Taxation and the International Mobility of Inventors*

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Abstract

This paper studies the effect of top tax rates on inventors' mobility across OECD countries since 1977. We put special emphasis on "superstar" inventors, those with the most and most valuable patents. We use panel data on all inventors from the United States and European Patent Offices to track inventors' locations over time and combine it with international effective top tax rate data. We construct a detailed set of proxies for inventors' counterfactual incomes in each possible destination country including, among others, measures of patent quality and technological fit with each potential destination. We find that superstar top 1% inventors are significantly affected by top taxes rates when deciding on where to locate. The elasticity of the number of domestic inventors to the net-of-tax rate is relatively small, between 0.04 to 0.06, while the elasticity of the number of foreign inventors is much larger, around 1.3. The elasticities to top net-of-tax rates decline as one moves down the quality distribution of inventors. Inventors who have worked in multinational companies are more likely to take advantage of tax differentials. On the other hand, if the company of an inventor has a higher share of its research activity in a given country, the inventor is less sensitive to the tax rate in that country.

Keywords: Taxation, Migration, International Mobility, Superstars, Innovation, Patents, Invention.

JEL Codes: F22, H24, H31, J44, J61, O31, O32, O33

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"Let me tell you how it will be, There's one for you, nineteen for me,
Cos I'm the taxman, yeah, I'm the taxman
Should five per cent appear too small, Be thankful I don't take it all
Cos I'm the taxman, yeah I'm the taxman
If you drive a car, I'll tax the street. If you try to sit, I'll tax your seat.
If you get too cold I'll tax the heat. If you take a walk, I'll tax your feet."

The Beatles, "Taxman," **1966**

1 Introduction

In 1876, Alexander Graham Bell invented the telephone, and created the Bell Telephone Company one year later. By 1886, more than 150,000 people in the United States owned telephones. In 1916, James L. Kraft patented a pasteurization technique for cheese and established his company, Kraft Foods Inc., that would grow into a conglomerate responsible for creating some of the United States' most popular food products and employing more than 100,000 people. In 1968, Ralph Baer created a TV game unit that allowed players to control on-screen action with paddle controls. Today, the video gaming industry is worth $66 billion dollars. In the early 1970s, Michael Ter-Pogossian developed the positron emission tomography (PET) scanner, used today in countless medical examinations. In the mid-1970s, Samar Basu, through a series of patents, invented the technology that allowed the lithium ion batteries used in innumerable consumer products to be recharged multiple times. In 1981, Charles Simonyi started developing some of Microsoft Office's most profitable products. In addition to being very prolific inventors, these innovators had something else in common: they were all *immigrants*.

According to World Intellectual Property Organization data, inventors are highly mobile geographically with a migration rate around 8%.[1] But what determines their patterns of migration? In particular, how does tax policy affect migration? The fear of a "brain drain" and the exodus of economically valuable agents in response to higher taxation has led to a vivid public debate regarding the taxation of high income people. For instance, in response to the New York Times' (Feb, 2013) article entitled "The Myth of the Rich Who Flee From Taxes,"[2] following Gerard Depardieu's Russian exodus for tax purposes, Forbes issued an article entitled "Sorry New York Times, Tax Flight of the Rich Is Not a Myth."[3] In this paper, we study of the effects of top income taxes on the international migration of inventors, who are key drivers of technological progress.

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[1] For a recent study using this data, see Miguelez and Fink (2013). High skilled workers are in general more mobile that low skilled workers, with inventors being among most high-skilled immigrants. Docquier and Marfouk (2005) also find that highly skilled workers are 6 times more likely to emigrate than low-skilled workers.

[2] Article by James B. Stewart, published February 15, 2013.

[3] Article by Paul Roderick Gregory, published February 17, 2013.

While an important issue, international migration responses to taxation have remained under-explored due to the lack of a large-scale international panel dataset. An exception is the study of the migration responses of football players, a set of economic agents very different from inventors, by Kleven, Landais, and Saez (2013). In our analysis, we use panel data on all inventors from the U.S. and European patent offices in an unusual way, namely to track the international location of inventors since the 1970s. The benchmark data is a panel data from the Disambiguated Inventor Data by Lai *et al.* (2012), based on inventors who patent with the United States Patent Office (USPTO). The focus is on the 8 OECD countries that represent the bulk of USPTO filings for the period 1977-2003: Canada, France, Germany, Great Britain, Italy, Japan, Switzerland, and the United States. The novel disambiguated European inventor data is from Coffano and Tarasconi (2014). The U.S. and European patent offices together account for a very large fraction of worldwide filings, so that our sample contains most of the universe of inventors who patent.[4] We combine this inventor data with international effective marginal top tax rate data from Piketty, Saez, and Stantcheva (2014).

We put a particular emphasis on "superstar" inventors, namely those with the most abundant and most valuable innovations. The distribution of inventor quality, as captured by citations – an often-used measure of the economic value of patents – is highly skewed:[5] As can be seen in Figure 1, while the median and mean inventors have, respectively, 11 and 42 citations, the average top 1% superstar inventor has 1019 citations.

The patent data allows us to construct detailed proxies for inventors' qualities and counterfactual earnings in different countries based, among others, on their patents, citations and technological fields, as well as their ranking in the inventor quality distribution. The benchmark measure of quality is citations-adjusted patents, but we also consider the number of patents, average citations per patent, and the maximum citations per patent.[6] Citations are an important determinant of inventors' incomes. Indeed, Bell *et al.* (2015) use administrative data covering the population of patent applicants in the United States and show that earnings rise sharply immediately after individuals file patent applications, particularly for patents that later become highly cited (see also the papers reviewed in Section 2.4 which document the link between patent citations and income in countries other than the U.S.). For the benchmark quality measure (and for each of the other measures), we construct a corresponding quality distribution, conditional on region of origin and the year of observation and determine the rank of each inventor in this distribution. We define superstar inventors as those in the top 1% of the quality distribution.

We also exploit information about what type of institution the inventor works for, notably whether he is employed by a multinational, and the share of the innovative activity of his company

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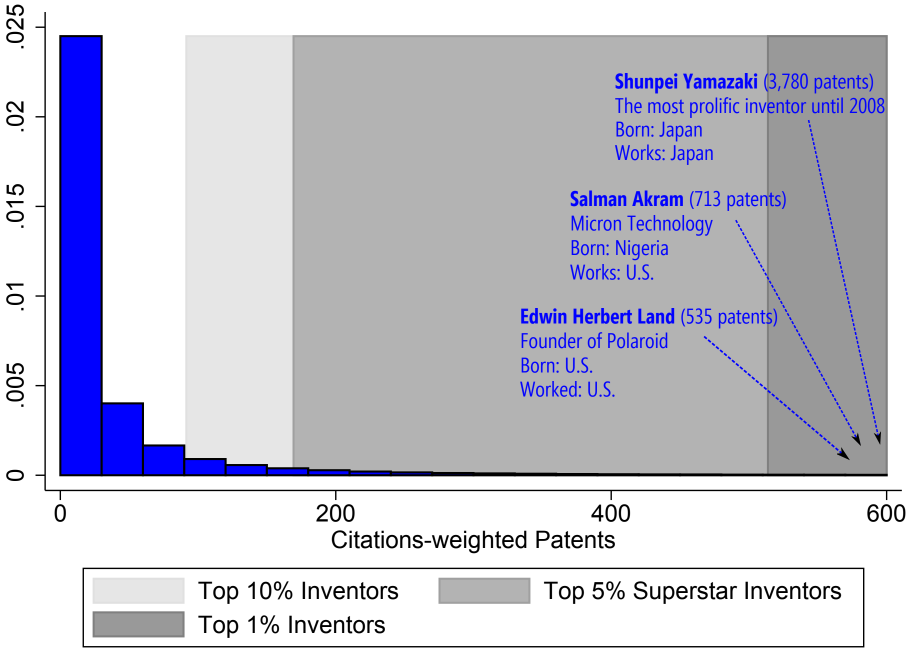
[4] By considering all inventors who patent in either patent office, we circumvent the possibility that, for instance, an European inventor might only patent in the USPTO if he has intentions of moving to the U.S..

[5] For a recent discussion on the link between patent value and citations and for a survey of the literature, see Abrams, Akcigit, and Popadak (2013).

[6] The three regions used are i) Europe and Canada, ii) Japan, iii) the United States. See Section 2.3 for a detailed description of how we construct quality measures for inventors and for alternative definitions of "superstars."

Figure 1: Distribution of citations-weighted patents



Notes: This figure plots the distribution of citations-weighted patents (see formula (1)) across inventors in the U.S. Patent Office data 1977-2003 from 8 countries: Canada, Great Britain, Germany, France, Italy, Japan, Switzerland, and the United States. For a detailed description of the data, see Section 2.3.

performed in each potential destination country.

We start by documenting some stylized macroeconomic facts about the relation between mobility and top tax rates. Since 1977, the top marginal retention rate (defined as the net-of-tax rate) has been significantly positively correlated with the fraction of top 1% superstar inventors who remain in their home country. This positive relation remains but weakens progressively as one moves from the top 1%, to the top 1-5%, the top 5-10% and the top 10-25% inventors.

We then estimate a detailed multinomial location choice model to obtain the elasticities to top tax rates for foreign and domestic inventors. We exploit variation in top tax rates across time and countries, as well as variation in their effective impact on very successful inventors (those in the top 1%) as opposed to moderately successful inventors (those in the top 1-5%), and less successful inventors (those below the top 5%).[7] These estimated elasticities are the answer to the question of how much a country's stock of domestic and foreign inventors of various qualities would change for a small change in marginal top tax rates. They are not necessarily interpretable as "net-of-tax income elasticities." First, there are additional tax considerations that determine full net income, such as capital taxes. Second, for those lower quality inventors not in the top tax bracket, the

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[7] The benchmark results in Table 3 all contain country-year fixed effects. We also check what happens if we use cross-country-time variation to identify the coefficients in Table 7.

top tax rate is a "success" tax that they can expect to pay only if they do very well. Note also that we are not trying to understand the effects of the taxation of *direct* patent income (such as royalties or corporate income).[8] Indeed, we restrict our benchmark sample to those inventors who are employees of companies and who are not the assignees of the patents. We are instead interested in salary and bonus earnings, for which personal income taxes are the main consideration.

We find that the superstar top 1% inventors are significantly affected by top tax rates when choosing where to locate. As one moves down the quality distribution of inventors, the sensitivity to top tax rates decreases. The elasticity of the number of top 1% domestic inventors to the net of tax rate is small, around 0.04. On the other hand, the elasticity of foreign top 1% superstar inventors is much larger, around 1.3. Put differently, for a 10 percentage point decrease in top tax rates, the average country would be able to retain 1% more domestic superstar inventors and attract 38% more foreign superstar inventors. To put these numbers into perspective, the elasticity of the number of domestic football players in Kleven, Landais, and Saez (2013) to the net of tax rate ranges from 0.07 to 0.16 depending on the estimate, and the elasticity of the number of foreign players ranges from 0.6 to 1.3.

The role of companies in the migration decision appears to be important: Inventors who have worked for multinationals in the previous period are more likely to take advantage of tax differentials. On the contary, they are much less sensitive to the tax rate in a given country if their company has a significant share of its innovative activity in that country. We also find some evidence consistent with sorting by ability and general equilibrium wage effects.

We then perform extensive robustness checks on these benchmark results. First, we consider three different measures of inventor quality and alternative proxies for earnings. Second, we contrast short term and long-term mobility in response to taxation and find, as could be expected, that long-term mobility is less driven by tax considerations. Third, we address the potential selection based on patenting behavior by two methods: by imputing data for years in which inventors do not patent (and, hence, for which their location is not observed) and by estimating a Heckman selection model that exploits a 1994 reform to patent protection in the United States. Finally, we reproduce the analysis on the disambiguated inventor data from the European Patent Office and find similar, if somewhat larger, baseline elasticities of 0.06 of migration to the net of tax rate.

Related Literature: That high skilled migration and its drivers are important considerations has been highlighted in the literature (see the seminal paper by Kerr (2013) and the extensive references therein). Kerr (2013) finds that high-skilled immigrants account for roughly 25% of U.S. workers in innovation and entrepreneurship and contribute disproportionately to patents or start-ups. Kerr and Lincoln (2010) estimate that immigrants account for a majority of the net increase in the U.S. STEM workforce since 1995. In turn, not just the receiving, but also the sending country is affected. It could either be suffering from a "brain drain," by loosing highly skilled people or gaining from a "brain gain," if people invest in human capital more with the prospect of immigration or from

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[8] This would lead to issues such as capital or corporate taxation.

remittances. Indeed, oversea diasporas have been studied as important determinants of knowledge flows (Foley and Kerr, 2013). Inventor migration and the formation of geographical knowledge clusters and their spillovers have also received attention (Miguelez and Moreno (2014), Miguelez (2013), Breschi, Lissoni, and Tarasconi (2014) and the references therein).

