// NO.23-004 | 02/2023

DISCUSSION PAPER

// JORDAN BISSET, DIRK CZARNITZKI, AND THORSTEN DOHERR

High Skilled Mobility Under Uncertainty

Leibniz Association

ZEW

High Skilled Mobility Under Uncertainty*

Jordan Bisset † Dirk Czarnitzki‡ Thorsten Doherr §

December 2022

Abstract

Previous work suggests a general uncertainty surrounding the migration process acts as a barrier to outmigration. In this paper, we argue that this barrier is exacerbated when relative economic policy uncertainty is higher in the target country and mitigated when relatively higher in the origin country. We use a novel inventor career panel to observe inventor migration from 12 European countries between 1997 and 2012 and test the premise that a higher relative uncertainty in the origin country raises the probability of inventor outmigration. Our results suggest a 1 standard deviation increase in the relative uncertainty of the home country is associated with a near 20% increase in the probability of inventor outmigration. The relationship is highly non-linear, with relative uncertainty values in the top centile leading to an increase of over 70%. The observed effects can be amplified or dampened by inventor specific characteristics, as would be expected given the prior art.

Keywords: Outmigration, Uncertainty, Human Capital, Inventors

JEL codes: J61, O15

---

*Czarnitzki gratefully acknowledges financial support by the Research Foundation Flanders (FWO, grant number G0C5921N). An earlier version of this paper was circulated under the title 'Policy Uncertainty and Inventor Mobility'.

†Faculty of Economics and Business, KU Leuven. Contact: jordan.bisset@kuleuven.be (**Corresponding Author**)

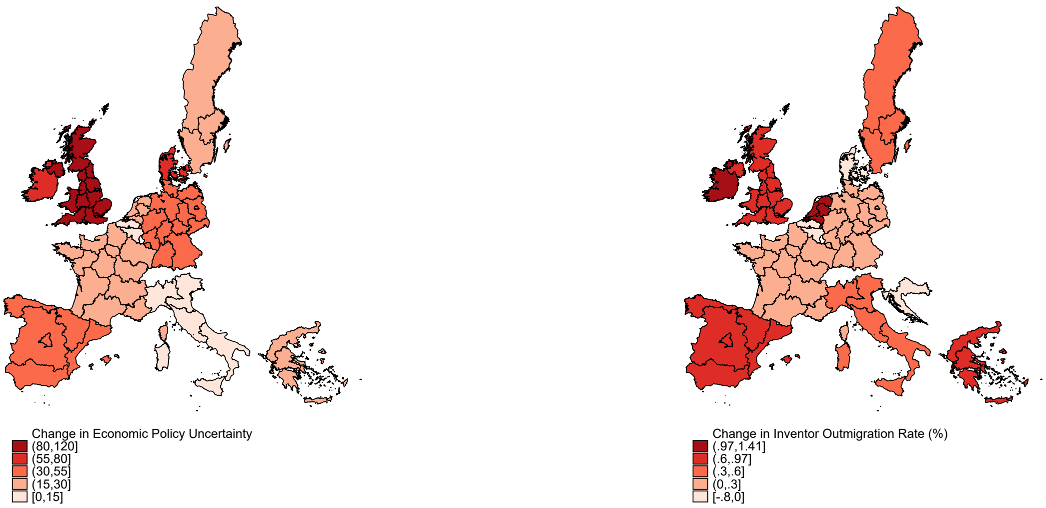
‡Faculty of Economics and Business, KU Leuven; Center for R&D Monitoring at KU Leuven, and Centre for European Economic Research (ZEW). Contact: dirk.czarnitzki@kuleuven.be

§Centre for European Economic Research (ZEW). Contact: thorsten.doherr@zew.de

1 Introduction

In recent decades uncertainty has surged globally. In Europe Economic Policy Uncertainty increased almost 61% between 2001 and 2011 (Baker et al., 2016). Over the same period Europe has seen a notable increase in outmigration.[1] At a more granular level, the below maps (Figure 1) show that countries which experienced larger increases in uncertainty generally experienced larger increases in the inventor outmigration over the same period. The potential relationship between uncertainty and outmigration has largely been ignored. However, there are large distinct streams of literature which provide evidence of behavioural changes under uncertainty, and on the determinants of outmigration. Given the role of migration in facilitating international labour flows and powering demographic change, it is important to investigate potential determinants of outmigration.

Figure 1: Heat Maps



(a) Uncertainty Change Map **(b)** Inventor Outmigration Map

Figure (a) illustrates the change in the economic policy uncertainty level (Baker et al., 2016) between 2001 and 2011. Figure (b) illustrated the change in the inventor emigration rate across the same time frame (2001 - 2011). The outmigration rate is calculated based on data obtained from Doherr (2021). In both cases the map contains only our sample countries: Belgium, Croatia, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and United Kingdom. The change in each variable is split into five bins. The bin corresponding to the largest increase is shaded the darkest red and the bin corresponding the smallest increase (or decrease) is shaded the faintest red.

[1]Based on information from the Eurostat emigration database. Available here: `https://ec.europa.eu/eurostat/databrowser/view/migr_emi2/default/table?lang=en`

Our study contributes to this literature through evidencing the role of uncertainty as a determinant of outmigration for the high-skilled. The current extensive literature on migration classifies such determinants as push or pull factors. Here we consider uncertainty as a country level push factor. Other discussed push factors include climate change (Mullins and Bharadwaj, 2021), corruption (Cooray and Schneider, 2016) and exposure to higher tax brackets. The latter being shown to be particularly influential to the location choices of high-skilled individuals. Football stars (Kleven et al., 2013), high earning expats (Kleven et al., 2014), scientists (Moretti and Wilson, 2017) and inventors (Akcigit et al., 2016) have all been found to choose location in order to avoid higher tax burdens. Pull factors such as individual ability and network or cohort effects (Beine et al., 2011; Hanson and McIntosh, 2010) can be influential in providing stronger opportunities for the migrant in the destination country or allowing the individual to benefit from selective immigration policies. Relatedly, individuals of a higher ability may self select into migration due to expectations of a higher income (Kennan and Walker, 2011) or higher reward to skill (Grogger and Hanson, 2011) in the destination country.

However, migration can have highly skewed payoffs (Tunali, 2000) which are difficult to evaluate ex-ante. The difficulty in predicting the payoffs of migration has been highlighted by studies which emphasise the role of risk in the migration decision. This stream of studies often utilizes self reported risk preferences from survey data in order to test the role of risk aversion in migration. Gibson and McKenzie (2011) survey high skilled individuals from Oceania and find risk preferences to be a stronger migration determinant than income. Jaeger et al. (2010) exploit German survey data and document a lower likelihood to migrate in risk averse individuals. Studies using non-survey data are even more sparse. Goldbach and Schlüter (2018) and Hao et al. (2016) offer some empirical validation that risk preferences can be more a influential migration determinant than other individual level factors such as ability or international networks.

Our setup builds on the risk literature, and the more general literature on country level push factors in migration. Our approach differs from the prior literature in two key respects.

First, we consider the probability of various payoffs to be unknown to the inventor at the point of the outmigration decision. Therefore the risk faced in outmigration would be better captured as uncertainty, per the seminal distinction of Knight (1921). We exploit recent developments in measuring uncertainty (Baker et al., 2016) which provides variation in uncertainty across both countries and time to allow us to test the hypothesis that the national uncertainty of both the origin and destination country can influence the individual migration decision.

Second, the issue of payoffs being more difficult to determine in outmigration compared to remaining in the origin country, discussed in the risk preference literature, is captured by a baseline level of uncertainty that is present for all inventors in our setup. This generally refers to uncertainty surrounding the migration process. The primary contribution of our framework is to introduce the relative uncertainty of the origin country compared to the destination country. This then either exacerbates the issue of uncertainty in the migration decision when uncertainty is higher in the target country or reduces the importance of uncertainty in the migration decision, by introducing the difficulty in forecasting future outcomes to the origin country, when uncertainty is higher in the origin country.

We then estimate the role of the relative uncertainty of the origin country, compared to the set of possible destination countries, on the inventor level outmigration decision. We are able to estimate the effects of relative uncertainty as a country level push factor through controlling for much of the inventor level pull factors that could likewise influence the outmigration decision. This is done through constructing a novel inventor level career panel.

Our inventor career panel identifies an inventor's country of residence each time they file a patent at the European Patent Office, allowing us to follow the location of individual inventors throughout our sample window. Through this we can identify any outmigration of individual inventors and observe time variant characteristics of individual inventors which could affect their propensity to migrate. As noted earlier prior studies highlight both the role of individual level factors in the migration decision and aspects of the destination country which encourage the individual to relocate there. For instance, Kennan and Walker (2011) model the migration decision as a job search problem whereby the individual searches for the location where they expect to receive the highest return for their skill.

In our setting technological opportunity varying across countries could provide inventors with higher rewards to their expertise in certain locations. To deal with this we construct an inventor-country specific measure of technological opportunity. This takes the share of patents filed in the inventor's specific field of expertise in their origin country relative to the possible destination countries.[2] Under the argument that a higher share of total innovation in the inventor's area of expertise in the origin country (compared to abroad) provides better prospects for employment or career progression, and vice versa. We also exploit time varying information on inventors' patent stock, citations per patent and foreign collaborators to account for other potential inventor level pull factors. Such as ability or networks (Beine et al., 2011).

While controlling for factors suggested in prior studies, our results unanimously suggest relative uncertainty is a determinant of outmigration. We find a 13.73-20.94% increase in the probability of inventor outmigration when the relative uncertainty of the origin country increases by 1 standard deviation. We find evidence of substantial heterogeneity in our results. Estimations of the effect of various percentile bins of relative uncertainty on inventor outmigration suggests the effect is insignificant outside the top quartile. Within the top quartile, we find an 23.2% increase in the probability of inventor outmigration for relative uncertainty values between the 75th and 95th percentile. Relative uncertainty values in the top centile are associated with an 77.32% increase in the probability of inventor outmigration.

