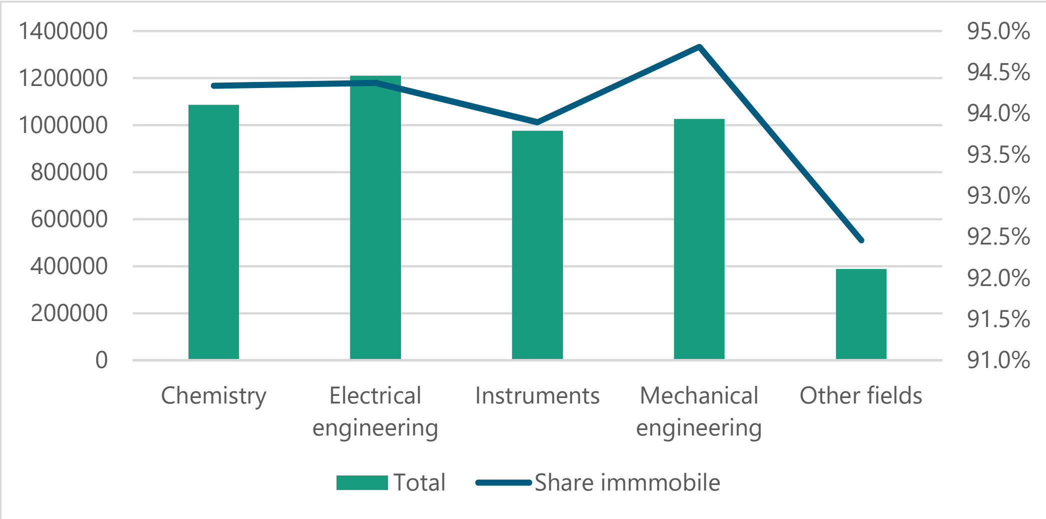


**Figure 6 Prevalence of inventors in WIPO-5 technology classes, share of immobile.**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

Looking at Germany and selected comparator countries, differences in technological specialisation are revealed. Germany (Figure 7) specialises in mechanical engineering and the share of immobile inventors is also the highest there (93%). For other countries (Figure 7, Figure 8[1]) there is significant variation in both specialisation and in the relative distribution of mobile researchers. France, Sweden and Denmark demonstrate similar technological profile to Germany with specialisation in mechanical engineering. Generally, we observe higher prevalence of immobile inventors in mechanical engineering and lower - in electrical engineering, however, not in all countries. In countries with higher prevalence of electrical engineering (USA, Canada, South Korea, Japan), electrical engineer inventors are less mobile than on average.

[1] Full table of WIPO-5 distribution of inventors in Germany and comparator countries can be accessed in Appendix Table A1.

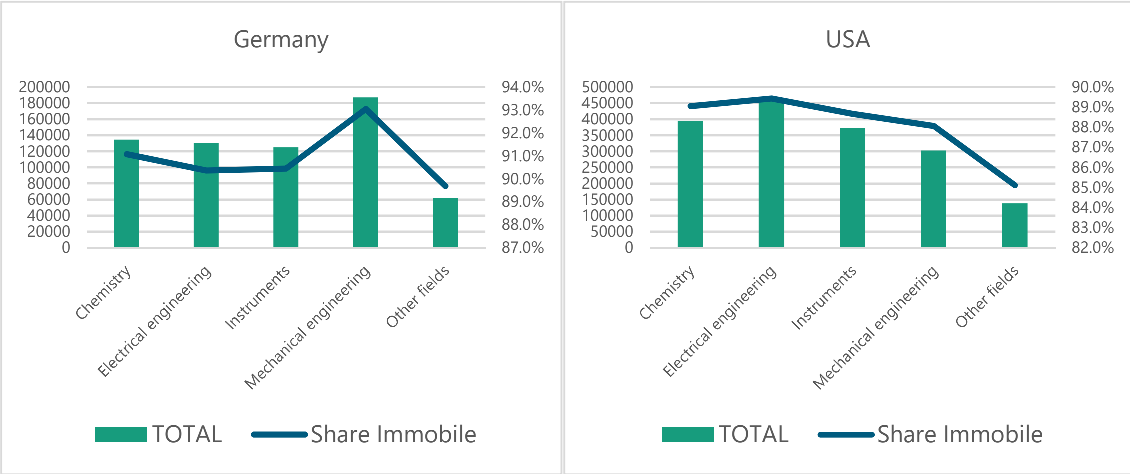


**Figure 7 Prevalence of inventors in WIPO-5 technology classes - Germany, USA**
Source: Fraunhofer ISI analysis based on EPO PATSTAT


**Figure 1 Distribution of inventors in WIPO-5 technology classes - selected countries**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

**Table 1 Distribution of mobile inventors in WIPO-35 technology classes in selected countries**

| Technology class | AU | CA | CH | DE | DK | FR | GB | JP | KR | NL | SE | US |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis of biological materials | 29.9% | 28.3% | 24.0% | 15.2% | 17.6% | 10.7% | 33.2% | 3.4% | 7.2% | 18.5% | 15.1% | 16.2% |
| Audio-visual technology | 41.0% | 30.9% | 25.6% | 13.4% | 18.0% | 13.4% | 39.4% | 1.9% | 4.2% | 24.8% | 17.8% | 18.9% |
| Basic communication processes | 55.3% | 34.6% | 29.3% | 15.7% | 26.4% | 14.0% | 45.7% | 2.8% | 7.7% | 43.3% | 19.6% | 23.6% |
| Basic materials chemistry | 34.4% | 30.1% | 23.4% | 12.0% | 18.0% | 11.9% | 33.1% | 2.1% | 5.3% | 16.1% | 21.3% | 16.1% |
| Biotechnology | 26.3% | 25.0% | 21.4% | 15.0% | 12.6% | 9.5% | 28.9% | 3.1% | 6.2% | 13.4% | 15.7% | 14.5% |
| Chemical engineering | 30.8% | 27.4% | 20.3% | 10.9% | 15.5% | 10.3% | 33.3% | 2.3% | 5.1% | 16.6% | 14.3% | 16.8% |
| Civil engineering | 22.9% | 24.5% | 19.4% | 11.3% | 14.3% | 10.2% | 31.8% | 2.7% | 4.3% | 12.3% | 12.5% | 18.6% |
| Computer technology | 32.3% | 25.7% | 25.5% | 14.9% | 21.9% | 11.0% | 34.2% | 2.4% | 4.2% | 27.5% | 15.2% | 13.2% |
| Control | 33.0% | 29.2% | 22.2% | 11.7% | 21.7% | 10.8% | 37.3% | 2.4% | 5.1% | 29.3% | 13.1% | 17.3% |
| Digital communication | 43.9% | 23.5% | 31.1% | 16.1% | 23.8% | 11.2% | 37.8% | 3.4% | 4.7% | 32.1% | 13.5% | 17.1% |
| Electrical machinery, apparatus, energy | 36.7% | 28.7% | 19.0% | 10.1% | 17.6% | 9.9% | 34.9% | 1.7% | 4.2% | 23.9% | 14.3% | 18.4% |
| Engines, pumps, turbines | 40.3% | 28.7% | 22.8% | 10.6% | 12.3% | 8.3% | 31.2% | 2.0% | 5.6% | 25.6% | 13.5% | 17.4% |
| Environmental technology | 30.3% | 26.4% | 27.4% | 12.3% | 18.0% | 10.1% | 36.0% | 2.2% | 4.8% | 20.7% | 14.2% | 20.0% |
| Food chemistry | 28.5% | 29.2% | 18.1% | 15.0% | 12.2% | 9.9% | 34.8% | 2.3% | 4.4% | 9.1% | 17.2% | 18.7% |
| Furniture, games | 25.8% | 27.2% | 18.1% | 13.0% | 15.9% | 11.2% | 33.3% | 2.8% | 4.5% | 15.3% | 14.2% | 16.5% |
| Handling | 28.7% | 29.7% | 16.2% | 10.2% | 15.2% | 10.2% | 34.3% | 2.1% | 5.1% | 12.4% | 11.4% | 16.7% |
| IT methods for management | 28.5% | 28.1% | 29.0% | 17.7% | 26.7% | 13.7% | 41.8% | 2.8% | 4.5% | 28.6% | 18.5% | 13.7% |
| Machine tools | 37.0% | 29.2% | 16.6% | 9.5% | 20.1% | 10.2% | 39.8% | 1.9% | 4.9% | 18.6% | 11.8% | 18.5% |
| Macromolecular chemistry, polymers | 40.2% | 33.0% | 24.2% | 12.2% | 21.7% | 12.2% | 38.6% | 2.1% | 5.3% | 16.4% | 20.1% | 18.6% |
| Materials, metallurgy | 29.8% | 29.4% | 22.9% | 11.3% | 22.1% | 9.7% | 37.0% | 1.9% | 5.5% | 20.7% | 15.3% | 20.5% |
| Measurement | 32.2% | 26.4% | 16.0% | 10.7% | 18.7% | 9.9% | 31.9% | 2.1% | 5.1% | 24.4% | 13.8% | 16.7% |
| Mechanical elements | 31.9% | 28.2% | 20.5% | 9.0% | 17.7% | 9.4% | 33.0% | 1.9% | 5.3% | 18.4% | 13.0% | 18.4% |
| Medical technology | 27.0% | 25.7% | 16.1% | 13.6% | 13.6% | 10.8% | 31.9% | 2.4% | 5.3% | 21.1% | 12.3% | 12.3% |
| Micro-structural and nano-technology | 32.8% | 35.8% | 23.7% | 15.9% | 30.5% | 12.5% | 48.9% | 4.1% | 7.8% | 34.2% | 19.8% | 23.7% |
| Optics | 42.5% | 32.6% | 23.1% | 14.2% | 24.4% | 12.1% | 38.8% | 1.9% | 5.0% | 17.4% | 19.6% | 19.4% |
| Organic fine chemistry | 36.7% | 28.4% | 22.5% | 13.2% | 17.9% | 10.8% | 29.4% | 2.6% | 5.5% | 18.2% | 19.6% | 16.6% |
| Other consumer goods | 30.2% | 30.8% | 17.8% | 11.9% | 20.9% | 10.1% | 31.6% | 2.8% | 4.3% | 20.2% | 16.2% | 18.1% |
| Other special machines | 27.7% | 25.6% | 20.6% | 10.7% | 15.6% | 9.9% | 34.5% | 2.1% | 4.4% | 13.3% | 14.2% | 16.2% |
| Pharmaceuticals | 25.9% | 25.2% | 19.8% | 15.2% | 12.7% | 9.7% | 27.3% | 2.9% | 5.7% | 15.6% | 14.1% | 14.2% |
| Semiconductors | 49.8% | 43.7% | 25.2% | 14.6% | 35.5% | 13.0% | 44.2% | 2.0% | 4.9% | 27.7% | 25.0% | 19.5% |
| Surface technology, coating | 37.5% | 30.1% | 22.9% | 11.6% | 22.4% | 11.9% | 40.5% | 1.9% | 6.0% | 21.4% | 16.1% | 16.9% |
| Telecommunications | 42.4% | 27.8% | 31.2% | 14.7% | 23.0% | 11.9% | 39.4% | 2.5% | 4.4% | 31.8% | 15.2% | 18.8% |
| Textile and paper machines | 43.6% | 34.8% | 17.7% | 11.5% | 22.2% | 12.2% | 37.7% | 2.2% | 5.7% | 16.0% | 12.2% | 17.9% |
| Thermal processes and apparatus | 35.0% | 29.9% | 21.5% | 11.0% | 15.7% | 10.0% | 38.1% | 2.3% | 4.5% | 18.2% | 15.0% | 22.0% |
| Transport | 30.2% | 26.2% | 27.3% | 9.2% | 25.0% | 7.4% | 32.7% | 1.9% | 4.6% | 18.8% | 10.3% | 18.4% |

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Share of mobile inventors in each technology class and country is calculated as the percentage of total inventors in that technology class and country. Note: higher share of mobile inventors is related to double counting of their patents when the patents are assigned to multiple or different technology classes.

A deeper insight is provided by the analysis of technology classes split into 35 categories (Table 1). There is significant variation in prevalence of mobile inventors in nearly all countries. For example, in Sweden and Denmark mobile inventors are active in a small number of technology classes, while in countries like the US and France differences in mobile inventor prevalence in different technology classes are smaller. In Germany, prevalence of mobile inventors varies from 9.0% in mechanical elements to 17.7% in IT methods for management.

Overall, technology classes with higher mobility rates are related to:

- ICT fields (basic communication processes, computer technology, digital communication, telecommunications)
- Applied physics fields (micro- and nanotechnology, semiconductors, optics)
- Fields related to chemistry and biology (analysis of biological materials, food chemistry, macromolecular chemistry and polymers).

On the opposite side, there are technology classes in which mobility rates are significantly lower than average for most selected countries. For Germany, low mobility classes are related to transport and machinery (electrical machinery, machine tools, mechanical elements, transport, measurement, other special machines). These dynamics are likely linked to the industry structure in these technology classes: for example, mechanical engineering is dominated by large firms, where inventors are less mobile. This also provides an explanation for the lower mobility rates in Germany, where mechanical engineering patents (and in particular the automotive industry) are prevalent.

### *2.4.2 Types and characteristics of mobile inventors*

Now we examine mobility trajectories of inventors. With inflow and outflow analysis, we estimated the overall rates at which inventors were coming to and leaving each country. The analysis of mobility trajectories offers a more nuanced view of how inventors navigate international mobility opportunities. For each country in the analysis, we distinguish between the following categories:

- Immobile inventors: inventor stayed in the country of origin;
- Mobile inventors: undertook at least one international move. Among them are:
    - Incomers: inventor transitioned to the country once and stayed;
    - Outgoers: inventors who left their country of origin and never returned;
    - Returnees: inventor left their country of origin, but then returned at least once;
    - Visitors: inventor moved to the country, but then left.

The share of each type of mobile inventors indicates the country's ability to attract and retain mobile inventors. Figure 9 shows the composition of mobile inventor groups.

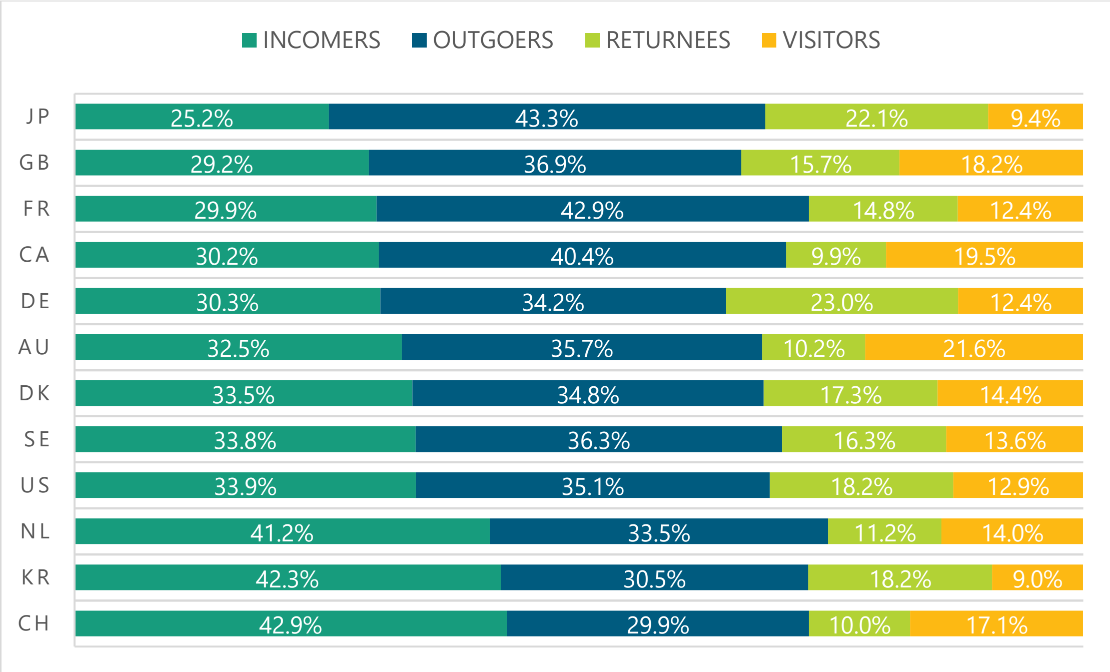


**Figure 9 Composition of inventor mobility trajectories in selected countries, mobile inventors**

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

A set of country demonstrates a smaller share of incomers and a larger share of outgoers among mobile inventors: these are Japan, the UK, France and Canada. These countries also have smaller shares of returnees (except for Japan), consistent with the overall negative mobility balances. The majority of countries, including Germany, have a balance between incomers and outgoers. On the opposite end of the scale, the Netherlands, South Kore and Switzerland have significantly more incomers compared to outgoers among mobile inventors. South Korea in particular has higher than average share of returnees, and Switzerland attracts a particularly high number of visitors. Other English-speaking countries (except for the US) also have higher number of visitors in their composition of mobile inventors.

Germany stands out as the country that attracts the highest share of returnees, followed by Japan, the US and South Korea. This means that a significant share of mobile inventors (up to 23%) who leave Germany eventually return.

### *2.4.3 Productivity and performance of mobile inventors*

An average inventor in the dataset has 4.1 patents, but the differences in the productivity between immobile and mobile inventors are significant. Mobile inventors apply for between three and six times more patents than their immobile counterparts (Table 2). The difference between inventor productivity is the highest in Australia (six times more patents) and the lowest in Germany (three times more patents by mobile inventors). These findings are consistent with previous studies, which established a causal link between inventor mobility and productivity (Hoisl, 2007).

Among the mobile groups, there is further differentiation: Returnees and Visitors both have significantly more patents than other types of mobile inventors. The reasons for this differentiation is not entirely clear. On the one hand, there is a bias in how mobile groups are defined: since at least three patents are needed to identify an inventor as a Visitor or Returnee, these inventors would be more likely to have more patents compared to other groups. However, the significant difference in patent productivity could also be explained by other factors. For instance, those who move several times are more likely to be project managers and other senior people in companies. They are more likely to be listed on inventor teams than 'ordinary' R&D personnel and thus accumulate more transnational patents.

Across the selected countries, immobile inventors based in Germany are particularly productive: they have on average 5.2 patents compared to the 3.4 patent average of immobile inventors. Among mobile inventors, inventors in South Korea lead in the productivity with over 23 patents per inventor on average. Mobile inventors in Germany follow in the 4th place with 15.4 patents on average.