Our paper adds to a recent literature that studies the international migration of people in response to taxation. Most closely related are the papers by Kleven, Landais, Saez, and Schultz (2014) and Kleven, Landais, and Saez (2013). Kleven, Landais, Saez, and Schultz (2014) find very high elasticities of the number of high income foreigners in Denmark using a preferential tax scheme on high-earning foreigners implemented by Denmark in 1992 that reduced top tax rates for 3 years.[9] Kleven, Landais, and Saez (2013) study the migration of football players across European clubs. While we find somewhat lower elasticities for domestic inventors, the authors already stated that football players might be substantially more mobile than other high-skilled workers, because they earn most of their lifetime income over a short period and their profession involves little country-specific capital. In addition, their sample exclusively considers migration across European countries, while we also include the United States, Canada, and Japan. Expanding the study to other continents might, one would expect, reduce the tax elasticities of migration. Other related papers consider migration within countries. Bakija and Slemrod (2004) use Federal Estate Tax returns to show that the effect of higher state taxes on the migration of wealthy individuals across states in the U.S. is very small.[10] Closer to our study are Moretti and Wilson (2014a) who consider aggregate state level effects of adopting subsidies for biotech employers –such as increase in R&D tax incentives– on the inflows of star scientists (see also Moretti and Wilson (2014b)).[11]

Estimating the elasticity of migration to the tax rate is also important for the theoretical literature of optimal taxation with migration, as it enters the optimal tax formulas (Mirrlees (1982), Wilson (1980), Wilson (1982)). Most relevant are the recent papers by Simula and Trannoy (2010) and especially Lehmann, Simula, and Trannoy (2014) who consider optimal nonlinear income taxation in the presence of migration. Our paper can shed some light on how big their proposed modifications to standard optimal tax formulas have to be empirically. The same applies for the macro structural literature that includes migration channels and needs to calibrate the migration elasticities (see Cosar, Guner, and Tybout (2010)). Turning to the macroeconomic taxation literature, the reaction of superstar inventors to high top tax rates could also lend support to the theoretical finding in Jaimovich and Rebelo (2012) that, at high levels, taxes can have a negative effect on growth. The migration channel could also further bolster recent findings that the room for higher tax revenue through more progressive taxes is limited in Guner, Lopez-Daneri, and Ventura (2014), as well as in Holter, Krueger, and Stepanchuk (2014) and Kindermann and

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[9] By contrast, Young and Varner (2011) study the effects of a change in the millionaire tax rate in New Jersey on migration and find small elasticities.

[10] Liebig, Puhani, and Sousa-Poza (2007) study mobility within Switzerland, across cantons and find small sensitivities to tax rates.

[11] In contrast to the mobility of people, there is much more work on the international mobility of capital, see for instance the recent papers by Zucman (2013) and Zucman (2014), and the references cited there.

Krueger (2014).[12] Finally, international differences in taxation could be another channel for the misallocation of talent (Hsieh, Hurst, Jones, and Klenow, 2013).

The rest of the paper is organized as follows. Section 2 presents the setting and data, as well as a simple model of inventor migration. Section 3 shows some stylized macro facts on the relation between top tax rates and superstar inventors' migration. Section 4 describes the multinomial location model estimation and the main results. Section 5 contains several robustness checks and extensions. Section 6 repeats the analysis on inventors who patent with the European Patent Office. Section 7 concludes.

2 Setting and Data

This section provides some background information on inventors, patents, and the patent data. We explain how we use the patent data for the study of the effects of taxation on inventor mobility with the help of a simple location choice model.

2.1 Inventors and patents: Background

Inventors are the authors of innovations. They can be employees of companies, work for research institutions, or be self-employed "garage inventors." Patents protect the intellectual property of the innovation. They are legally granted to an assignee. The assignee is either an individual (possibly, but not necessarily, one of the inventors on a given patent), a national, local, or state government, an institute, a hospital or medical institute, or a university.

Inventors seem to be more mobile than the general population, which is consistent with a positively documented relation between skill and mobility. As summarized in Miguelez and Fink (2013), the global migration rate in 2000 for the population above 25 years old is 1.8%, ranging from 1.1% for the unskilled to 5.4% for those with tertiary education. In our benchmark sample, 2.3% of inventors move at least once over their lifetime in the sample (an average of 12 years) and 4.6% of the superstar inventors move over the same duration."

2.2 A Simple Model of Inventor Migration

To motivate our empirical analysis, consider the following very simple model of inventor migration. There are C countries, labeled by $c \in \{1, ..., C\}$. The wage of inventor i in country c' at time t is denoted by $w^i_{c't}$. Let $\tilde{w}^i_{c't}$ denote the marginal product of the inventor in country c' at time t. The index i allows the marginal product to depend on several inventor characteristics, such as his technological class, his age, as well as characteristics of the firm or employer he works for. If the international labor market is perfectly competitive, each inventor is paid his marginal product, so that $\tilde{w}^i_{c't} = w^i_{c't}$, $\forall c', t, i$.

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[12] Especially if inventors are particularly productive agents.

Suppose that in country c, an inventor with home county h^i has to pay a tax rate τ_{ch^it} on his total income at time t. The tax rate is allowed to depend on the country of origin because foreigners can sometimes face different tax regimes in different countries. For instance, U.S. citizens are taxed on their worldwide income.

In addition to the income earned, there is also a net utility benefit denoted μ^i_{ct} from locating in country c at time t for inventor i. This benefit is person-specific and can include, among others, a home bias, technological strengths and characteristics of the country, language differences, or distance to the home country. It can also capture country-specific characteristics of the company the inventor works for, such as the share of innovative activities the company performs in country c at any given time.

Total utility from choosing country c at time t for inventor i is given by:

$$U^i_{ct} = u\left(w^i_{ct}\left(1-\tau_{ch^it}\right)+\mu^i_{ct}\right)$$

We assume that to a first order there are no adjustment costs of moving, so that the inventor can choose where to live period by period. This is appropriate for two reasons. First, it avoids us having to make potentially unrealistic assumptions about the expectations of future tax rates, on which there is little empirical evidence and which could be country-specific. Second, while the utility from living in any country does not depend on the utility of living in any other, the home country plays a special role. It enters as a non-time varying individual characteristic, and the utility from locating in any country can depend on characteristics relative to the home country, for instance, through a home bias, geographical distance to or language differences with the home country. Hence, country c will be chosen in period t if and only if:

$$u\left(w^i_{ct}\left(1-\tau_{ch^it}\right)+\mu^i_{ct}\right) = \max_{c'}\left\{u\left(w^i_{c't}\left(1-\tau_{c'h^it}\right)+\mu^i_{c't}\right)\right\}$$

As is well-known, it is the average tax that matters for the supply of inventors in a country. The probability that inventor i locates in country c will depend on the full vector of tax rates in all countries, $(\tau_{1h^it}, ..., \tau_{ch^it}, ..., \tau_{Ch^it})$. However, for the empirical analysis, we make the assumption that, to a first order, the tax rate of any other country only has a negligible impact on the supply of inventors in country c. This is a good approximation if there are many possible origin and destination countries and each is relatively small. Hence, to a first order, the probability that inventors from country k locate in country c will depend only on τ_{ckt} and the relation should be negative.

Note that other preferences as captured by μ could be so strong that they completely dominate any tax differences. As a result, strong location preferences unrelated to net income will reduce the observed sensitivity to tax rates. In the empirical analysis, we will explore such factors related to the type of job and company the inventor works in, in addition to the standard factors such as home bias, language differences and geographical distances.

General equilibrium and sorting effects: If the labor market is not perfectly flexible, and employers of innovators instead have a rigid demand for inventors, then the wage is not equal to the marginal product. There can be general equilibrium effects of the tax rate on the supply and demand for inventors of different characteristics, which can lead to sorting. To a first order then, the wage rate $w^i_{c't}$ would be a function of the tax system as well. We will return to this issue in Section 4.1 when we discuss all the ways in which we control for the inventor's wage and in Section 4.4 where we estimate these potential general equilibrium effects.

2.3 The Inventor Data

Our main data source is the Disambiguated Inventor Data (hereafter, DID) by Lai *et al.* (2012), which identifies unique inventors in the U.S. Patent Office (USPTO) data. The USPTO data contains 4.2 million patent records and 3.1 million inventors for the period 1975-2010, which represents 18% of worldwide direct patent filings and 26% of all patents.

We limit the sample to the 8 major countries which account for 89% of all patent filings with the USPTO. The U.S. accounts for 55% of the UPSTO filings, Canada for 2.3%, Great Britain for 3%, Germany for 7.6%, Italy for 1.2%, Japan for 19.6%, France for 2.9% and Switzerland for 1.3%. These representation differences reflect the different propensities that countries have for filing a patent with the USPTO: 58% of U.S. patent filings, 48% of Canadian filings, 19% of British filings, 16% of German filings, 20% of Italian filings, 13% of Japanese filings, 17% of French filings and 12% of Swiss filings are filed with the USPTO.[13]

But propensities to file and representation in the patent data are not necessarily correlated with migration propensities. Indeed, while it is true that the largest migration corridors are the Great Britain-U.S. and Canada-U.S. corridors, the Japan-U.S. and Switzerland-U.S. migration corridors for instance are very small, although these countries have a high propensity of filing patents in the U.S.

The DID contains inventors' disambiguated names and residential address, which allows us to track the location of the inventor over time.[14] Each of the inventor's patents has a patent number, application year, grant year, and assignee name. In addition, to get information on each patent's characteristics, such as citations or technological class, we merge the inventor data to the NBER patent data. Because of the truncation issue for patents' citations, we limit the sample to the years 1977-2003. Table 1 provides some summary statistics for the inventor data.

The DID and the NBER patent data have been the benchmark in the innovation literature. Only very recently has a similar effort of disambiguation been undertaken for the European patent data (Coffano and Tarasconi (2014), Breschi, Lissoni, and Tarasconi (2014)). Despite the fact that there has been less work on this data and that the disambiguation algorithm is less-well established to date, it offers some advantages. The biggest of these is that the U.S. is less disproportionately

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[13] Source: Authors' calculations based on WIPO data available at: `http://ipstats.wipo.int/ipstatv2/index.htm?tab=patent`.

[14] According to Lai *et al.* (2012), the addresses are private residential addresses of inventors.

Table 1: Summary Statistics

Variable	Average
Patents of Superstar (Top 1%) Inventors	54
Patents of Superstar (Top 5%) Inventors	29.3
Patents of Non-superstar (Below Top 5%) Inventors	3.4
Average patents per year while in sample	1.5
Max citations per patent of Superstar (Top 1%) Inventors	149.9
Max citations per patent of Superstar (Top 5%) Inventors	102.6
Max citations per patent of Non-superstar (Below Top 5%) Inventors	23
Number of Patents (per country per year)	13,824.4
Number of Inventors (per country per year)	19,207.9
Number of immigrants (per country per year)	122.8
# of immigrants per year to the U.S.	532.8
# of immigrants per year to CA	83.9
# of immigrants per year to CH	57.3
# of immigrants per year to DE	97
# of immigrants per year to FR	48.3
# of immigrants per year to GB	99.3
# of immigrants per year to IT	15
# of immigrants per year to JP	48.5
% Superstar (Top 1%) Inventors who move over life in sample	4.6%
% Superstar (Top 5%) Inventors who move over life in sample	3.6%
% Non-superstar (Below 5%) Inventors who move over life in sample	0.6%
Average duration of stay in years conditional on move	5.17
% of inventors who are employees	73.5%
% of employees who work for multinationals	75%
Average years between first and last patent in sample	5.2

Notes: Summary statistics are based on inventor and patents data set described in Section 2.3 for the period 1977-2003. The data includes inventors in 8 countries: Canada, France, Germany, Great Britain, Italy, Japan, Switzerland, and the United States. The sample contains 4,154,792 observations with 1,868,967 unique inventors.

represented and European countries are more represented.[15] We analyse inventor mobility using this data as well. The details on the European data and analysis are in Section 6.

As an additional piece of macro evidence, we perform a simple graphical analysis using an alternative data source on inventor's locations. This dataset is described in detail by Miguelez and Fink (2013) and extracted from patent applications that are filed under the Patent Cooperation Treaty (PCT), a treaty administered by the World Intellectual Property Organization (WIPO) that offers some advantages for seeking international patent protection. This data is described in Section 3.2.

Constructing quality measures for inventors: Citations received have traditionally been used

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[15] In addition, as explained in detail below, the data might be less oriented toward European inventors who patent with the USPTO office because they potentially plan to move to the U.S.

as measures of the economic and technological significance of a patent (Hall, Jaffe, and Trajtenberg, 2001). We construct four different dynamic measures of the inventor's quality, which place different importance on the quantity versus value of an inventor's patents. Let p_{ijt} be the number of truncation-adjusted forward citations received by patent j of inventor i by time t. The truncation adjustment, which takes into account the fact that more recent patents have less time to accumulate citations, is described in Hall, Jaffe, and Trajtenberg (2001). Let P_{t-1}^{i} be the set of patents of inventor i by the end of period $t-1$. Our benchmark measure is the lagged citations-weighted dynamic patent stock of the inventor. Formally, we denote this measure by $q1_t^i$ and it is equal to:

$$q1_t^i = \sum_{j \in P_{t-1}^{i}} p_{ij} \tag{1}$$

Measure $q1$ takes into account both the quantity and the quality of an inventor's patents. The priority is given to citations accumulated as a measure of one's influence. Our second measure, denoted $q2_t^i$ is the lagged patent count of the inventor namely:

$$q2_t^i = |P_{t-1}^{i}| \tag{2}$$

where $|P_{t-1}^{i}|$ is the cardinality of the set P_{t-1}^{i}. This measure ignores the quality of patents and purely focuses on their quantity and is hence not our preferred measure.[16] The third measure, $q3_t^i$, is the lagged mean number of citations per patent:

$$q3_t^i = \frac{\sum_{j \in P_{t-1}^{i}} p_{ij}}{|P_{t-1}^{i}|} \tag{3}$$

which measures the average quality of an inventor's inventions to date. The fourth measure, $q4_t^i$, is the max number of citations ever received on a patent by inventor i:

$$q4_t^i = \max_{j \in P_{t-1}^{i}} p_{ijt} \tag{4}$$

which captures the best an inventor has ever achieved and whether he ever had a "home-run" invention. The additional results for our non-benchmark measures $q2$, $q3$, and $q4$ are in Section 5.