[2]See section 2.4 for a full explanation.

Allowing for the relationship between relative uncertainty and outmigration to depend on inventor characteristics provides further evidence of heterogeneity. A higher reward to skill in the origin country dampens the increase in probability of outmigration under uncertainty while an existing network of collaborators abroad seems to amplify the effect of relative uncertainty on outmigration.

In all, our results offer novel evidence of a new determinant of outmigration: relative uncertainty. We show our results are robust to alternative move timing assumptions, conditioning on previous period uncertainty and placebo tests. Our results remain impactful at the aggregate level. In a simple illustrative exercise we show that a transient increase in the relative uncertainty of the origin country could lead to a significant amount of lost invention through additional inventor outmigration.

The remainder of the paper is structured as follows. Section II introduces the data and describes our approach to identify variation in inventor level outmigration and country level uncertainty. Section III presents our main estimation framework and results. Section IV explores potential non-linearity and heterogeneity in our results, and tests for robustness. Section V contains a simple policy exercise to frame our results at the aggregate level. Section VI concludes.

2 Data

2.1 Inventor Career Panel

We construct an inventor career panel through name disambiguation. Starting from the raw patent data of the European Patent Office we use a text mining algorithm based on names and addresses of inventors, patent applications, and invention characteristics (such as technology fields and citation patterns) (Doherr, 2021).[3] This gives an initial sample of 2,597,650 inventor careers between 1980 and 2015.

[3]See Doherr (2021) for more details.

In order to use the panel to identify migration under uncertainty we impose the following conditions. We remove 14,402 inventor careers because they at some point take part in a "temporary" migration.[4] Temporary migrations are defined if an inventor migrates to a country which they have had designated as their location on a patent in the prior 4 years e.g. any country which they have had a visible return migration from in the previous 4 years. This reduces our sample to 2,583,248 inventor careers.

Next we isolate our scope to countries for which we have uncertainty data. This imposes the restriction that the inventor is located within our sample countries: Germany, France, United Kingdom, Italy, Netherlands, Spain, Sweden, Denmark, Ireland, Belgium, Croatia and Greece. Leaving 762,526 distinct inventor careers. This is then reduced to 620,289 inventor careers when we isolate our sample to inventors active between 1997 and 2012. Prior to 1997 uncertainty data is available for very few of our countries of interest. And as of 2013 our patent based inventor panel becomes increasingly afflicted with a truncation issue (Hall et al., 2001) as we move towards the end date of the data set (2015).

Finally, we remove inventors who are only observed once across our sample period. This ensures we can identify the location of all inventors at at least two points in time throughout our sample window.[5] This leaves us with 235,274 inventor careers or a total of 1,545,539 inventor-year observations. Figure 2 shows the distribution of inventor careers by the number of times of the inventor is observed in our sample period. Each possible observation count (2-16 times) forms between 2.5 and 13% of inventor careers. There is a general reduction in inventors as we move towards more frequent career observations albeit with a spike at 16 observations for the prolific inventors who are observed every year in our sample. This is to be expected given

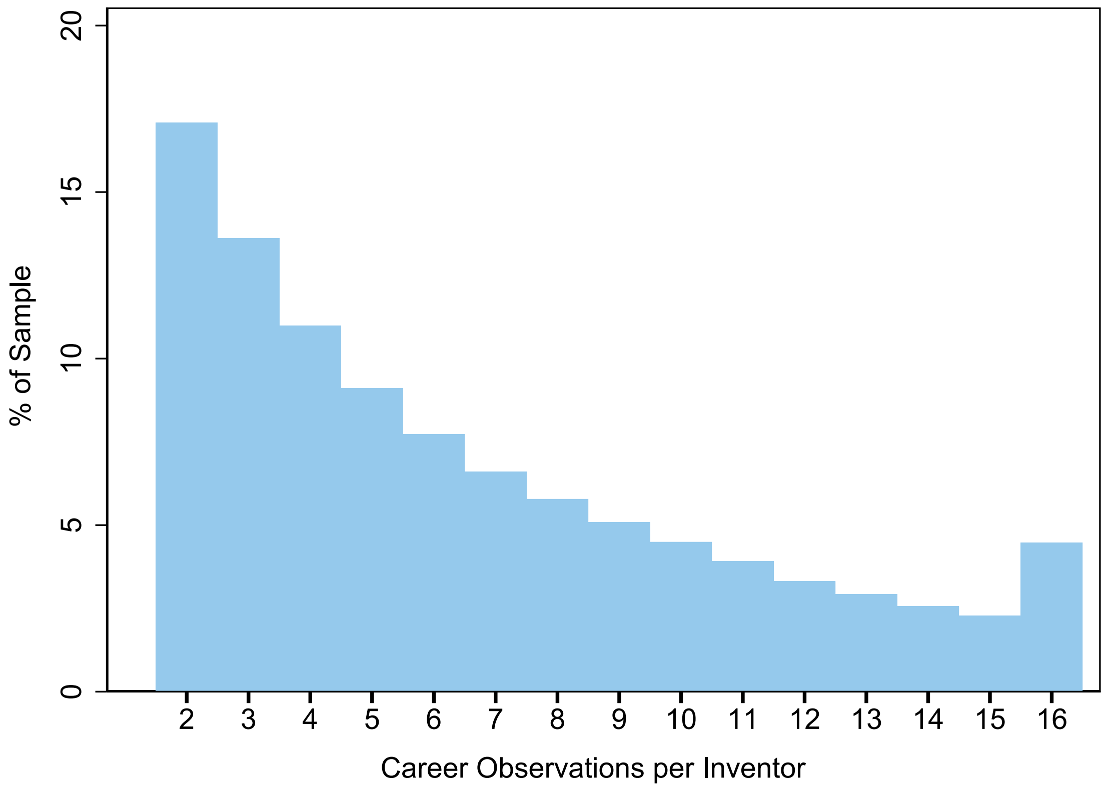
[4]Inventors located within multinational companies can be temporarily relocated for projects in other countries.

[5]Single observation inventors are unsuitable for study of migration because it is ambiguous whether they remain in their original location or not.

many inventors are 'born' into our sample after the start date so have a smaller window of observation than the full 16 years. The average inventor career has 7.2 inventor year observations.

We can then identify outmigration when an inventor has an observed change in address. As the majority of these inventors are not observed every year we are forced to make an assumption on the exact timing of an outmigration. We define an inventor to have migrated in the year prior to the patent priority date in the destination country. For 38.5% of the migrating inventors in our sample we can confirm the assumption as the migration occurred between patents with consecutive priority years. The remaining 61.5% are not observed in consecutive years surrounding the outmigration so the assumed timing could be afflicted with an error.

Figure 2: Distribution of observation per inventor career



The histogram shows the distribution of number of times each unique inventor career is observed in our sample.

In order to test our outmigration timing assumption, we conduct a validity check through searching for a random sub-sample of the migrating inventors in our sample on LinkedIn. LinkedIn can help overcome the problem that we only observe inventor data on patent priority days (inventors who patent sporadically may update their LinkedIn profiles more consistently) and has been shown to be a more accurate source of information on inventor careers than patent data (Ge et al., 2016). Based on the information in our inventor career panel and information retrieved from LinkedIn we calculate the error in our outmigration timing assumption as the outmigration year defined on the inventors' LinkedIn profile minus the outmigration year assumed in our sample. Such that when an inventor migrates a year earlier on LinkedIn than our assumption, we assign an error of -1. And when an inventor migrates a year later on LinkedIn than our assumption, we assign an error of +1. The resulting error distribution is shown below (Figure 3).

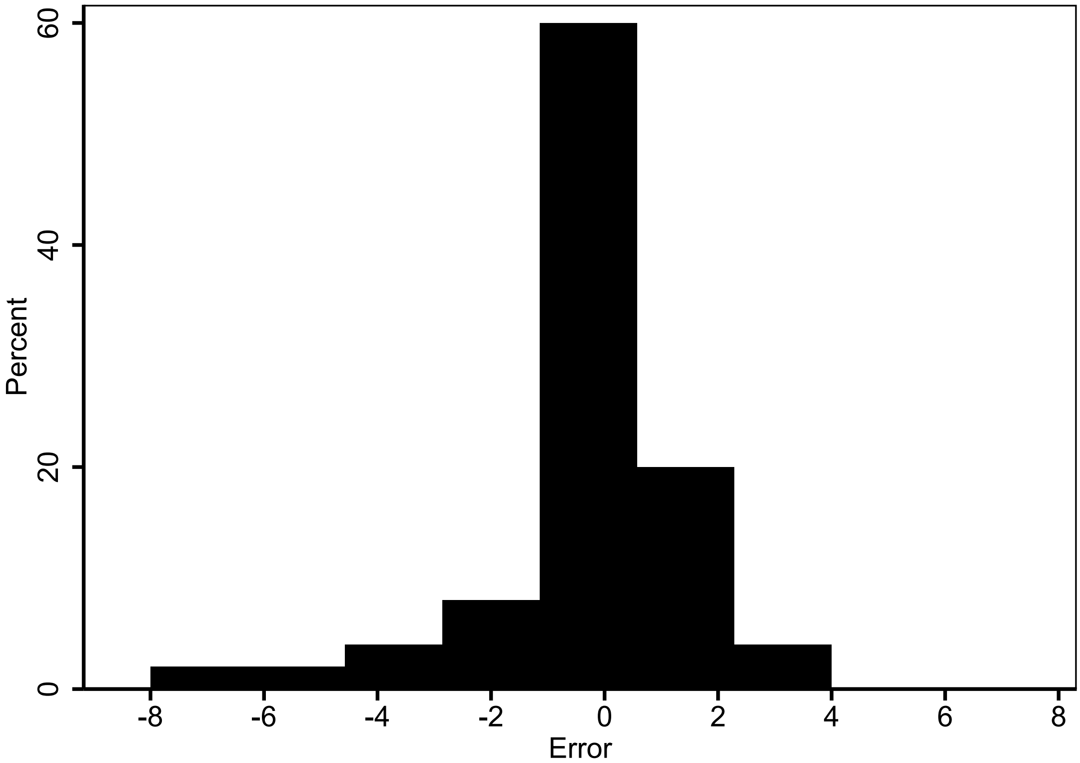
We see that the distribution is centered close to zero with few observations in the tails. The exact central moment is at -0.5 suggesting a slight average error in our assumption. In particular, assuming the migration to have occurred 2 years prior to the patent priority date in the destination would have given a similarly small error. We later conduct a robustness check were the migration year is set to 2 years prior to the patent priority year in the new country (Table 6, column (1-2)). This does not significantly alter any of our main results. For the remainder of the paper we move forward with the assumption that inventors with a patent priority year in the destination country at time T migrated to that country at time $T-1$.