**Table 2 Productivity of mobile inventors in selected countries**

| | Immobile | Mobile | Incomers | Outgoers | Returnees | Visitors |
|---|---|---|---|---|---|---|
| **Average Patents** | 3.4 | 14.7 | 9.1 | 11.8 | 21.2 | 25.1 |
| **AU** | 2.0 | 12.3 | 5.9 | 10.9 | 10.9 | 21.9 |
| **CA** | 2.4 | 13.4 | 7.3 | 10.3 | 11.1 | 27.5 |
| **CH** | 3.1 | 12.1 | 8.8 | 8.4 | 13.5 | 23.3 |
| **DE** | 5.2 | 15.4 | 9.4 | 11.6 | 24.2 | 21.8 |
| **DK** | 3.1 | 13.8 | 9.4 | 10.3 | 20.2 | 21.7 |
| **FR** | 2.9 | 10.5 | 7.1 | 8.4 | 14.0 | 20.2 |
| **GB** | 2.7 | 13.7 | 7.4 | 9.1 | 16.7 | 25.6 |
| **JP** | 4.0 | 16.2 | 7.6 | 13.0 | 22.4 | 36.2 |
| **KR** | 4.8 | 23.3 | 24.7 | 13.3 | 35.6 | 22.7 |
| **NL** | 3.0 | 13.5 | 11.3 | 9.6 | 19.5 | 21.6 |
| **SE** | 3.8 | 15.3 | 9.7 | 11.5 | 19.7 | 31.3 |
| **US** | 3.5 | 16.7 | 9.0 | 13.8 | 22.3 | 28.3 |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

An alternative measure for the performance of mobile inventors can be calculated based on citation data. Based on the works by Dornbusch/Neuhäusler (2015), we measure performance of mobile inventors via a combination of forward and backward citations of their patents. We calculate the number of forward citations a patent received within a 4-year window since the application year. The idea behind this indicator is that the number of citations a patent receives from subsequent patent filings indicates patent quality or technological significance (Carpenter et al. 1981; Trajtenberg 1990), whereas backward citations indicate a patent's originality, i.e. patents with a large number of backward citations can be assumed to build on a larger given pool of already existing knowledge, whereas patents with only a few backward citations have a small existing knowledge stock on which to build (Rosenkopf, Nerkar 2001). Relating the two measure to each other thus indicates what is called catalysing effect of an invention (Dornbusch/Neuhäusler 2015).

On average, patents of mobile inventors have a higher number of both forward and backward citations than an average inventor in the dataset (Table 3). In Germany, as in most other countries, mobile inventors receive modestly more forward citations per patent and cite significantly more patents than average. The difference in forward citations between mobile and immobile inventors is especially significant in the case of returnees: in nearly all countries, returnees have the highest average number of forward and backward citations on their patent applications compared to the other mobile inventor groups. Visitors, on the other hand, is the only group where, in some cases, patents of mobile inventors have fewer forward or backward citations than average.

Mobile inventors in Germany do not have outstandingly higher number of forward and backward citations compared to other countries, but Germany received visitors whose patents have a higher average number of forward and backward citations than most other selected countries. Outgoers from Germany appear to be on the higher end regarding citation rate, both in terms of forward and backward citations.

We proceed by measuring patent value compared to its originality total for the countries and among mobile inventor groups. To do this, we adopt the approach described in Dornbusch and Neuhäusler (2015). The results are presented in Figure 10 and Figure 11. Overall, the selected countries fall either to the upper right quadrant or in the lower left quadrant. The upper right quadrant indicates that patents of inventors in these countries cite many patents and are cited by many patents. This is an indication that these patents contribute to extensive, dynamically developing technological fields. Denmark, United Kingdom, Sweden and the Netherlands in particularly exemplify this trend.

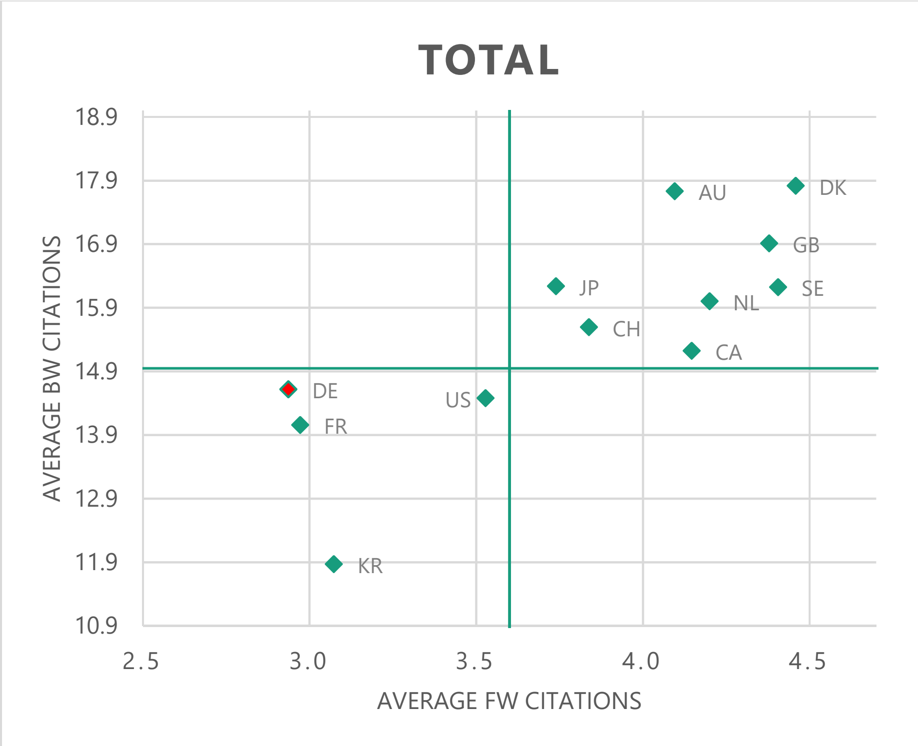


**Figure 10 Impact and originality of patents in selected countries**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

The countries in the lower left quadrant cite and are cited by a lower number of patents than average. South Korea, France and Germany are located in this quadrant in particular. Patents from these countries do not receive as many forward citations, meaning they are less likely to have technological significance, but are more likely to contain a degree of technological originality (or, alternatively, specialisation), since they rely on a relatively more narrow extant knowledge base. The impact of mobile researchers' patents with regard to their originality differs across the mobile groups. Inventors that come to Germany (incomers, returnees, visitors) file patents that are relatively more novel (fewer backward citations), but tend to not spur further inventions (fewer forward citations). In contrast, inventors that leave Germany - outgoers - have patents that build on extensive previous knowledge (more backward citations) and also tend to spur fewer further inventions and thus have relatively lower technological significance compared to outgoer inventors leaving other countries. Inventors whose patents seem to catalyse further innovations (higher forward citations) are mobile inventors in Sweden: all groups belong in the lower right quadrant. Canada-based inventors (incomers and visitors) and South Korea-based inventors (outgoers and visitors) are also found there. A bigger cluster of countries attracts mobile inventors that have inventions that extend existing technological base (more forward citations), but may be more incremental (more backward citations): for example, Denmark and UK-based mobile inventor groups are found there.

**Table 3 Forward and Backward Citations of mobile inventor groups in selected countries**

| | AVERAGE FORWARD CITATIONS | | | | | AVERAGE BACKWARD CITATIONS | | | | | FORWARD TO BACKWARD CITATION RATIO | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Incomer | Outgoer | Returnee | Visitor | Total | Incomer | Outgoer | Returnee | Visitor | Total | Incomer | Outgoer | Returnee | Visitor |
| **AU** | 4.1 | 4.6 | 3.9 | 5.5 | 4.5 | 17.7 | 18.0 | 16.6 | 21.3 | 17.1 | 0.231 | 0.252 | 0.232 | 0.257 | 0.261 |
| **CA** | 4.1 | 4.9 | 4.3 | 6.3 | 4.2 | 15.2 | 15.4 | 14.8 | 18.6 | 15.5 | 0.272 | 0.318 | 0.290 | 0.338 | 0.272 |
| **CH** | 3.8 | 5.1 | 4.1 | 4.7 | 3.8 | 15.6 | 18.0 | 15.9 | 17.9 | 15.1 | 0.246 | 0.285 | 0.255 | 0.263 | 0.253 |
| **DE** | 2.9 | 4.0 | 4.0 | 3.7 | 4.1 | 14.6 | 16.3 | 16.8 | 16.8 | 16.3 | 0.201 | 0.245 | 0.238 | 0.223 | 0.254 |
| **DK** | 4.5 | 5.1 | 5.1 | 5.6 | 4.6 | 17.8 | 19.6 | 17.7 | 21.7 | 17.6 | 0.250 | 0.262 | 0.289 | 0.258 | 0.259 |
| **FR** | 3.0 | 4.4 | 4.3 | 4.1 | 4.1 | 14.1 | 16.2 | 16.2 | 16.8 | 17.5 | 0.211 | 0.274 | 0.264 | 0.243 | 0.236 |
| **GB** | 4.4 | 4.7 | 4.7 | 5.3 | 4.4 | 16.9 | 16.7 | 17.0 | 18.6 | 16.8 | 0.259 | 0.283 | 0.277 | 0.284 | 0.264 |
| **JP** | 3.7 | 4.0 | 4.3 | 4.7 | 2.9 | 16.2 | 15.5 | 15.8 | 16.7 | 12.2 | 0.230 | 0.258 | 0.270 | 0.279 | 0.235 |
| **KR** | 3.1 | 3.3 | 5.8 | 3.9 | 4.3 | 11.9 | 13.0 | 13.5 | 12.9 | 14.9 | 0.259 | 0.258 | 0.430 | 0.302 | 0.286 |
| **NL** | 4.2 | 5.0 | 4.9 | 5.7 | 4.4 | 16.0 | 18.0 | 15.9 | 18.3 | 16.9 | 0.262 | 0.277 | 0.308 | 0.312 | 0.258 |
| **SE** | 4.4 | 5.5 | 4.7 | 5.1 | 4.2 | 16.2 | 15.3 | 15.6 | 17.4 | 15.0 | 0.271 | 0.358 | 0.300 | 0.295 | 0.283 |
| **US** | 3.5 | 4.5 | 3.5 | 4.4 | 3.7 | 14.5 | 15.8 | 13.7 | 15.9 | 14.8 | 0.244 | 0.288 | 0.252 | 0.276 | 0.250 |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

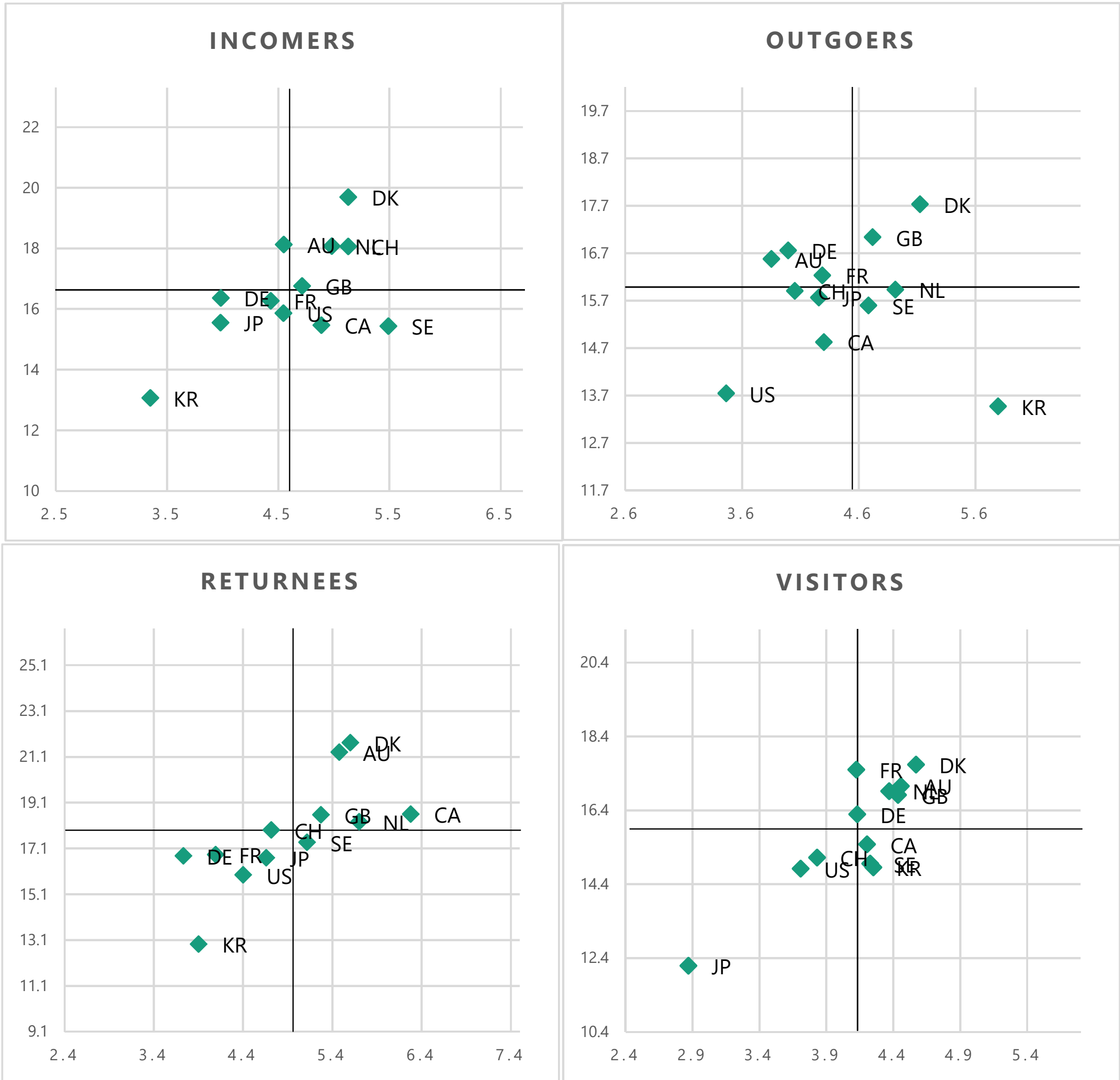


**Figure 2 Impact and originality of mobile inventor patents in selected countries**
Source: Fraunhofer ISI analysis based on EPO PATSTAT

### *2.4.4 Productivity and performance of multi-patent inventors*

To provide a more robust analysis, we also calculate the productivity and performance of inventors by limiting the analysis to only multi-patent inventors: those inventors who have at least two patents in two separate years. Since immobile inventors may only have one patent and mobile inventors need to have at least two patent applications in two separate years to be indentified, the restriction of the data to inventors with two patents or more levels the playing field. This dataset contains around 1.6 million inventors (43% of the whole dataset), 91% of which are immobile (compared with 96% in the whole dataset).

The average patent count doubled in this dataset, from 4.1 to 8.1 patents per inventor. However, the gap between mobile and immobile inventors persists, albeit the gap is much smaller: on average, immobile inventors have around 7 patent applications (compared to 3.4 in the whole dataset); mobile inventors have 15 patent applications.

The distribution across groups and countries is available in Table 4. Regarding the average patent count, German inventors were the most productive in the whole dataset, but among multi-patent inventors, they yield the first place to inventors from South Korea. in general, the balance of average patent count remains relatively the same across countries.

**Table 4 Productivity and citation statistics of multi-patent inventors**

| | **Avg Patent Count** | | **Avg BW Citations** | | **Avg FW Citations** | |
|---|---|---|---|---|---|---|
| | Immobile | Mobile | Immobile | Mobile | Immobile | Mobile |
| **AU** | 4.4 | 12.3 | 22.4 | 17.1 | 4.8 | 4.3 |
| **CA** | 5.3 | 13.4 | 16.4 | 15.3 | 4.9 | 4.3 |
| **CH** | 6.3 | 12.1 | 16.6 | 16.4 | 4.1 | 4.3 |
| **DE** | 9.1 | 15.4 | 14.8 | 16.3 | 2.9 | 3.8 |
| **DK** | 6.6 | 13.8 | 19.4 | 18.4 | 4.9 | 5.0 |
| **FR** | 5.8 | 10.5 | 14.2 | 16.5 | 2.8 | 4.1 |
| **GB** | 5.8 | 13.7 | 19.2 | 17.0 | 5.1 | 4.6 |
| **JP** | 7.3 | 16.1 | 16.7 | 15.2 | 3.9 | 4.0 |
| **KR** | 10.1 | 23.3 | 11.9 | 13.2 | 3.1 | 4.0 |
| **NL** | 6.5 | 13.5 | 16.8 | 16.8 | 4.5 | 4.8 |
| **SE** | 7.6 | 15.3 | 17.2 | 15.7 | 4.8 | 4.6 |
| **US** | 7.0 | 16.7 | 15.5 | 14.7 | 3.9 | 3.8 |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

Considering the backward and forward citations, immobile inventors in five countries - Australia, Canada, United Kingdom, Sweden and the US - have both higher average number of backward and forward citations in their patents than mobile inventors. In Germany, France, and South Korea, mobile inventors have lower average number of both forward and backward citations than average.

### *2.4.5 Mechanisms of international inventor mobility*

Intra-organisation transfers are a specific mobility mechanism, which is available mostly to inventors working in multi-national corporations (MNCs). We define within-organisation transfers as those where inventors change the country of address in the patent application, but the applicant stays the same[2]. Within-organisation mobility is more accessible to inventors working in MNCs because it is associated with lower risk. Such mobility can be relatively short-term - e.g. for a project; or longer-term, e.g. a secondment or a relocation.

We present the results in Figure 12. It can be seen that in all selected countries, within-organisation mobility is dominant: in all countries, over 90% of inventors moved internationally within one organisation. Within- organisation mobility is the highest in Canada, Australia and the UK at above 96%. In Germany, around 95% of mobile inventors moved within one organisation. In the context that our data likely under-estimates within-organisation mobility, it is clearly a dominant channel of international inventor mobility.

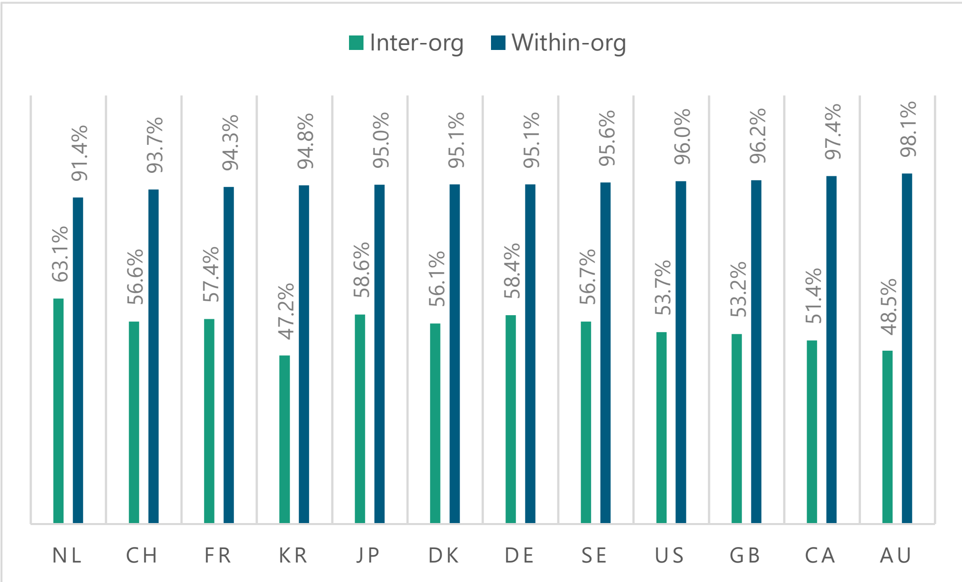


**Figure 12 Inter-organisation and within-organisation inventor mobility**
Source: Fraunhofer ISI analysis based on EPO PATSTAT. Percentage is calculated as the share of all international moves.

