The Careers of Women Inventors*

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Abstract

We analyze the careers of female inventors in Germany using unique data that link patent records to social security information. Our findings reveal significant gender gaps in patenting outcomes, as well as in wages, earnings, labor force participation, and the likelihood of holding managerial positions. While male and female inventors follow similar patenting and career trajectories early in their careers, women are more likely to stop patenting over time. We rule out industry and occupation at the time of patenting as primary drivers of these disparities. Although gender gaps between male and female inventors widen significantly during childbearing years, they are also not driven by child penalties or gender norms. Instead, child penalties and gender norms primarily explain differences between female inventors with and without children.

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1 Introduction

Despite significant progress in reducing gender disparities across various professions over the past few decades, substantial and persistent gaps remain (Olivetti et al., 2024).These disparities are especially pronounced in areas of innovation, research and development (Bell et al., 2019; Kim and Moser, 2024; Lubczyk and Moser, 2024). As shown in Figure 1, in 2019, among high-innovation countries,[1] Denmark had the highest share of female inventors at only 14 percent, followed by the United States at 12 percent. In contrast, the percentage dropped to 6 percent in Germany and 5 percent in Austria. Pronounced gender imbalances in innovation are likely to have significant repercussions for economic growth and the direction of innovation (Einiö et al., 2019; Koning et al., 2021), and reflect an inefficient allocation of talent (Hsieh et al., 2019; Brouillette, 2021). In this paper, we examine the career trajectories of female inventors, show how their careers differ from those of male inventors, and investigate the underlying causes.

A main contribution of our paper is to reveal significant gender gaps in patenting outcomes in the life cycles of inventor careers. Gaps are also apparent in wages, earnings, participation and in taking up managerial positions over the life cycle. Although male and female inventors have similar patenting trajectories early on, women stop patenting more frequently than men. Compared to men, women inventors disproportionally switch out of the occupation, the firm and the industry that they first patented in.

Using administrative datasets that merge social security details with patent records, encompassing about 70 percent of all German DOCDB patent families, we uncover a number of findings. On average, female inventors earn more than double the amount of their counterparts in STEM professions. Despite this, they earn 50 to 60 percent less in daily gross wages compared to male inventors. Among female inventors, those without children have approximately 19 percent higher earnings. Notably, the career trajectories of male and female inventors in terms of patenting likelihood follow a similar pattern until the age of 30, after which they diverge significantly. Male inventors reach the peak of their inventing productivity in their mid-30s, while for female inventors, the sharp drop-off at age 30 could prevent them from reaching their highest potential.

To understand the divergence in career trajectories between male and female inventors post-age 30, we examine the potential differential impacts of both positive and negative shocks by gender. Taking advantage of our comprehensive data set—which enables the tracking of inventors' career paths even before their first patent application—we document the returns to having a first patent application separately for male and female inventors. Although both male and female inventors benefit from applying for a first patent, the positive impact is short-lived for female inventors, lasting only three years. In contrast, for male inventors, these benefits accumulate and double in the ten years post-application.

[1]Defined as countries with 1 or more patents per 1 million inhabitants

This difference cannot be accounted for by the differential success rate of their application.

While the gender gaps between male and female inventors largely expand during childbearing years, we show that they are not driven by child penalties. Instead, child penalties are more relevant for explaining the differences between women inventors with children and those without children. Following the birth of their first child, the likelihood of female inventors of filing for a patent drops by 50 percent. This decline is also mirrored in their earnings, with the standard measure of childbirth penalty, daily gross wage, showing a decrease of 30 percent following the birth of a first child. Moreover, this reduction intensifies to 40 percent within five years of childbirth. Finally, we analyze the career trajectories of male and female inventors in East Germany, a former state socialist country with progressive gender norms, where mothers were strongly encouraged to participate in the full-time labor market (Boelmann et al., 2021). Consistent with progressive gender norms, there is minimal child penalty between mothers and non-mothers inventors in East Germany. However, the gap with men in patenting and career advancement persists at a similar magnitude, suggesting that factors beyond gender norms contribute to these disparities.