Approximately 3.4% of inventor careers register a migration at some point during our sample window. The exact number of inventor outmigration events per country each year is show in Figure 4.

2.1.1 Other Inventor Level Characteristics

Much of the migration literature has noted issues of selection bias when estimating individual migration decisions (Tunali, 2000). Individuals of a higher ability, as an

Figure 3: Move Timing Error Distribution



The figure shows the distribution of errors when our outmigration timing assumption is compared to the outmigration year listed on the inventor's LinkedIn profile. The distribution is composed of 50 random inventors who both migrate in our sample and have a listed change in employment between the same two countries on their LinkedIn profile.

example, may be more likely to migrate if they expect a relatively higher reward for their skills in a certain destination.

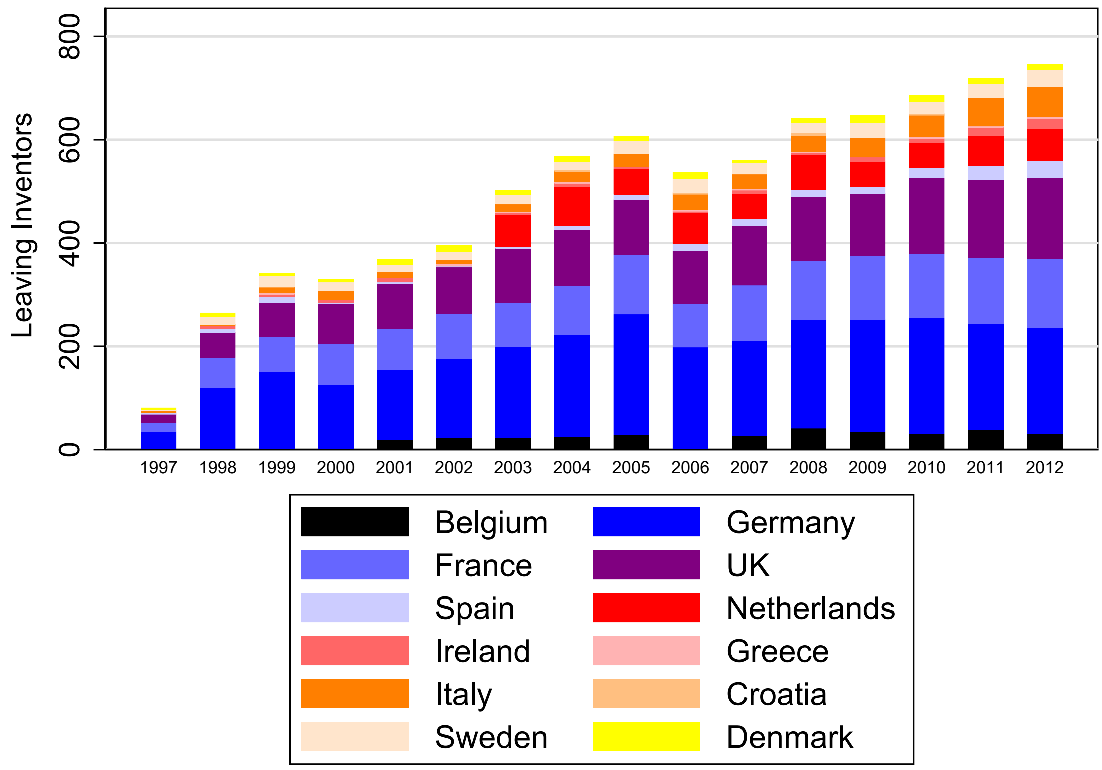
Here, we address selection bias by controlling for individual inventor characteristics, both time invariant, through inventor level fixed effects, and time variant, through information obtained from our inventor career panel.

In this sub-section we outline the various time variant inventor characteristics that could lead an inventor to self-select into migration and explain our approach to control for such characteristics.

Rewards to Skill

High skilled individuals have been documented to make location choices based on returns to skill. In the case of inventors this could mean relocating to the destination where their specific area of innovative expertise is most highly valued. We

Figure 4: Outmigrations Per Year



The graphic shows the number of outmigration instances in our total sample each year. The colored sections denote the number of outmigration instances in a specific country each year.

do not directly observe monetary returns to inventors. However, prior literature has shown a pass through whereby inventors receive a monetary reward in exchange for patenting (Toivanen and Väänänen, 2012). Through this inventors will receive a higher reward in locations with a higher patenting intensity in their technological field. We also assume that such locations will offer better prospects for career progression and employment opportunities more generally. In order to control for such factors, we construct an inventor specific measure of technological opportunity. We specify technological fields using Schmoch (2008) classification of IPC codes present in PATSTAT. This gives us 35 technological fields. An inventor is assigned to the field in which they patent most frequently. From this we calculate the share of patents in the inventor's assigned field in their origin country and divide this by the average share of patents in the inventor's assigned field across the set of possible destination countries. Equation (1) then measures the goodness of fit between the inventor and their origin country relative to the possible destination countries, or captures technological opportunity or potential rewards to skill the individual can expect in a certain location.

$$techopp_{i,j,-j,t} = \frac{innov_{i,j,t}/total_{j,t}}{innov_{i,-j,t}/total_{-j,t}} \tag{1}$$

Ability

The patent stock and patent citations are used to measure the productivity of the individual inventor. Patent citations in particular have been used as a measure of the value of an invention (Trajtenberg, 1990). This motivates the assumption that inventors with higher ability will produce higher value inventions and therefore may benefit from selective visa programs or employee sponsorship. Either of which would facilitate migration. Even though we also employ inventor fixed effects in our estimation which account for time constant ability, the ability of an individual will vary with the breadth and depth of their experience. For instance, the cumulative nature of patent citations suggest that inventors continually improve on their innate talents, without regressing, albeit at different rates. We include the individuals' patent stock and citations to reflect a time-varying measure of ability.

Networks

We also include a measure for foreign networks. Existing literature on networks, diasporas and cohorts (Beine et al., 2011; Hanson and McIntosh, 2010) illustrate that connections in a possible destination could act as a pull factor for migration. Inventors often collaborate across borders and it seems plausible that those with existing collaborators abroad may have higher likelihood of outmigration. We generate a dummy variable equal to 1 if an inventor has previously jointly patented with another inventor in a foreign country. The basic descriptive statistics on the inventor level variables are shown in the Supplementary material (section 1). These show that almost 7% of inventors have some form of foreign network.

2.2 Uncertainty

To measure uncertainty for each individual country we use the Economic Policy Uncertainty index (Baker et al., 2016). This is a country level text based index which rises based on the frequency of combinations of uncertainty suggesting terms appearing within the major newspapers of the given country.[6] It has significant variation across countries and time, allowing us to identify any effects of uncertainty on outmigration.

The index correlates with both economic and policy uncertainty. The lack of a distinction between the two is not problematic for our estimation. We require a country level measure of uncertainty which - when higher- reflects an environment in which inventor level payoffs are more difficult to predict. Both economic and policy uncertainty can capture this. When it becomes more difficult to forecast future economic conditions or the future policy environment, it seems highly feasible that it becomes more difficult for the individual to forecast their own future payoffs in that country.

In our setting, we wish to capture the relative uncertainty between the origin and possible destination countries. We create our relative uncertainty variable ($REPU_{i,t}$) through dividing the policy uncertainty of the origin country (j) with the average policy uncertainty of the set of destination countries ($-j$).

$$REPU_{i,t} = EPU_{j,t} / \frac{\sum_{-j=1}^{n} EPU{-j,t}}{n} \tag{2}$$

Therefore, $-j$, can be thought to reflect the set of possible possible destination countries, $-j \neq j$. The measure is then standardised to 1 such that if uncertainty were equal across both the origin and possible destination countries, $REPU = 1$.

[6]The terms are "Uncertainty", "Economic" and a policy term. The latter differs by country but typically includes the name of the central bank, legislation, regulation and budget. See Baker et al. (2016) for exact details on the construction of the index. See the supplementary material (section 4) for the specific sources of the country based indices used to form our sample.

When uncertainty is greater in the origin country then $REPU > 1$. And when uncertainty is relatively higher abroad $REPU < 1$. Including a relative uncertainty measure as our main regressor allows us to directly test our theory that higher relative uncertainty in the origin country increases the probability of inventor out-migration.