Based on these quality measures, we can define a ranking for inventors and, in particular, identify "superstar" inventors. We could in principle use a worldwide ranking of inventors. However, the propensity to patent is quite different for different countries and thus the quality measures are not necessarily directly comparable at a global level. This is why we group our 8 countries into 3 groups based on comparable patenting intensity: 1) the U.S., 2) Japan, 3) European countries and Canada. The U.S. and Japan stand out as the biggest patenting countries with 55% and 26% of all

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[16] Many patents have no real economic value and are never cited by any subsequent patent (see for instance Abrams, Akcigit, and Popadak (2013)).

granted patents in the sample period (1977-2003).[17] We assign each inventor to a region based on whether his "home" country is in that region. Since we do not observe actual nationality in this data, we call home country the country in which the inventor is first observed in our sample. We define superstars at time t as those in top 1% of the regional quality distribution at time t. The top 5%, top 10%, and top 25% are calculated in a similar way.[18] From now onwards, we use the notation "top 1-5%" to denote inventors who are in the top 5% excluding the top 1%, and, similary the top 5-10% and top 10-25% to respectively denote inventors in the top 10% excluding the top 5%, and in the top 25%, excluding the top 10%.

2.4 Making use of the Inventor and Top Tax Rate Data

The DID provides us with the location of inventors, through the addresses recorded at each patent filing. Income and social security taxes on labor earnings are typically computed on the basis of geographical residence. We limit the sample to inventors who are employees and who hence receive the bulk of their income as ordinary personal income. These inventors innovate within companies and, typically, their employers are the owners of the patents produced. To a first order, this allows us to abstract from other forms of taxation such as capital or corporate taxation, or the taxation of royalties and focus on personal income taxation.[19]

There are some complications with foreign tax rules and regimes across different countries, which we are not able to account for given our data. For instance, an inventor living temporarily in the UK but domiciled abroad can choose to some extent how to be taxed on his income earned abroad (on an "arising basis" or on a "remittance basis"). Depending on the inventor's legal arrangement, as well as future plans, which we cannot see in the data, this might lead to somewhat different effective marginal tax rates. In the analysis, we assume that, to a first order, the inventor pays the taxes of the country he physically resides in. The exception is for U.S. inventors who are taxed on their worldwide income, a fact we take into account in our analysis. Incidentally, in Section 5.3, we consider long-term mobility, which potentially allows a clearer equivalence between geographical location and tax residency.

The model highlighted two crucial considerations for migration: the counterfactual income that an inventor could receive in any country at any time, and the tax rate he would pay there. We describe both of these in turn.

Using inventor quality to proxy for income: The patent data gives us a rich set of measures that can proxy for an inventor's counterfactual earnings. Among them are the previously described quality measures, $q1 - q4$, in formulas (1)-(4). Patent quality to date is a composite, dynamic

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[17] The other countries each account from 1.16% to 8.85% of patents. Furthermore, the mean number of patents per inventor in the U.S., Japan and the rest of the countries is, respectively, 3.95, 4.7 and 3.3.

[18] As a check, we also defined the reference distribution and ranking separately for each country, instead of by region, and the results, available on demand, were virtually unchanged.

[19] If other taxes matter to inventors this would tend to reduce their elasticity to income tax rates and we would see in our results that income taxes are not significant drivers of migration decisions.

statistics that takes into account an inventor's past achievements. In that sense, it is a measure of inventor ability or earnings potential, and a reflection of the inventor's "invention resume." As described in detail in Section 4.1, we will allow the ability of the inventor to be rewarded differently in different countries and we will introduce ability and country specific trends in compensation. Additional characteristics used to control for the counterfactual wage are described there as well. Here, we would like to point out why inventor quality, as measured by the quality of his patents, is an important component of compensation.

First, it is worth emphasizing that we are not necessarily trying to measure the income flow from any given patent but rather to proxy for an inventor's full earnings using quality measures based on his patents. Of course, the increase in income observed as a function of the quality of an inventor's patent portfolio can be a composite of two elements. First, there are direct rewards and bonuses for specific innovations, driven potentially by legal or contractual arrangements and dependent on the economic value of the patent to the employer. Indeed, in many countries, "fair share" agreements determine a financial compensation for the employee as a function of the value of the patent to the company and the contribution of the employer (for instance, in the UK, Germany, and France). Second, and most relevant for our purposes, there can be more indirect compensation for an inventor's ability. An employer could pay a higher salary or promote star innovators, with a stellar track record of patent quality, in order to both attract and retain crucial talent (Chesbrough (2006)).[20]

Whatever the exact channel, there does seem to be a strong link between the value and quality of patents and the inventor's income. Furthermore, the distribution of rewards for patents seems to be highly skewed towards high quality inventors. Toivanen and Väänänen (2012) find that Finnish inventors receive a temporary reward equal to 3% of earnings for any patent grant. This hides important heterogeneities based on patent quality: moderately cited patents (with 20 to 30 citations) generate a premium of around 20% in annual earnings, while highly cited patents receive an earnings premium of 30% three years after the grant. Harhoff and Hoisl (2007) use data for Germany, where the employer has the right to claim the invention and, if he does, needs to reasonably compensate the employee in proportion to the value of the invention. The share of the salary received as a compensation for an invention is highly skewed with a few top inventions doubling the inventor's salary. Top 5% inventors receive a 20-50% increase in their salary per invention. Similarly, as a compensation for all inventions, the top inventors' salaries can be multiplied by a factor of 5. That rewards are highly skewed towards top inventors is corroborated by Ernst, Leptien, and Vitt (2000), who also find that among German companies, inventors' technological innovations are very concentrated among a few key inventors. Giuri *et al.* (2007) find in the PatVal European inventors survey that 42% of inventors receive a monetary award for their patents, and that for 4% of the respondents, these monetary rewards are permanent. Most importantly, Bell *et al.* (2015) find using administrative data covering the population of patent applicants in the United States

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[20] (Chesbrough, 2006) states that "R&D managers often use the number of patents generated (..) as a metric to judge the productivity of (...) [a] person or organization."

that earnings rise sharply immediately after individuals file patent applications, particularly for patents that later become highly cited and that the distribution of income is highly skewed towards superstar inventors.

Employers should naturally do their best to attract the inventors with the best patenting and inventing ability. The importance of such "stars" has been emphasized by Zucker and Darby (2014). Indeed, star researchers and inventors play a crucial role in the formation or transformation of many industries. For a lot of companies, patent licensing is also a major source of revenues, justifying the need to hire the best innovators. For instance, IBM collects more than $1 billion in licensing revenues. Furthermore, there is a well-documented link between patent citations and the economic value of patents (see the detailed survey of the literature in Abrams, Akcigit, and Popadak (2013)), further justifying the use of patent citations measures as components of inventor quality.

Inventors' income distributions: It is useful to get a sense of inventors' income distributions across different countries from survey data. In particular, we are interested in how much top 1% of inventors are earning. Top inventors are high-skilled workers and typically advantageously placed in the income distribution. Using data from the 2003 National Survey of College Graduates public-use microdata from NSF (NSF, 2003), Figure 2 shows that 44% of inventors are in the top 10% of the U.S. income distribution, and 18% and 1% are in the top 5 and the top 1, respectively. If our quality measures are indeed good indicators of inventor earnings, the top 1% of inventors is likely to be quite high up in the income distribution.

In European countries and in Japan, Figure 3 highlights that the top 1% of inventors in terms of income is comfortably in the top income tax brackets.

Using the effective top tax rate: Given these income distributions, our strategy is to use the top marginal tax rate as our tax measure. Conditional on being in the top tax bracket, the top tax rate is exogenous to earnings, unlike the average tax rate. The top tax rate is also a good approximation to the average tax rate for top earners.[21] We include in the regression interactions of the retention rate with dummies for being in the top 1%, the top 1-5%, the top 5-10%, and the top 10-25%. As these groups have different likelihoods of being in the top bracket and, hence, being subject to the top tax rate, they should have different sensitivities to the top tax rate. In particular, we would expect that as we move down the quality distribution, inventors become less and less elastic to the top tax rate.

Our analysis can also take on another interpretation, even if the top tax rate is only an imperfect measure of the actual average tax rate. The top tax is a measure of the "success tax" in any given country. The top tax rate might have a "motivation" effect even if inventors are not yet in the top bracket yet. A successful invention could push an inventor higher up the income distribution and a higher top tax rate could act as a disincentive for such large innovations. This effect should be

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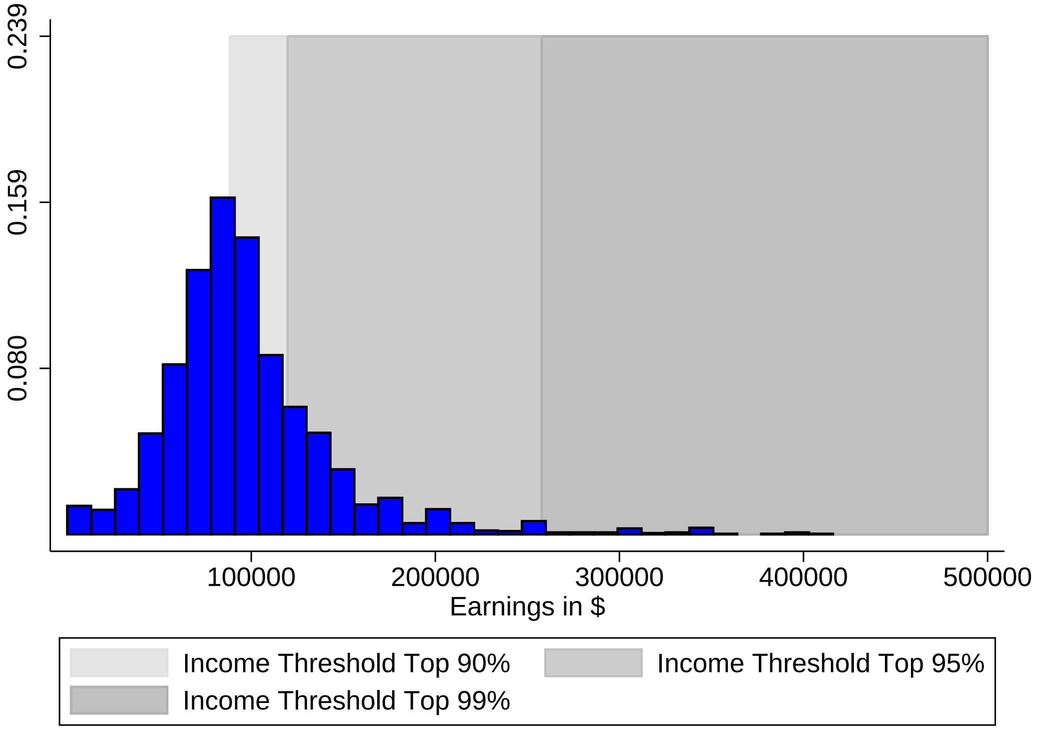
[21] Reassuringly, Kleven, Landais, and Saez (2013) show that the elasticities obtained for football players using the marginal top tax rate versus actual average tax rates are very similar. This hinges on the fact that those football players considered are well above the top tax bracket in terms of earnings.

Figure 2: Distribution of Inventor Earnings in the NSF Survey 2003



Notes: The data is from the 2003 National Survey of College Graduates public-use microdata from NSF (NSF, 2003). The earnings represented are those of the college graduates with at least one patent and who report being currently employed. The sample size is 3142.

stronger if the inventor is closer to the top bracket and foresees a higher chance of landing in the top bracket soon. Again, the interactions of the retention rate with the ranking of the inventor captures the fact that the motivation effect should be stronger the closer people are to the top bracket.

Top tax rate data: The top marginal tax rate is computed including all relevant taxes on labor income: the individual local, state, and national tax rates, the uncapped payroll taxes, and value-added taxes. These series come from Piketty, Saez, and Stantcheva (2014). For U.S. citizens, who are taxed on worldwide income, a special top tax rate is computed for each possible location choice, taking into account the Foreign Tax Credit formula.[22] We drop people in the years in which they are observed in different countries within the same year, as it is not clear what tax rate their yearly income was subject to in those years.