This paper contributes to multiple strands of literature, particularly on gender gaps in the labor market. Economic research has long sought to uncover the underlying causes of these disparities (Olivetti et al., 2024). We extend this literature by focusing on an understudied group–female inventors–contributing to the growing body of research on gender gaps in science and innovation (Bell et al., 2019; Kline et al., 2019; Kim and Moser, 2024; Waldinger et al., 2022; Akcigit and Goldschlag, 2023; Hochberg et al., 2023; Lubczyk and Moser, 2024). To study female inventors, we leverage unique data that, for the first time to our knowledge, not only include patent information but also provide a comprehensive view of inventors' careers from labor market entry onward. This dataset offers yearly information on wages, employment, industry, occupation, firm affiliation, and maternity leave status, allowing us to analyze gender disparities with unprecedented detail. Our life-cycle analyses rule out industry and occupation at time of patenting (Blau and Kahn, 2017) as primary drivers of gender disparities in employment, wages, and innovation, contrasting with recent findings for U.S. female scientists (Lubczyk and Moser, 2024). We also investigate the role of children—a key factor in slowing women's career progression (Kleven et al., 2019a,b)—in shaping gender gaps among inventors.[2] However, our findings suggest that the child penalty does not drive gender disparities among inventors, in contrast to recent evidence for U.S. female scientists (Kim and Moser, 2024). By studying inventors in East Germany, we further rule out gender norms—another culprit in explaining gender gaps in the labour market (Fernández, 2013; Boelmann et al., 2021)—as a primary driver of gender gaps among inventors. Finally, we contribute to the literature

[2]Maternity leave can indeed lead to skill depreciation (Adda et al., 2017), and women often work fewer hours after returning to the workforce (e.g., Bertrand et al., 2010; Kleven et al., 2019b).

on talent allocation, showing that women remain severely underrepresented as inventors in Germany. This misallocation of talent carries significant economic consequences in terms of equity, growth, and productivity (Hsieh et al., 2019; Brouillette, 2021; Lubczyk and Moser, 2024).

2 Data

We use the Linked Inventor Biography Data (INV-BIO ADIAB) that was created in a joint effort by the Institute for Employment Research (IAB), the Max Planck Institute, and the University of Mannheim (see Dorner et al. (2019) for more detailed information about the data construction). The data set combines information from patent filings of the PATSTAT data provided by the European Patent Office (EPO) with social security information from the Integrated Employment Biographies (IEB) provided by the German Federal Employment Agency (BA).

The PATSTAT data includes worldwide bibliographical and legal information from patent applications and granted publications including more than 100 million patents and 200 million legal status records from more than 90 million patent issuing authorities. This data contains information such as the names and addresses of inventors and legal patent holders, about application and publication dates, backward and forward citations, and technology areas.

The INV-BIO ADIAB organizes the patent data at the level of DOCDB patent families that cover applications and publications of the same technological innovation in different jurisdictions at different points in time (see Martinez (2010) for more details about patent families). The PATSTAT data is merged to social security records from the IEB using the names and addresses of inventors. The resulting INV-BIO ADIAB data identifies social security records of 152,350 unique inventors who have applied for at least one patent between 1999 and 2011. In addition, this data follows the employment and patent histories of all identified inventors for the period between 1980 and 2014.[3]

The social security records of the IEB contain the entire population of German social security records from 1980 through 2014. They cover all employees subject to social security contributions and persons who claim unemployment benefits, except students, military personnel, civil servants, and the self-employed.[4] Moreover, individuals might leave the country or die.

The data contains precise information about earnings, wages, unemployment benefits,

[3]Although the data only includes inventors who have applied for at least one patent between 1999 and 2011, we can follow their employment history and their patent applications even before 1999 and after 2011.

[4]We can observe self-employed workers if they pay a wage to themselves. As doing so has tax advantages for many smaller business, the data probably contains a quite large fraction of self-employed workers.

occupations, and many other individual labor market characteristics. Moreover, unique person and establishment identifiers identify all individuals and establishments, allowing us to follow all workers and firms over time. We merge this data with data from the establishment history panel (BHP) that contains firm information (e.g., firm size, median wages, industry, etc.) for all German establishments with at least one worker with social security contributions at the effective date of the 30^{th} of June in any given year.