If an inventor moves more than once, they may combine within-organisation and inter-organisation mobility. In Figure 13, we visualise the share of mobile inventors whose international mobility took place exclusively within one organisation and inventors whose international mobility was fully inter-organisation. It can be clearly observed that within-organisational mobility is the main mobility mechanism. In countries like south Korea and Australia over 50% of internationally mobile inventors move only between international offices of their parent organisation. In European countries (including Germany) and Japan, a lower share of inventors move only within one organisation, with the lowest share in the Netherlands at around 37%.

2 Since the Leuven algorithm does not identify company subsidiaries, we expect the the rate of intra-company mobility to be under-reported - as e.g. a move from Belgium to Germany would typically also move the legal lieu of application from the Belgian to the German subsidiary of the MNC, without that actually implying a change of company.

Against the background that over 90% of inventors in all mobile categories experienced within-organisation mobility, the prevalence of exclusively within-organisation mobility channel is higher among inventors who move once: incomers and outgoers (Figure 14). Inventors who move more than once combine different mobility channels.

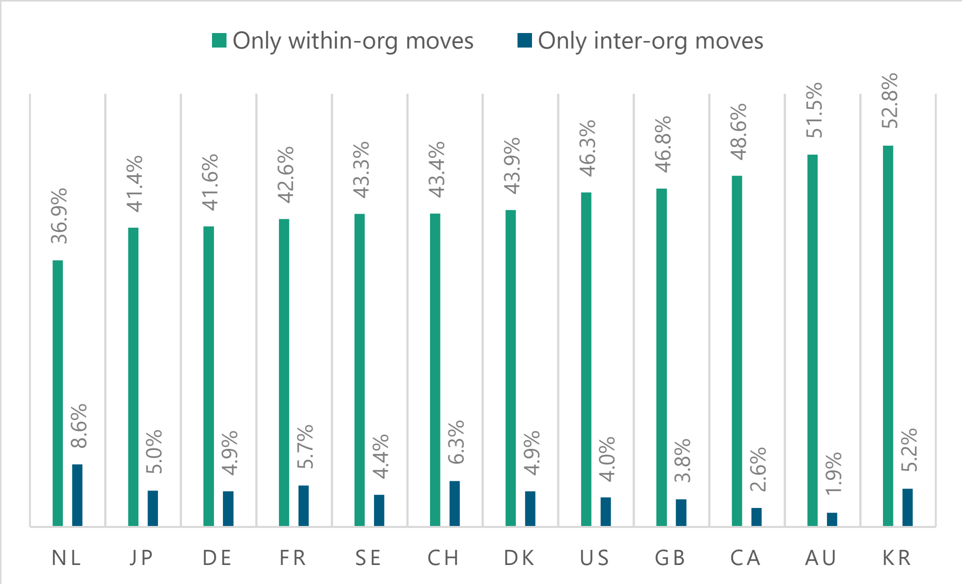


**Figure 13 Exclusively inter-organisation and within-organisation inventor mobility in selected countries**

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Percentage is calculated as the share of all international moves.

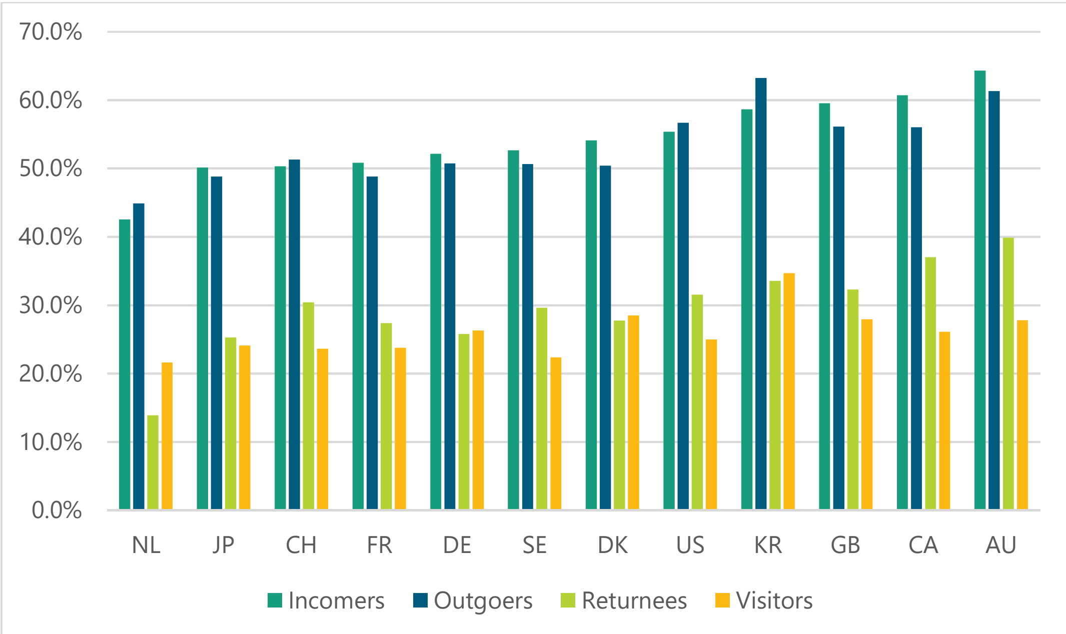


**Figure 14 Prevalence of exclusively within-organisation mobility channel among mobile inventor groups in selected countries**

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Percentage is calculated as the share of all international moves.

## 2.5 In-depth analyses for Germany

We carry out a number of additional analyses only for Germany in order to gain a more in-depth understanding of inventor mobility flows and their composition.

### *2.5.1 In-depth analysis of inventor mobility flows*

Figure 15 presents the distribution of inflows and outflows of mobile inventors in Germany according to the sending countries (countries inventors came from to Germany) and countries of destination (countries inventors left to after Germany). It can be observed that the major countries of origin and destination match: these are the US Austria, United Kingdom, the Netherlands and France. Taiwan, Italy and Switzerland are in additional major sending countries, while most destination countries are in Europe, except China and Japan.

Table 5 presents a more nuanced breakdown of mobile inventors' sending and destination countries based on their type of mobility. The US is the major country with which Germany has mobile inventor exchanges. In the second place is Austria, which is both a major sending and receiving country for all inventor groups, especially returnees. United Kingdom, France, the Netherlands, Denmark and Belgium are also in the top of both sending and destination countries. Taiwan is a major source of returnees to Germany, but is otherwise not a significant mobility destination. Italy and Switzerland are present among the top sending countries, but not destination countries.

With regard to the country of origin of mobile inventors - that is, the country of their first patent application - the US is also the major origin country, with over 37% of inventors starting their patenting activity in the US. This is followed by Austria (11.5% of mobile inventors) and the UK (9.6% of mobile inventors). Other major countries of origin are in Europe (France, the Netherlands, Italy, Sweden, Denmark, Belgium). The only non-European major country of origin besides the US is Japan (2% of mobile inventors).

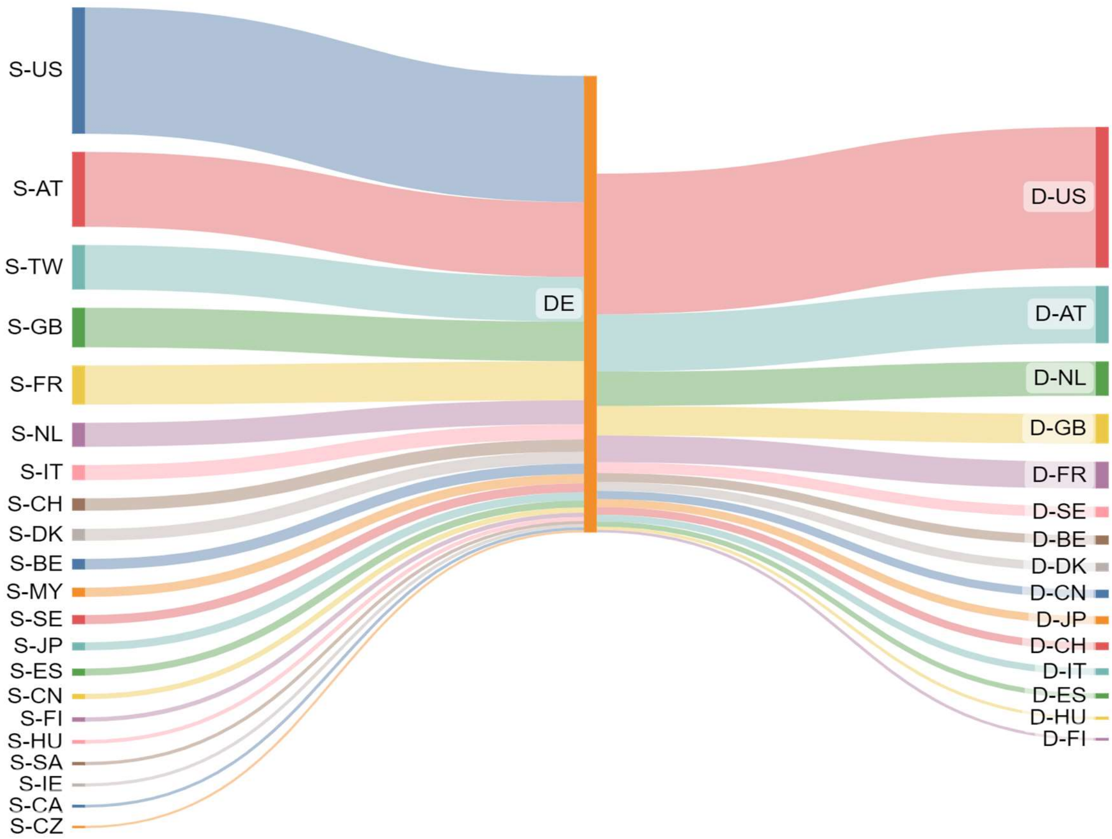


**Figure 15 Sending and destination countries of mobile inventors in Germany**
Source: Fraunhofer ISI analysis based on EPO PATSTAT. Only countries with more than 50 inflows or outflows are depicted.

**Table 5 Top sending countries and destination countries of mobile inventors**

| | Sending Country | | | Destination Country | | |
|---|---|---|---|---|---|---|
| | Incomers | Returnees | Visitors | Outgoers | Visitors | |
| **US** | 37.7% | 0.0% | 34.2% | 38.1% | 35.7% | **US** |
| **AT** | 12.8% | 24.4% | 12.4% | 16.2% | 12.8% | **AT** |
| **TW** | 0.0% | 34.7% | 0.0% | | | |
| **GB** | 8.6% | 6.2% | 10.5% | 7.2% | 9.8% | **GB** |
| **FR** | 9.5% | 6.3% | 7.9% | 6.8% | 7.9% | **FR** |
| **NL** | 6.7% | 0.1% | 7.6% | 9.8% | 7.4% | **NL** |
| **IT** | 4.3% | 2.1% | 1.9% | | | |
| **CH** | 1.9% | 3.5% | 3.3% | | | |
| **DK** | 2.2% | 2.4% | 3.4% | 2.1% | 3.0% | **DK** |
| **BE** | 2.1% | 3.1% | 1.5% | 2.8% | 1.5% | **BE** |
| | | | | 2.7% | 3.3% | **SE** |
| | | | | 1.4% | 4.4% | **CN** |
| | | | | 2.2% | 1.9% | **JP** |

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Percentages are calculated as share of the total in each mobile inventor group.

### 2.5.2 *Female inventors*

The next step is the analysis of the representation of female inventors, which is presented in Table 6. The share of female inventors is around 10% in Germany. The share of female inventors among immobile is also around 10% and 7% among mobile inventors, indicating that female inventors experience less mobility. The share of women is even lower among mobile inventors who move more than once and is the lowest among returnees to Germany (3%). It seems like when female inventors move internationally, they tend to move only once, and multiple moves are very rare.

**Table 6 Female inventors in Germany**

| | Total | Mobile | Incomers | Outgoers | Returnees | Visitors |
|---|---|---|---|---|---|---|
| **All Inventors** | 319,138 | 18,336 | 5562 | 6280 | 2917 | 2275 |
| **Female Inventors** | 32,019 | 1,223 | 463 | 517 | 86 | 120 |
| **Share Female** | 10.0% | 6.7% | 8.3% | 8.2% | 2.9% | 5.3% |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

Looking at the time series data (Figure 16), we observe some increase in the share of mobile female inventors over time throughout the 2000s: from around 3% of all mobile inventors in 2000 to around 5% in 2012. Afterwards, the number of mobile female inventors decreased and has fluctuated at around the 4.7% point.

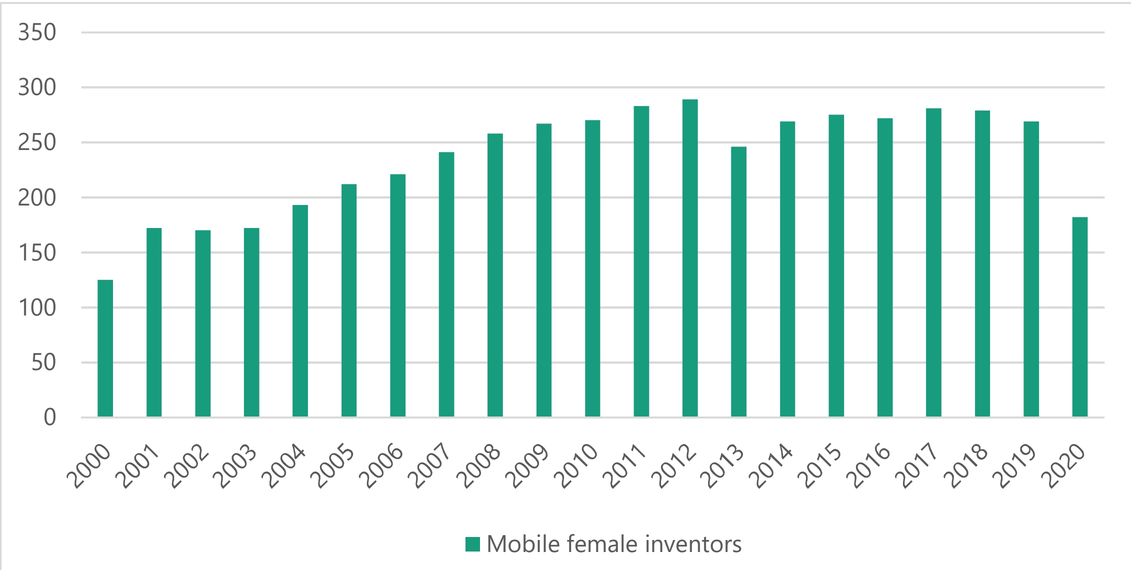


**Figure 16 Mobile female inventors in Germany over time**

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

### 2.5.3 *Further analyses of international inventors in Germany*

Figure 17 shows the share of international inventors in Germany over the observation period, which has increased incrementally from 12.6% in 2000 to 17.7% in 2020.

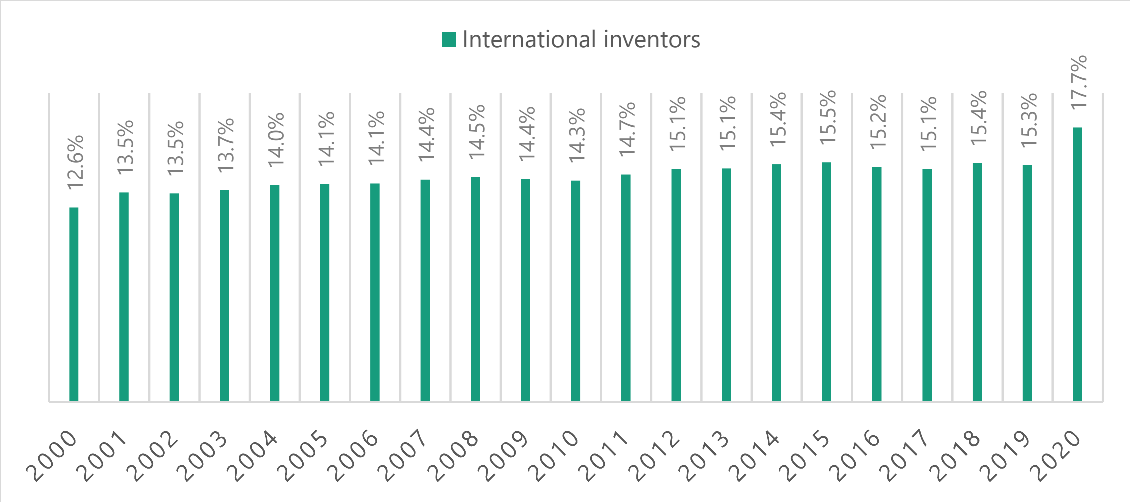


**Figure 17 Share of international inventors in Germany over time**
Source: Fraunhofer ISI analysis based on EPO PATSTAT.

We continue the analysis with the types of organisations in which mobile inventors work in Germany (Table 7). The largest share of mobile inventors can be found in universities and university hospitals (around 15%) followed by Non-university PROs (13%). These likely academics may be mobile within the research system. Consistently with the results of our literature review, inventors employed by large firms are the least mobile.

Next, we examine the distribution of mobile inventors across German Federal States (Table 8). As expected, the innovation powerhouses of Bayern, Baden-Württemberg and Nordrhein-Westfalen host the largest number of inventors in Germany: around 63% of German inventors and 61% of mobile inventors are located in these three States. These three regions also host the vast majority of mobile inventors. Mobile inventors are more concentrated in the small number of Federal States than inventors in general. Hessen, Lower Saxony and North Rhine Westphalia also have relatively higher share of mobile inventors (more than 8%).

**Table 7 Type of organisation employing mobile inventors**

| Organisation Type | Total | Mobile | Share Mobile |
|---|---|---|---|
| **Small Firms** | 108,255 | 97,322 | 10.1% |
| **Large Firms** | 222,695 | 206,314 | 7.4% |
| **Inventor is Applicant** | 172,851 | 158,202 | 8.5% |
| **Non-Uni Research Organisations** | 25,193 | 21,902 | 13.1% |
| **Universities And University Hospitals** | 26,058 | 22,091 | 15.2% |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

**Table 8 Distribution of mobile inventors in German Federal States**

| Federal State | Total | Mobile | Share Mobile |
|---|---|---|---|
| **Baden-Württemberg** | 82,921 | 6,008 | 31.3% |
| **Bayern** | 83,869 | 6,290 | 32.7% |
| **Berlin** | 14,471 | 1,088 | 5.7% |
| **Brandenburg** | 4,917 | 336 | 1.7% |
| **Bremen** | 1,823 | 124 | 0.6% |
| **Hamburg** | 8,040 | 847 | 4.4% |
| **Hessen** | 28,938 | 2,172 | 11.3% |
| **Mecklenburg-Vorpommern** | 2,035 | 150 | 0.8% |
| **Niedersachsen** | 25,385 | 1,595 | 8.3% |
| **Nordrhein-Westfalen** | 66,872 | 4,252 | 22.1% |
| **Rheinland-Pfalz** | 18,154 | 1,555 | 8.1% |
| **Saarland** | 2,921 | 286 | 1.5% |
| **Sachsen** | 11,748 | 866 | 4.5% |
| **Sachsen-Anhalt** | 3,220 | 216 | 1.1% |
| **Schleswig-Holstein** | 7,297 | 512 | 2.7% |
| **Thüringen** | 6,361 | 460 | 2.4% |

Source: Fraunhofer ISI analysis based on EPO PATSTAT. Share of mobile inventors is calculated as percentage of the total number of mobile inventors in Germany.