Figure 5: Relative Uncertainty distribution

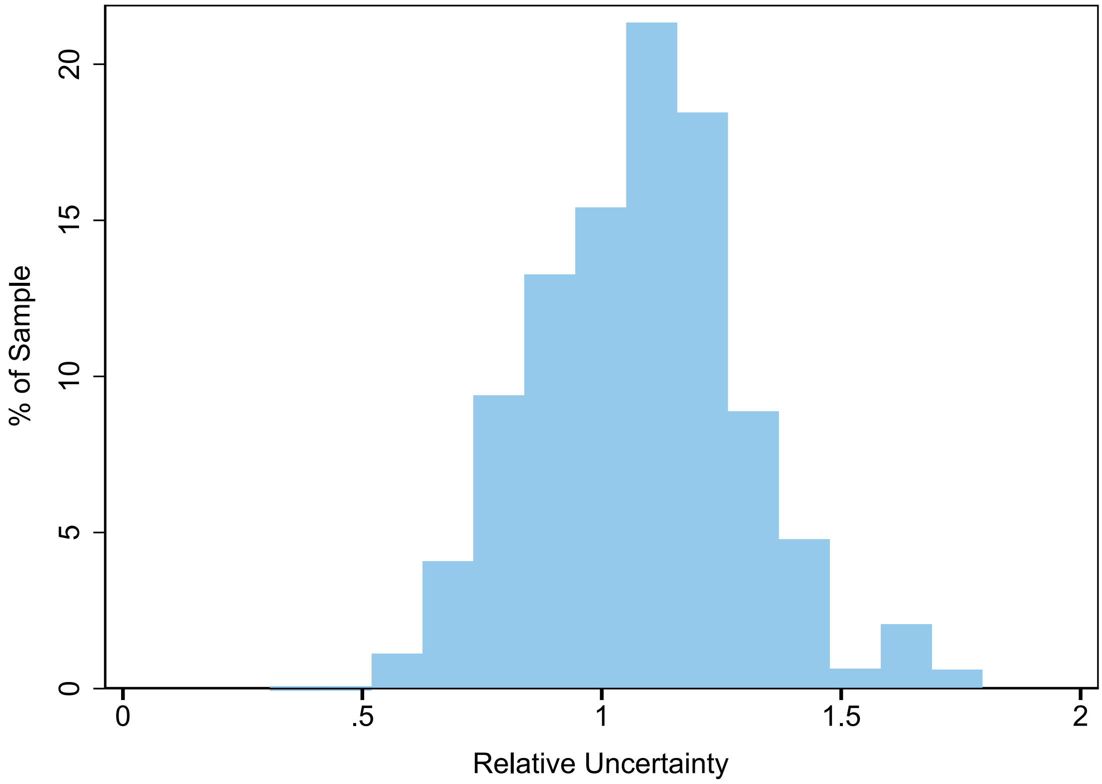


Figure 5 shows the distribution of our relative uncertainty measure. The majority of the mass is centered around 1 and the distribution is close to normal as we would expect from a standardised measure. The distribution has a fat right tail with a large number of values more than one standard deviation away from the median.[7] This indicates that there are a series of events in our data which lead to a significant increase in uncertainty in one country, but not in the remainder of our sample countries. Such spatial variation is important in identifying the effects of relative uncertainty on outmigration, and the large number of relative uncertainty values

[7]The median is 1.069 and standard deviation 0.212.

in the tail allows us further probe on the impact of 'extreme' values of relative uncertainty. We later test for non-linear effects (section 4.2) and find evidence that the probability of inventor outmigration further increases for top centile values of relative uncertainty.

2.2.1 Other Country Level Characteristics

Our country control vector includes factors of the origin relative to possible destination countries which could feasibly act as push factors in the migration decision.

In the case of income we face the limitation that our inventor level data unfortunately does not allow us to identify the exact income of each inventor. Our second choice measure would be to construct a more general inventor income measure for country-year pairs using occupational wage data on inventive professions. However, occupational wage data is limited for our sample. We include GDP per capita under the assumption that inventors will earn more in countries with higher income levels. However, countries with higher GDP per capita may not necessarily have higher incomes in inventive professions. With inventors frequently earning incomes in the upper quantiles of the income distribution (Bell et al., 2019). Countries which offer high salaries in inventive professions but have lower per capita income would violate the above assumption. To reflect this we include the top quantile of countries' income distribution as an income proxy.

We obtain top marginal tax rates from Piketty et al. (2014) and, where absent, supplement with data from the OECD.[8] The other variables we include in our country control vector are the crime rate, research and development intensity, institutional quality, the inflation rate and the employment rate. It should be noted that our country control vector omits some previously discussed outmigration determinants from consideration. In particular, the exchange rate, and variables for a shared language or colonial past are omitted with each being highly unlikely to

[8]Where necessary OECD data is treated to account for differences in methodology between the two data sources.

explain outmigration in our sample. Given almost all our sample countries use the Euro (with the exception of UK and Sweden), none of our countries share a language and none have held significant colonial interests in the other (with the exception of UK and Ireland, in the latter two cases).

All of our country control variables are transformed into relative measures in a setup identical to uncertainty (see equation (2) for reference), with the exception of the inflation rate for which only the value of the inventor's origin country is used.[9] Table 1 shows that as expected all our relative variables have a mean and median close to 1. Variables with less country specific variation such as GDP per Capita and the employment rate have a lower range and standard deviation once transformed into relative measures.[10] Whereas variables like R&D intensity and, our primary variable of interest, relative uncertainty show larger variation, suggesting that increases are more specific to individual countries. The data sources used to collect our country controls are listed in the supplementary material (section 4).

Table 1: Descriptive statistics on country level variables.

Variable	Mean	St.Dev	Median	Min	Max	N
Relative Uncertainty	1.072	0.212	1.069	0.307	1.795	1,545,539
Relative Top Tax Rates	1.00	0.101	0.988	0.766	1.265	1,545,539
Relative Top Income Quantile	1.12	0.104	1.146	0.458	1.436	1,545,539
Relative Crime Rate	0.881	0.213	0.791	0.540	2.224	1,545,539
Relative Employment Rate	1.006	0.086	0.986	0.755	1.251	1,545,539
Relative R&D Intenisty	1.332	0.360	1.451	0.294	2.543	1,545,539
Relative GDP Per Capita	1.053	0.074	1.041	0.455	1.354	1,545,539
Relative Institutional Quality	1.075	0.164	1.093	0.452	1.412	1,545,539
Inflation Rate	1.700	0.782	1.666	-4.478	6.077	1,545,539

[9]The inflation rate is remarkably similar for the countries within our sample scope.

[10]When any individual country undergoes a notable change the rest of our sample countries also undergo a similar change.

3 Estimation & Results

We estimate the effect of relative uncertainty on the inventor outmigration decision using the within fixed effects estimator. Equation 3 shows the linear specification.[11] Our dependent variable is an inventor level dummy variable which equals 1 if inventor i migrates at time t. $REPU_{i,t}$ quantifies the uncertainty of inventor $i's$ origin country (the country in which they are active at the beginning of the period) relative to all possible destination countries (the remainder of our sample countries) for the year t. Our primary parameter of interest is δ which measures the effect of $REPU_{i,t}$ on inventor outmigration.

$$LEAVE_{i,t} = \alpha_i + \delta REPU_{i,t} + \beta_1 X_{i,t} + \beta_2 X_{j,-j,t} + \beta_3 X_{j,-j,t-1} + \beta_4 X_{i,j,-j,t} + \gamma_t + \lambda_{j,t} + \epsilon_{i,t}, \tag{3}$$

The remainder of the estimating equation conditions on characteristics of the origin country, potential destination countries or individual inventors in order to assist in an unbiased estimation of δ.

Time invariant characteristics that are common to our entire sample are controlled for through time fixed effects (γ_t).[12] α_i are inventor level fixed effects which control for time invariant inventor characteristics - such as preferences or innate ability - which could affect their likelihood of outmigration. Time variant characteristics are controlled for through numerous control vectors. $X_{i,t}$ are time varying inventor characteristics, $X_{j,-j,t}$ are country level controls, most of which are measured for the inventor's origin country (j) relative to the set of possible destination countries ($-j$), $X_{j,-j,t-1}$ are lagged country level (relative) controls. Variables at the country level which could themselves be an outcome of relative uncertainty could be afflicted

[11]We also estimate our model using the conditional fixed effects logit estimator. This does not significantly alter our main result. The results are given in Apppendix B.

[12]Our sample cover a fairly small total geographical distance so time fixed effects should net out factors related to climate change and policy changes the European level.

with the bad control problem (Angrist and Pischke, 2009) and introduce bias to δ. To avoid this we take the first lag of major macroeconomic variables which feasibly vary in response to relative uncertainty. $X_{i,j,-j,t}$ is the inventor-country technological opportunity variable ($techopp_{i,j,-j,t}$) which captures the share of patents in the inventor ($i's$) primary technological field in the origin country (j) relative to the possible destination countries ($-j$). When $X_{i,j,-j,t}$ is high a larger share of innovation is occurring in the inventor's field of expertise in the origin country relative to elsewhere, and when low a larger share of innovation is occurring in the relevant field in potential destination countries. Finally, a country specific linear time trend ($\lambda_{j,t}$) is included to condition for any country specific evolution which could alter the propensity of an inventor to migrate. For instance, the origin country becoming more open and attracting more inward migration could lead to a greater degree of competition for the inventor and increase the probability of outmigration.

$\epsilon_{i,t}$ is the error term. The latter is heteroscedastic by construction therefore we use heteroscedasticity robust clustered (at the inventor level) standard errors throughout the empirical analysis. As our dependent variable is at the microeconomic level (inventors) and our independent variable at the macroeconomic level (relative uncertainty) a Moulton bias is possible (Moulton, 1990). To account for this we also replicate all our major results with bootstrapped standard errors although this does not prove to be meaningfully impactful. The results are shown in the supplementary material (section 3).

3.1 Main Results

Table 2 presents the estimated coefficients for relative uncertainty along with the various sets of inventor and country characteristics. The first column presents the results for the regression of the outmigration dummy on relative uncertainty, for our full sample, with only inventor and time fixed effects included. In the second column country level controls are introduced, and the sample diminishes (due to the lagged controls). The third column also includes inventor level characteristics. The fourth column introduces our inventor-country technological opportunity measure. The fifth column includes all covariates and a linear country specific time trend.