As civil servants and self-employed workers do not pay social security contributions in Germany, our data set does not cover all German inventors. For example, we cannot observe publicly employed professors or private firm owners who apply for patents as inventors. Nevertheless, between 1999 and 2011, our data covers approximately 70 percent of all German DOCDB patent families[5] in the PATSTAT data. In total, our data contains 2,918,593 observations of 152,320 unique inventors. Of those inventors 140,688 are men and only 11,632 are women.

Finally, we use the German Sample of Integrated Labour Market Biographies (SIAB), a two percent sample of the IEB provided by the Institute for Employment Research for public use, to create a comparison group of non-inventors in comparable sectors and occupations (see Antoni et al. (2016) for more details about the data).

2.1 Labor Market Characteristics

Our main labor market outcomes are monetary outcomes—i.e., daily wages, annual earnings, and annual labor income—and non-monetary outcomes—i.e., annual days of receiving unemployment benefits, annual employment days, and part-time work. We measure all monetary outcomes in 2010 Euros. We only remove a few observations with earnings below the social security thresholds, because these observations are likely to be incorrect data entries. We measure the workers' daily wages at the effective date (30^{th} June) in every given year to align the individual level data from the IEB with the firm data from the BHP. Annual earnings measure the sum of wages from all employment spells in a given year and annual labor income adds the unemployment benefits to the annual earnings.

Our monetary outcomes contain missing values, because workers leave the social security system when they entirely leave the labor market, study, serve compulsory military service, or become civil servants. As is common in the literature, we consider these missing values as non-employment and assign them zero outcomes. In addition to our main analysis variables, we also have information about the workers' occupation, education, age, gender, experience, tenure, and other relevant labor market characteristics.

Although the employment and earnings data are highly reliable, because the BA collects this information for calculating social security benefits, the data have three minor limitations. First, the education variables are sometimes inconsistent and contain miss-

[5]German patent families contain at least one inventor whose workplace is located in Germany.

ing values.[6] To eliminate these inconsistencies and to impute the missing values of the education variables, we follow the standard approach of previous studies (e.g., Dustmann et al., 2009) and apply the imputation procedure of Fitzenberger et al. (2006).[7] Second, the earnings data are censored (top-coded) for high-wage workers at the annual German social security contribution ceiling, which applies to approximately 10 percent of all workers. To impute the missing upper tail of the wage distribution, we again follow the standard approach in the literature (e.g., Card et al., 2013) and apply a two-stage stochastic imputation procedure.[8]

Third, the data does not contain any household information for employed workers[9]—particularly, we have no direct information about whether women give birth. As motherhood is very likely to be a major determinant for women's decision to become inventors, information about women's fertility is crucial for our study. We overcome this limitation by applying the approach by Müller et al. (2022) and use maternity leave information to approximate women's fertility.[10] As maternity leave is mandatory for women in Germany and commonly leads to a social security entry, this information allows us to approximate women's fertility with decent accuracy. Indeed, Schönberg (2009) shows that maternity leave entries allow correctly identifying 90 percent of all birth in West Germany.

More specifically, we identify all women as giving birth when they take up maternity leave and do not resume work before the mandatory maternity leave period of 97 days has ended.[11] Finally, we compute the *expected* date of delivery by adding 42 days to the date of the women's last employment spell before taking up maternity leave, which starts six week before the estimated childbirth.[12]

[6] As the BA does not need this information for administrative purposes, it records these variables with lower quality than the earnings and employment variables.

[7] Specifically, we perform an imputation in the style of the IP1 procedure described in Fitzenberger et al. (2006). If an individual is observed in multiple parallel spells in the same period, we assign all observations to the individual's highest education category. As a worker's highest education cannot decline over time, we then forward extrapolate an individual's highest educational degree to all following spells. Additionally, in case of missing data, we write an individual's degrees back to the age when these degrees are typically obtained (as observed in the data).

[8] In a first stage, we fit a series of Tobit models for each year and education group. In a second stage, we calculate the imputed values for each censored observation using the estimated parameters of the first-stage models plus a random draw from the associated (left-censored) distribution. The control variables contain the worker's gender, age, age^2, a dummy for "older" individuals, tenure, and tenure squared. We then use these imputed values for a second round of imputations, where we include each worker's average log wage in all other periods and the average annual wage of his current co-workers (leave-out means). If a worker is only observed once, we set his mean wage in all other years to the sample mean and include a dummy in the model. Similarly, we set the wage of the co-workers to the sample mean and include a dummy if a worker is the firm's only employee.