### *2.5.4 In-depth analysis of specific technology fields*

We continue with the analysis of high-technology patents and mobile inventors in selected technology fields: Artificial Intelligence (AI), Industrial and Manufacturing Engineering (with the focus on Advanced manufacturing) and Biotechnology.

Mobile inventors constitute around 5.8% of all inventors of high-technology patents, but they co-invented around 30% of them. Overall, the productivity of high-tech mobile inventors is also higher: they file the average of 11.6 patent applications compared to 2.0 patent applications of immobile inventors.

The analysis of selected technology fields is presented in Table 9. The highest number of patents is found in Industrial and Manufacturing Engineering followed by Biotechnology. 4,323 AI patents were identified in our search and AI is the most mobile technology field out of the three: around 25% of German AI inventors are mobile. They filed around a half of AI patent applications. The other two fields also boast a higher prevalence of mobile inventors than on average in Germany, but a lower prevalence than certain other technology classes, such as ICT and Nanotechnology. The contribution of mobile inventors to biotechnology is also very significant at 44%.

In terms of productivity, mobile inventors in the selected fields are also more productive than immobile, however, the differences are not as significant as in the case of high technology patents. For example, mobile AI inventors file on average 2.0 patent applications, while immobile inventors file 0.7 applications. The ratios are 2.1 vs 1.0 in Industrial and Manufacturing Engineering; 3.3 vs 1.0 in Biotechnology.

**Table 9 Distribution of mobile inventors in selected technology fields**

| | No. Patents | No. Inventors | Mobile Inventors | Patents By Mobile Inventors |
|---|---|---|---|---|
| **Artificial Intelligence** | 4,323 | 4,687 | 24.6% | 51.5% |
| **Industrial And Manufacturing Engineering** | 43,654 | 46,457 | 10.3% | 22.8% |
| **Biotechnology** | 26,146 | 21,960 | 15.6% | 43.6% |

Source: Fraunhofer ISI analysis based on EPO PATSTAT.

## 2.6 International inventor cooperation

We conclude this chapter with the analysis of international inventor cooperation. We include all selected countries in the analysis, but focus on Germany.

The share of patents with a single inventor in Germany is around 37% and the rest of the patents are co-invented. Distinguishing between domestic and international co-invention, around 26% of the co-invented patents are international co-inventions. The USA is the main international co-invention partner for Germany, with around 44% of international co-patents containing a co-inventor from the US. China is Germany's second most important collaborator with 22% of German international co-patents having a co-inventor in China. Other top international partners for Germany are in Europe, with the Switzerland (10.7%), France (9.6%) and the UK (8.5%) being the most important collaborators. The international inventor co-operation network of Germany and selected countries can be found in Figure 18.

Considering the distribution of international co-patents across technological fields, we find the majority of them in Chemistry, followed by Electrical Engineering and Instruments (Figure 19). Mechanical Engineering has the lowest international co-invention rate. The distribution of international co-inventions is not strongly associated with technology classes where international inventors are prevalent. Considering the distribution of international co-invented patents in WIPO-35 technological classes, the classes that are the most internationally connected do not fully overlap with the ones where we observed the highest mobility rates. Highest co-invention rate is observed in Pharmaceuticals (around 43%), Food chemistry (38.9%), Digital Communication (37.7%), Biotechnology (37.0%), and Organic Fine Chemistry (36.5%). The full list can be accessed in the Annex Table A2.

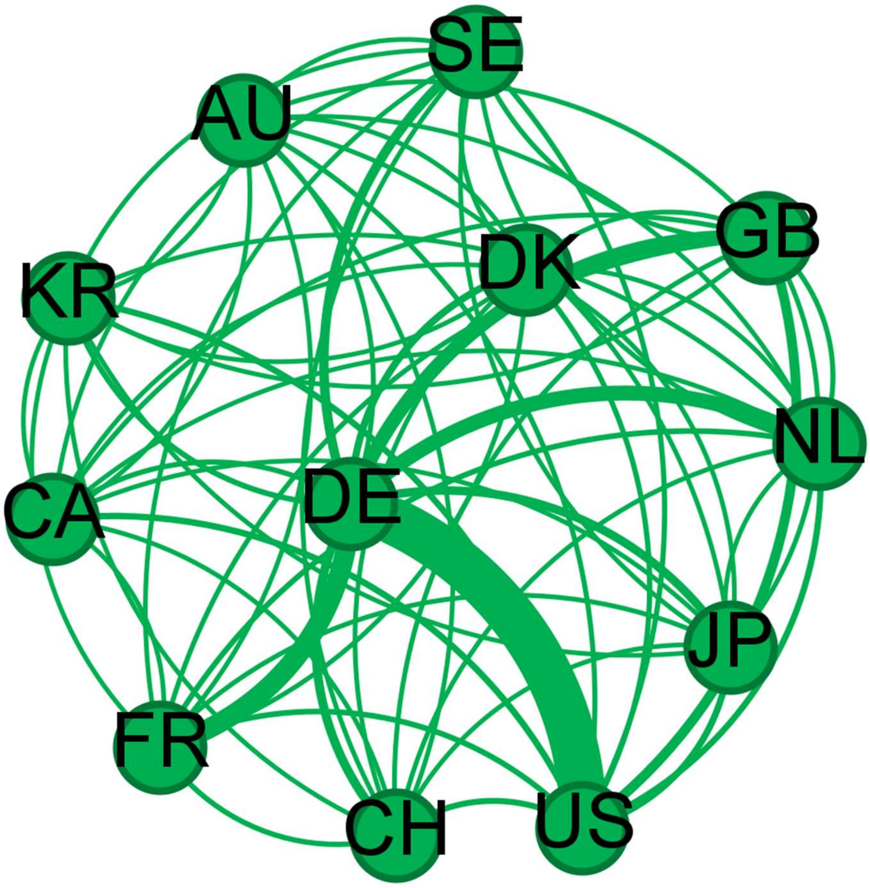


**Figure 18 International inventor co-operation network**
Source: Fraunhofer ISI analysis based on EPO PATSTAT. Yifan Hu layout. Nodes represent the selected countries and the edges reflect co-inventions between each pair of countries. Edge thickness depicts co-invention volume.

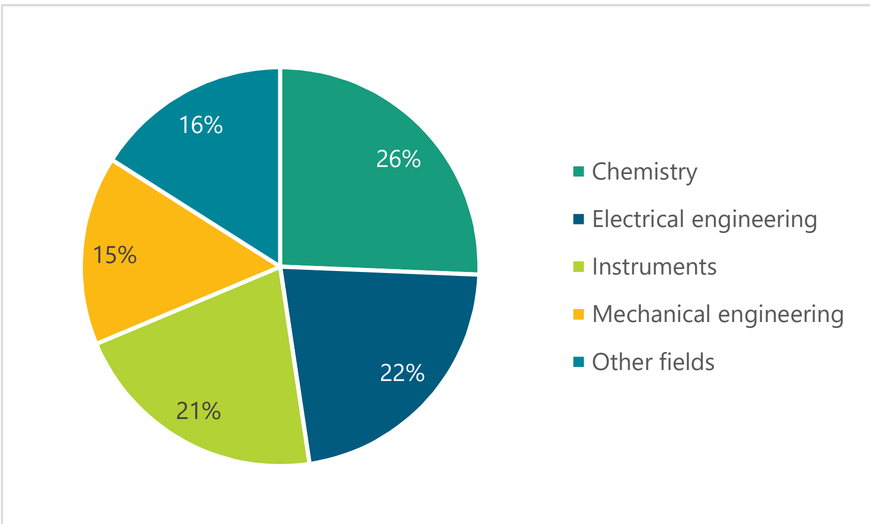


**Figure 19 Composition of co-invented German patents across WIPO-5 technology classes**
Source: Fraunhofer ISI analysis based on EPO PATSTAT.

## 2.7 Recommendations for research and innovation policy

This study provides a comprehensive overview of Germany's international inventor mobility and cooperation in the context of selected comparator countries. We found that Germany occupies a specific place in international inventor mobility and cooperation flows: although its net inventor inflows are relatively low, it experiences a significant turnover of mobile inventors and if the key hub in international cooperation as well. This position provides Germany an advantage in international knowledge exchange flows, including embodied mobility flows. Yet, inventor mobility is significantly different from researcher mobility. Familiar researcher mobility concepts and categories should be used cautiously to interpret inventor mobility data.

Our findings also revealed that internationally mobile inventors are a valuable source of talent. They are more productive than immobile inventors and they are also more likely to produce patents that collect a high number of forward citations. Inventors who are highly mobile (Returnees and Visitors) have an amplified effect. At the same time, a lion share of inventor mobility takes place within one applicant, which means that mobile inventors mostly move between offices of multi-national enterprises. Here, the exact nature of knowledge spillovers in both sending and receiving countries stemming from such mobility should be investigated.

Based on these insights, we propose the following recommendations for policy:

- Inventor mobility to and from Germany should be further encouraged, especially temporary and shorter-term mobility within companies, in order to generate more links and knowledge exchange. This should lead to further cementing of Germany as the international inventor mobility and co-operation hub in Europe; to strengthening Germany's place in global flows of knowledge and people;
- Particular attention should be paid to encouraging inbound international inventor mobility in high-tech and emerging technology fields where they generate particular value;
- Since internationally mobile researchers represent a significant source of internationally mobile inventors, knowledge exchange in the innovation system should pay particular attention to encouraging innovation activities by international academics;

Besides revealing new insights, our findings generally corroborated both what was known in the literature about inventor mobility before and the findings of our previous study for EFI (Neuhäusler and Frietsch, 2014) in terms of the rate, channels and productivity of mobile inventors. However, some of our findings did not align with the previous literature and some are inconclusive. On the one hand, the amount of literature on inventor mobility remains relatively low and comes from a narrow range of sources. On the other hand, our study was conducted based on a novel name disambiguation approach and other methodological choices may have affected our results.

Therefore, our final recommendation is to conduct a further study into international inventor mobility. Our results indicate that organisational strategy may play a significant role in inventor mobility. Furthermore, corporate strategy also influences whether an invention gets to be patented. Therefore, drivers of international inventor mobility are likely to be located on the organisational, not necessarily on the individual level. A deeper focus on the organisational level will lead to more insight regarding the causes and mechanisms of international inventor mobility.

# 3 Lot 3: Critical career transitions in the German research system

## 3.1 Introduction

This chapter analyses characteristics and mobility patterns of researchers in critically important career positions in the German research system: the holders of the European Research Council (ERC) grants and Emmy-Noether fellowship awards, directors of German non-university research organisations and professors in German universities. These positions are important on the one hand because they are markers of research career success in Germany: early career in the case of Emmy Noether fellowships, and late career in the case of institute directors. On the other hand, researchers in these critically important, elite positions have significant influence over steering German research, both intellectually and socially. In the past decades, German research organisations went through the process where significant effort was made to open up the traditionally exclusionary and elitist positions to more diverse researchers coming from more diverse range of backgrounds, including internationally. This study feeds into understanding of whether and via which means international researchers gain access to critical positions in the German research system.

This study pursues two goals: 1) analyse diversity of researchers in critical career positions, in terms of international experience and gender; 2) analyse mechanisms and determinants of international researchers' transitions to critical career positions. To achieve them, we constructed a unique dataset in which researchers in critical career positions in Germany are matched with their Scopus publication records. Transitions to critical positions in the German science system in 2005-2021 are analysed.

This chapter is structured as follows. Section 3.2 describes the dataset construction and the methodology. Then critical research groups are characterised in the Section 3.3. International mobility balances of these groups are analysed in the Section 3.4. Section 3.5 covers mechanisms and determinants of their international moves. Recommendations are offered in Section 3.6.

## 3.2 Methodology

### *3.2.1 Dataset construction*

The dataset was constructed by combining multiple data sources (Table 10). The data on the recipients of ERC grants and Emmy-Noether program awards was collected from public sources.

Concerning past and present directors, all major German PROs - The Max Planck Society, The Helmholtz Association, the Leibniz Association and The Fraunhofer Society - were approached directly. All except Fraunhofer shared lists of current and past directors. In the case of Fraunhofer, we employed a mixed approach of web-based data collection combined with reaching out directly to individual institutes. The data on professors currently working in German universities was collected from University Teacher Directory (*Hochschullehrerverzeichnis*), which documents on an annual basis all staff of German, Austrian and Swiss universities with teaching responsibilities[3]. This study used the 2022 version of the Directory. From this dataset, we delineated a subset of professors employed in research-intensive universities, i.e. those organised in the TU9 - Alliance of Leading Universities of Technology[4], and/or the U15 - Association of major research-intensive and medical universities[5]. This data was cleaned manually: all adjunct professors, emeriti/ae and other non-research staff were removed. Among the various data sources, the data in ERC grantees, Emmy-Noether program awardees and PRO directors contains all relevant researchers over the whole observation period. The university professor dataset only lists researchers in professorship position in 2022. This adds a limitation to this study that professors who left German universities prior to 2022 are not known due to the nature of the source data.

After the names and other available data of researchers in critical positions was collected, it was matched with Scopus records. The primary matching strategy included the combination of last name, organisation name, email address and first name initial. The rates of matching were high for PRO directors, ERC and Emmy-Noether grantees (above 90%), but lower for professors. We assume that teaching-only and adjunct professors who are included in the University Teaching Directory, but are less likely to have Scopus publications, were not matched. The list of research university professors had higher matching rate than the overall list, but lower matching rate than other groups.

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3 This is an excerpt from Kürschner's German Scholars' Calendar (*Kürschners Deutscher Gelehrten-Kalender*), which also includes deceased staff. The data in the

4 TU9 members are WTH Aachen University, Technische Universität Berlin, University of Braunschweig - Institute of Technology, Technical University of Darmstadt, Technische Universität Dresden, Leibniz University Hannover, Karlsruhe Institute of Technology, Technical University of Munich and University of Stuttgart.

5 U15 members are Freie Universität Berlin, Humboldt-Universität zu Berlin, Rheinische Friedrich-Wilhelms-Universität Bonn, Universität zu Köln, Goethe-Universität Frankfurt am Main, Albert-Ludwigs-Universität Freiburg, Georg-August-Universität Göttingen, Universität Hamburg, Universität Heidelberg, Universität Leipzig, Johannes Gutenberg-Universität Mainz, Ludwig-Maximilians-Universität München, Westfälische Wilhelms-Universität Münster, Eberhard Karls Universität Tübingen, Julius-Maximilians-Universität Würzburg.

**Table 10 Dataset construction**

| Researcher type | Collected | Scopus match | Included in dataset |
|---|---|---|---|
| **ERC Grantees** | 1,931 | 1,828 (94%) | 1,575 (81,6%) |
| **Emmy Noether Program Awards** | 1,538 | 1,509 (97%) | 1,375 (89,4%) |
| **German PRO Directors** | 803 | 769 (96%) | 655 (81,6%) |
| **German University Professors** | 112,650 | 85,177 (75,6%) | 70,279 (62,4%) |
| **Research University Professors** | 27,103 | 22,475 (79%) | 15,904 (58,7%) |

Source: Fraunhofer ISI.

The dataset includes researchers who published at least once in Germany in the period of 2005-2021. Further, we restrict it to researchers who published at least twice in two separate years. In total, 592,302 authors are included in the final dataset. Similarly to the previous step, the share of PRO directors, ERC and Emmy-Noether grantees remains high (above 80%) in our final dataset compared to the original name list. The share of professors further decreases to around 62% of those listed in the University Teacher Directory. This, too, was to be expected as it is known that a good share professors hardly ever publish through the formal channels covered by Elsevier, most prominently in the Arts and the Humanities but also in other fields of science. Additionally, professors who only worked in Austria and Switzerland were not included.

### *3.2.2 Approach to data analysis*

The data is analysed on the author-year level. If an author did not publish in between the years, this author will not have any entry for that given author-year. Hence, author observations vary across years. We end up with pooled longitudinal data containing the authors' publication activity at different points in time. For each author in each year of observation, a main country is assigned. If an author reports several countries in one year, the most reported country is selected. Otherwise, the main country from the year before is chosen. If the main country is still unclear, the main country from the following year is considered. In the small number of cases when the country is still unclear, one is chosen at random. Due to Scopus coverage, the analysis of researcher career trajectories is limited to the period of 1996-2021. In order to account for variations in data, the analysis of mobility balances is performed for the time period of 2005-2021 and for the 5-year periods of 2005-2010; 2011-2015, and 2016-2021.

We define the author's mobility based on the change of the country reported in author's affiliation address. The first reported country, i.e. the country of first academic publication, is assigned to be their *country of origin*. So defined, country of origin may not match researcher's nationality or ethnicity. An *international move,* or *transition,* is identified when a researcher changes affiliation country and reports the new country for at least three consecutive publication years. Moves are calculated on an annual basis. If a researcher has multiple addresses in one year, the most reported country is counted as the main country for that year. Through this method, we allocate 92% of the authors in our dataset to a country. The remaining are authors that have the same number of publications for two or more of the countries for a given year. In that case, we select the country where the author had published the most in the years prior.

By imposing the conditions that each new affiliation must be reported for at least three years, we identify long-term job mobility of researchers while intentionally excluding temporary mobility, research stays, other shorter-term activities as well as artefacts caused by virtual double affiliations, which may never prompt real mobility. Where, in the following, we do refer to what we technically detect as short-term (1 or 2 year) mobility, we will designate it as "international exposure", acknowledging while such identification surely provides evidence of some sort of international involvement, it can hardly serve to attest mobility in the sense of changing residence.

Based on these definitions, the following researcher mobility trajectories are analysed in this chapter:

- *Immobile researchers* are those that for all author-years only have affiliations with German organisations.
- *Mobile researchers* undertook at least one international move. Among them are:
  - *Incomers*: researchers who first published outside Germany, moved to Germany and stayed;
  - *Outgoers*: researchers left Germany and never returned. They may or may not have started in Germany[6];
  - *Returnees*: researchers who were in Germany, transitioned outside Germany and at some point later transitioned to Germany again. They may or may not have started in Germany, but all have two observations in Germany and one observation outside Germany in between.
- *Researchers with international exposure* only have one- or two-year international research stays, whom we categorise are neither immobile nor mobile. International mobility was not sufficiently long to ascertain that they moved between jobs, especially at the senior level examined in this analysis. However, their international mobility experience is also substantially different compared to immobile researchers.