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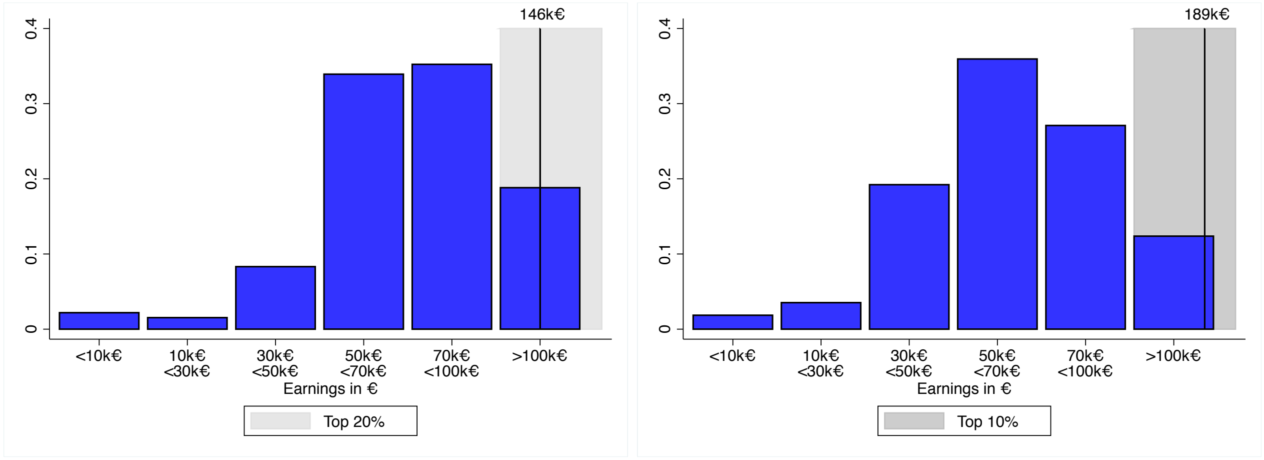
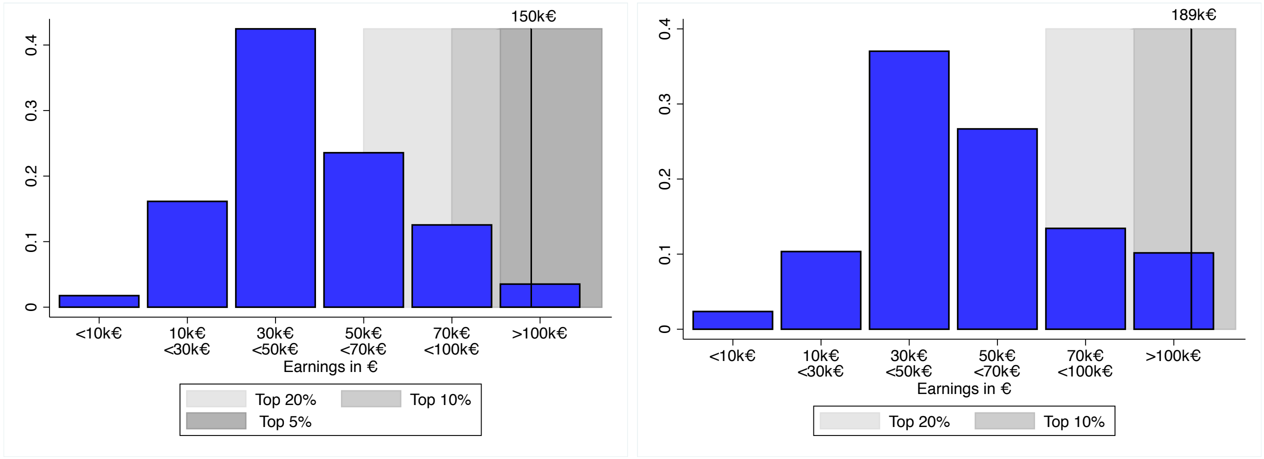
[22] Given the Foreign Tax Credit rules for U.S. citizens, we set the tax rate for U.S. citizen abroad equal to the U.S. tax if and only if the foreign tax rate is smaller than the U.S. tax rate: this was frequently the case before 1985 for the 8 countries under consideration, but not the case anymore after 1985.

Figure 3: Income Distributions of Inventors



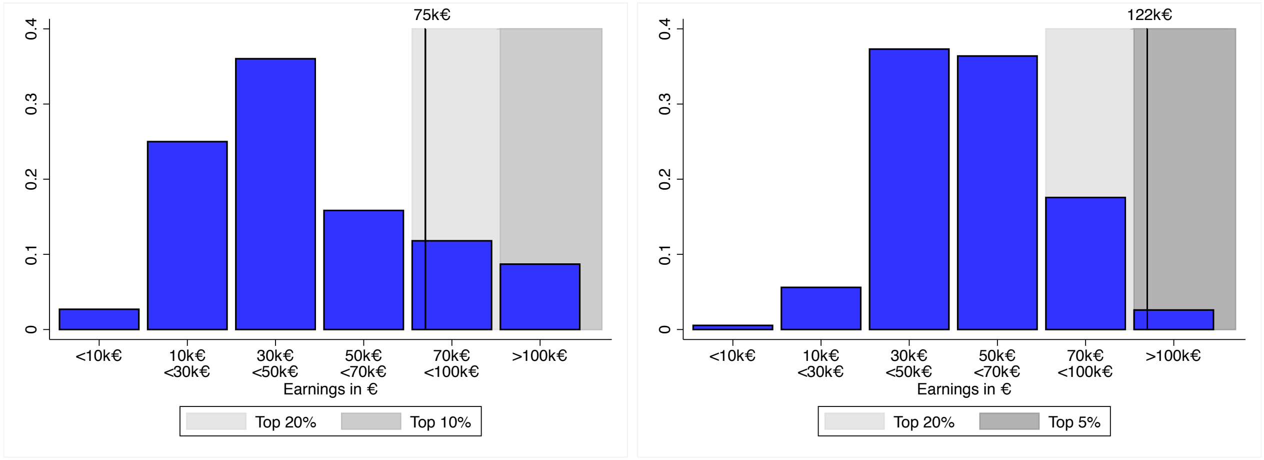
(a) Switzerland

(b) Germany



(c) France

(d) Great Britain



(e) Italy

(f) Japan

Notes: Survey data from Gambardella *et al.* (2014). The number of respondents for each country are: Switzerland: 457, Germany: 3403, France: 1307, Italy: 966, Great Britain: 551, Japan: 2927. The black vertical line represents the top income tax bracket in each country for individuals.

Table 2: Fraction of inventors who stay in home country

	(1) Top 1%	(2) Top 1-5%	(3) Top 5-10%	(4) Top 10-25%	(5) Top 25-50%	(6) Bottom 50%
Elasticity to $1-\tau$	0.165^{**}	0.147^{**}	0.0876^{***}	0.0565^{***}	0.0332	0.0143
	(0.0627)	(0.0577)	(0.0186)	(0.00978)	(0.0255)	(0.0304)
Observations	216	216	216	216	216	216

Notes: OLS regression of the log of the fraction of domestic inventors who remain in their home country each year on the log of the top retention rate. Each column reports results for a subset of inventors, namely those in the top 1%, the top 1-5%, top 5-10%, top 10-25%, top 25-50% and Bottom 50% as ranked by the benchmark measure of citations-weighted patents computed according to formula (1). The coefficients are the elasticities to the top retention rate of domestic inventors in each quality group. All regressions control for year fixed effects, country fixed effects, GDP per capita, and yearly patent stock of the country. Regressions are weighted by the number of inventors in each country. Standard errors clustered at the country level are in parentheses. ${}^{*}p < 0.1, {}^{**}p < 0.05, {}^{***}p < 0.01$

3 Reduced-Form Macro Facts

We start by providing some stylized macroeconomic facts about the correlations between top retention rates and migration. This evidence is suggestive that, even at an aggregate level, there is a significant correlation between migration and top taxes that is concentrated among superstar inventors. While clearly not necessarily disentangling causal effects, these regressions are unlikely to suffer from a reverse causality problem (i.e., that the migration of top inventors (who are a very small fraction of the overall population) induces changes in top tax rates. To capture for potentially contemporaneous macro-level effects, we always include country and year fixed effects.

3.1 Reduced form macro correlations in the inventor data

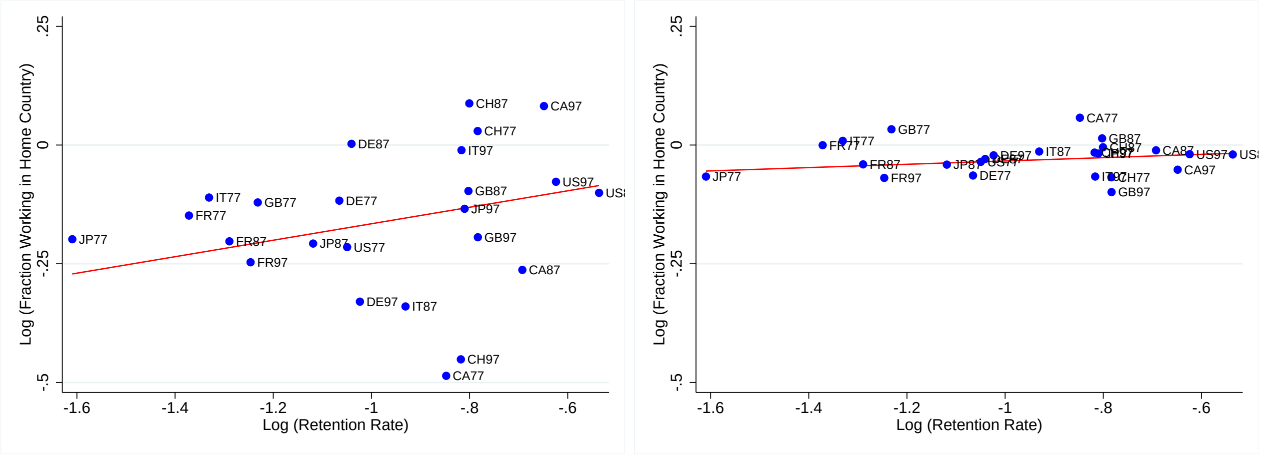
We start by documenting the link between top tax rates and the fraction of domestic inventors who remain working at home. Figure 4 plots the fraction of domestic workers who work in their home country for each country over the period 1977-2003 against the log top retention rate over the same period. The numbers are 8-year country averages and are adjusted for the log GDP per capita, the log patent stock, as well as country fixed effects and year fixed effects. Panel (a) focuses on the superstar inventors, namely those in the top 1% of the quality distribution as measured by citation-weighted patents and as described in detail in Section 2.3. There is a clear positive relationship between top retention rates and the fraction of domestic superstar inventors who remain in their home country. On the other hand, those inventors in the top 25-50% of the quality distribution (panel (b)) and those in the bottom 50% of inventors in panel (c) exhibit an essentially flat relation.

Table 2 shows the corresponding regression results controlling for the country's GDP per capita, yearly patent stock, year fixed effects and country fixed effects. The superstar top 1% inventors are significantly sensitive to top tax rates with an elasticity of 0.165 at the aggregate level. As expected based on the arguments in section 2.4, as we move down the quality distribution of inventors, the elasticity to the top retention rate decreases and becomes insignificant below the top 25%.

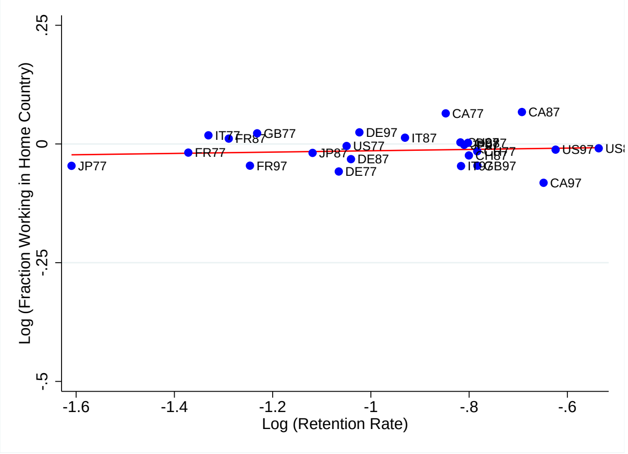
Figure 4: Top $(1-\tau)$ and % of inventors working in home country 1977-2003

(a) Top 1% inventors

(b) Top 25-50% inventors

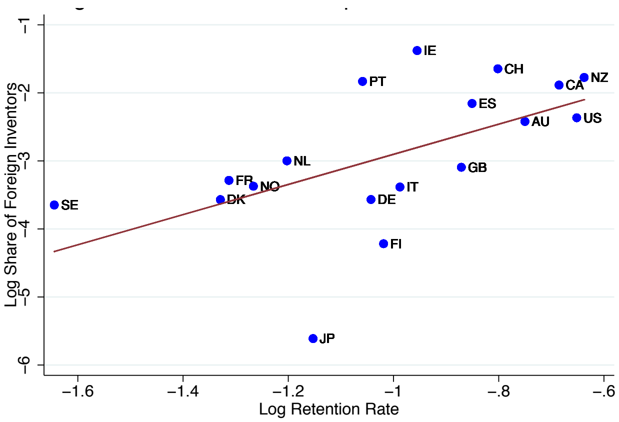


(c) Bottom 50% inventors



Notes: These graphs illustrate the regressions from Table 2. The regression lines are depicted in red. They plot 8-year country averages over the period 1977-2003. FR = France, DE = Germany, IT = Italy, JP = Japan, CH = Switzerland, GB = United Kingdrom, U.S. = United States. In panel (a), the fraction of top 1% inventors working in their home country is defined, for each country and year, as the number of top 1% inventors from that country who remain to work there in that year divided by the total number of top 1% inventors from that country in that year. This fraction is adjusted for the country's yearly patent stock, GDP per capita, country fixed effects and year fixed effects. This is depicted against the top retention rate. Panels (b) and (c) repeat the same analysis for the top 25-50% and the bottom 50% of inventors. While the top 1% of inventors shows a significantly positive relation to top retention rates (with an elasticity of 0.165 according to Table 2, column 1, the top 25-50% and the bottom 50% do not show any significantly positive relation (see also columns 5 and 6 in Table 2.

Figure 5: Taxation and fraction of foreign inventors 1980-2004



Note: Figure based on the PCT data described in Miguelez and Fink (2013). It plots the log share of foreign inventors (number of foreign inventors over the total number of inventors in a given country) against the log of the top retention rate. All numbers are averages over the 1980-2004 period.