[9] The register data contains household information for unemployed workers (e.g., household size, partner id, and number of children) because this information is relevant for the UI benefit payments.

[10] As men only can take parental leave it is difficult if not impossible do identify when men become fathers as many men do not take up parental leave or take parental leave long after the birth of their children.

[11] Women might resume work before the period of 97 if they miscarry or when we misspecify extended periods of sickness leave as maternity leave.

[12] Only 4 percent of all childbirths happen exactly at the expected date of delivery. The reader needs

2.2 Patenting Information

The patent data contain extensive information about patent applications and publications of granted patents. We follow the common approach in the literature and backdate all patent information to the earliest application date within a patent family—including the information of granted patents. The earliest application date is closest to the process of the real invention and allows us to assess how workers and firms contribute to the process of innovation. Because of data protection legislation, the patent data does not include information about the exact dates of patent applications, but only reports the quarter of application. However, this limitation is of minor importance for the purpose of this study because we collapsed our entire data set to an annual panel.

From this data we created five sets of variables to measure the quantity and quality of patents. First, we created a variable that counts the number of weighted inventor patent applications year. More specifically, the variable only counts the earliest application for each patent family according to the DOCDB classification, and weights this number with the inverse of the number of inventors within each patent family.

Second, we use 5-year forward citations of patent families to assess the quality of patents. Therefore, we distinguish between citations that the respective patent family receives from patents at the German patent office, the European patent office, the US patent office, and from all other patent offices. All citation variables are capped at the 99-percentile of citations.

Third, we create a variable measuring the generality and originality of patents. Our measure for generality mirrors the number and distribution of forward citations over 34 IPC classes. The definition follows Trajtenberg et al. (1997) and assign higher values to more general patents. More precisely, our generality measure is $1 - \sum_j S_{pf}^2$, where S_{pj} represents the share of forward citations to patent p from IPC technology class j. Our measure for originality relies on the number and distribution of backward citations. The variable is constructed in the same way as our originality measure, but it relies on backward rather than forward citations. Again, higher values are associated with innovations that are more radical.

Fourth, we create broad measures for the technology classes of patent families. The classification used in the INV-BIO data is a slightly modified version of the WIPO classification (Schmoch and Schubert, 2008) that originally proposes 35 technology areas, however, the classes 21 (surface technology) and 22 (nanotechnology) are merged. For the purpose of our study, we start by using five broader categories that are very common for German inventors: electrical engineering, instruments, chemistry, mechanical engineering, and other.

Fifth, we create a set of variables to measure the diversity within teams of inventors.

to be aware of this inaccuracy.

These include the number of foreign applicants, the number foreign inventors of granted patent, and the number of male and female inventors in the team.

2.3 Descriptive Evidence

This Section provides a descriptive overview of the characteristics of the average female inventor in terms of patenting and labor market outcomes, and initial firm and team characteristics. We define an inventor as an individual, who in our sample has at least one patent granted between 1999 to 2011. Female inventors with kids are female inventors who have at least one child while female inventors without kids are female inventors that never have children during the period that we study. To analyze the role of motherhood we compare female inventors with children with female inventors that never have children. We also compare female inventors with male inventors, and we benchmark the labor market outcomes of female inventors with those of their most similar counterparts, females working in STEM[13] that do not invent.

As shown in Table 1, the average woman inventor with children earns significantly less than the average male inventor (almost 130 euro net on gross daily wage conditioned on participating in the labor market), is younger by around six years, is 31 percent more likely to work part-time, is 6 percent more likely to work in East Germany, 1.4 percent less likely to have gone to be highly-educated. The average female inventor without kids earns significantly less than the average male inventor (almost 100 euros net on gross daily wage), is 12 percent more likely to work part-time, is younger by around four years, is 6 percent more likely to work in East Germany, and is 9 percent less likely to be highly educated. The average female inventor with kids earns significantly less than the average woman inventor without kids (almost 32 euro net on gross daily wage), is 19 percent more likely to work part-time, is younger by around two years, and 5 percent more likely to be highly educated.