6 Researchers also must lose their German affiliation to be counted as the outgoer. This category of 'outgoers' also include the category of 'visitors' (see Lot 1 and Lot 2). In this Lot 3, 'visitors' were merged with 'outgoers' to streamline reporting. Both categories are very small and only play a peripheral role in the analysis.

We will refer to incomers and returnees jointly as *international researchers currently working in Germany*.

Finally, we estimate inflows and outflows of researchers in 2005-2021 and in separate time periods. There, we restrict the definitions of immobile, incoming, outgoing and returning researchers to their mobility within the specified period of time. For example, a researcher may be categorised as immobile in 2005-2010 and as outgoing in 2016-2021. Overall, the trajectory type will be defined as 'outgoer'.

## 3.3 International researchers in Germany

Among nearly 600 thousand researchers who published research articles with an address in Germany in 2005-2021, we identified around 93 thousand professors in German universities, among whom around nine thousand worked in research-intensive universities; 1,574 ERC grantees, 1,371 Emmy Noether program award winners, and nearly 700 directors of non-university PROs (Table 11). Taken together, researchers in the critical groups constitute around 18% of all researchers who published in Germany during the reference period. As the sizes of the groups vary significantly, this chapter will present them in a disaggregated way. They are juxtaposed to the reference dataset, which is labelled 'Total' in the rest of the chapter.

**Table 11 Mobile Researcher Groups**

| | Total | Emmy Noether | ERC | PRO directors | Professors | RU Professors |
|---|---|---|---|---|---|---|
| **All Researchers** | 592,302 | 1,371 | 1,574 | 681 | 93,265 | 9,034 |
| **Mobile Researchers** | 10.3% | 27.1% | 36.1% | 25.3% | 6.4% | 16.5% |
| ***Among Them:*** | | | | | | |
| **Incomers** | 4.4% | 14.2% | 24.0% | 15.7% | 4.1% | 10.8% |
| **Returnees** | 0.7% | 10.0% | 11.4% | 8.7% | 1.7% | 5.6% |
| **Outgoers** | 5.3% | 3.0% | 0.8% | 0.9% | 0.5% | 0.2% |
| **Researchers with International Exposure** | 15.8% | 39.5% | 25.5% | 14.1% | 11.3% | 13.2% |
| **Immobile Researchers** | 73.8% | 33.3% | 38.4% | 60.6% | 82.3% | 70.3% |

Source: Fraunhofer ISI analysis based on Scopus data. Percentages are calculated as the share of the total number of researchers in the critical group.

The prevalence of mobile researchers varies across the critical groups (Figure 20). Emmy-Noether awardees and ERC grantees are much more mobile than others: over 60% of researchers in these groups are either mobile or had international exposure. Around a quarter of PRO directors are mobile. RU professors are only slightly more mobile (16.5%) than researchers on average in the reference dataset (10.5%), and the general university professor group demonstrates the lowest rates of mobility: over 80% are immobile.

Among the ERC grantees, we further distinguished between the holder of Starting Grants (46.7% of ERC grantees), Advanced Grants (27.8%) and Consolidator Grants (25%). The breakdown of the grant holders among mobile researchers is very similar to this general balance: 49% of mobile ERC researchers received a Starting Grant, and the rest are split nearly evenly between Advanced and Consolidator Grant holders. It interesting that among immobile researchers, a higher than average share received Advanced grants (38% of all ERC grants received by immobile researchers).

Regarding the prevalent type of mobility trajectory, there are also variations across the groups (Figure 21). Compared to the reference dataset, all critical groups except for university professors have higher share of incomers than average. These shares are the highest among ERC grantees, PRO directors and Emmy Noether awardees. The share of outgoers among ERC grantees, PRO directors and Emmy Noether awardees is also significantly lower than on average in the reference dataset, which could indicate some retaining capacity of the award[7]. All critical groups, including university professors, have higher share of returnees than on average in the reference dataset, however, the share of returnees varies across groups: from 1,7% among university professors to 11,4% among ERC grantees. This could indicate that prestigious grants and positions are capable of attracting diaspora researchers to come back to Germany.

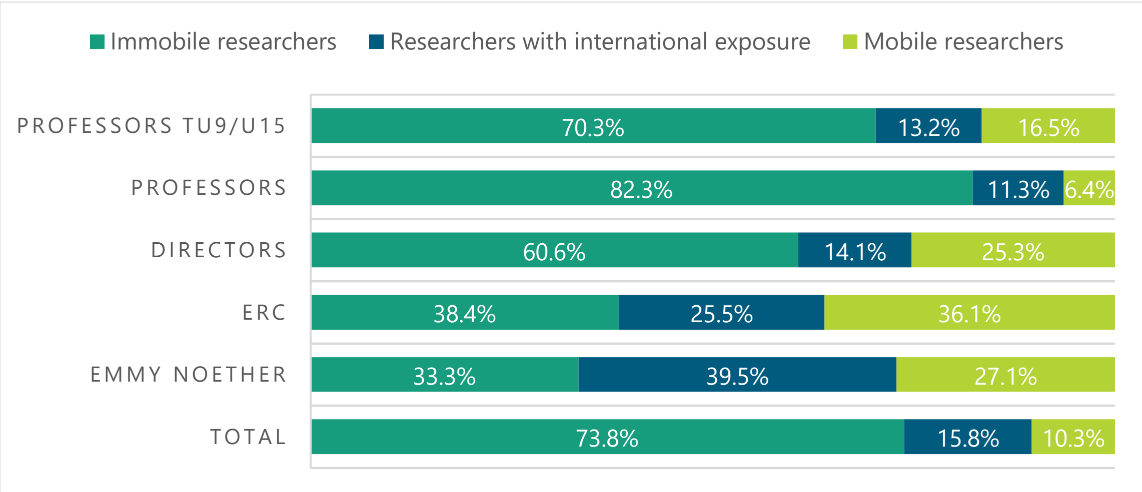


**Figure 20 Share of Mobile Researchers in critical career groups**
Source: Fraunhofer ISI analysis based on Scopus data. Percentages are calculated as the share of the total number of researchers in each critical group

[7] We calculated the share of outgoers by removing ERC and Emmy Noether researchers whose grants have not yet ended from the dataset. This changed the share of outgoers by 0.2-0.5%.

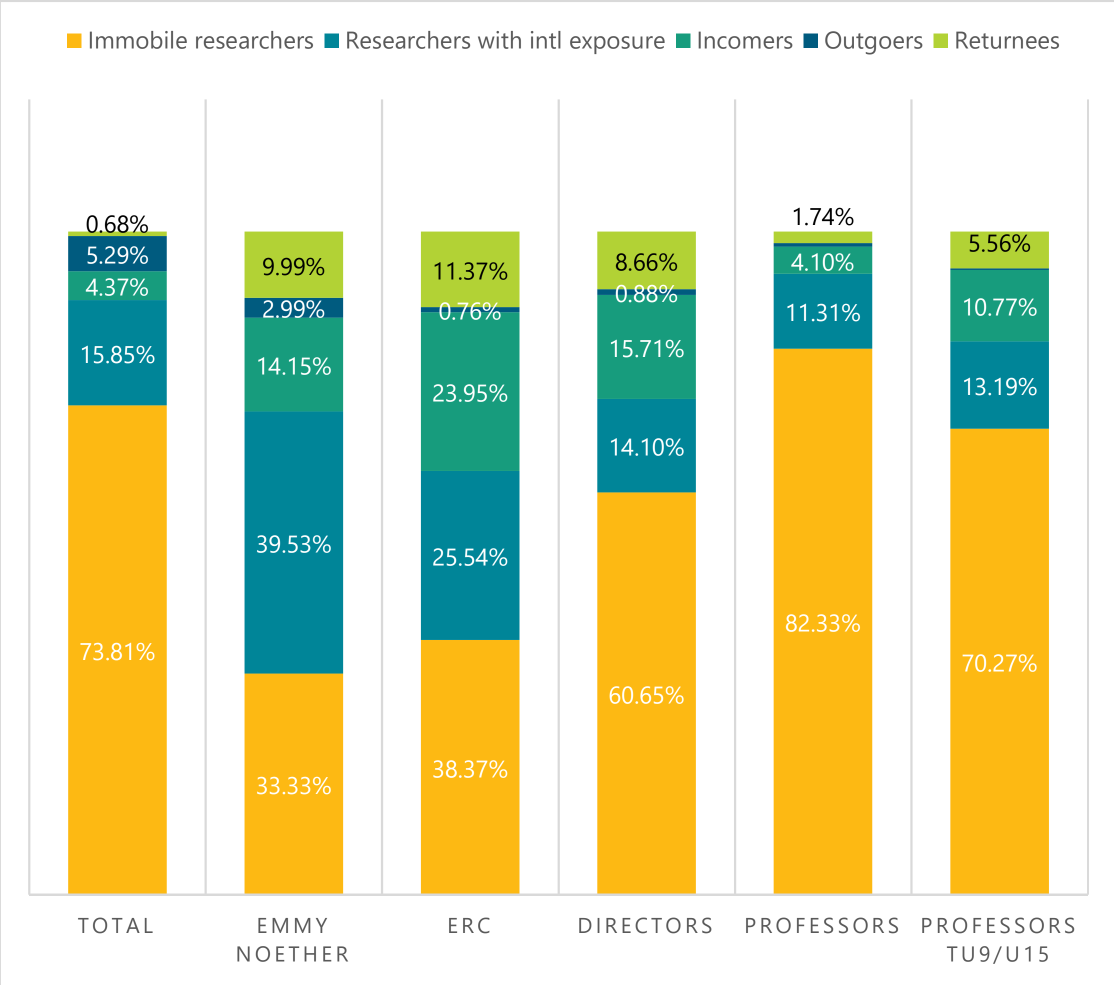


**Figure 21 Distribution of mobility trajectory types in critical career groups**
Source: Fraunhofer ISI analysis based on Scopus data. Percentages of incomer, outgoer and returnee researchers are calculated as the share of the total number of researchers in respective critical groups. Share of outgoer researchers among Professors and RU Professors is nil due to the dataset properties.

### *3.3.1 International female researchers in Germany*

Next, we review the representation of female researchers among the critical groups (Table 12). Female researchers are identified based on their name. The female dummy variable takes a value of 1 if an author by the time of publishing identified as female and 0 otherwise[8].

[8] Since some names cannot with certainty be identified as female names, here we report share of researchers who are likely to be women compared with the corpus of male researchers together with researchers whose gender could not be assigned.

**Table 12 Female mobile researcher groups**

| | All researchers | Emmy Noether | ERC | PRO directors | Professors | RU professors |
|---|---|---|---|---|---|---|
| **All Researchers** | 592,302 | 1,371 | 1,574 | 681 | 93,265 | 9,034 |
| ***Female Researchers-*** | | | | | | |
| **Number** | 182,974 | 351 | 324 | 98 | 23,206 | 1,731 |
| **Share** | 30.9% | 25.6% | 20.6% | 14.4% | 24.9% | 19.2% |
| **Female Mobile Researchers** | 24.6% | 27.2% | 25.4% | 23.3% | 21.2% | 19.9% |
| ***Among Them:*** | | | | | | |
| **Incomers** | 27.0% | 30.9% | 27.6% | 26.2% | 22.8% | 20.2% |
| **Returnees** | 18.7% | 25.5% | 21.2% | 20.3% | 17.7% | 19.5% |
| **Outgoers** | 23.4% | 14.6% | 16.7% | 0.0% | 20.1% | 10.5% |
| **Female Researchers with Intl Exposure** | 26.4% | 23.4% | 16.7% | 17.7% | 20.7% | 18.8% |
| **Female Immobile Researchers** | 32.7% | 26.9% | 18.7% | 9.9% | 25.7% | 19.1% |

Source: Fraunhofer ISI analysis based on Scopus data. Percentage of female researchers is calculated as the share of the overall number of researchers in each category: for example, female mobile researchers constitute 25.9% of all mobile researchers; female incomers constitute 27% of all incomers and so on.

Our first observation is that the share of female researchers in critical groups is lower compared to the reference dataset: it stands at around 31%, while the highest share of female researchers are among Emmy-Noether program awardees and university professors - standing at around a quarter of all researchers in these groups. The share of women is lower among PRO directors at only 14.5%, or only ninety-nine directors being women; research university professors and ERC grantees - for these groups, the value is around 20%.

These differences are expected: since women tend to be more represented in early-career positions, they would be more prevalent in the general dataset. On a positive note, they now remain comparatively well represented in high-potential early career programmes like Emmy-Noether. Among the critical career groups, the share of women is much lower in positions associated with leadership and prestige (directors, research university professors, ERC grantees). Women's challenges in advancing to senior and leadership positions are visible in our data. In addition, it today's directors, senior professors and even ERC grantees entered their scientific career at a time when women were even less represented in science so that their levels of representation among senior staff can also be seen as a reflection of these earlier, even more discriminating framework conditions which prevailed until very recently.

The share of mobile female researchers does not significantly differ from the overall share of female researchers in the critical groups. For some groups - ERC grantees, PRO directors - the share of women among mobile researchers is higher than the share of women among immobile researchers and researchers with international exposure. This indicates that international mobility could be positively associated with opportunities for women to secure ERC grants and director positions.

This point is made stronger when the prevalence of female researchers who move to Germany is examined. The share of women is higher among incomers in every type of critical position. The discrepancy is especially large for PRO directors: only 14.6% of PRO directors are women, but 26% of incomer directors. Therefore, it looks like primarily long-term international mobility can be a mechanism for female researchers to gain access to prestigious grants and elite positions in German research organisations. However, this instrument does not seem to work for women who were trained in Germany: the share of women among returnees is around the same as among researchers overall in every critical group.

In the past decade, Germany has been making effort to advance gender equality in academia. Some initiatives target specifically appointment of women to senior positions in academia (BMBF, 2023). Among the critical career groups, we see a degree of positive dynamics of women's representation over time, especially among PRO directors and (research) university professors (Figure 22). This is congruent with the increase of female researchers in the reference dataset: from 27.1% in 2005-2010 to 32.2% in 2016-2021. However, the share of women did not change substantially among mobile researchers, as well as among Emmy Noether awardees and ERC grantees. While a certain level of improvement seems to have been reached earlier at early career stages, the following stagnation seems to indicate the continued presence of unaddressed, more structural barriers to gender equality.

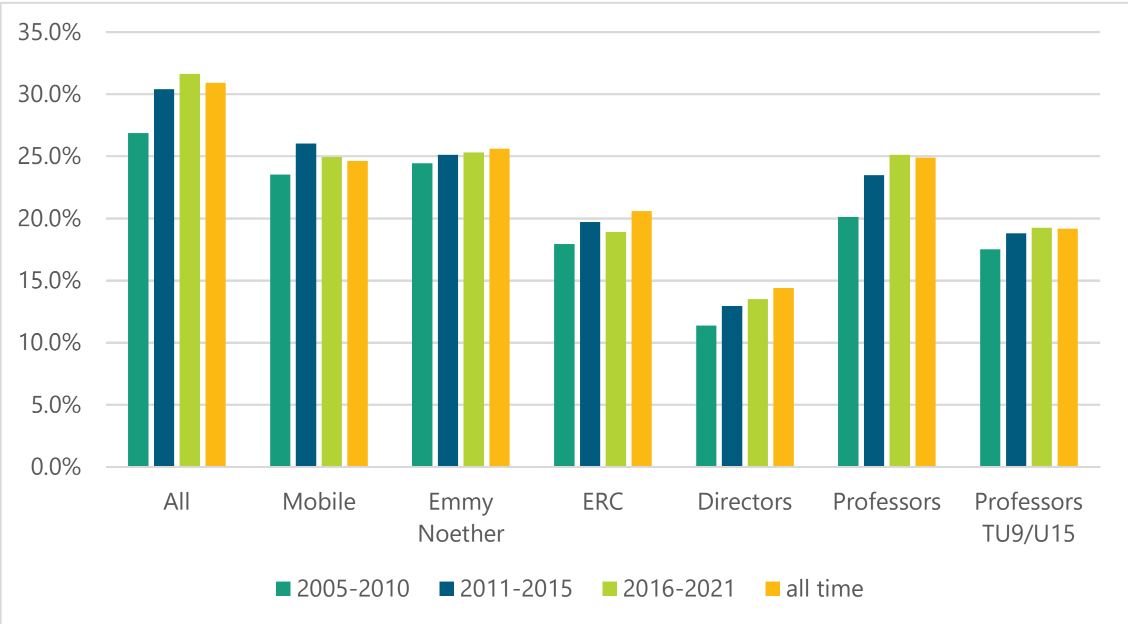


**Figure 22 Share of female researchers, time series perspective**
Source: Fraunhofer ISI analysis based on Scopus data. Percentage of female mobile researchers in each time period in each group is calculated as the share of all researchers in that time period and group.

### *3.3.2 Scientific fields*

Furthermore, we split the sample by scientific fields to analyse whether there are any noteworthy differences between different areas of research. We aggregate authors by the main fields of engineering, medicine, natural sciences, and social humanities. We select an author's main scientific field based on the ASJC field of journals in which the author has published most frequently.

We first assess the extent to which mobility is prevalent in the four fields of science (Figure 23). In line with expectations, we find that Medical Sciences and Engineering are fields with less mobility (only 6.3% and 8.5% of researchers in these fields are mobile). Natural sciences and Social sciences and humanities have higher prevalence of mobile researchers and also researchers with international exposure. Natural sciences is consistently revealed as the field with the highest share of mobile researchers across all critical groups. However, among ERC grantees and Emmy-Noether award winners, engineers and medical scientists appear to be more mobile than social scientists. Among PRO directors, medical scientists also appear to be more mobile than in the reference dataset, while the distribution of mobile researchers among (research) university professors is consistent with the overall distribution of mobile researchers across fields in the reference dataset.

The differences in distributions observed in the various critical career groups may be attributed to the differences in mobility opportunities created by dedicated awards, or high-level mobility to prestigious positions (in the case of PRO directors). Award-related mobility seems to create more opportunities for researchers in engineering and medical fields.