The results show a significant effect of relative uncertainty on the probability of inventor outmigration. In the first column this is a 0.0053 increase in the probability of inventor outmigration for a one unit increase in $REPU$. However, a one unit rise in relative uncertainty would be uncommonly large. For instance, there are no instances in our entire sample of an annual increase in relative uncertainty of 1 unit or more. To reflect this, we deflate our relative uncertainty coefficients to what would be a 1SD deviation (0.212) rise in relative uncertainty. We then divide the resultant coefficient ($0.0053 * 0.212 = 0.00124$) by the baseline probability of outmigration in our sample (0.00124/0.005173) to obtain the increase in the probability of inventor outmigration (0.217) for a 1 standard deviation increase in the relative uncertainty of the origin country. For column one this represents a 21.7% increase in the probability of inventor outmigration.

This effect rises slightly as time varying country and inventor characteristics are included and then declines as the model becomes more saturated with the introduction of country specific linear time trends. For the most conservative estimate in column 5 the point estimate has fallen to 0.0042 with 95% confidence bounds of 0.00335 to 0.00511. Using the earlier method to convert the bounds into changes in the baseline outmigration probability, this would suggest the increase in the probability of inventor outmigration is between 13.73% and 20.94% for a one standard deviation increase in the relative uncertainty of the origin country.

The signs on the country level characteristics are either insignificant or as would be expected given the prior art in our preferred specification (column 5). The signs on the inventor level and inventor-country match variables are discussed in more detail in section 4.2.

Table 2: Basic Results

	(1)	(2)	(3)	(4)	(5)
Relative Uncertainty	0.0053***	0.0056***	0.0056***	0.0056***	0.0042***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Country Level Variables:					
Relative R&D Intensity		0.0227***	0.0222***	0.0221***	-0.0035**
		[0.0000]	[0.0000]	[0.0000]	[0.0259]
Relative Top Marginal Tax		0.0432***	0.0433***	0.0430***	0.0317***
		[0.0000]	[0.0000]	[0.0000]	[0.0000]
Relative Crime		0.0009	0.0009	0.0010	0.0002
		[0.6582]	[0.6743]	[0.6292]	[0.8764]
Lagged Country Level Variables:					
Relative Top Income Quantile		0.0060***	0.0059***	0.0059***	0.0015
		[0.0008]	[0.0009]	[0.0010]	[0.3432]
Relative GDP Per Capita		-0.0083	-0.0081	-0.0080	-0.0026
		[0.1276]	[0.1395]	[0.1426]	[0.5693]
Inflation Rate		0.0007***	0.0007***	0.0007***	0.0005**
		[0.0011]	[0.0009]	[0.0008]	[0.0255]
Relative Employment		-0.0700***	-0.0712***	-0.0720***	-0.0442***
		[0.0000]	[0.0000]	[0.0000]	[0.0000]
Relative Institutional Strength		0.0045	0.0047	0.0045	-0.0002
		[0.2128]	[0.1934]	[0.2109]	[0.9287]
Inventor Level Variables:					
Citations			0.0000	0.0000	0.0000
			[0.6766]	[0.6486]	[0.7994]
Patent Stock			-0.0007***	-0.0007***	-0.0007***
			[0.0000]	[0.0000]	[0.0000]
Foreign Collaborators			-0.0067***	-0.0067***	-0.0063***
			[0.0000]	[0.0000]	[0.0000]
Inventor-Country Variables:					
Technological Opportunity				-0.0039***	-0.0017*
				[0.0000]	[0.0549]
Inventor Fixed Effects	Yes	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country Specific Time Trend	No	No	No	No	Yes
N	1545539	1307855	1307855	1307855	1307855

All standard errors are robust to heteroscedasticity and clustered at the inventor level. Given the small probability coefficients, and particularly the standard errors, require numerous decimal places we opt to report p values in brackets rather than the traditional standard errors (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$).

3.2 Do leaving inventors seek lower uncertainty?

If our proposed mechanism is correct and inventors are encouraged to engage in outmigration due to higher relative uncertainty in the home country, then we would expect that inventors who migrated in the previous period would then be subsequently observed in a destination with lower relative uncertainty.

In this section, we investigate whether inventors who migrate in our sample do so to destinations facing a lower level of relative uncertainty. To do so we difference the relative uncertainty measure ($REPU_{i,t+x} - REPU_{i,t}$) to create a measure of the change in relative uncertainty inventor i is exposed to between periods t and $t+x$ ($\Delta REPU_{i,t+x}$). We then regress this on the inventor level outmigration dummy ($LEAVE_{i,t}$) such that the coefficient of interest (δ) gives us an estimate of the change in relative uncertainty the migrating inventor is exposed to between t and $t+x$ compared to their non migrating peers. Equation (4) documents our estimating equation.

$$\Delta REPU_{i,t+x} = \delta LEAVE_{i,t} + \gamma_t + \alpha_i + \lambda_{j,t} + \epsilon_{i,t+1} \tag{4}$$

We estimate the coefficient of interest (δ) for $x = 1, 2, 3$ under the expectation that $x = 1$ provides a negative coefficient, as the inventor relocates to a destination facing lower relative uncertainty, which fades in subsequent periods ($x = 2, 3$) as the destination country is hit with uncertainty shocks that the inventor would be unlikely to expect at the time of the migration decision. γ_t and α_i denote inventor and time fixed effects, as earlier. The fact that the outmigration dummy has substantial within country innovation allows us to employ country-time fixed effects ($\lambda_{j,t}$) and filter out any country-year specific shocks. For instance, it could be argued that we are evidencing a reverse causality issue whereby the inventor migrating from the origin country leads to an increase in the relative uncertainty of the home country, and for this reason the inventor is naturally exposed to lower relative uncertainty in the destination country. While this is highly unlikely in our framework, where

Table 3: Post Emigration Uncertainty

	$\Delta REPU_{i,t+1}$	$\Delta REPU_{i,t+2}$	$\Delta REPU_{i,t+3}$
Outmigration dummy	-0.0292***	-0.0211**	-0.0006
	[0.0000]	[0.0117]	[0.9485]
Inventor Fixed Effects	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes
Country X Year Fixed Effects	Yes	Yes	Yes
N	1362382	1074991	879925

All standard errors are robust to heteroscedasticity and clustered at the inventor level. As throughout, we report p values in brackets rather than the traditional standard errors (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$).

the outmigration dummy is at the inventor level and the outmigration of a single inventor would not be enough to create variation in country level uncertainty, it could nevertheless be argued that the outmigration of individual inventors is correlated and such a large outmigration of the high skilled could impact country level uncertainty. The country X time fixed effects would control for a country specific migration shock at time T, preventing such a bias.

Table 3 shows that inventors who engage in outmigration are exposed to a significantly lower level of relative uncertainty in the subsequent years. The first column shows the change in relative uncertainty the migrating inventor experiences in the next year $(t + 1)$, this is negative and statistically significant. The second column shows that this effect persists (although diminishes) into the 2nd year $(t+2)$, where inventors are exposed to lower relative uncertainty than they were in the origin country. The third column shows that by the third year post outmigration the effect has evaporated and the inventor experiences an indistinguishable relative uncertainty to their non-migrating peers.

this effect evaporates by the third year after outmigration and the inventor is no longer exposed to significantly less relative uncertainty than their non-migrating peers.

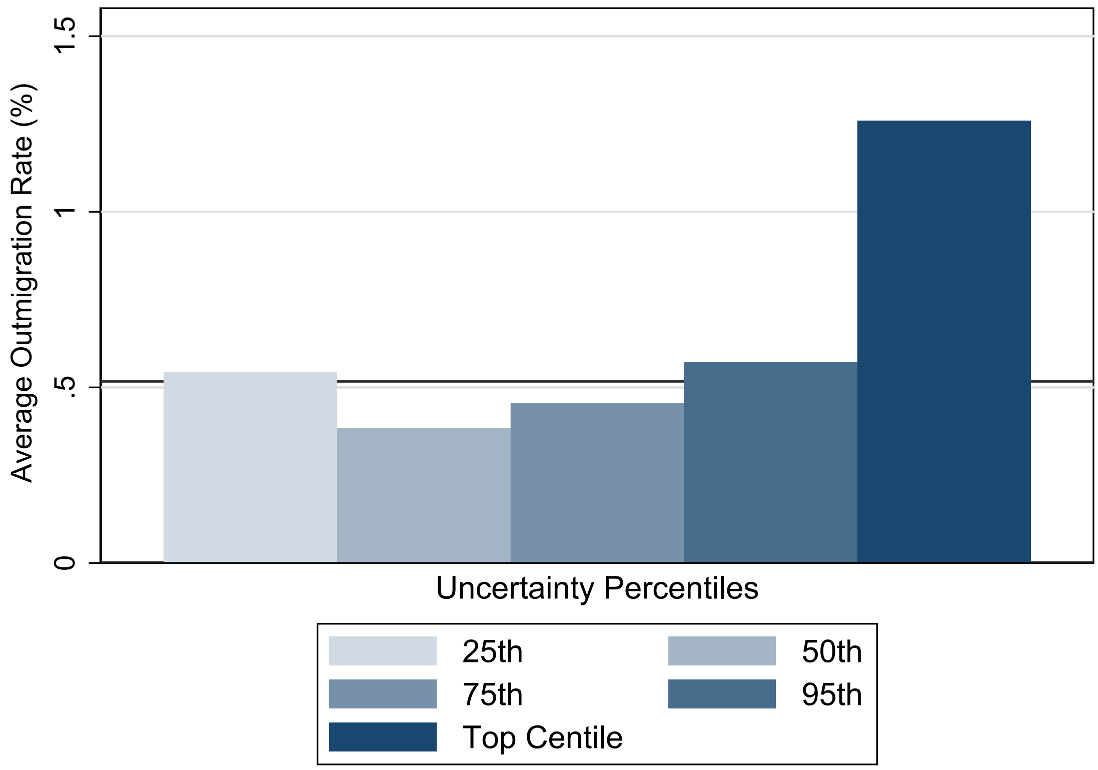
4 Extensions

4.1 Non-linear Effects

In this section we allow for relative uncertainty to have a non-linear effect on the probability of inventor outmigration. Previously, we have documented an average change in the probability of inventor outmigration for a 1 standard deviation increase in the relative uncertainty of the origin country. However, our earlier reasoning suggested that a higher relative uncertainty in the origin country would increase the probability of outmigration because when uncertainty becomes more prevalent in the origin country the role of the general migration uncertainty becomes less dominant in the migration decision. It is perfectly possible that the role of uncertainty in the migration decision is prominent enough that only large increases in relative uncertainty of the origin country lead to a higher probability of outmigration.