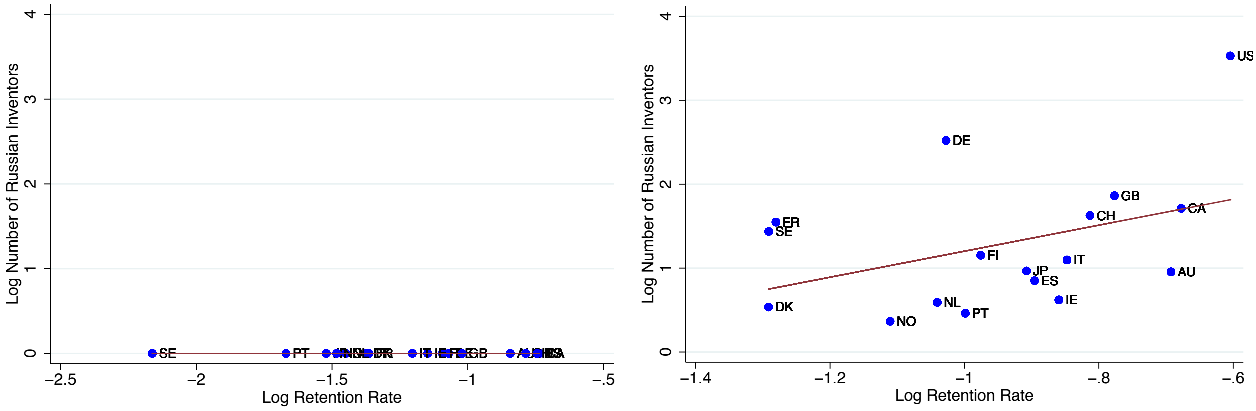
3.2 Cross-check using the Patent Cooperation Treaty data

As an additional piece of macro evidence, we perform a simple graphical analysis using an alternative data source on inventors' locations, introduced in Section 2.3, and described in detail in Miguelez and Fink (2013). This data comes from patent applications filed under the Patent Cooperation Treaty (PCT).

The PCT data contains 54% of all international patent applications, but accounts for only 8% of worldwide filings. Countries are still differentially represented as in the DID. Most importantly, however, only bilateral migration counts are recorded from 1978 to 2012: there is not yet the possibility to track inventors by name over time in a panel, as it is in our benchmark DID. As a result, the migration counts are somewhat biased and, for instance, every inventor could be counted several times as a migrant. There are also no counts of domestic inventors who remain at home. However, the great advantage of this dataset is that it contains nationality information. Figure 5 plots the average share of foreign inventors in each country against the average top retention rate over the period 1980-2004. There is a significantly positive relationship, confirming our earlier macro-level results in the DID.

To exploit the nationality information, we consider a clear-cut migration wave, namely the special case of Russian inventors after the collapse of the Soviet Union. Before 1990, Russia was closed to outmigration, a phenomenon that changed drastically after the change of regime in 1990. Figure 6 plots the average number of Russian immigrants in different countries as a function of the average top retention rate pre and post 1990. Before 1990, the relationship is flat: Russians were not able to react to tax differentials because of stark migration restrictions. By contrast, after 1990, there is a significantly positive relationship between Russian inventors and top retention rates.

Figure 6: Russian inventors' migration and top tax rates



(a) Pre 1990: No possible migration

(b) Post 1990: Migration positively (significantly) correlated to top tax rates.

Note: The figures show the log number of Russian inventors present in each country as a function of the log top retention rate. Panel (a) focuses on the pre-1990 period during which migration was strongly restricted because of the Soviet Union, while panel (b) focuses on the post-1990 period.

We now turn to exploring more rigorously the relation between top tax rates and migration at the inventor level.

4 Location Choice Model Estimation

In this section, we present the resuts from a multinomial location model estimation that exploits variation in top income tax rates across countries, over time, and across the quality distribution of inventors. We first describe the empirical specification considered. We then present our benchmark results and turn to analyzing in more detail the role of companies in the location decision of inventors.

4.1 Specification and Estimation

Utility specification and controls: To model the location choice of innovators, we adopt a multinomial discrete-choice model. Recall from section 2.2 that inventor i in country c at time t obtains utility:

$$U_{ct}^{i} = u\left(\left(1-\tau_{ch^{i}t}\right) w_{ct}^{i}\right) + \mu_{ct}^{i} \tag{5}$$

Assuming log utility, we can rewrite U_{ct}^{i} in (5) as a separable function of the pre-tax earnings and the average tax rate:

$$U_{ct}^{i} = \alpha \log\left(1-\tau_{ch^{i}t}\right) + \alpha \log\left(w_{ct}^{i}\right) + \mu_{ct}^{i} \tag{6}$$

The core of the analysis is to model i) the idiosyncratic preference component μ_{ct}^{i} and ii) the counterfactual wage w_{ct}^{i} as detailed and flexibly as possible.

Controlling for the idiosyncratic preference component: We model the innovator's idiosyncratic preference for any given country at time t as follows. It is assumed to depend on:

i) Individual-level characteristics $\mathbf{x}_{ti}$: These include the inventor's age, his dynamic quality measure, his technological field, and whether he works in a multinational. In addition, we include indicator variables for whether the inventor is in the top 1%, top 1-5%, top 5-10%, or top 10-25% of inventors as ranked by quality and explained in section 2.3. The benchmark measure used is the citations-weighted patents to date, but we consider all of the measures $q1 - q4$ from Formulas (1)-(4). The effect of these individual characteristics is allowed to vary by country.[23] We assign one of six technological fields to the inventor based on the field in which he has most patents. These six fields include chemical, computer and communications, drugs and medical, electrical and electronic, mechanical and others.[24]

ii) Country-level covariates, denoted by $\mathbf{x}_{ct}$: the country's patent stock and GDP per capita, as well as unobservable country characteristics captured by country fixed effects γ_c and, importantly, country-year fixed effects (γ_{ct}).

iii) Controls for inventor-country pairs, denoted by $\mathbf{x}_{cti}$ that capture the quality of a potential "match" between country c and inventor i at time t. First, a home dummy h_{c}^{i} equal to 1 if country c is the home country of inventor i in order to capture a potential home bias. Second, these include the patent stock of country c at time t in the inventor's technological field, which proxies for the quality of professional fit between the inventor and the potential destination country. Third, we include the distance between the inventor's home country and the destination country, and a dummy for whether the home and destination countries have a common language. These could all affect the ease of moving to the potential destination country.

For the more detailed results in Section 4.3 we also consider other country-inventor specific covariates such as the share of the innovative activity of the inventor's company in each destination country.

We hence obtain the econometric specification:

$$U_{cti} = \alpha \log\left(1 - \tau_{ch^{i}t}\right) + \alpha \log\left(w_{cti}\right) + h_{ic} + \mathbf{x}_{ti}\beta_c + \zeta \mathbf{x}_{ct} + \eta \mathbf{x}_{cti} + + \gamma_c + \gamma_t + \gamma_{ct} + v_{cti} \qquad (7)$$

Controlling for the counterfactual wage: One important consideration is how to control for the counterfactual wage w_{cti} that inventor i would receive in any country c at time t, as well as for his actual wage. Part of the wage variation is well absorbed by the aforementioned controls (i)-(iii), which capture aggregate effects at the country-year level and the technological class level. In addition, we consider three more benchmark specifications that progressively add the following,

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[23] That is, these characteristics are all interacted with country fixed effects.

[24] Using a finer classification does not change our results.

more detailed controls:

1) First, we control for the quality of the inventor at time t, interacted with country fixed effects. This controls for aggregate country-specific effects that vary by ability. Our benchmark measure is, as explained in Section 2.3, citation-weighted patents to date. Alternative quality measures are considered in the robustness checks in Table 8. Note that the ability measure for an individual is dynamic and changes over life. However, the measure only depends on past information, and hence avoids endogeneity with current location choices.

2) Second, we add country and ability specific trends, i.e., we control for year times country fixed effect times the ability measure, in order to capture differential evolutions over time in the wage premium in different countries.

3) Finally, we also introduce country, ability and technological field specific trends by controlling for year times country fixed effects times ability times technological field dummies.

Sample and estimation: Denote by $P^i_{ct} \equiv Prob(U^i_{ct} > U^i_{c't}, \forall c')$ the probability of inventor i to locate in country c at time t. If the error term v^i_{ct} has a type I extreme value distribution, this model can be estimated as a multinomial logit.

Our benchmark sample for the multinomial analysis contains an unbalanced panel of those inventors who have *ever* been in the top 25% inventors as defined by citations-weighted patents over their lifetime. We restrict the sample to the 8 countries which account for around 90% of all patents in the USPTO. Hence, in each year, inventors face a choice between the United States, Canada, Germany, Great Britain, France, Japan, Italy and Switzerland.

We include in the regression interactions of the retention rate with dummies for being in the top 1%, in the top 1-5%, in the top 5-10%, in the top 10-25% and below the top 25%.[25]

Computing Elasticities: To go from the coefficients on the retention rate to elasticities, we follow the computations in Kleven, Landais, and Saez (2013) that we present only very briefly here. In the multinomial model, the elasticity of the probability of inventor i of locating in country c at time t to the net of tax rate $(1-\tau^i_{ct})$, denoted by ε^i_{ct}, is:

$$\varepsilon^i_{ct} \equiv \frac{d\log P^i_{ct}}{d\log(1-\tau^i_{ct})} = \alpha(1-P^i_{ct})$$

The authors then define the elasticity of domestic inventors in country c, ε^c_d, and the elasticity of foreign inventors in country c, ε^c_f. Letting I_c and I^f_c be the set of all, respectively, domestic and non-domestic inventors from country c:

$$\varepsilon^c_d \equiv \frac{d\log(\sum_{i\in I_c} P^i_{ct})}{d\log(1-\tau_{ct})} = \frac{\alpha\sum_{i\in I_c} P^i_{ct}(1-P^i_{ct})}{\sum_{i\in I_c} P^i_{ct}} \tag{8}$$

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[25] Note that the sample cut is based on a static measure of inventor quality, namely those who have *ever* been in the top 25% in their lifetime, while the ranking within that sample is dynamic and can change for a given inventor from year to year. Table 8 considers how the results change if we also rank inventors by the static measures.

Similarly:

$$\varepsilon_f^c \equiv \frac{d\log(\sum_{i\in I_c^f} P_{ct}^i)}{d\log(1-\tau_{ct})} = \frac{\alpha\sum_{i\in I_c^f} P_{ct}^i(1-P_{ct}^i)}{\sum_{i\in I_c^f} P_{ct}^i} \tag{9}$$

Average domestic and foreign elasticities, ε_d and ε_f, then are defined as the weighted average elasticities across all countries:

$$\varepsilon_d \equiv \frac{d\log(\sum_c\sum_{i\in I_c} P_{ct}^i)}{d\log(1-\tau_{ct})} = \frac{\alpha\sum_c\sum_{i\in I_c} P_{ct}^i(1-P_{ct}^i)}{\sum_c\sum_{i\in I_c} P_{ct}^i} \tag{10}$$

Similarly:

$$\varepsilon_f \equiv \frac{d\log(\sum_c\sum_{i\in I_c^f} P_{ct}^i)}{d\log(1-\tau_{ct})} = \frac{\alpha\sum_c\sum_{i\in I_c^f} P_{ct}^i(1-P_{ct}^i)}{\sum_c\sum_{i\in I_c^f} P_{ct}^i} \tag{11}$$

4.2 Benchmark Results

Table 3 contains the estimation results using the top marginal retention rate, interacted with dummies for the ranking of inventors in the quality distribution. Column 1 contains all controls i) - iii) described in Section 4.1. The coefficient on the retention rate for the top 1% inventors is significantly positive and large. Below the regression estimates, the table reports the values and the standard errors of the elasticities to the net of tax rate of, respectively, domestic and foreign inventors, as computed from formulas (10) and (11). The elasticity of domestic inventors is close to 0.04, while the elasticity of foreign inventors is 1.29. Consistent with our discussion above, the effect of the top retention rate decreases as we move down the inventor quality distribution. Top 1-5% inventors are still significantly sensitive to the top tax rate, but below the top 5%, the effects become insignificant. The gap between the domestic and the foreign elasticity comes from the fact that most inventors remain in their home country (see formulas formulas (10) and (11)) and hence, the bases on which these elasticities are computed are very different.

In addition to the standard controls, column 2 introduces the ability of the inventor interacted with country fixed effects. Column 3 adds country and ability specific trends and column 4 adds country, ability and tech field specific trends. The effect of the top tax rate on superstar inventors is very stable across the different specifications.

For comparison, Kleven, Landais, and Saez (2013) find that the domestic elasticity of football players is between 0.07 and 0.16, depending on their specification, while the foreign elasticity is between 0.6 and 1.3. The authors suggested that their elasticities might be upper bounds, as football players are highly mobile individuals. In addition, Kleven, Landais, and Saez (2013) only consider the European football market, while we also include mobility between different continents.[26]

We can also compute the elasticities of domestic and foreign inventors country by country, as in formulas (8) and (9). Table 4, columns 1 and 2 show, respectively, the elasticity of domestic and foreign inventors to the top net-of-tax rate. The U.S. and Japan stand out with their relatively low

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[26] Note that the corresponding elasticities in the European patent office data in Section 6, where European countries are more strongly represented, are also larger and closer to the football players' elasticities.