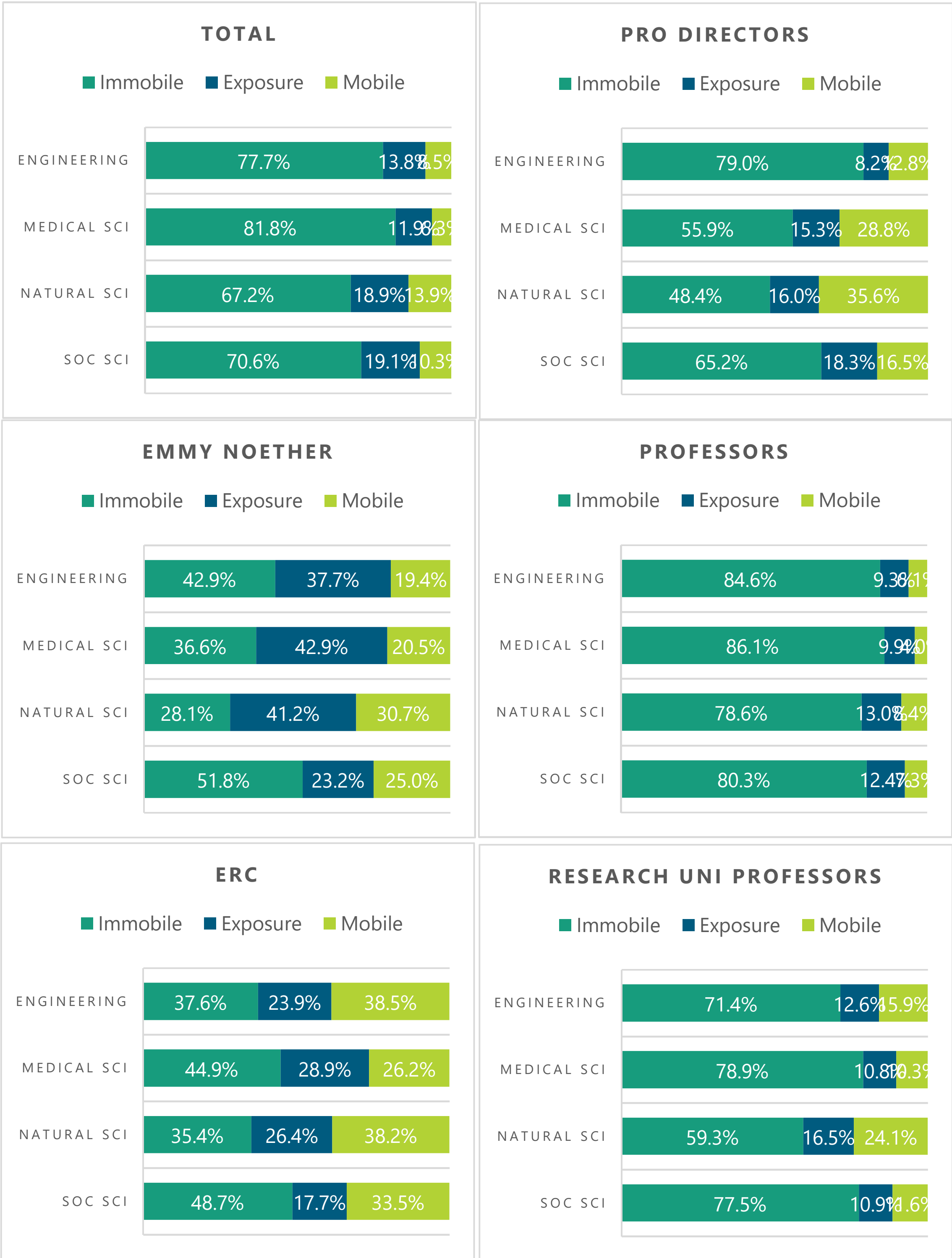


**Figure 23 Mobility in scientific fields**
Source: Fraunhofer ISI analysis based on Scopus data. Percentage of (im)mobile researchers in each field and category is calculated as the share of all researchers in that field and category.

### 3.3.3 Researchers with German background

Now we analyse the share of researchers with German background among incomers and returnees in order to provide extra insight about who comes to Germany. A common limitation of bibliometric methodologies is the assumption that the country of researcher's first publication is their country of origin. With the high rates of student mobility and the increase in shares of foreign-born doctoral students in European and North American universities, this assumption does not always hold true.

Name-based analysis offers an additional source of information about researchers' mobility trajectory, because it makes the assumption that researchers with names originating from certain countries are culturally linked with these countries, e.g. as first or second generation migrants. This enables the analysis to gain deeper insight into a researcher's origin beyond their publication history.

We use Namsor Applied Onomastic to identify name origin. Namsor is based on a machine learning approach to origin and ethnicity identification. Trained on over several billion names, it uses the combination of first and last name to assign probable countries of origin to a name. Using this tool, we identified names of German and Austrian origin in our dataset. We group the two countries together due to similarities of their naming traditions: distinguishing between German and Austrian names accurately is not feasible using only name data[9].

The results are interesting. As expected, the share of researchers of German/Austrian origin among returnees is higher than among incomers (Table 13). However, their prevalence among critical career groups is much higher than in the reference dataset overall: for example, around 60% of (research) university professors who started their career abroad and at some point moved to Germany have German or Austrian names. Against the low rates of mobility among professors overall, this observation reveals potential further hurdles for international researchers to achieve professorial positions in Germany. There, international experience does not appear to hold an advantage. In addition, even among international researchers, the majority are of German origin, which implies perhaps that they are able to teach in German. This would be an additional obstacle for non-German speaking scientists.

The prevalence of researchers with German or Austrian names is relatively lower among PRO directors and ERC grantees, two senior, prestige-based critical groups (albeit the shares are still higher than in the reference dataset overall). Especially among PRO directors, the share of researchers with German/Austrian background is low even among returnee directors: only 42% compared to the minimum of 60% in other critical groups. This perhaps means that the

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9 Since Namsor does not distinguish German Swiss names from French and Italian Swiss names, we did not add names of Swiss origin in this group to minimise noise in the results.

recruitment process for directors really focuses on excellence and the German cultural background matters less.

**Table 13 Share of researchers of German / Austrian origin among incomers and returnees**

| | Total | Emmy Noether | ERC | Directors | Professors | RU Professors |
|---|---|---|---|---|---|---|
| **Incomers** | 9.2% | 50.5% | 34.5% | 32.7% | 60.8% | 57.7% |
| **Returnees** | 31.1% | 74.5% | 62.0% | 42.4% | 73.3% | 72.7% |

Source: Fraunhofer ISI analysis based on Scopus data.

The higher prevalence of incomers and returnees with German background among researchers in critical career positions could signify several things. First, being German maybe makes it easier for researchers to advance to these positions, meaning there are barriers for non-German researchers. Second, German scientists may be more committed to coming back to Germany even if they start their research careers abroad or spend substantial period of time abroad, while other international researchers keep their options open. In any case, we can conclude that Germany has the power to attract researchers with German origin trained abroad (reverse the brain drain), especially those capable to advancing to critical positions in the research system.

The prevalence of incomer and returnee researchers with German/Austrian names has been decreasing in the recent time periods compared to the early 2000s, both in the reference dataset and across critical groups (Figure 24). Among ERC grant holders, the share of researchers with German/Austrian origin dropped by half from 41% in 2005-2010 to 22% in 2016-2021. This indicates that Germany is becoming more attractive to a wider range of international researchers overall, and it is possible for non-German incomer researchers to advance to critical positions in the research system.


**Figure 3 Share of Researchers with German and Austrian background among incomers and returnees, time series perspective**

Source: Fraunhofer ISI analysis based on Scopus data.

## 3.4 Migration balances in critical researcher groups

In this section, we deepen our understanding of the presence of international researchers in critical positions in Germany by analysing time series data. Here we analyse the rates at which international researchers attain critical career positions over time[10]. Our analysis is split into three time periods: 2005-2010; 2011-2015; and 2016-2021.

Overall, we observe a positive migration balance for the critical groups and negative balance in the reference dataset (Table 14). The overall negative value of international migration balance represents around 23% difference between inflows and outflows of researchers to Germany in 2005-2021. The gap between inflows and outflows narrowed down in the most recent time period of 2016-21 to around 6% difference. In contrast, in critical career groups, very high retention rate is observed: around 88% of Emmy Noether awardees and over 96% ERC grantees and PRO directors are either incomers or returnees. Outflow rates are very low. This means that most researchers who take one of these positions very likely remain in Germany.

**Table 14 International mobility balances in critical groups**

| | Total | Emmy Noether | ERC | Directors | Professors | RU Professors |
|---|---|---|---|---|---|---|
| **2005-2021** | -5,958 | 244 | 464 | 127 | 3318 | 1,049 |
| **2005-2010** | -2,099 | 80 | 141 | 45 | 1,306 | 439 |
| **2011-2015** | -3,199 | 103 | 198 | 52 | 1,252 | 402 |
| **2016-2021** | -660 | 61 | 125 | 30 | 760 | 208 |

Source: Fraunhofer ISI analysis based on Scopus data

Against the overall negative trend, the balances between inflows and outflows changed over time. In the critical groups, in the period of 2011-15, the inflow rate increased for Emmy Noether awardees, ERC grantees and PRO directors. However, in the period of 2016-2021, while the mobility balances remained positive, inflow rates decreased significantly for all critical groups.

[10] It is important to keep in mind that our data regarding university professors is heavily biased towards researchers who are currently in Germany due to the data source used. It under-reports rates of outgoing researchers. Thus we focus mostly on incoming researchers. Data on ERC and Emmy Noether grant recipients, and on PRO directors is free of this bias.

### *3.4.1 Sending and Receiving Countries*

Next, we consider which countries international researchers worked in before they moved to Germany (*sending countries*[11]) and which countries they move to when they leave Germany (*receiving countries*). We calculate these inflow and outflow rates for incomers and returnees together. The overall distribution of sending countries of incomers is similar to what is reported below, with one difference is in higher prominence of European countries as the source of returnees compared to the relative significance of non-European countries, such as China, Russia and India as the source of incomers.

The top sending countries and regions are presented in Table 15. The USA, United Kingdom and Switzerland are the top sending countries for all critical groups and in the reference dataset overall. Although Germany has negative mobility balances with all three, they are at the same time jointly accountable of at least 60% of incoming researchers. In the case of PRO Directors, over 70% came from these three countries. These shares are much higher than 36.6% of researchers who came to Germany from the top-3 countries in the reference dataset. Altogether, the top-10 sending countries are accountable for at least 80% of critical group researcher inflows to Germany (90% in the case of PRO directors). Again, this concentration is higher than in the reference dataset, where 67.5% of inflows come from the top-10 countries.

There are differences in the relevance of certain sending countries groups: Switzerland, the Netherlands and Austria are particularly important as sending countries for PRO directors and (research) university professors, while France, Italy and Spain are more prominent as sending countries for Emmy Noether awardees and ERC grantees.

Researchers in critical groups move to Germany nearly exclusively from Europe and North America. Although the US is the most important source country, Europe is the most important source region of international researchers coming to Germany: between 55% and 61% of sending countries for researchers in the critical groups are in Europe. The concentration is higher in the reference dataset and stands at 60%. The difference here is that in the overall dataset, a broader range of sending countries supply researchers to Germany, while among critical groups, a few major European countries play the biggest role.

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[11] The results for sending countries significantly overlap with the analyses where the country of origin (the country of researcher's first publication) is considered instead. Thus, analysis of country of origin is not presented in the main text of the report.

## Table 15 Sending Countries and Regions

| | Total | Emmy Noether | ERC | Directors | Professors | RU Professors |
|---|---|---|---|---|---|---|
| ***Top-10 sending countries*** | | | | | | |
| **USA** | 18.4% | 38.1% | 35.8% | 39.2% | 28.6% | 30.0% |
| **UK** | 10.4% | 19.0% | 14.9% | 19.3% | 13.7% | 12.9% |
| **Switzerland** | 7.9% | 11.5% | 12.2% | 12.7% | 15.7% | 17.2% |
| **France** | 5.6% | 6.0% | 6.1% | 2.4% | 4.4% | 4.3% |
| **Netherlands** | 5.3% | 4.2% | 6.1% | 9.0% | 6.3% | 7.9% |
| **Italy** | 4.9% | 2.1% | 2.7% | 1.2% | 2.5% | 2.8% |
| **Austria** | 4.7% | 2.1% | 4.3% | 5.4% | 8.0% | 7.7% |
| **China** | 4.1% | 0.6% | 0.7% | 0.6% | 0.9% | 0.5% |
| **Spain** | 3.4% | 1.5% | 2.5% | 0.6% | 1.4% | 1.1% |
| **Russia** | 2.8% | 0.9% | 0.7% | 0.0% | 0.8% | 0.5% |
| ***Distribution of sending countries by region*** | | | | | | |
| **Europe** | 59.0% | 54.7% | 55.4% | 56.6% | 61.6% | 61.8% |
| **North America** | 20.5% | 41.1% | 38.7% | 39.8% | 30.7% | 32.2% |
| **Asia** | 13.3% | 2.1% | 3.8% | 3.0% | 3.9% | 3.1% |
| **South America** | 3.0% | 0.0% | 0.2% | 0.0% | 0.9% | 0.5% |
| **Africa** | 2.5% | 2.1% | 1.8% | 0.6% | 2.3% | 2.0% |
| **Oceania** | 1.5% | 0.0% | 0.2% | 0.0% | 0.7% | 0.3% |

Source: Fraunhofer ISI analysis based on Scopus data. Share of sending country/region in each critical group is calculated as the percentage of researchers who moved to Germany from that country/region compared to the overall number of researchers in the critical group.

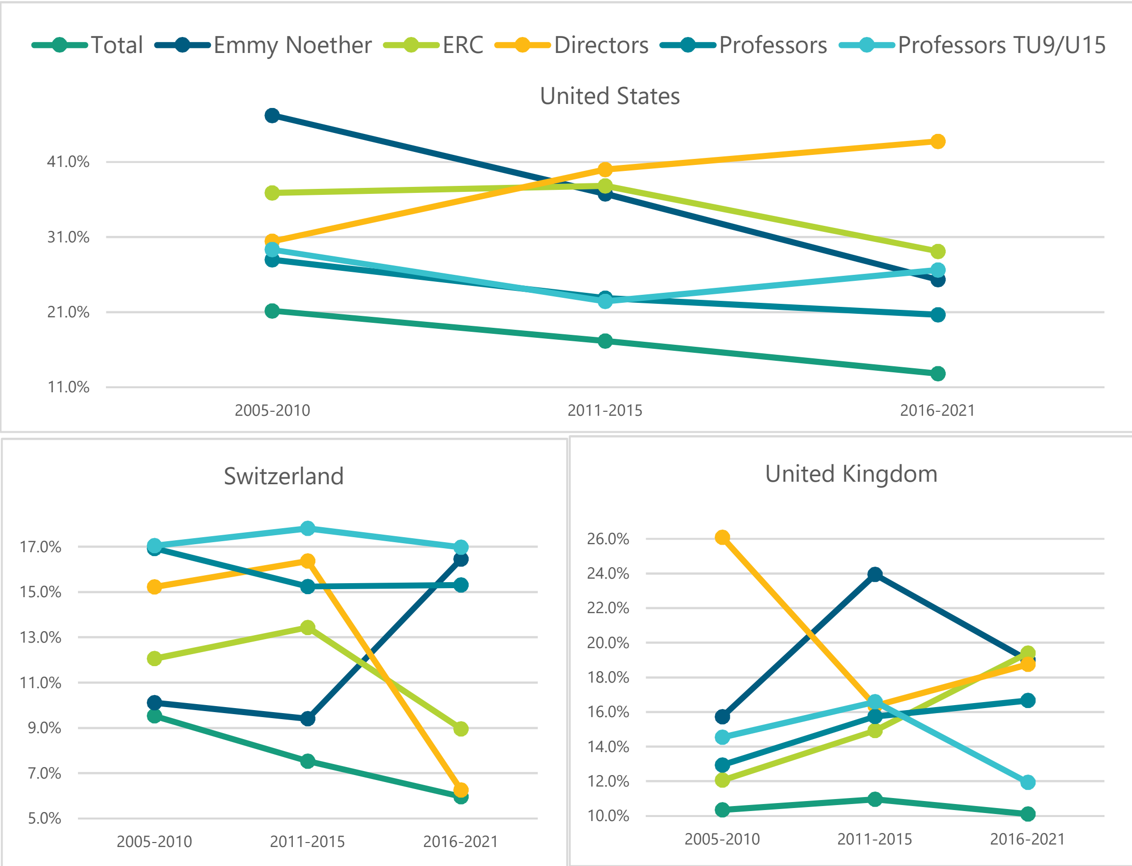


**Figure 25 Changes in Importance of sending countries over time**
Source: Fraunhofer ISI analysis based on Scopus data.

Over time, the relative importance of major sending countries underwent some change. The main trend observed for all critical career groups and in a reference dataset is the decline in the relative importance of the US as the source of talent and the relative increase of other sending countries (Figure 25). The significance of the US increased only for PRO directors in the latest time period. For example, nearly half of Emmy Noether fellows came to Germany from the US in 2005-2010, but only a quarter in 2016-2021. The significance of the UK increased for PRO directors, ERC grantees and university professors, but decreased for other critical groups in the most recent time period.

We limit the analysis of outgoing researchers to Emmy Noether awardees, ERC grantees and PRO directors, since outflow rates of university professors are under-reported in our dataset. However, as explained previously, outflow rates for the other critical career groups are also very low: 41 Emmy Noether awardees, 12 ERC grantees and 6 PRO directors left Germany. Emmy Noether awardees left to Switzerland (7 researchers), the UK (6 researchers), the US and Canada (5 researchers each). Three ERC grantees left to the US and Switzerland, two left to the UK. All PRO Directors left to the US except for one who left to Italy.

### 3.4.2 *Sending and Receiving Organisations*

A more nuanced picture is revealed in the analysis of sending and receiving organisations. There is a degree of overlap in the major sending universities among the critical groups: ETH Zurich, University of California, University of Oxford, CNRS, and University of Cambridge are present among the top-10 sending universities among the critical groups and in the reference dataset. Another four organisations - Harvard University, Massachusetts Institute of Technology, Harvard Medical School and Stanford University - are present among the top-20 sending organisations among all critical career groups and the reference dataset. Tables A3 - A6 in the Appendix contain the lists of sending organisations.

The results indicate that source organisations for critical career transitions to Germany are elite, world-leading institutions. This is a sign of high quality talent flows and high capacity of Germany to attract international talent. Researchers in critical career groups seem to be more likely to move to Germany from elite international organisations: if in the reference dataset, 11% of researchers came from the top 20 elite organisations, the share is 19% for Emmy Noether fellows, 15% for ERC grantees and PRO directors, 12% for research university professors, and the same 11% for all university professors.

Differences are revealed when groups are compared. Around a half of the top 50 sending organisations of ERC grantees and PRO directors are US universities. Most of these are highly prestigious organisations that occupy high positions in international league tables. Among them, there are a few elite organisations from other countries, such as the University of Vienna (Austria), and IEEE (Hong Kong).

In contrast, sending organisations of (research) university professors include more universities from German-speaking countries. 11 out of top 20 sending organisations of university professors are located in Austria and Switzerland, compared to 3 of PRO directors and ERC grantees. More professors also come from Dutch universities, in particular, University of Amsterdam and University of Groningen.

It is likely that the mechanisms attracting researchers to professorship positions and to ERC/director positions are different: the former seem to be elite and motivated by the logic of excellence. The latter seem to also include geographic and language factors.