The average woman inventor with kids earns significantly more than the average woman working in STEM with kids (almost 28 euro net on gross daily wage), is 1 percent more likely to work part-time, is older by around one year, is 3 percent less likely to work in East Germany, and is 5.2 percent more likely to be highly-educated. The average female inventor with kids earns significantly more than the average woman working in STEM without kids (almost 50 euro net on gross daily wage), is 1.2 percent more likely to work part-time, is younger by around 7 years, 7 percent less likely to work in East Germany, and 5.6 percent more likely to be highly-educated.

The sectoral allocation of inventors differs for female and male inventors, as shown in Figure 2. The largest share of female inventors is active in the field of mathematics,

[13]STEM includes occupations in Science, Technology, Engineering and Mathematics (abbreviated as MINT in German). We use the MINT-occupations definition based on the 2010 classification of occupations (KldB 2010) in Germany.

biology, and chemistry, with nearly 45 percent of all women inventors, while only 15 percent of male inventors are working in this sector.

In terms of firm characteristics, the average woman inventor with kids works in a smaller firm than the average male inventor (almost 190 employees less) and in a firm that pays 6 euros daily less on average, as shown in Table 2. The average woman inventor without kids in turn works in a smaller firm than the average woman inventor without kids (almost 567 employees less). Women inventors are slightly more likely to switch occupations, firms, and sectors than men inventors. In addition, if they have kids they are even more likely to switch.

For a subset of inventors, we have information on all team members who worked on the same patent. Women are more likely to work in bigger teams than men, particularly if they are mothers, and more likely to work with foreign inventors.

In terms of patenting outcomes, the average woman inventor has submitted 2 to 3 patent applications over her lifetime, of which 0 or 1 patents are granted, as shown in Table 3. Meanwhile, the average male inventor has 3 to 4 patent applications, of which 1 or 2 have been granted. In a given year, the likelihood of a woman submitting a patent application is 0.17, while for a man it is 0.23. The likelihood of a patent being granted is 0.08 for a woman and 0.11 for a male inventor. In terms of field, male inventors have more patents granted in every field except in chemistry. Patents by a male inventor are ten percentage points more original, more general and have more citations in the long term on average in comparison to patents of women inventors.

In terms of motherhood, the average woman inventor with kids is not significantly different from the average woman inventor without kids in terms of patent applications or patents granted. However, women inventors with kids have a slightly higher number of lifetime patent applications and patents granted. In terms of fields, women inventors with kids are more likely to have patents in electrical engineering than women inventors without kids. In addition, women inventors with kids have more patent citations even ten years after the patent was granted than women inventors without kids.

The summary statistics indicate a difference in the timing of the first patent, that might reflect on factors such as gender and motherhood. On average, women with kids first submit a patent application when they are 34 years old while women with kids submit at age 36, compared to male inventors' first patent application at 40 years.

To understand whether the differences in patenting behavior are due to differences in returns of patenting we plot event studies graphs where the event is the first patent application. In Figure 3, we plot event study regression coefficients relative to one year before the first patent and control for year and age fixed effects. While both men and women experience immediate positive returns to patenting, men's wages continue to grow consistently over time, whereas women's wage growth stagnates after the initial three years and start to grow again after the sixth year. By the tenth year, men's wages significantly

exceed those of women.

A similar pattern emerges when analyzing annual earnings. In the year of the first patent application, both men and women experience a significant increase in annual earnings, averaging approximately 5,000 euros. However, their trajectories diverge significantly after. For men, earnings exhibit steady growth, doubling by the tenth year post first patent application. In contrast, women's earnings even decrease by the third year and show no further growth. For women the age of their first patent application is quite close to their age of giving birth, which could contribute to these disparities. In Section 4, we examine the penalties due to giving birth in more detail.

The likelihood of filing subsequent patents diverges over time. Men are 30 percent more likely to patent again while women's likelihood of patenting is around 20 percent ten years after. Patent citations also exhibit a gender gap. Both men and women experience an increase in citations following their first patent application, but over time, men's patents receive significantly more citations. This gap may be driven by differences in the types of patents filed, the industries in which inventors operate, or due to the differences in overall number of patents filed by men and women.