Table 3: Effect of the top retention rate on innovators' mobility

	(1)	(2)	(3)	(4)
Log Retention Rate × Top 1	1.543***	1.641***	1.642***	1.606***
	(3.71)	(3.93)	(3.87)	(3.81)
Log Retention Rate × Top 1-5	1.043**	1.148**	1.142**	1.097**
	(2.73)	(2.99)	(2.93)	(2.84)
Log Retention Rate × Top 5-10	0.737	0.847*	0.839*	0.790*
	(1.94)	(2.23)	(2.17)	(2.06)
Log Retention Rate × Top 10-25	0.432	0.551	0.545	0.497
	(1.16)	(1.48)	(1.44)	(1.33)
Log Retention Rate × Below Top 25	0.187	0.336	0.323	0.290
	(0.50)	(0.89)	(0.84)	(0.76)
Quality× Country FE	NO	YES	YES	YES
Quality × Country FE × Year	NO	NO	YES	YES
Quality×Country FE×Year×Field FE	NO	NO	NO	YES
Domestic elasticity	.037	.039	.038	.038
s.e	(.0098)	(.0098)	(.0101)	(.0098)
Foreign elasticity	1.293	1.381	1.377	1.345
s.e	(.348)	(.351)	(.356)	(.353)
Observations	9274992	9246912	9246912	9246912

Notes: Multinomial logit regressions. Robust standard errors clustered at the inventor level in parentheses. Regressions are based on the inventor data set described in Section 2.3 for the period 1977-2003. The data includes inventors in 8 countries: Canada, France, Germany, Great Britain, Italy, Japan, Switzerland, and the United States. All columns contain the following controls also listed in the text. In terms of country-level controls, we include country fixed effects, country-year fixed effects, country patent stock, country GDP per capita. In terms of country-inventor pair controls, we include a home country dummy, the patent stock of the country in the inventor's technological field, the distance between the inventor's home and the country, and a dummy for whether the country shares a common language with the inventor's home country. The following inventor-level variables are all included and interacted with country fixed effects: inventor age, technological field of the inventor, a dummy for whether the individual works in a multinational firm. All columns also contain indicator variables for whether the inventor is in the top 1, top 1-5, top 5-10, top 10-25 or below the top 25 of inventors as ranked by quality and explained in section 2.3. Column 2 contains in addition the inventor's citations-weighted patent stock to date interacted with country fixed effects. Column 3 contains quality and country-specific time trends. Column 4 contains quality, country and technological field specific time trends. The first row reports the coefficient on the log retention rate interacted with an indicator variable for being in the top 1 of inventors. The second, third, fourth and fifth rows, respectively, report the coefficients from the retention rate interacted with being in, respectively, the top 1-5, top 5-10, top 10-25 and below the top 25 of inventors. "Domestic elasticity" is the elasticity of domestic players with respect to a change in the domestic retention rate, while "Foreign elasticity" is the elasticity of foreign players with respect to a change in the foreign retention rate. They are computed, respectively, according to formulas (10) and (11). $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

elasticities of both foreign and domestic inventors, while inventors from Great Britain and Canada are particulary elastic. France, Italy and Switzerland have moderately elastic domestic inventors, but highly elastic foreign inventors. Columns 3 and 4 compute the percent change in, respectively, domestic and foreign inventors for a 10 percentage point top tax rate reduction from the actual level in each country. At the low end of the spectrum, the U.S. would gain 0.1% domestic inventors, Japan 0.3%, and Denmark 1.9%. At the high end of the spectrum, Great Britain and Canada would gain, respectively, 10.6% and 7.9% domestic inventors. At the same time, the US would gain

Table 4: Migration Elasticities across Countries

Country	Domestic elasticity	Foreign elasticity	% change in domestic inventors	% change in foreign inventors
United States	0.004	1.25	0.1%	23.7%
Great Britain	0.48	1.60	10.6%	35.1%
Canada	0.41	1.59	7.9%	30.6%
Denmark	0.07	1.57	1.9%	43.8%
France	0.17	1.59	6.1%	56.4%
Italy	0.18	1.59	4.0%	35.5%
Japan	0.02	1.59	0.3%	32.6%
Switzerland	0.24	1.59	5.5%	36.1%

Notes: Elasticities per country are calculated for the year 2000. To compute the percent change in domestic inventors and the change in foreign inventors, we consider a 10 percentage points decrease in taxes their actual level in the country. Similar changes can of course be computed for any percentage point change in taxes.

23.7% foreign inventors, while France would gain 56.4% foreign inventors.[27]

Economic Gains from Lower Taxes: A back of the envelope calculation can reveal the yearly economic gain from lower taxes through the channel of inventor migration. Suppose that top retention rates in country c change by $d(1-\tau_{ct})$. We compute the economic value gained from attracting more domestic and foreign top 1% superstar inventors as:

$$dV_{ct} = \frac{d(1-\tau_{ct})}{(1-\tau_{ct})} \times (\varepsilon_d^c \times N_c^d + \varepsilon_f^c \times N_c^f) \times N_p \times V_p \tag{12}$$

where ε_d^c and ε_f^c are as defined in equations (8) and (9), N_c^d and N_c^f are the number of, respectively, domestic and foreign inventors who live in country c, N_p is the average number of patents per year of top 1% superstar inventors (2.7 in our sample), and V_p is the value per patent.

To assign an average value per patent, we first follow Giuri *et al.* (2007) who find that in the PatVal survey of inventors, the average value per patent is 3 million euros (equivalently, 3.3 million USD). This is likely to be an understatement of the value of the patents from superstar top 1% inventors. Indeed, the top 3% most valuable patents are worth between 30 million and 100 million euros, with the top 1% worth more than 100 million euros. Given that top 1% superstar inventors are also responsible for the most valuable patents, we can perform a second calculation assuming a value per patent for the superstar top 1% inventors of 100 million euros (112 million USD). These two calculations are shown in table 5 for a 5 percentage point tax change and for a 10 percentage point tax change.

The economic gains per country from decreasing top tax rates depend on the domestic and foreign elasticities (in Table 4), but also on the size of the inventor base. The U.S. has the largest

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[27] Note that the heterogeneous elasticities of migration to tax rates across countries could be another reason for why some countries can tax more than others (Kleven, 2014).

Table 5: Economic Gains Across Countries (in million USD)

Country	Small Patent Value: 5% points tax change	Small Patent Value: 10% points tax change	Large Patent Value: 5% points tax change	Large Patent Value: 10% points tax change
United States	84	168	2,796	5,593
Great Britain	24	48	795	1591
Canada	26	51	852	1,704
Germany	26	52	871	1,742
France	16	33	546	1,091
Italy	4	9	145	289
Japan	12	25	416	832
Switzerland	8	16	267	535

Notes: All numbers are in millions. Elasticities per country are calculated for the year 2000. To compute the change in domestic inventors and the change in foreign inventors, we consider a 10 percentage points decrease in top tax rates from the actual tax rate in each country. The economic gain per year is computed as in formula (12). Columns 1 and 2 assume a patent value per superstar top 1% inventor equal to the average patent value across all inventors from Giuri *et al.* (2007) (3 million). Columns 3 and 4 assume a large patent value equal to the top 3% percentile of the patent value distribution in Giuri *et al.* (2007). These effects could be underestimating the economic value lost if there are positive spillovers from having superstar inventors locally (as documented in the papers cited in the Introduction and in Section 2.3.

economic gain, despite the small elasticities, while Italy has the smallest economic gains, which is a combination of a relatively low elasticity of domestic inventors and a relatively small inventor base.

These effects could be underestimating the economic value lost if there are positive spillovers from having superstar inventors locally (as documented in the papers cited in the Introduction and in Section 2.3. To a first-order we could imagine that they would scale up for a tax decrease that lasts several years.

4.3 The Role of Companies

What is the role of employers in determining inventors' mobility? One might expect that role to be important. Indeed, large companies often recruit internationally. In the U.S., Qualcomm Inc. and Microsoft have an immigration rate (ratio of foreign inventors to total inventors in the company) of, respectively, 51% and 57%. In Switzerland, Alstom Technology Ltd. and Syngenta Participation AG both have immigration rates of 67%.[28] The employer might affect the inventor's elasticity to taxation through several possible channels. The most important and natural consideration is whether the inventor works for a multinational company. In theory, the effects on international mobility of working for a multinational company are ambiguous. On the one hand, it might make an international move easier for the worker either directly within the company, or by giving him access to a wider international network built over the course of his career in a multinational. Of

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[28] WIPO report available at `http://www.wipo.int/edocs/pubdocs/en/intproperty/941/wipo_pub_941_2013.pdf`.

Table 6: The Role of Companies for Inventor Mobility

	(1)	(2)
Log Retention Rate × Top 1	1.417***	1.767***
	(0.316)	(0.488)
Log Retention Rate × Top 1-5	0.827**	1.312**
	(0.276)	(0.427)
Log Retention Rate × Top 5-10	0.463	1.077*
	(0.272)	(0.424)
Log Retention Rate × Top 10-25	0.0946	0.833*
	(0.264)	(0.412)
Log Retention Rate × Below Top 25	-0.308	0.705
	(0.273)	(0.419)
Log Retention Rate × Not multinational	-0.239*	
	(0.124)	
Log Retention Rate × Activity abroad		-0.545***
		(0.133)
Quality× Country FE	YES	YES
Quality × Country FE × Year	YES	YES
Quality×Country FE×Year×Field FE	YES	YES
Domestic elasticity	.035	.529
s.e	(.0077)	(.1464)
Foreign elasticity	1.206	1.743
s.e	(.267)	(.481)
Observations	7669176	8015760

Notes: Multinomial logit regressions. Robust standard errors clustered at the inventor level in parentheses. See the explanatory footnote to table 3. All regressions contain the same covariates as in table 3, column 4. Column 1 adds an interaction term of the log retention rate with whether the inventor was employed by a non-multinational company in the last period observed. Employees from non multinationals appear significantly less sensitive to the tax rate, which can indicate that they are less able to move internationally to take advantage of lower taxes. Column 2 adds as a control the share of innovative activity of the inventor's company that takes place in the destination country and an interaction of the activity share with the top retention rate. Inventors are significantly less sensitive to the top tax rate in any destination country if their company has a large share of its innovative activity in that country. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

course, workers more likely to take advantage of tax differentials in the future could also simply self-select into a multinational with the expectation to move in response to tax rates. On the other hand, if the company at least partially participates in the decision about the worker's location, it might bring to the table other considerations for relocating the worker, which are orthogonal to the personal income tax rate. In this latter case, the observed sensitivity to the top personal income tax rates should be lowered.

Column 1 of Table 6 reports the results from the benchmark specification, adding the interaction of the top retention rate with a dummy equal to 1 if the inventor did *not* work for a multinational company in the previous period during which he was observed in the sample. Inventors who are not in multinationals are significantly less sensitive to the top tax rate. It seems, then, that working for a multinational company facilitates taking advantage of tax differentials.

Next, we compute the share of innovative activity of the inventor's company that takes place in each potential destination country. The share of innovative activity in a given country is defined as the fraction of yearly patents of the company assigned to inventors from that country. Column 3 shows that if the company of the inventor has a higher share of its innovative activities in some destination country, the inventor is less sensitive to the retention rate in that destination country. The elasticity for those inventors whose company has no share of activity in the foreign country is very large, but declines very rapidly in the share of activity abroad.

This has at least two possible interpretations, following the two hypotheses raised above. First, a higher activity share abroad might mean that the idiosyncratic preference μ of the inventor is large for that destination country, due to for instance career concerns, and this difference is sufficiently large to outweigh tax differentials. Second, if the company plays a role in the decision to relocate the inventor, it might want to relocate inventors to high activity places for reasons unrelated to the personal income tax. In either case, the inventor will appear to be less sensitive to tax rates.

4.4 General Equilibrium and Sorting Effects

The migration of some inventors can have general equilibrium effects and spillovers on other inventors, depending on the structure of the labor market. For instance, if demand for inventors by companies in different countries is rigid, a lower top tax rate could lead to sorting by higher quality inventors, to the detriment of lower quality inventors.[29]

The country-year fixed effects included in all regressions in Tables absorb aggregate country-year changes such as a higher supply of high quality inventors, and of the changes in labor market rigidities in different countries over time. To gauge the importance of general equilibrium and sorting effects, table 7 repeats the same regressions as table 3, but replacing the year-country fixed effects by less flexible country-specific *linear time trends*. These trends of course leave out a lot of variation at the country-year level. Sorting and general equilibrium effects now are loaded on the coefficients of the interactions of the log retention rate with the quality rankings of inventors.

The results are quite different from the results with country-year fixed effects. The top 1% of inventors is less sensitive to top retention rates: the domestic elasticity is reduced by 35% to 0.024. In addition, the elasticity declines rapidly as one moves down the quality distribution for inventors, and, strikingly, becomes negative for below top 10% inventors (and significantly so for below top 25% inventors). One possible interpretation for this pattern of results is that, indeed, a high influx of top 1% and top 5% inventors displaces lower quality inventors.[30]

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[29] Kleven, Landais, and Saez (2013) also explore sorting effects in a rigid demand model for football players.

[30] Another possible interpretation, is that there are direct aggregate effects of the top tax rate through tax revenue, which benefits lower quality inventors. This, however, does not seem important, since controling for total tax revenue per capita in country c and time t leaves the elasticities to tax rates at different quality levels entirely unchanged.