## 3.5 Mechanisms and determinants of international mobility

In this section, we analyse a number of parameters characterising researchers who moved to Germany in order to gain some understanding behind the reasons and mechanisms of their transition. In particular, we ask four questions:

- How early in their career do researchers who eventually occupy critical career positions move to Germany?
- Did incomers and returnees collaborate with German organisations prior to moving?
- Do researchers who move to Germany demonstrate higher levels of scientific visibility prior to transition?
- How do researchers who move to Germany manage their affiliations?

### *3.5.1 Timing of Transition*

First, we consider the issue of transition timing. Using the data on scientific age, we infer career stage at which researchers move to Germany. Scientific age is counted from the year of researcher's first publication. Typically, scientific age under five is associated with doctoral and postdoctoral early career stages. We then associate scientific age between five and ten years with mid-career stage and researchers with scientific age of over ten are considered more senior-level researchers.

We first analyse transition timing of incoming researchers (Figure 26). In the reference dataset, the observe mobility taking place among early and mid-career researchers and declining steadily with scientific age. Nearly half of the incomers to Germany (48%) transitioned to the country at scientific age of 4 or younger. By scientific age of 10, 87% of mobility has taken place.

This distribution is similar for Emmy Noether awardees: the majority (45%) come to Germany as early-career researchers, with the peak transition at scientific age five. This is congruent with the early-career focus of the Emmy-Noether award. Perhaps the award could be the mechanism enabling the transition.

University professors also tend to transition to Germany earlier in their career: nearly 40% moved to Germany at both the early and mid-career stage. Since university professorships may require from researchers in-depth understanding of the German research system, extensive local networks and/or a *Habilitation*, in contrast to Emmy-Noether awardees, it is more likely that these researchers moved to ordinary positions in the research system and then advanced into professorships later in their career. Only a minority - around 23% - transitioned to Germany at scientific age above 10, indicating that it may be difficult for researchers from abroad to transition straight into professor positions. Such move may be easier in research universities that receive a higher share of senior-level international researchers.

In contrast, PRO directors overwhelmingly move to Germany at late stages of their career: 74% transitioned at scientific age above ten. Probably, international researchers do not 'advance through the ranks' to PRO directorships: they are more likely to be headhunted or move to Germany at senior career levels as established scientists with excellent reputation. ERC researchers also seem to move to Germany predominantly in mid- and senior career stages.

In the analysis of returnees, return rates researchers in critical groups peak in the mid- to late-career stage, at scientific age of around ten (Figure 27). Similarly to incomers, Emmy Noether returnees are more likely to be earlier in their career than other groups when they move back to Germany. The award may be the driver of many such transitions. Similarly, return timing of ERC grantees peaks in scientific age years eight and nine, which may be linked to receiving the grant. PRO directors, also similarly, mostly return to Germany later in their career

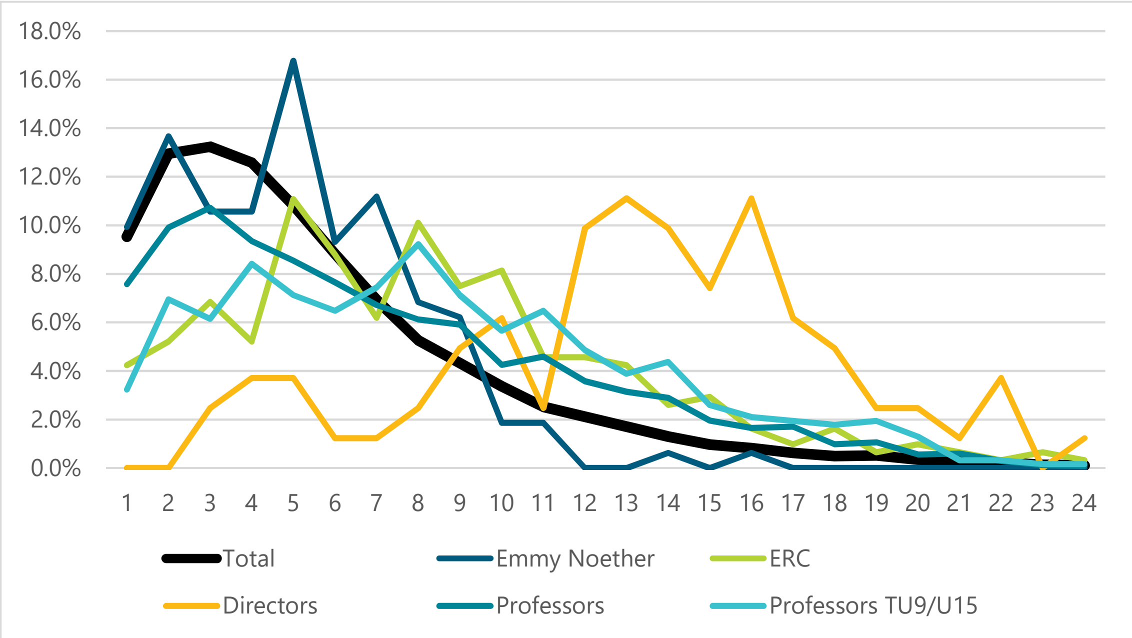


**Figure 26 Timing of transition to Germany - incomers**

Source: Fraunhofer ISI analysis based on Scopus data. X-Axis shows scientific age in the year of transition; Y-Axis shows the share of researchers in each critical group that transitioned in that year compared to the overall number of researchers in the critical group.

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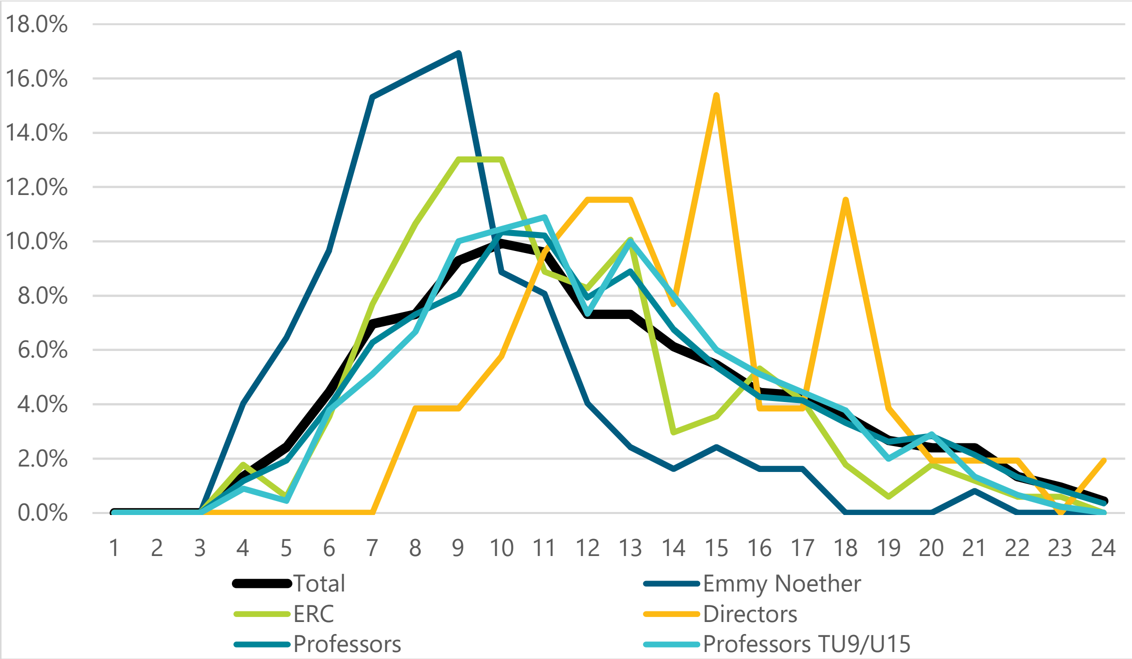


**Figure 27 Timing of transition to Germany - returnees**

Source: Fraunhofer ISI analysis based on Scopus data. X-Axis shows scientific age in the year of transition; Y-Axis shows the share of researchers in each critical group that transitioned in that year compared to the overall number of researchers in the critical group.

We also consider the timing of transition of international Emmy-Noether awardees and ERC grantees. We matched the year of the grant start date of these two researcher groups against their main country in that year. The main country was calculated as the country reported in the majority of a researcher's publications in that year. If the researcher did not publish in the award year, the country of the previous year was considered[12].

The results show a nearly even split between grant holders that were inside and outside Germany in the year they received the award. A slightly higher share of Emmy Noether awardees were already in Germany (54.1%) than outside (45.9%), contrasted with the slightly higher share of ERC grantees that were outside Germany in the award year (57.7%) than inside (42.3%). Thus, ERC grants seem to have a slightly higher potential to attract international researchers to Germany from abroad, while international Emmy Noether awardees tend to come to Germany first and then receive the award. The shares are consistent when incomers and returnees are considered separately. A highlight is that around 61% of returnee ERC grant holders were outside Germany in the year they received the award, indicating a higher importance of the ERC grant in attracting returnees back to Germany.

[12] The two data points (grant award year and publication year) have a time lag with respect to the researcher's location; in the analysis, we assume that the lag is comparable.

### 3.5.2 Do researchers collaborate with Germany prior to transition?

Another consideration is that a transition to Germany may be underpinned by ongoing collaboration with a German organisation. Social capital accumulated via sustained exchanges that entail research collaboration could help international researchers gain an understanding of the German system and be recognised in the German research community for their achievements.

In this analysis, we check two indicators: (i) whether incoming researchers co-published articles with colleagues based in Germany at any point in their career prior to moving; and (ii) whether incoming researchers co-published articles with colleagues based in Germany in five years prior to moving. For each indicator, researcher is assigned to the 'published' group if they had at least one co-publication with a co-author based in Germany.

The results are presented in Table 16 as the share of authors with co-publications with co-authors in Germany. Overall, a higher share of researchers in critical groups co-published with colleagues in Germany prior to their mobility: the lowest value is around 37% for university professors and the highest is over 66% for PRO directors compared to around a third of researchers in the reference dataset.

**Table 16 Mobile researchers with co-authors in Germany prior to moving**

| | Total | Emmy Noether | ERC | Directors | Professors | RU Professors |
|---|---|---|---|---|---|---|
| **All Years** | 33.8% | 40.2% | 49.6% | 66.4% | 38.9% | 46.6% |
| **Five Years** | 33.0% | 38.7% | 45.9% | 59.8% | 37.3% | 44.0% |

Source: Fraunhofer ISI analysis based on Scopus data. Shares are calculated as a percentage of researchers in the critical group with co-publications in Germany compared to the total number of incomers and returnees in that critical group.

The differences between co-publications with Germany in the five years leading to transition and co-publications with Germany overall are relatively small for all researcher groups. This means that the majority of incoming researchers either build or reactivate their collaborations with Germany-based colleagues in the years before their move to Germany. One exception here are PRO directors: a higher share have co-publications with Germany more than five years prior to their move there. Since we know that most directors move to Germany in late career stages, they may not research active anymore at that stage. Alternatively, they may be headhunted to take up prestigious directorship positions. Therefore, for them, recent research collaboration with Germany may be less important.

### 3.5.3 Do researchers with high scientific visibility come to Germany?

Another relevant dimension is to consider whether researchers who move to Germany are already high-potential scientists with excellent scientific visibility, even when they move before they advance to critical career positions, or they develop their potential already in Germany. We analyse mean normalised citation rate of researchers incoming to Germany compared to immobile researchers. We analyse this data per year of scientific age to account for the influence of accumulated citations.

The results are available on Figure 28. Overall, incoming researchers have higher citation rates at the time of coming to Germany compared to their immobile peers. The difference is stable at around three extra citations accumulated by mobile researchers at all values of scientific age. The gap widens after scientific age of 8, indicating that researchers who move to Germany in mid- and senior career stages tend to have higher scientific visibility.

These differences are similar for (research) university professors, who demonstrate higher scientific visibility at the time of transition to Germany than their immobile colleagues (although the difference is on average 1.84 citations for professors and 2.4 citations for research university professors, lower than in the reference dataset). Thus, international researchers who move to Germany and become professors do not have significantly higher scientific visibility in terms of citation rate. Whether they move to Germany in early career stages and advance to professorship positions afterwards, or they make professor-to-professor moves later in the career does not play a role.

International PRO directors have significantly higher scientific visibility than their immobile colleagues do. The trends in this data need to be interpreted carefully due to the low number of observations in each scientific age bracket. Since nearly all incomer directors moved to Germany at scientific age of 10 or more, we focus on this time period. There, international directors have 2.7 times more citations than immobile directors (19.55 vs 7.17). The explanation for this difference is likely related to the difference channels through which Germany-based and international researchers gain director positions. It is likely that international PRO directors are 'star scientists' who are recruited specifically to assume these leadership positions, potentially for the first time in their career at that level. In contrast, while immobile directors may also have significantly high scientific visibility, the fact that they may have spent a longer period in a director role already could imply that they have invested substantive time in leadership and management tasks rather than research proper. Hence, the gap in citations between international and immobile directors will most likely tells us more about career progress than about differences in research performance. What it does confirm, in a positive sense, is that internationally recruited directors indeed bring in substantive potential in to the German science system.

Emmy-Noether awardees and ERC grantees do not demonstrate the same clear-cut differences in scientific visibility between incoming and immobile researchers compared to other critical groups. In fact, international Emmy-Noether awardees have fewer citations than immobile researchers do at scientific age of two and four. Similarly, incoming ERC grantees do not differ significantly from their immobile counterparts except in scientific age four, five and eight. These results show that these awards target high-potential researchers regardless of whether they are in Germany or abroad. In the case of Emmy-Noether fellowship, this indicates that the award does not discriminate against researchers based on their location. In the case of the ERC grant, this indicates that applicants from abroad who choose Germany as the grant location country match the scientific visibility of successful applicants already located in Germany.

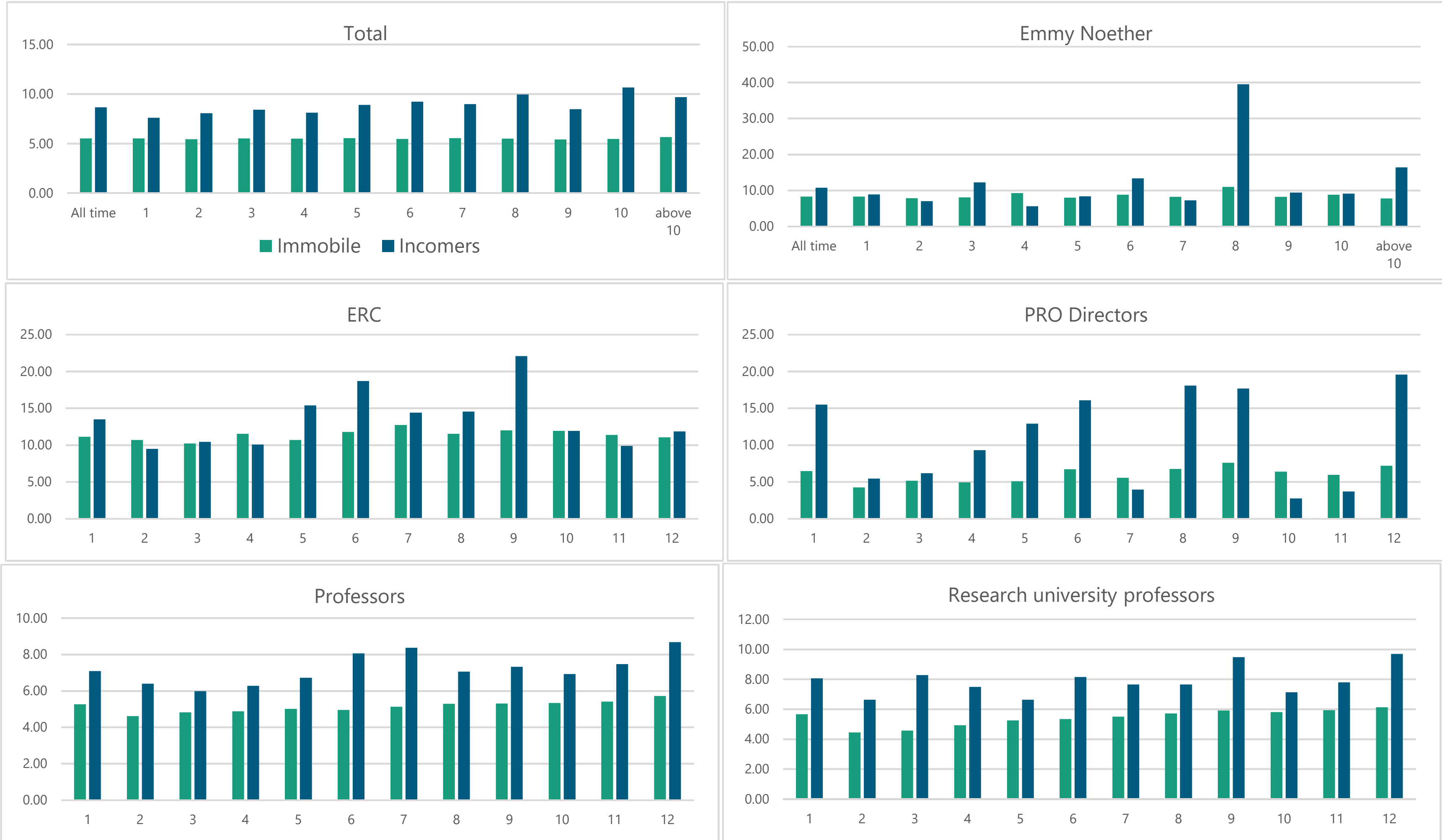


**Figure 4 Mean normalised citation rates of mobile and immobile researches in critical groups**

Source: Fraunhofer ISI analysis based on Scopus data. X-Axis shows citation number. Y-Axis shows scientific age at the time of transition to Germany for incoming researchers and average citation rate in that scientific age of immobile researchers.

### *3.5.4 How do incomers manage affiliations?*

Since our methodology focuses on gaining and holding affiliations in order to track mobility, we can examine how mobile researchers manage affiliations in their publications. Typically, it is assumed that an author's first affiliation on a publication should indicate the location where research was performed, while secondary affiliations relate to other employment arrangements. Thus, we analyse whether and how incomers and returnees report their German affiliations, in particular, we examine (i) whether they maintain one or multiple affiliations, and (ii) whether they report Germany as primary or secondary affiliation. We only consider researchers with multiple international affiliations here. Germany is counted the main affiliation country if a German address is listed as first affiliation on the majority of their publications after moving there. Since in our approach, the transition takes at least 3 years, we analyse researchers' reporting behaviour in the first and in the last year of transition.

The results are depicted on Figure 29 and Figure 30. In the reference dataset, the majority of researchers have only one affiliation and most incomers change their main affiliation to Germany already in the first year of transition (63%). Fewer returnees report Germany as the only country (43%). By the third year, nearly all incomers (93%) and returnees (82%) list Germany as the only or primary affiliation. In the critical groups of (research) university professors, we observe a similar trend. Affiliation reporting behaviours of ERC grantees and PRO directors demonstrate a difference. In both groups, a significantly lower share of researchers reported Germany as the main affiliation country in the first year, however, by the third year of transition Germany was reported as the main country by nearly all researchers in these groups as well.