Figure 6 shows various percentile bins of economic policy uncertainty and the corresponding rate of inventor outmigration (country level). At the descriptive level, there are signs of significant heterogeneity in the effect of uncertainty on outmigration. With almost no increase over the baseline outmigration rate outside of the top centile of EPU values.

Figure 6: Out Migration Rates by Uncertainty percentile



The graphic shows the outmigration rate associated with various uncertainty percentile bins. 25th indicates values in the 0-25th percentile range, 50th indicates values in the 25th-50th percentile range, 75th indicates values in the 50th-75th percentile range, 95th indicates values in the 75th - 95th percentile range, and top centile indicates the 95th percentile and above of uncertainty values in our sample.

In order to explore this further, we re-estimate equation 3 with the continuous covariate of interest from earlier ($REPU_{i,t}$) replaced by a vector of dummy variables which equals 1 when the relative uncertainty of the origin country is within a certain area of it's distribution. The relative uncertainty dummy variables are defined as shown in figure 3, with a dummy for the first quartile of relative uncertainty values ($REPU25th_{i,t}$), second quartile ($REPU50th_{i,t}$), third quartile ($REPU75th_{i,t}$), 75th - 95th percenile ($REPU95th_{i,t}$) and for values above the 95th percentile ($topcentile_{i,t}$).

We take the second quartile ($REPU50th_{i,t}$) as the baseline and estimate the adapted specification of equation 3 with all controls, fixed effects and the linear

Table 4: Relative Uncertainty Percentiles

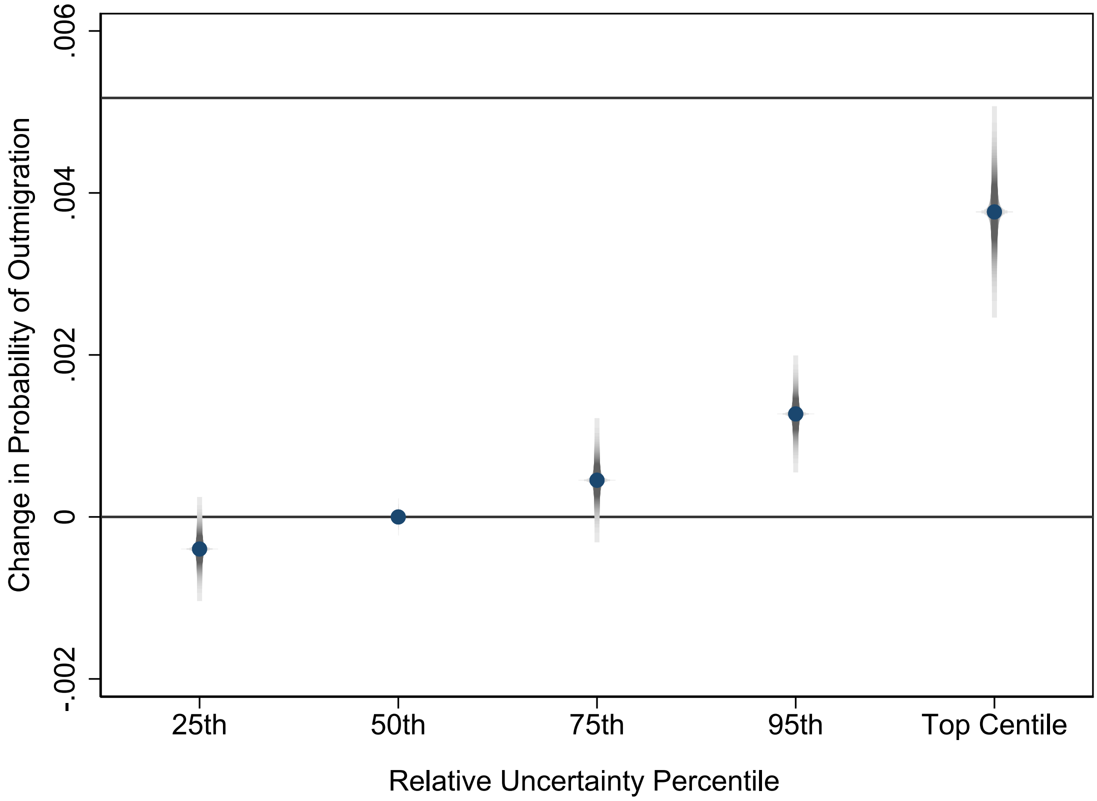
	(1)	(2)	(3)	(4)
Relative Uncertainty- 25th Percentile	-0.0005*	-0.0010***	-0.0010***	-0.0004
	[0.0534]	[0.0003]	[0.0003]	[0.1124]
Relative Uncertainty- 75th Percentile	0.0015***	0.0007**	0.0007**	0.0005
	[0.0000]	[0.0327]	[0.0357]	[0.1277]
Relative Uncertainty- 95th Percentile	0.0015***	0.0021***	0.0020***	0.0013***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Relative Uncertainty- Top Centile	0.0042***	0.0045***	0.0045***	0.0038***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Time Fixed Effects	Yes	Yes	Yes	Yes
Inventor Fixed Effects	Yes	Yes	Yes	Yes
Country Controls	No	Yes	Yes	Yes
Inventor Controls	No	No	Yes	Yes
Inventor-Country Control	No	No	Yes	Yes
Country Specfic Time Trend	No	No	No	Yes
N	1545539	1307855	1307855	1307855

The table shows the results of the estimation of the effect of relative uncertainty percentile dummy variables on the probability of inventor outmigration. The coefficients in column 4 are those used in Figure 7. All standard errors are robust to heteroscedasticity and clustered at the inventor level. Given the small probability coefficients, and particularly the standard errors, require numerous decimal places we opt to report p values in brackets rather than the traditional standard errors ($*p < 0.1$, $**p < 0.05$, $***p < 0.01$).

country specific time trend included. The results are shown in table 4. Figure 7 plots the estimated coefficients for the relative uncertainty bins.

We find evidence of that effect of relative uncertainty on outmigration is non-linear. For values in the bottom quartile, the probability of inventor outmigration decreases. Recall, that for relative uncertainty values below one (when uncertainty is higher in the potential destination countries than in the origin country) we would expect a decrease in the probability of inventor out migration. As relative uncertainty becomes higher in the origin country the effect becomes positive and, as expected, the coefficient on the third quartile dummy ($REPU75th_{i,t}$) becomes positive, albeit statistically insignificant. At the 75th-95th percentile ($REPU95th_{i,t}$) the coefficient becomes statistically significant and represents a 23.2% increase in the probability of inventor outmigration. For the top centile of relative uncertainty

Figure 7: Coefficient Plot: Relative Uncertainty Percentiles



The y-axis shows the change in the probability of inventor outmigration for an exhaustive set of relative uncertainty bins. The horizontal line passing through the origin represents no change in the probability of inventor outmigration. The upper horizontal line represents a doubling of the probability of inventor outmigration. The plotted estimation corresponds to column (4) of table 4. 1,307,855 observations.

values the effect grows significantly and represents an increase in the probability of inventor outmigration of 77.32%.

This suggests that there is an exponential increase in the probability of inventor outmigration as the relative uncertainty of the origin country grows relative to the possible destination countries. This is consistent with the idea that there is a significant uncertainty surrounding the migration process which is only overcome in the migration decision when uncertainty becomes high enough in the origin country to significantly alter the payoffs the inventor would receive from staying at home.

4.2 Heterogeneous Effects: Inventor Characteristics

As noted earlier, individual characteristics have received significant attention in the prior migration literature. In particular, ability, expectations on returns to skill in a certain location, and networks have all been shown to affect the probability of outmigration or likelihood of choosing a certain destination (Grogger and Hanson, 2011; Kennan and Walker, 2011; Hanson and McIntosh, 2010; Beine et al., 2011; Tunali, 2000). It is plausible that such characteristics act by amplifying or dampening the individual outmigration response to relative uncertainty.

In order to explore such heterogeneity we re-estimate equation 3 but now allow for interactions between citation per patent, the individual patent stock, the foreign network dummy or the inventor-country technological opportunity measure with relative uncertainty. The results are shown in Table 5. We find strong evidence in favour of heterogeneous responses at the inventor level. Column 1 shows that there is a small but statistically significant negative effect when relative uncertainty is interacted with patent stock, a statistically and economically insignificant effect on the interaction with citations, and large significant effects when interacted with the inventor-country technological opportunity measure and the foreign collaborator dummy.

The results provide strong evidence of heterogeneity based on inventor characteristics. Notable are the coefficients shown in columns 3 and 4. The interaction coefficient in columns 3 suggests that a higher degree of technological opportunity (or rewards to skill) in the origin country reduces the probability of outmigration under uncertainty. Perhaps suggesting that the effect is dampened by the individual having more secure employment, or a larger pool of opportunities, in their current location. The positive coefficient on the network interaction is in contradiction to the sign of the non-interacted variable. This suggests that inventors with an existing network of collaborators abroad feel less need to migrate for projects or opportunities in times of low uncertainty but that networks can facilitate outmigration, possibly through a reduction in the general uncertainty surrounding the migration process,

Table 5: Heterogeneous Effects: Inventor Characteristics

	(1)	(2)	(3)	(4)
Relative Uncertainty	0.0048***	0.0040***	0.0074***	0.0041***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Citations Per Patent	0.0000	-0.0001	0.0000	0.0000
	[0.8012]	[0.7801]	[0.7947]	[0.8010]
Patent Stock	-0.0004***	-0.0007***	-0.0007***	-0.0007***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Technological Opportunity	-0.0017*	-0.0017*	0.0012	-0.0017*
	[0.0513]	[0.0547]	[0.3738]	[0.0569]
Foreign Collaborators	-0.0063***	-0.0063***	-0.0063***	-0.0097***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
REPU x Patent Stock	-0.0002**			
	[0.0338]			
REPU x Citations Per Patent		0.0001		
		[0.7111]		
REPU x Technological Opportunity			-0.0028***	
			[0.0012]	
REPU x Foreign Network				0.0031*
				[0.0601]
Inventor Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Country Specific Time Trend	Yes	Yes	Yes	Yes
Country Controls	Yes	Yes	Yes	Yes
N	1307855	1307855	1307855	1307855

All standard errors are robust to heteroscedasticity and clustered at the inventor level. Given the small probability coefficients, and particularly the standard errors, require numerous decimal places we opt to report p values in brackets rather than the traditional standard errors (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$). The dependent variable is the inventor level outmigration dummy in all columns.

when the inventor is searching for a destination due to higher relative uncertainty in the home country.