Table 7: Exploring general equilibrium effects

	(1)	(2)	(3)	(4)
Log Retention Rate × Top 1	0.963***	0.964***	1.032***	1.021***
	(4.83)	(4.78)	(5.03)	(4.95)
Log Retention Rate × Top 1-5	0.460***	0.468***	0.531***	0.512***
	(3.59)	(3.62)	(4.10)	(3.94)
Log Retention Rate × Top 5-10	0.153	0.167	0.230*	0.207
	(1.38)	(1.50)	(2.12)	(1.90)
Log Retention Rate × Top 10-25	-0.153	-0.131	-0.0633	-0.0851
	(-1.69)	(-1.45)	(-0.74)	(-0.99)
Log Retention Rate × Below Top 25	-0.401***	-0.350**	-0.281*	-0.290*
	(-3.63)	(-3.03)	(-2.44)	(-2.50)
Quality× Country FE	NO	YES	YES	YES
Quality × Country FE × Year	NO	NO	YES	YES
Quality×Country FE×Year×Field FE	NO	NO	NO	YES
Domestic elasticity	.024	.024	.025	.025
s.e	(.0046)	(.0045)	(.0048)	(.0049)
Foreign elasticity	.808	.808	.865	.856
s.e	(.166)	(.169)	(.172)	(.174)
Observations	9274992	9246912	9246912	9246912

Notes: Multinomial logit regressions. Robust standard errors clustered at the inventor level in parentheses. See the explanatory footnote to table 3. All regressions contain the same covariates as in table 3, column 4, except that the year-country fixed effects have been replaced by country specific linear time trends. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

5 Alternative Specifications and Extensions

This section provides an extensive series of robustness checks and extensions of our benchmark results.

5.1 Inventor quality measures

Our measure of inventor quality and the corresponding ranking of inventors is central to our analysis. Therefore, we here explore how the results change if we consider the different quality measures.

Static versus dynamic measures, wage formation and employer expectations: Our use of the lagged dynamic citations-weighted patent stock as the main quality measure of an inventor assumes that only the current quality matters for income. This corresponds to a situation in which the employer has no foresight at all about the inventor's future potential or there are no job search and matching frictions that would prevent firms from firing a worker and hiring a better one in a future period in which information about the inventor's quality is revealed. Symmetrically, it also implies that past experience, conditional on the current value of the quality measure, no longer matters.

However, suppose that the employer has additional information about the inventor's current ability that is not necessarily reflected in his current patents, either based on past experiences or

TABLE 8: ROBUSTNESS CHECKS

	Alternative quality Measures				Imputing location
	(1)	(2)	(3)	(4)	(5)
Log Retention Rate × Top 1-5	1.283**	0.737*	1.679***	1.442***	1.166***
	(3.29)	(2.33)	(3.82)	(3.75)	(3.69)
Log Retention Rate × Top 5-10	0.786*	0.593	1.127**	0.896*	0.923**
	(1.99)	(1.93)	(2.61)	(2.35)	(2.98)
Log Retention Rate × Top 10-25	0.518	0.586	0.512	0.509	0.733*
	(1.35)	(1.95)	(1.20)	(1.37)	(2.44)
Log Retention Rate × Below Top 25	0.355	1.165***	-0.193	0.385	0.820**
	(0.75)	(3.79)	(-0.45)	(1.02)	(2.71)
Quality× Country FE	YES	YES	YES	YES	YES
Quality × Country FE × Year	YES	YES	YES	YES	YES
Quality×Country FE×Year×Field FE	YES	YES	YES	YES	YES
Domestic elasticity	.035	.009	.021	.04	.041
s.e	(.0097)	(.006)	(.005)	(.0095)	(.0091)
Foreign elasticity	1.276	.561	2.002	1.563	1.353
s.e	(.342)	(.361)	(.459)	(.363)	(.302)
Observations	9246912	11563176	9032456	8644176	18395768

Notes: Multinomial logit regressions. Robust standard errors clustered at the inventor level in parentheses. See the footnote to table 3. All regressions contain the same covariates as in table 3, column 4. Column 1 uses the lifetime measure of inventor ranking ("has ever been in top 1," etc..). Column 2 uses the patent count to date as a measure of quality and to establish the rankings of top5, top10, etc.. Column 3 uses as a quality and rank measure the inventor's average citations per patent to date. Column 4 uses the max citations per patent of an inventor to date. Column 5 is based on a balanced panel, where inventors' location for years in between patents is imputed. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

future expectations. To take a concrete example from academia, a university might hire a promising young Ph.D. graduate without any publication or patent record, based on his revealed skills during conversations and seminars. This new hire may have a high marginal product as measured by his impact on graduate students and colleagues that is not yet reflected in his publication record. Alternatively, a senior professor with several very high impact publications, but who is no longer producing at a level that would classify him in the current top 1% of researchers is probably still highly paid based on his past record.

In both these situations, a more appropriate measure of the wage would be based on a lifetime, static quality. In particular, we can redefine an inventor as being in the top 1% of inventors if, over the course of his life, he will *ever* be in the top 1%. The results for this alternative quality measure are in column 1 of Table 8. The elasticity measure is only very slightly lower than the benchmark (column 4 in Table 3). In reality, wages are probably set to some extent based on current marginal product and to some extent based on potential and past information, especially if there are search and matching frictions that make the employer want to lock in promising employees. It is hence reassuring that even a fully static measure still maintains our main result.

Patent quality versus quantity measures: As described in section 2.3, there are several different quality measures based on patents and citations that put different emphasis on the quality versus the quantity of patents. The correlations of these various measures, although significantly positive at the 5% level, are nevertheless small. For instance, the correlation between measure $q1$ (citations-weighted patents) and $q2$ (number of patents) is 0.70, the correlation between $q1$ and $q3$ (average citations per patent) is 0.32 and the correlation between $q2$ and $q3$ is only 0.05 (see the full correlation matrix in Appendix Table A.1). Hence, these measures capture different aspects of an inventor's skill.

Therefore, we provide three more tests by using patent counts ($q2$), average citations per patent ($q3$), and max citations per patent ($q4$) as alternative measures. The worry about using a purely quantity based measure, such as the patent count, is that the number of patents also affects the likelihood of observing an inventor in the data and, consequently, the likelihood of observing a move. Hence, the observed relation could be mechanical. However, column 2 of Table 8 reassures us that the results are not artificially driven by observing people with more patents more frequently. Using simple patent counts, the coefficient on the top retention rate becomes much smaller and close to insignificant for top 1% inventors. Using average citations per patent, as in column 3, maintains our benchmark results, while using the max citation per patent as a quality measure as in column 4 even strengthens our results.

5.2 Accounting for potential selection

One problem about using the patent data to track inventors' locations is that we only observe inventors in years in which they patent, but not in the years between consecutive patents. We perform two checks to address this problem. First, we make sure that the results do not change much when we impute the inventors' locations for missing years. Second, we estimate a selection model.

Imputing location for missing years: To impute observations for years in which inventors do not patent, we use the following imputation algorithm: if the inventor is seen in country A in year X and in country B in year $Y > X$, we assume that he has been in country A until year $X + (Y - X)/2$ and in country B thereafter and until year Y. We do not impute years before the first or after the last patent. Column 5 of Table 8 shows that the elasticity, if anything, increases when we use the imputed data.

Binary Selection Model: To check for selection based on the number of patents, we also use a formal selection model. To simplify the computational burden, we only study the mobility between the U.S. and Canada. The U.S.-Canada corridor is very large and among inventors who migrate within this corridor, very few also migrate to another country. Among 1,047,251 U.S.-born inventors, 987 are observed only in Canada later, while 69 are observed both in Canada and some other country. Among 55,748 CA-born inventors, 1,334 are observed only in the U.S. later and 42 are observed both in the U.S. and some third country.

First, we estimate a simple probit model where the dependent variable takes the value 1 if an inventor locates in the U.S. The dependent variables are analogous to the ones described in Section 4.1, with some small modifications. Again, we include the same set of controls i)-iii), and we consider progressively more detailed specifications for the counterfactual wages, by adding quality measures, quality-country specific trends and quality-country-field specific trends. The retention rate is the U.S. top retention rate, interacted with inventor rankings (top 1%, top 1-5%, ..).

Next, we perform a formal Heckman selection model with exactly the same controls and compare its results with those from the simple probit model without selection. We exploit a reform enacted in 1995 and introduced by the "Patent Term and Publication Reform Act of 1994" to synchronize patent terms with requirements of the Uruguay Round Agreements Act. The main changes were that the patent term of 17 years (counted from the patent grant year) was changed to 20 years from the patent's earliest application year. Given that on average the patent grant period is less than 3 years, this is typically an effective increase in the patent term.[31] In addition, the fact that protection is granted right from the application should also increase the incentive to file a patent faster as it gives a protection from infringement from an earlier stage. It should be particularly true for patents in fast-changing technologies. Hence, we use a dummy for post-1994 in our selection model.

Table 9 shows the results from the simple probit model and the corresponding selection model for all specifications. It confirms that the coefficients remain very similar after controlling for selection. To sum up, the results using imputed data showed that imputing missing years leaves the results unaffected (column 5 in table 8). The results from section 5.1 using patent count as a quality measure showed that the relation between patenting and moving was not mechanical. Combined with the formal selection model results, this tends to show that selection based on patenting is likely not the driver of our results.

Sample selection: One might be worried that the choice of patenting in the USPTO is not innocuous for foreign inventors: First, it could be that inventors who plan to migrate to the U.S. tend to patent more heavily in the USPTO. This would tend to make the observed sample more mobile on average than a fictitious sample in which inventors are randomly assigned to patent offices. On the other hand, however, conditional on appearing in the sample, those who had planned to migrate to the U.S. (and, accordingly, had decided to patent with the USPTO) may not be driven at all by tax considerations, which would tend to reduce the elasticity to taxes. To address this issue we first repeat the analysis on inventors who patent with the EPO: those inventors are for the majority Europeans and hence should naturally patent with the EPO. These results are presented in Section 6 and confirm our previous results. Second, since Japanese inventors account for the largest fraction of foreign patents in the U.S., we repeat the analysis in Appendix Table A.2,

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[31] In a study conducted by Dennis Crouch, out of 50,000 patents examined, the effective protection under the new system increased for 64% of patents. The full discussion is available here: `http://patentlyo.com/patent/2010/12/one-of-the-most-important-attributes-of-a-patent-is-its-term-or-duration-of-enforceability-in-1995-the-us-patent-system-beg.html`

dropping Japanese inventors. This retains the significance of the tax effect on superstar inventors, and even increases the elasticity.

TABLE 9: HECKMAN SELECTION MODEL ON CANADA-U.S.

	(1) Probit	(2) Selection	(3) Probit	(4) Selection	(5) Probit	(6) Selection	(7) Probit	(8) Selection
US log retention rate × Top 1	1.184***	1.182***	1.225***	1.224***	1.274***	1.276***	1.265***	1.265***
	(4.23)	(4.22)	(4.36)	(4.35)	(4.52)	(4.52)	(4.49)	(4.49)
US log retention rate × Top 1 - 5	0.215	0.215	0.242	0.241	0.307	0.310	0.275	0.276
	(1.08)	(1.08)	(1.21)	(1.21)	(1.54)	(1.56)	(1.39)	(1.39)
US log retention rate × Top 5 - 10	0.119	0.121	0.142	0.139	0.212	0.212	0.184	0.183
	(0.77)	(0.78)	(0.92)	(0.90)	(1.36)	(1.37)	(1.18)	(1.18)
US log retention rate × Top 10 - 25	0.115	0.118	0.128	0.125	0.211*	0.212*	0.172	0.172
	(0.94)	(0.96)	(1.04)	(1.02)	(1.71)	(1.72)	(1.40)	(1.39)
US log retention rate × Below top 25	-0.0266	-0.0255	-0.0168	-0.0191	0.0822	0.0857	0.0496	0.0504
	(-0.22)	(-0.21)	(-0.14)	(-0.16)	(0.63)	(0.66)	(0.38)	(0.38)
US log retention rate × Top 1		0.388***		0.112		0.799***		0.528***
		(5.87)		(1.60)		(10.11)		(6.66)
US log retention rate × Top 1 - 5		0.214***		-0.0198		0.678***		0.378***
		(4.15)		(-0.36)		(10.21)		(5.77)
US log retention rate × Top 5 - 10		0.0858*		-0.121**		0.574***		0.250***
		(1.71)		(-2.24)		(8.92)		(3.98)
US log retention rate × Top 10 - 25		0.0371		-0.114**		0.574***		0.225***
		(0.77)		(-2.20)		(9.31)		(3.75)
US log retention rate × Below top 25		0.111**		-0.00660		0.763***		0.408***
		(2.31)		(-0.13)		(12.63)		(6.94)
Quality× Country FE	NO	NO	YES	YES	YES	YES	YES	YES
Quality × Country FE × Year	NO	NO	NO	NO	YES	YES	YES	YES
Quality×Country FE×Year×Field FE	NO	NO	NO	NO	NO	NO	YES	YES
Observations	612966	1247867	612966	1247867	610853	1245754	610853	1245754

Notes: Estimation a sample limited to the United States and Canada. Probit regressions in columns (1), (3), (5), and (7), with dependent variable equal to 1 if the inventor locates in the United States. Heckman selection estimations in columns (2), (4), (6) and (8), using a dummy for post-1994 as an instrument. Robust t-statistics clustered at the inventor level in parentheses. All column pairs contain the same covariates as the columns of Table 3. The probit and selection models yield very similar coefficients on the interaction of top 1% inventors and the U.S. top retention rate. $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

5.3 Long-term Mobility

The mobility of inventors has different economic implications if it is short-term versus long-term. In this section, we consider the effects of taxation exclusively on long-term mobility. We define a long-term move as a move that is never followed by a move back to the origin country during the time the inventor is in the sample. Recall that the average time in the benchmark sample for an inventor is 12.1 years. We expect long-term mobility to be much less sensitive to contemporaneous tax rates, since people should normally re-optimize only once future tax changes happen. Still, long-term mobility could be correlated with tax changes if tax changes are highly persistent and people are aware of this fact, or if people overestimate the persistence of tax changes and are then faced with moving costs that prevent them from moving back during the average period of 12.1 years that we observe them. Indeed, the results in column 1 of Table 10 confirm that long-term mobility is less sensitive to tax rates, but still significantly affected by it. However, for long-term moves, it does not seem to matter whether the inventor works for a multinational (column 2) or how concentrated the research activity of the employer is (column 3).