3 Career Life Cycles

In this Section we investigate how the careers of female and male inventors evolve over their prime labor market life cycles. We distinguish between male inventors and female inventors with and without children. Outcomes are plotted for cross-sections and focus on inventors aged 25 to 55.

3.1 Methodology

To analyze the extent of gender gaps over the life cycle, we estimate the following regression:

$$Y_{\mathrm{it}\tau} = \sum_k \beta_k \cdot I[k = age_{\mathrm{it}}] + Female_i + \eta_\tau + \eta_\tau * Female_i + X_{\mathrm{i}} + \nu_{it},$$

Where i refers to individual, t to year, τ to birth cohort year. $Y_{\mathrm{it}\tau}$ is the outcome variable for individual i of birth cohort τ in year t, $Female_i$ is a dummy variable equal to 1 when the inventor is a woman, η_τ is birth-year cohort and $\eta_\tau * Female_i$ is the interaction. X_{i} includes control variables for education, one-digit occupation and 2 digits industry at time of first patent application. After estimating the above regression for each outcome variable, we predict and adjust residuals for each gender, to net out the effect of the control variables and only show the unexplained component. The adjusted residuals are plotted for each age using locally weighted scatter plot smoothing for women inventors with children, women inventors without children and male inventors.

3.2 Results

The life cycles of inventors reveal significant gender gaps in patenting outcomes, despite controlling for industry and occupation at first patent application. Gaps are also apparent in wages, earnings, participation and in taking up managerial positions. These gaps in outcomes between male and female inventors are associated with less frequent patenting by women. Compared to men, women inventors switch out of the occupation, the firm and the industry that they first patented in more. Gaps between male and female inventors cannot be fully attributed to child penalties. Instead, child penalties are more relevant in explaining the differences between women with children and those without. We obtain similar gender gaps if we control for the patent class at time of first patent application, thus ruling out sorting into industry, occupation and patent class as drivers of the gender gaps between male and female inventors.

Likelihood of patenting. Women inventors with and without children and men patent at similar rates until the age of 30, as shown in Figure 4. Most women with kids have their first patent between the age 25-35. Women with kids and without kids reach maximum patenting at the age of 30, while male inventors continue to follow an upward trend and patent most at the age of 35. After the age of 35, both women with kids and without kids experience a decline that is sharpest for women with kids. For men the decline is smoother and more similar to women without kids. However it should be highlighted that for women with kids, the likelihood of patenting significantly increases after the age of 40 and catches up with women with kids and men.

Similar trends are observed also for the likelihood of patents being granted in Figure 4. It is striking that now the peak for having a patent granted for women with kids is still at 30 but the magnitude is higher compared to women inventors without kids. After the peak for each gender, the likelihood of patents being granted starts to decline but the decline is sharper for women than men. During child-birth years women with kids have a lower likelihood of granted patents than women without kids.

Impact on wages, earnings, participation and becoming a manager. In particular in terms of wages and earnings, gender gaps between men and women start to appear after the age of 25 and remain big after, as shown in Figure 5. For men, wages and annual earnings continue to grow steadily through their mid-career years. In contrast, women without children experience slower wage growth beginning around their early 30s, while women with children face a much sharper decline, particularly following the birth of their first child. After the age of forty the gap due to kids start to close and at fifty-five women with and without kids have similar wages and earnings. However, for women without kids after the age of forty five log earnings start to decline which could be attributed to a decline in participation rates.

Significant child penalties in participation rates for women with kids are visible. How-

ever at the age of forty participation rates for women with kids significantly improve and remain steady 15 years after. However, there is a decline in participation rates for women without kids which could be driven by other factors than childbirth. However, men experience only small declines in participation rates during their life cycle.

In managerial roles, the gender gap similarly widens after age 30. While women without kids do not experience the sharp decline as those with kids, their likelihood of attaining managerial positions falls mid-career, even below that of women with kids. For women with kids, at the age of forty five the likelihood of becoming a manager significantly increases and reaches those of men. It could be that women with kids that return to their jobs after having kids are positively selected.