4.3 Robustness Tests

Alternative outmigration timing assumption

The first two columns re-estimate our models with an alternative assumption on the date of inventor outmigration. Throughout we have assumed the outmigration to occur one year before the patent priority year in the destination country. Or that an inventor observed in the destination country at T migrated there at $T-1$. Earlier we justified this assumption through a small exercise in which we cross-referenced the outmigration date for a random sample of our inventors using LinkedIn data (Figure 3). The exercise suggested assuming the outmigration occurred one year earlier ($T - 2$) could also have been a valid option. To ensure our results are robust to our outmigration timing assumptions we replicate our key results with the outmigration timing year switched to define an outmigration to have occurred two years prior to the patent priority data in the destination country. Column 1 and 2 of Table 6 show that our earlier evidence on the average, top quartile and top centile effects of relative uncertainty are all robust to a change in the outmigration timing assumption.

Persistent Relative Uncertainty

Even with more clarity on the outmigration timing assumption, there could still be a problem whereby the effect of relative uncertainty on outmigration transmits across years. This would seem especially likely if the origin country experiences persistently high relative uncertainty for several years. In this case inventor's migrating in the present period may be doing so as a result of uncertainty last year, or because it has now become apparent that the increase in relative uncertainty in their origin country is not transient.

Table 6: Robustness Tests

	Alternative Move Timing Assumption		Previous Period Uncertainty		Placebo test	
	(1)	(2)	(3)	(4)	(5)	(6)
Relative Uncertainty	0.0033***		0.0041***	0.0042***	0.0026***	
	[0.0000]		[0.0000]	[0.0000]	[0.0001]	
Relative Uncertainty- 95th Percentile		0.0013***				
		[0.0000]				
Relative Uncertainty- Top Centile		0.0038***				
		[0.0000]				
High Relative Uncertainty $(T-1)$			0.0007***			
			[0.0003]			
High Relative Uncertainty $(T-2)$				0.0002		
				[0.2747]		
Relative terror						0.0002
						[0.7250]
Country Controls	Yes	Yes	Yes	Yes	Yes	Yes
Inventor Controls	Yes	Yes	Yes	Yes	Yes	Yes
Inventor-Country Control	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Inventor Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country Specific Time Trend	Yes	Yes	Yes	Yes	Yes	Yes
N	1304774	1304774	1307855	1307855	989488	989488

The first two columns report the coefficients from the estimation of our main model (equation 3) and the regression of the outmigration dummy on relative uncertainty percentile bins, with the outmigration timing assumption switched to define an outmigration to have occurred two years prior to the patent priority date in the destination. Column 3 includes a dummy variable which equals one if relative uncertainty were high in the previous period. Column 4 includes a dummy variable which equals one if relative uncertainty were high in both previous periods. Column 5 estimates equation 3 on a restricted sample to provide context to column 6. Column 6 provides the results of a placebo test where relative uncertainty is replaced by a relative terror index. All standard errors are robust to heteroscedasticity and clustered at the inventor level. Given the small probability coefficients, and particularly the standard errors, require numerous decimal places we opt to report p values in brackets rather than the traditional standard errors (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$).

To test whether there is additional outmigration from persistent outmigration we expand equation 3 to estimate any additional effect observed in year T if relative uncertainty were high in the inventor's origin country in the previous periods. We introduce dummy variables for high uncertainty in the previous year or high uncertainty in the previous two years. The latter equals one if relative uncertainty were higher in the origin country in both of the previous years, i.e. if $REPU_{i,t-1} > 1$ and $REPU_{i,t-2} > 1$, and the former equals one if relative uncertainty was high in the origin country in the previous year.

Columns 3 and 4 show the results. The second column shows that a high relative uncertainty in the prior year increases the probability of inventor outmigration by 0.0007. Or, raises the increase in the probability of inventor outmigration from 17.21% to 30.33%.[13]. In the third column we fail to find evidence of additional effect from relative uncertainty being persistently high for the previous two years.

Overall, we find some evidence of a persistence effect if relative uncertainty remains high for several years. This does, however, seem to be confined to the previous year and has almost no effect on the coefficient of relative uncertainty in the present period. A high relative uncertainty in the prior years seems to accelerate rather than crowd out the instantaneous effect.

Placebo Test

If our premise is correct and relative uncertainty increases the probability of outmigration through mitigating the importance of general migration uncertainty in the migration decision then this should require a large enough increase in the relative uncertainty in the origin country to counteract the general uncertainty in

[13]The increase in the probability of inventor outmigration in column (1) is the coefficient (0.0042) deflated by one standard deviation (0.212) and then divided by the baseline probability (0.005173). Or a 17.21% change. The main coefficient of the second column deflated by one standard deviation (0.0041*0.212=0.0087), combined with the additional outmigration from high relative uncertainty last year (0.00087 + 0.0007 = 0.00157) and then divided by the baseline outmigration probability (0.00157/0.005173 = 0.3033) gives an increase in the probability of outmigration of 30.33%.

the migration decision. We provided evidence of this in section 4.1. Now we conduct a placebo test where we replace relative uncertainty with a relative terror measure. Under the assumption that terror will contribute only a small amount of the annual variation in relative uncertainty in our sample, and should not alone identify any significant effects in outmigration. We the Global Terrorism data from the Institute for Economics and Peace as an input and create a relative terror measure identical in setup to the relative uncertainty measure used throughout (equation 2). We then estimate the effect of relative terror on the probability of outmigration. The results are shown in column 6 of table 6.[14] As expected the results are statistically insignificant and of little magnitude.

5 Aggregate Implications

To put our results in perspective at the aggregate level we now work through a simple exercise which offers an estimate of the $ value of invention lost through inventor outmigration under uncertainty.

We analyse the situation of a hypothetical country (the unweighted average of our 12 sample countries) in the year 2011. The baseline situation for this country-year combination is the outmigration of 60 inventors who, based on on the average inventor productivity in our sample (figure 2), will patent 7.2 times throughout their career. This assumes that all outgoing inventors are of an average quality, which seems fair given our failure to find any heterogeneous effect based on individual ability (see section 4.2), and that the inventor will patent 7.2 times post outmigration. The latter clearly not being the case in our sample, as the inventor must patent at least once in their origin country in order to be considered, but our sample forms a very small window of an inventor's total career with 16 years being the maximum

[14]Column 5 shows the results of our main estimation (Table 2, column 5) re-estimated on the restricted sample for which we were able to collect terror data.

possible observation window.[15] This suggests our assumption of 7.2 patents post outmigration, conditional on the inventor having at least two patents during our sample, is likely a conservative estimate.

Based on the baseline case of 432 lost patents ($60 * 7.2$) we calculate the change in lost invention due to relative uncertainty by multiplying the baseline lost patents by the change in probability of inventor outmigration under a 1SD deviation increase in the relative uncertainty of the origin country (see section 3.1) or a relative uncertainty of the origin country above the 75th percentile or in the top centile (see section 4.1). We then adjust each additional lost patents into monetary terms by multiplying by estimates of the value of a patent from the innovation literature (Bessen, 2009; Scherer and Harhoff, 2000; Gambardella et al., 2008; Kogan et al., 2017).

Figure 8 shows change in the probability of inventor outmigration on the x axis (with the relevant coefficients marked by dashed lines) and the dollar value of lost invention on the y axis. We show four curves in the space, each of which correspond to a certain estimate on the value of a patent. Only in the most conservative area of the graph is the lost invention less than 1 billion dollars, and for top centile relative uncertainty values the additional outmigration of inventors may lead to lost invention of several billion dollars.

The results of this simple exercise should naturally be interpreted with caution. The exercise is entirely home country centric, assuming all subsequent invention by migrating inventors would be of no value to the home country, which is unlikely to hold true in practice. It also should be considered that the international movement of high-skilled labor, such as inventors, may be considered optimal by a global social planner. On the other hand, there are clear benefits- such as knowledge spillovers - to the origin country which will be in large part lost after inventor

[15] Most inventors are 'born' into our sample i.e. they patent for the first time after our first year of observation.