These findings signify that types of transitions, it takes time for researchers to release publications with results from their previous workplace, and therefore some years pass until Germany is clearly visible as the main country where they do research.

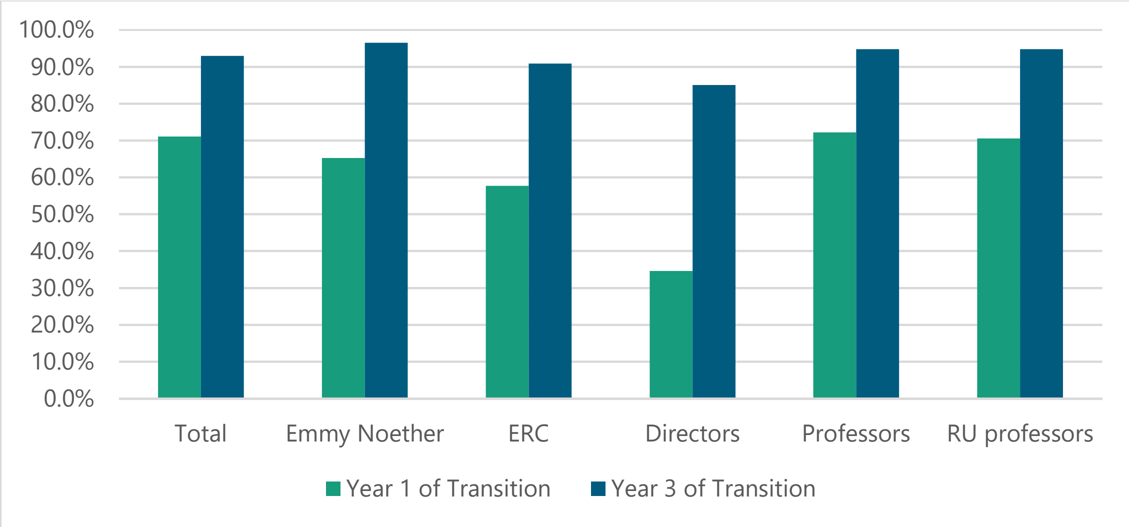


**Figure 29 Germany as the main or only affiliation country - incomers**

Source: Fraunhofer ISI analysis based on Scopus data. The share of researchers in each critical group is calculated as a percentage of researchers with that affiliation type compared to all incomers in that group.

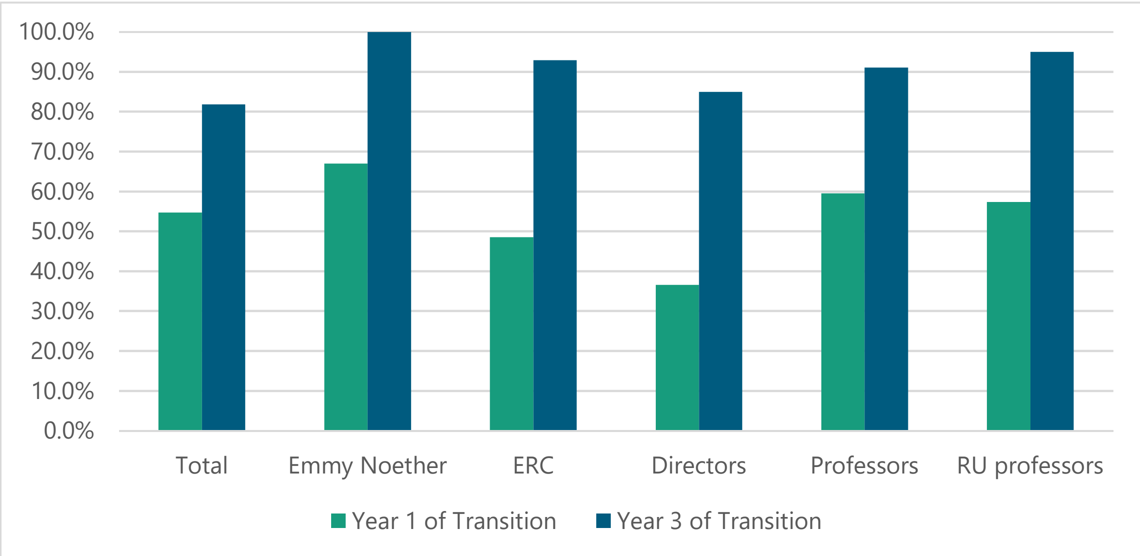


**Figure 30 Germany as the main or only affiliation country - returnees**

Source: Fraunhofer ISI analysis based on Scopus data. The share of researchers in each critical group is calculated as a percentage of researchers with that affiliation type compared to all returnees in in that group.

## 3.6 Conclusions and Recommendations

Our results show that researchers in critical career positions constitute a small, but important minority among scientists based in Germany. Their characteristics differ significantly from other researchers in the dataset. There are also significant differences between these critical groups.

We found, in general, higher representation of international researchers (incomers and returnees) in critical career positions than overall among researchers working in Germany. Researchers in critical positions also had higher degree of international exposure compared to researchers in the reference dataset. Although overall international mobility rates in the reference dataset are increasing, the rates at which international researchers came to Germany have decreased in the latest time period.

We distinguish three mobility channels to Germany for researchers in critical positions. First is grant-linked mobility: it is likely that international ERC grantees and Emmy-Noether awardees use grants to move to Germany. Germany demonstrates good retaining capacity for ERC grantees and Emmy Noether awardees. Although some of them may maintain secondary appointments abroad, the majority stay in Germany. Grants also provide mobility opportunities for researchers from the fields of science, which are typically not very mobile (e.g. medical).

The second channel is elite researcher mobility of PRO directors. Though only a minority of directors are international researchers, they appear as 'star scientists' with very high scientific visibility who are headhunted to take up leadership positions in German PROs. PRO directorships are critical positions with the most power in the German research system. They are the least inclusive type of position with the lowest share of women and international researchers, most of whom have German or Austrian origin.

The third channel is 'ordinary mobility' of (research) university professors, which is consistent with international mobility patterns in the reference dataset. It looks like the system nurtures international researchers who later become professors in Germany. Instead of recruiting rising stars, Germany attracts future professors when they do not differ much in terms of scientific visibility from their peers. These researchers develop their potential already in Germany at early career stages and advance to professorships later in their career. Such pattern means that international university professors in Germany are deeply familiar with the system, because they enter the system at relatively early stages of their career and advance through the ranks. On the other hand, if the window of opportunity for international researchers to enter the German system is open mostly in early career stages, there are likely barriers in place for high potential mid- and senior career researchers to move to professorship positions in German universities.

The majority of international researchers working in Germany are of German origin - either by training, or based on their name. Although the trend is towards decrease, the German research system does not seem to be as open to international researchers without connections there. There may be structural barriers in the system, such as the need to teach in German - evidenced, for example, by the prevalence of Austrian and Swiss German universities in among sending organisations for professors.

Based on these summary conclusions, we propose the following recommendations:

- Grants are the mechanism for international researchers to enter the German system. More understanding is required to analyse how grant holders stay in Germany after the end of the award and how these transitions could be better supported. Further opportunities for mid-career and senior researchers could be created to facilitate transitions to professorial positions in higher education organisations.
- Strengthen linkages and exchanges with Switzerland and Austria, in terms of mutual training and German language scientific exchanges. There are many possibilities for productive mutual exchanges within the German-speaking region. Focus further on other high-potential productive exchanges, especially within the European region. More understanding is needed about how Germany can be made an attractive place for research beyond opportunities provided by prestigious grants like Emmy Noether.
- Create international mobility opportunities for researchers advancing through the ranks in the German higher education sector. If professors do not have international mobility experience, they are not likely to encourage international mobility of their staff and therefore, low rates of mobility will persist.
- Create opportunities for international researchers to transition to mid- and senior-career positions in the German research system. Since we did not find the 'double peak' of international professorial-level mobility, questions can be raised about why international professors move to Germany less and which aspects of recruitment and promotion processes should be targeted in reform.
- Continue to implement measures to advance gender equality in the German research system, with the focus on critical positions in the research system. Continue to implement measures to promote international mobility opportunities among women. This will likely also lead to increase in female researchers in critical positions in the research system.
- Need for further research on critical groups and the factors facilitating international researchers' advancement to these positions. In addition, research on what international researchers in critical positions in sub-systems of the German system (universities, universities of applied sciences, PROs, others...) do differently compared to immobile researchers, what effect their increased representation will likely have on the German research system.

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# 5 Appendix

**Table A1. Distribution of mobile inventors by WIPO-5 technology classes**

| | Class Name | Total | Immobile | Inflows | Outflows |
|---|---|---|---|---|---|
| **AU** | Chemistry | 16962 | 13423 | 2438 | 2515 |
| **AU** | Electrical engineering | 14502 | 10856 | 2449 | 2607 |
| **AU** | Instruments | 15042 | 11597 | 2358 | 2495 |
| **AU** | Mechanical engineering | 14270 | 11103 | 2173 | 2328 |
| **AU** | Other fields | 10267 | 8089 | 1515 | 1628 |
| **CA** | Chemistry | 29730 | 23930 | 3737 | 4240 |
| **CA** | Electrical engineering | 33352 | 26869 | 4048 | 4673 |
| **CA** | Instruments | 27507 | 21766 | 3746 | 4177 |
| **CA** | Mechanical engineering | 24806 | 19756 | 3358 | 3681 |
| **CA** | Other fields | 12986 | 10004 | 2050 | 2290 |
| **CH** | Chemistry | 23733 | 20210 | 2555 | 2096 |
| **CH** | Electrical engineering | 17212 | 14356 | 2018 | 1810 |
| **CH** | Instruments | 22200 | 19123 | 2222 | 1904 |
| **CH** | Mechanical engineering | 21516 | 18688 | 2027 | 1828 |
| **CH** | Other fields | 9406 | 7952 | 1103 | 954 |
| **DE** | Chemistry | 134146 | 122165 | 8311 | 8828 |
| **DE** | Electrical engineering | 130010 | 117484 | 8645 | 9153 |
| **DE** | Instruments | 124825 | 112904 | 8187 | 8884 |
| **DE** | Mechanical engineering | 186981 | 173978 | 9041 | 9408 |
| **DE** | Other fields | 61748 | 55375 | 4687 | 4950 |
| **DK** | Chemistry | 11599 | 10401 | 823 | 840 |
| **DK** | Electrical engineering | 7582 | 6535 | 712 | 758 |
| **DK** | Instruments | 8537 | 7463 | 713 | 783 |
| **DK** | Mechanical engineering | 10119 | 9061 | 750 | 755 |
| **DK** | Other fields | 4489 | 3899 | 433 | 449 |
| **FR** | Chemistry | 72621 | 67220 | 3294 | 3910 |
| **FR** | Electrical engineering | 67712 | 62218 | 3381 | 3913 |
| **FR** | Instruments | 60064 | 54985 | 3137 | 3679 |
| **FR** | Mechanical engineering | 78919 | 73761 | 3182 | 3770 |
| **FR** | Other fields | 27476 | 24931 | 1633 | 1904 |
| **GB** | Chemistry | 57007 | 44684 | 8248 | 9301 |
| **GB** | Electrical engineering | 53870 | 40099 | 9181 | 10133 |
| **GB** | Instruments | 49352 | 36927 | 8464 | 9331 |
| **GB** | Mechanical engineering | 48085 | 36770 | 7802 | 8535 |
| **GB** | Other fields | 26356 | 19174 | 5076 | 5636 |
| **JP** | Chemistry | 271849 | 267724 | 2430 | 3231 |
| **JP** | Electrical engineering | 319405 | 314752 | 2704 | 3590 |
| **JP** | Instruments | 235700 | 231752 | 2403 | 3047 |
| **JP** | Mechanical engineering | 277825 | 274083 | 2229 | 2962 |
| **JP** | Other fields | 70110 | 68465 | 1019 | 1362 |

| | | | | | |
|---|---|---|---|---|---|
| **KR** | Chemistry | 64809 | 62310 | 1848 | 1464 |
| **KR** | Electrical engineering | 100670 | 97650 | 2139 | 1812 |
| **KR** | Instruments | 54529 | 52280 | 1686 | 1337 |
| **KR** | Mechanical engineering | 50457 | 48657 | 1395 | 1077 |
| **KR** | Other fields | 28566 | 27496 | 867 | 669 |
| **NL** | Chemistry | 29319 | 25780 | 2475 | 2167 |
| **NL** | Electrical engineering | 25960 | 20956 | 3391 | 3092 |
| **NL** | Instruments | 25868 | 21427 | 3158 | 2648 |
| **NL** | Mechanical engineering | 24709 | 21767 | 2106 | 1797 |
| **NL** | Other fields | 10995 | 9482 | 1114 | 944 |
| **SE** | Chemistry | 16318 | 14586 | 1129 | 1266 |
| **SE** | Electrical engineering | 19738 | 17619 | 1428 | 1416 |
| **SE** | Instruments | 16426 | 14694 | 1178 | 1228 |
| **SE** | Mechanical engineering | 20964 | 19310 | 1137 | 1176 |
| **SE** | Other fields | 7236 | 6383 | 625 | 626 |
| **US** | Chemistry | 394420 | 351199 | 28704 | 31156 |
| **US** | Electrical engineering | 460929 | 412188 | 32568 | 33562 |
| **US** | Instruments | 373107 | 330836 | 28553 | 30172 |
| **US** | Mechanical engineering | 301951 | 265884 | 24822 | 26093 |
| **US** | Other fields | 138340 | 117739 | 14695 | 15359 |

**Table A2 Share of international co-patents in Germany by WIPO-35 technology classes**

| | International Co-Patents | Share Of International Co-Patents |
|---|---|---|
| **Analysis Of Biological Materials** | 3072 | 30.66% |
| **Audio-Visual Technology** | 3650 | 24.68% |
| **Basic Communication Processes** | 1266 | 26.09% |
| **Basic Materials Chemistry** | 9732 | 33.03% |
| **Biotechnology** | 8988 | 36.95% |
| **Chemical Engineering** | 6260 | 25.37% |
| **Civil Engineering** | 3443 | 19.36% |
| **Computer Technology** | 9297 | 29.47% |
| **Control** | 3286 | 20.03% |
| **Digital Communication** | 10008 | 37.69% |
| **Electrical Machinery, Apparatus, Energy** | 11129 | 21.67% |
| **Engines, Pumps, Turbines** | 5757 | 19.89% |
| **Environmental Technology** | 2654 | 23.29% |
| **Food Chemistry** | 2174 | 38.88% |
| **Furniture, Games** | 2015 | 20.02% |
| **Handling** | 3525 | 18.33% |
| **It Methods For Management** | 1594 | 28.26% |
| **Machine Tools** | 3558 | 17.22% |

| | | |
|---|---|---|
| **Macromolecular Chemistry, Polymers** | 7172 | 33.31% |
| **Materials, Metallurgy** | 4612 | 25.98% |
| **Measurement** | 9295 | 22.91% |
| **Mechanical Elements** | 5666 | 16.61% |
| **Medical Technology** | 10234 | 31.99% |
| **Micro-Structural And Nano-Technology** | 541 | 30.99% |
| **Optics** | 3870 | 25.25% |
| **Organic Fine Chemistry** | 12765 | 36.53% |
| **Other Consumer Goods** | 2680 | 20.20% |
| **Other Special Machines** | 6081 | 21.95% |
| **Pharmaceuticals** | 13421 | 42.84% |
| **Semiconductors** | 4985 | 27.27% |
| **Surface Technology, Coating** | 4316 | 25.80% |
| **Telecommunications** | 3846 | 27.72% |
| **Textile And Paper Machines** | 3117 | 23.34% |
| **Thermal Processes And Apparatus** | 2696 | 20.62% |
| **Transport** | 8175 | 17.19% |

**Table A3 Sending organisations - Emmy Noether Awardees**

**Emmy Noether Awardees**

| Number | Country | Name |
|---|---|---|
| **25** | CH | ETH Zurich |
| **22** | US | University of California |
| **21** | GB | University of Oxford |
| **16** | FR | CNRS |
| **16** | US | Massachusetts Institute of Technology |
| **14** | GB | University of Cambridge |
| **10** | GB | Imperial College |
| **9** | US | Harvard Medical School |
| **8** | CH | University of Zurich |
| **8** | CH | University of Basel |
| **7** | CA | University of Toronto |
| **7** | GB | University of Edinburgh |
| **6** | US | Stanford University |
| **6** | US | Yale University |
| **5** | US | Howard Hughes Medical Institute |
| **5** | NL | Leiden University |
| **5** | NL | Radboud University |

**Table A4 Sending organisations - ERC grantees**

| Number | ERC Grantees<br>Country | Name |
|---|---|---|
| **48** | CH | ETH Zurich |
| **46** | US | University of California |
| **29** | GB | University of Oxford |
| **28** | FR | CNRS |
| **27** | GB | University of Cambridge |
| **23** | US | Harvard University |
| **21** | US | Stanford University |
| **19** | US | Howard Hughes Medical Institute |
| **17** | US | Massachusetts Institute of Technology |
| **17** | US | California Institute of Technology |
| **16** | GB | University College London |
| **14** | US | Harvard Medical School |
| **14** | CH | EPFL |
| **12** | US | Lawrence Berkeley National Laboratory |
| **12** | AT | University of Vienna |
| **12** | GB | Imperial College |
| **11** | CH | University of Zurich |

**Table A5 Sending organisations - PRO Directors**

| Number | PRO Directors<br>Country | Name |
|---|---|---|
| **29** | US | University of California |
| **14** | GB | University of Oxford |
| **10** | GB | University College London |
| **9** | CH | ETH Zurich |
| **9** | FR | CNRS |
| **9** | US | Massachusetts Institute of Technology |
| **8** | US | Harvard University |
| **7** | HK | IEEE |
| **7** | GB | University of Cambridge |
| **7** | US | Howard Hughes Medical Institute |
| **6** | US | Columbia University |
| **6** | US | California Institute of Technology |
| **5** | US | Lawrence Berkeley National Laboratory |
| **5** | US | Princeton University |
| **5** | US | Harvard Medical School |
| **5** | US | Stanford University |
| **5** | US | Cornell University |

**Table A6 Sending organisations - University Professors**

| University Professors | | |
|---|---|---|
| **Number** | **Country** | **Name** |
| **283** | CH | ETH Zurich |
| **221** | US | University of California |
| **192** | CH | University of Zurich |
| **131** | GB | University of Oxford |
| **128** | FR | CNRS |
| **124** | AT | University of Vienna |
| **106** | CH | University of Basel |
| **97** | CH | University of Bern |
| **91** | GB | University of Cambridge |
| **80** | US | Harvard Medical School |
| **77** | US | Stanford University |
| **75** | AT | University of Innsbruck |
| **74** | US | Massachusetts Institute of Technology |
| **70** | US | Harvard University |
| **65** | GB | University College London |
| **61** | AT | Vienna University of Technology |
| **58** | NL | University of Amsterdam |