Impact on switching. These differences are further reflected in mobility patterns and sectoral choices. In Figure 6 we plot the likelihood of switching occupation, firm and industry compared to the year of the first patent. Women have a higher likelihood of switching occupation, firm and industry compared to men. As these patterns are not correlated with higher wages it could mean that women may move to occupations, firms, or industries, that allow for more flexibility to accommodate family responsibilities. However, even for women without kids the likelihood of switching is higher than men. In addition, women are more likely to not patent again after their first patent than men.

To understand at what sectors women are more likely to move, we categorize sectors in terms of absolute patent numbers from zero to one. The higher the value to one the more patents that sector has. During the age of thirty to thirty five women with kids are more likely to work in patent-intensive industries, while after the age of thirty five both men and women have the same probability in working in these sectors.

Gender norms. Our life-cycle analysis reveals that the career trajectories of male and female inventors—measured by patent applications, wages, and participation rates—begin to diverge in the early thirties. This divergence cannot be explained by differences in industry or occupation at the time of the first patent application. Despite career trajectories differing between women with and without children, the persistent gender gap with men suggests that while children exacerbate this disparity, they do not fully account for it. To investigate whether gender norms contribute to this divergence, we focus on inventors in East Germany, where gender norms have historically been more progressive than in West Germany.[14] Gender norms and female labor supply diverged significantly between East and West during the four decades of division (Campa and Serafinelli, 2019), and even 20 years after reunification, child penalties and return-to-work behavior still differ substantially between the two regions (Boelmann et al., 2021). Figure 7 shows life-cycle

[14]rom 1945 to 1990, Germany was divided into two parts. Socialist East Germany (German Democratic Republic) actively promoted the participation of women in the labor force through a 'dual earner / state career model', which included extensive policy support for working mothers. In contrast, capitalist West Germany (Federal Republic of Germany) adhered to a more traditional male breadwinner model (Boelmann et al., 2021)

wages (top) and earnings (bottom) for inventors in West vs. East Germany. While the gap in wages, and to a lesser extent in earnings, between female inventors with and without children decreases significantly, the gender gap with male inventors remains large and persistent throughout the life cycle. This suggests that gender norms are not a primary driver of the gender gaps in career trajectories for inventors.

4 Child Penalties

4.1 Estimation Approach

To study the effects of giving birth on labor market outcomes, we ideally would randomly assign birth to a group of women and then compare the outcomes of women who gave birth to those women who did not give birth. As births cannot be randomly assigned, we follow the methodology of Kleven et al. (2019b) to analyze the career effects of motherhood. Kleven et al. use an event study specification, which exploits sharp changes around the timing of the first childbirth. They argue that even though deciding when to give birth is not exogenous, the unobserved determinants that impact labor market outcomes should be orthogonal and are not impacted by the fertility decision. This approach has the advantage of being precise and detailed as it tracks the dynamics of the effect on an individual level.

The methodology of Kleven et al. follows three steps. First, for the treated group which in our case are women inventors with kids (Ik) we use the following event study:

$$Y_{\text{ist}}^{Ik} = \sum_{j \neq -1} \alpha_{j}^{Ik} \cdot I[j = t] + \sum_{k} \beta_{k}^{Ik} \cdot I[k = age_{\text{is}}] + \sum_{y} \gamma_{y}^{Ik} \cdot I[y = s] + \nu_{ist}^{Ik} \tag{1}$$

where i refers to individual, s to year, t time from the event of child-birth, and m to mothers. Y is the outcome measured by gross daily wage, annual earnings, and participation rates. Patent outcomes are the likelihood of submitting a patent application and overall patent citations.