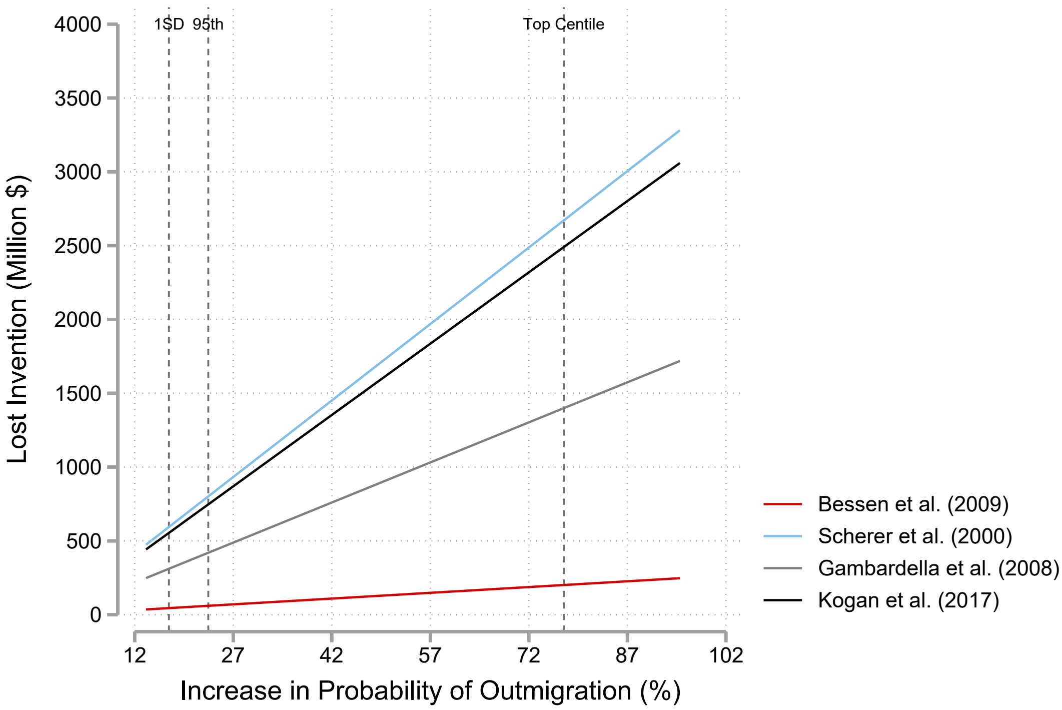


Figure 8: Aggregate Implications
The figure shows estimates on the value (in millions of dollars) of invention lost to the origin country after an increase in relative uncertainty lasting one year. The x-axis shows the change in the probability of outmigration. The continuous range is set based on key coefficient estimates throughout. The y axis shows the value of lost invention from the increase in the probability of outmigration during the relative uncertainty increase. Where necessary patent values are adjusted to 2011 dollars using data from the Federal Reserve Bank of Minneapolis and exchange rate data from the World Bank. The curves show the range of lost invention for four estimates of the private value of a patent.

outmigration (Agrawal et al., 2011; Myers and Lanahan, 2022). Accounting for knowledge spillovers would likely increase the estimates in Figure 8 significantly.

Overall, we offer some evidence that the increase in the probability of outmigration under relative uncertainty that we observe at the inventor level also has a noteworthy effect at the aggregate level.

6 Conclusion

We consider relative uncertainty as a determinant of outmigration in our sample of European inventors. We specifically consider that a a higher relative uncertainty in the inventor's origin country raises the probability of outmigration through reducing the importance of a general migration uncertainty in the migration decision.

In our empirical estimations we find strong evidence of increased outmigration under relative uncertainty. An increase in the relative uncertainty of the inventor's origin country raises the probability of outmigration by between 13% and 21%. This rises to over 23% for relative uncertainty values in the top quartile and to over 77% for values in the top centile, indicating significant non-linearites in the effect of relative uncertainty on outmigration. Characteristics of the individual give notable interaction with our results, with an existing foreign network making outmigration under uncertainty more probable and higher rewards to skill in the origin country making it less probable an inventor migrates under uncertainty. This is consistent with the prior art (Kennan and Walker, 2011; Beine et al., 2011; Grogger and Hanson, 2011; Tunali, 2000).

We confirm that inventors who migrate in our sample do so to destinations facing lower levels of relative uncertainty in the subsequent years. Further suggesting relative uncertainty was a motivating factor in the outmigration. A simple back of the envelope calculation suggests our results remain economically impactful at the aggregate level despite inventor outmigration being fairly rare in our sample.

Our approach could be expanded to explicitly model the expectations of the individual in a dynamic model. Future research on whether employers accelerate or dampen the outmigration response to uncertainty could be an interesting avenue of exploration, as could further evidence on the non-linearites our results suggests.

Acknowledgements

We thank Evelina Gavrilova-Zoutman, Katrin Hussinger, Adam Jaffe, Joep Konings, Paul Pelzl, Grid Thoma, Otto Toivanen, Leonard Treuren and Dennis Verhoeven as well as participants at the KU Leuven doctoral seminar (Leuven), 9th INNOPAT Conference (Mannheim) and the 10th summer school on Knowledge Dynamics, Industrial Evolution and Economic Development (Nice) for their comments.

References

Agrawal, A., Kapur, D., McHale, J., and Oettl, A. (2011). Brain drain or brain bank? the impact of skilled emigration on poor-country innovation. *Journal of Urban Economics*, 69(1):43–55.

Akcigit, U., Baslandze, S., and Stantcheva, S. (2016). Taxation and the international mobility of inventors. *American Economic Review*, 106(10):2930–81.

Angrist, J. D. and Pischke, J.-S. (2009). *Mostly harmless econometrics: An empiricist's companion.* Princeton university press.

Baker, S. R., Bloom, N., and Davis, S. J. (2016). Measuring economic policy uncertainty. *The quarterly journal of economics*, 131(4):1593–1636.

Beine, M., Docquier, F., and Özden, Ç. (2011). Diasporas. *Journal of Development Economics*, 95(1):30–41.

Bell, A., Chetty, R., Jaravel, X., Petkova, N., and Van Reenen, J. (2019). Who becomes an inventor in america? the importance of exposure to innovation. *The Quarterly Journal of Economics*, 134(2):647–713.

Bessen, J. (2009). Estimates of patent rents from firm market value. *Research Policy*, 38(10):1604–1616.

Cooray, A. and Schneider, F. (2016). Does corruption promote emigration? an empirical examination. *Journal of Population Economics*, 29(1):293–310.

Doherr, T. (2021). Disambiguation by namesake risk assessment. *ZEW-Centre for European Economic Research Discussion Paper*, (21-021).

Gambardella, A., Harhoff, D., and Verspagen, B. (2008). The value of european patents. *European Management Review*, 5(2):69–84.

Ge, C., Huang, K.-W., and Png, I. P. (2016). Engineer/scientist careers: Patents, online profiles, and misclassification bias. *Strategic Management Journal*, 37(1):232–253.

Gibson, J. and McKenzie, D. (2011). The microeconomic determinants of emigration and return migration of the best and brightest: Evidence from the pacific. *Journal of Development Economics*, 95(1):18–29.

Goldbach, C. and Schlüter, A. (2018). Risk aversion, time preferences, and out-migration. experimental evidence from ghana and indonesia. *Journal of Economic Behavior & Organization*, 150:132–148.

Grogger, J. and Hanson, G. H. (2011). Income maximization and the selection and sorting of international migrants. *Journal of Development Economics*, 95(1):42–57.

Hall, B. H., Jaffe, A. B., and Trajtenberg, M. (2001). The nber patent citation data file: Lessons, insights and methodological tools.

Hanson, G. H. and McIntosh, C. (2010). The great mexican emigration. *the Review of Economics and Statistics*, 92(4):798–810.

Hao, L., Houser, D., Mao, L., and Villeval, M. C. (2016). Migrations, risks, and uncertainty: A field experiment in china. *Journal of Economic Behavior & Organization*, 131:126–140.

Jaeger, D. A., Dohmen, T., Falk, A., Huffman, D., Sunde, U., and Bonin, H. (2010). Direct evidence on risk attitudes and migration. *The Review of Economics and Statistics*, 92(3):684–689.

Kennan, J. and Walker, J. R. (2011). The effect of expected income on individual migration decisions. *Econometrica*, 79(1):211–251.

Kleven, H. J., Landais, C., and Saez, E. (2013). Taxation and international migration of superstars: Evidence from the european football market. *American economic review*, 103(5):1892–1924.

Kleven, H. J., Landais, C., Saez, E., and Schultz, E. (2014). Migration and wage effects of taxing top earners: Evidence from the foreigners' tax scheme in denmark. *The Quarterly Journal of Economics*, 129(1):333–378.

Knight, F. H. (1921). *Risk, uncertainty and profit*, volume 31. Houghton Mifflin.

Kogan, L., Papanikolaou, D., Seru, A., and Stoffman, N. (2017). Technological innovation, resource allocation, and growth. *The Quarterly Journal of Economics*, 132(2):665–712.

Moretti, E. and Wilson, D. J. (2017). The effect of state taxes on the geographical location of top earners: Evidence from star scientists. *American Economic Review*, 107(7):1858–1903.

Moulton, B. R. (1990). An illustration of a pitfall in estimating the effects of aggregate variables on micro units. *The review of Economics and Statistics*, pages 334–338.

Mullins, J. T. and Bharadwaj, P. (2021). Weather, climate, and migration in the united states. Technical report, National Bureau of Economic Research.

Myers, K. R. and Lanahan, L. (2022). Estimating spillovers from publicly funded r&d: Evidence from the us department of energy. *American Economic Review*, 112(7):2393–2423.

Piketty, T., Saez, E., and Stantcheva, S. (2014). Optimal taxation of top labor incomes: A tale of three elasticities. *American economic journal: economic policy*, 6(1):230–71.

Scherer, F. M. and Harhoff, D. (2000). Technology policy for a world of skew-distributed outcomes. *Research policy*, 29(4-5):559–566.

Schmoch, U. (2008). Concept of a technology classification for country comparisons. *Final report to the world intellectual property organisation (wipo), WIPO.*

Toivanen, O. and Väänänen, L. (2012). Returns to inventors. *Review of Economics and Statistics*, 94(4):1173–1190.

Trajtenberg, M. (1990). A penny for your quotes: patent citations and the value of innovations. *The Rand journal of economics*, pages 172–187.

Tunali, I. (2000). Rationality of migration. *International Economic Review*, 41(4):893–920.

// IMPRINT

ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH Mannheim

ZEW – Leibniz Centre for European Economic Research

L 7,1 · 68161 Mannheim · Germany
Phone +49 621 1235-01
info@zew.de · zew.de