6 European Patent Office Inventors

All our results until now used the DID, derived from the USPTO. This data is naturally heavily dominated by U.S. inventors.[32] Therefore, it is very valuable to test whether the sensitivity of superstar inventors to top tax rates also holds in the European Patent Office (hereafter, EPO) data. The disambiguation of the EPO data has only recently been done and is the subject of ongoing research efforts (see Coffano and Tarasconi (2014), Breschi, Lissoni, and Tarasconi (2014)).

In this data, the representation of the same 8 countries we used for our benchmark analysis is as follows: Canada accounts for 1.3%, Switzerland for 3.3%, Germany for 23.7%, France for 7.7%, Great Britain for 6.2%, Italy for 3.8%, Japan for 16.4% and the U.S. for 27.5%. Hence, the biggest difference is the reduced share of the U.S. in the data. The construction of all variables and the sample is the same as for the benchmark analysis. For consistency, we also consider the exact same 8 countries. Appendix Table A.3 provides some summary statistics for the European patent office data.

Table 11 provides the counterpart of the benchmark results in Table 3 for the EPO data. We see the same pattern as in the DID: Superstar inventors are most sensitive to the top tax rate, but the effect declines as we move down the quality distribution of inventors. However, unlike in the DID, the effects remain strongly significant at all ability levels. In addition, the elasticities are consistently larger in the EPO data. This is not surprising, given that European countries are more represented in this data and mobility is easier across European countries.

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[32] In addition, as previously mentioned, foreigners who patent in the USPTO might be a more prone to moving to the U.S.

Table 10: Long-term mobility

	(1)	(2)	(3)
Log Retention Rate × Top 1	2.065**	1.600***	1.945**
	(0.649)	(0.471)	(0.747)
Log Retention Rate × Top 1-5	1.625**	1.134**	1.562*
	(0.597)	(0.410)	(0.622)
Log Retention Rate × Top 5-10	1.133	0.568	1.115
	(0.585)	(0.400)	(0.608)
Log Retention Rate × Top 10-25	0.901	0.267	0.938
	(0.577)	(0.391)	(0.597)
Log Retention Rate × Below Top 25	0.723	-0.117	0.808
	(0.584)	(0.402)	(0.608)
Log Retention Rate × Not multinational		-0.219	
		(0.171)	
Log Retention Rate × Activity abroad			-0.265
			(0.199)
Quality× Country FE	YES	YES	YES
Quality × Country FE × Year	YES	YES	YES
Quality×Country FE×Year×Field FE	YES	YES	YES
Domestic elasticity	.026	.02	.415
s.e	(.008)	(.0058)	(.1591)
Foreign elasticity	1.713	1.345	1.931
s.e	(.537)	(.394)	(.743)
Observations	8972248	7428552	7773552

Notes: Multinomial logit regressions. Robust standard errors clustered at the inventor level in parentheses. See the footnote to table 3. All regressions contain the same covariates as in table 3, column 4. The sample is restricted to only include long-term movers, defined as inventors who move without coming back during their time in the sample. Column 2 adds an interaction of the log retention rate with not having being the employee of a multinational firm in the previous period. Column 3 adds as a control the share of activity of the inventor's company in the destination country and an interaction of the activity share with the top retention rate. $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

7 Conclusion

In this paper, we consider the effects of taxation on the international mobility of inventors, who are economically highly valuable agents and key drivers of economic growth. We put particular emphasis on superstar inventors, those with the most and most valuable inventions. We use disambiguated inventor data, based on USPTO and EPO data, to track the international location of inventors over time, and combine it with effective top marginal tax rate data. We exploit variations in the top tax rate across time and countries, as well as its differential impact on inventors at different points in the quality distribution.

We first provided stylized macroeconomic facts that highlight the responses of superstar inventors to top taxes. We then estimate a multinomial location model and find that the baseline elasticity of the number of domestic inventors to the net-of-tax rate is small around 0.04. This translates into an increase of 1% in domestic inventors at home (on average) for a 10 percentage points decrease in top tax rates. The elasticity declines as one moves down the quality distribution

Table 11: Inventor mobility in the European Patent Office data

	(1)	(2)	(3)	(4)
Log Retention Rate × Top 1	3.214^{***}	2.828^{***}	4.177^{***}	3.248^{***}
	(9.20)	(10.07)	(10.11)	(8.58)
Log Retention Rate × Top 1-5	3.033^{***}	2.788^{***}	3.668^{***}	2.823^{***}
	(10.43)	(13.87)	(15.33)	(13.53)
Log Retention Rate × Top 5-10	2.841^{***}	2.622^{***}	3.391^{***}	2.555^{***}
	(10.49)	(15.17)	(17.43)	(14.57)
Log Retention Rate × Top 10-25	2.338^{***}	2.130^{***}	2.840^{***}	1.989^{***}
	(8.91)	(13.27)	(16.54)	(11.79)
Log Retention Rate × Below Top 25	1.981^{***}	1.773^{***}	2.442^{***}	1.573^{***}
	(6.54)	(8.08)	(10.95)	(6.84)
Quality× Country FE	NO	YES	YES	YES
Quality × Country FE × Year	NO	NO	YES	YES
Quality×Country FE×Year×Field FE	NO	NO	NO	YES
Domestic elasticity	.058	.051	.078	.058
s.e	(.0065)	(.0051)	(.0078)	(.0069)
Foreign elasticity	3.142	2.746	4.047	3.123
s.e	(.34)	(.273)	(.4)	(.364)
Observations	7538603	7532627	7532627	7532627

Notes: Multinomial logit regressions on data from the EPO. Robust standard errors clustered at the inventor level in parentheses. See the explanatory footnote to table 3. All regressions contain the same covariates as the same columns in table 3. $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

of inventors. The elasticity of the number of foreign inventors to the net-of-tax rate is much higher, around 1.3, which translates into a 38% increase in domestic inventors for a 10 percentage points decrease in top tax rates. Inventors who have worked for multinationals in the previous period are more likely to take advantage of tax differentials, possibly because working for a multinational makes a move abroad easier and grants the inventor international exposure. On the other hand, inventors whose company has a research activity that is highly concentrated in a given country are less sensitive to tax differentials in that country, presumably because career concerns (being located where the company's main research activity is) outweigh tax considerations. We also find evidence for sorting effects by ability and negative spillovers from high quality to low quality inventors.

We then perform extensive robustness checks on the measures of earnings and quality used, the length of the migration spells studied, and the potential selection based on patenting behavior. Our results strongly persist. We also reproduce the analysis on an alternative new disambiguated inventor dataset based on European Patent Office filings and find larger baseline elasticities to the net-of-tax rate of 0.06 of domestic inventors.

These results suggest that, if the economic contributions of these key agents is very important, their migratory responses to tax policy might represent a cost to tax progressivity. Our estimates could fruitfully be used to calibrate the models of optimal taxation in the presence of migration cited in the Introduction. An additional relevant consideration is that inventors may have strong spillover effects on their geographically close peers, making it even more important to attract and retain them domestically.

Because inventors are key determinants of economic growth, this paper speaks to the relation between taxation and growth. An interesting direction for future research would be to include the migration margin of inventors, together with their externalities, into a structural economic growth model with taxation.

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Appendix

A Data Construction

We construct the benchmark micro-level dataset using the following data sources. The Disambiguated Inventor Data is available from Harvard Dataverse Network[33]. Other details on patents come from the NBER patent data[34]. International data on top marginal income taxes comes from Piketty, Saez, and Stantcheva (2014)[35].

The forward citations for each patent are the truncation-adjusted citations, as defined in Hall, Jaffe, and Trajtenberg (2001). For each of the quality measures defined in Section 2.3, we define a reference distribution for each year and for each of the three regions (i) Europe and Canada, ii) United States, iii) Japan). We then rank inventors according to their percentile in that year. We take as our benchmark sample those inventors who have ever been in the top 25% in any year of their life in te sample. Note however that the quality measure used to define top 1%, top 1-5%, etc. and used in levels in the regressions is a dynamic measure, taking into account the quality of the inventor in each given year. Hence, an inventor can be ranked in the top 1% in some year, but not in some other year.

Following are the definitions of the constructed variables used in the micro-level regressions.
Home country of inventor: first country in which an inventor is observed in the data.
Inventor's age: age counted from the first year inventor is observed in the data.
Inventor's technological category: most frequent technological category of inventor's patents.
Country patent stock in year t: number of patents applied by firms in a country in year t.
Country patent stock in inventor's technological category in year t: number of patents applied by firms in a country in year t that belong to inventor's technological category.
Multinational firm: firm whose patents are issued by inventors located in at least two different countries.
Share of innovative activity of a company in a country: number of yearly patents issued by a company in a given country divided by the total number of patents issued in all countries.

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[33] invpat.zip file from `https://thedata.harvard.edu/dvn/dv/patent/faces/study/StudyPage.xhtml?globalId=hdl:1902.1/15705&studyListingIndex=1_cb493c4a38c48c6b3b3b31b31a44`

[34] pat76_06_assg.dta and assignee.dta from `https://sites.google.com/site/patentdataproject/Home/downloads`

[35] Available for download here: `http://scholar.harvard.edu/stantcheva/publications/optimal-taxation-top-incomes-tale-three-elasticities`.

APPENDIX TABLE A.1: CORRELATION MATRIX FOR THE FOUR QUALITY MEASURES

	Citations-weighted patent number	Number of patents	Average citations per patent	Max citations per patent
Citations-weighted patent number	1			
Number of patents	0.70	1		
Average citations per patents	0.32	0.05	1	
Max citations per patent	0.62	0.37	0.76	1

Note: The correlations between different dynamic measures of the inventor's quaility are computed across inventors for the period 1977-2003. The data includes inventors in 8 countries: Canada, France, Germany, Great Britain, Italy, Japan, Switzerland, and the United States. The sample contains 3,945,164 observations with 1,767,243 unique inventors. Citations-weighted patent number is measure $q1$ from the text as defined in (1). Number of patents is measure $q2$ as defined in (2). Average citations per patent is measure $q3$ as defined in (3). Max citations per patent is measure $q4$ as defined in (4).

APPENDIX TABLE A.2: INVENTOR MOBILITY EXCLUDING JAPAN

	(1)
Log Retention Rate × Top 1	2.205^{***}
	(0.432)
Log Retention Rate × Top 1-5	1.652^{***}
	(0.387)
Log Retention Rate × Top 5-10	1.218^{**}
	(0.381)
Log Retention Rate × Top 10-25	0.826^{*}
	(0.371)
Log Retention Rate × Below Top 25	0.741^{*}
	(0.377)
Quality× Country FE	NO
Quality × Country FE × Year	NO
Quality×Country FE×Year×Field FE	NO
Domestic elasticity	.065
s.e	(.0131)
Foreign elasticity	1.795
s.e	(.351)
Observations	5756240

Notes: Multinomial logit regressions on data from the USPTO, excluding Japanese inventors and movements to and from Japan. Robust standard errors clustered at the inventor level in parentheses. See the explanatory footnote to table 3. All regressions contain the same covariates as the same columns in table 3. $^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

Appendix Table A.3: Summary Statistics from the European Patent data

Variable	Average
Patents of Superstar (Top 1%) Inventors	47.7
Patents of Superstar (Top 5%) Inventors	23.9
Patents of Non-superstar (Below Top 5%) Inventors	2.3
Average patents per year while in sample	1.5
Max citations per patent of Superstar (Top 1%) Inventors	308
Max citations per patent of Superstar (Top 5%) Inventors	308
Max citations per patent of Non-superstar (Below Top 5%) Inventors	97
Number of Patents (per country per year)	5513.9
Number of Inventors (per country per year)	8648.7
Number of immigrants (per country per year)	32.1
# of immigrants per year to the U.S.	157.9
# of immigrants per year to CA	14.9
# of immigrants per year to CH	39.5
# of immigrants per year to DE	62.1
# of immigrants per year to FR	35.0
# of immigrants per year to GB	41.5
# of immigrants per year to IT	13.2
# of immigrants per year to JP	19.4
% Superstar (Top 1%) Inventors who move over life in sample	4.7%
% Superstar (Top 5%) Inventors who move over life in sample	3.3%
% Non-superstar (Top 25%) Inventors who move over life in sample	1.5%
% Non-superstar (Below 5%) Inventors who move over life in sample	0.3%
% of inventors who are employees (all inventors)	80.4%
% of inventors (Top 25%) who are employees	86.2%
% of inventors who work for multinationals	84.9 %
% of inventors (Top 25%) who work for multinationals	91.1 %
Average years between first and last patent in sample (all inventors)	2.8
Average years between first and last patent in sample (Top 25% Inventors),	6.9
Average duration of stay in years conditional on move	4.6

Notes: Summary statistics are based on inventor and patents data set described in Section 6 for the period 1978-2007. The data includes inventors in 14 countries: Canada, Denmark, Finland, France, Germany, Great Britain, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, and the United States. The sample contains 3,517,911 observations with 2,145,188 unique inventors.