Event time dummies as well as age dummies are included to control for life-cycle trends and year dummies to control for time trends. The event time dummy $t = -1$ is omitted, implying that the event time coefficients measure the impact of children relative to the year just before the first childbirth. Then we run the same event study but without including the event time dummies to predict the counterfactual outcomes:

$$\widetilde{Y}_{\text{ist}}^{Ik} = \sum_{k} \hat{\beta}_{k}^{Ik} \cdot I[k = \text{age}_{\text{is}}] + \sum_{y} \hat{\gamma}_{y}^{Ik} \cdot I[y = s]. \tag{2}$$

We calculate the child penalty effect in percentages as follows:

$$P_t^{Ik} = \hat{\alpha}_t^{\mathrm{Ik}} / E[\widetilde{Y}_{\mathrm{ist}}^{\mathrm{Ik}} | t]. \tag{3}$$

Therefore P_t^{Ik} is the percentage effect of having children in year t relative to the counterfactual outcome in the case of not having children. The second step is to calculate the percentage effects for the control group. Kleven et al. (2019b) use fathers as control group. In our case, we do not know the birth of the first child for fathers as our methodology involves predicting births for those who take parental leave. That is why we use as a first control group women inventors who never have kids and assign them placebo births. In order for our control group to be as clean as possible we need to keep only those who never will be mothers as control. We run a linear probability regression on the probability to have kids, controlling for region, age, and education and assign women inventors without kids who are younger than 40 at the last year of our dataset a probability score. Then we keep women with the highest score, where the share of the individuals that will never have kids is the same as in the previous cohort. Placebo births are assigned based on the distribution of age of birth of the generation cohort and education. Furthermore, we use women with kids that work in STEM fields but are not inventors as another control group to analyze whether women inventors have any additional penalty compared to other high educated women workers.

Third, for both of these groups, women inventors without kids (Ink) and women in STEM with kids (Sk), we calculate the percentages effects as explained above and calculate penalties as following where (Ik) refers to women inventors with kids:

$$P_t^a = \frac{\hat{\alpha_t^{Ink}} - \hat{\alpha_t^{Ik}}}{E[\widetilde{Y}_{ist}^{Ik} | t]} \tag{4}$$

and

$$P_t^b = \frac{\hat{\alpha_t^{Sk}} - \hat{\alpha_t^{Ik}}}{E[\widetilde{Y}_{ist}^{Ik} | t]}. \tag{5}$$

In the first case, P_t^a is the child penalty that estimates the percentage by which women inventors are falling behind women inventors who never have kids due to giving birth in event time t. In the second case, P_t^b is the child penalty that estimates the percentage by which women inventors are falling behind (or not) due to being inventors from women who work in STEM fields, and both groups give birth in event time t. In the second case, we want to estimate whether there is any additional penalty to being an inventor. We note that to properly identify short-term penalties the smoothness assumption should be fulfilled. Lastly, in the first year after giving birth the penalty can be attributed to the birth of the first child while longer-run penalties could capture also the penalty due to the birth of the second or third child.

4.2 Results

In this Section, we investigate the effects of having a first child on patenting outcomes and on the labor market trajectories for female inventors that have children from 2002 to 2009 in comparison with female inventors that never have children. In addition, we analyze how the child penalties for female inventors compare to female workers in different occupations. We also show child penalties for women inventors differentiated by working in East and in West Germany.

Impact on patent outcomes. Figure 8 displays a remarkable child penalty in the patent outcomes of inventors after giving birth. We look at the likelihood of submitting a patent application and the number of overall number of citations relative to t=-1. The penalties are estimated as percentages as explained in (3) for female inventors that in t=0 give birth to their first child and for female inventors that never have children and are assigned a placebo birth in t=0. We control for time and age trends. We observe a sharp decline in the likelihood of applying for a patent after the year that the first child is born in of around 48 percent. The penalty for overall citations is estimated at around 17 percent the year when the kid is born and around 38 percent five years after.

Impact on wages, earnings and participation. Figure 9 shows the child penalty for daily gross wages, annual earnings and the participation rate. For daily gross wages the penalty is around 40 percent five years after giving birth. The penalty of earnings for inventors with kids is around 52 percent, decreases the years following the birth but remains big even four and five years after (48 percent) and do not reach the level of earnings of female inventors without kids. The decrease in earnings can come from either a change in participation rate, wages or hours worked. Unfortunately in our data we do not have information on the numbers of hours each individual works but we can look into participation rates and wages. Both the decline in participation rate and decline in wages contributes to the child penalty in earnings. For participation rates the child penalty in percentages is around 35 percent in the year when the first child is born and decreases the years after, where in the fifth year after the first child the participation rate penalty is around 25 percent. For all three outcomes, the penalty persists even five years after the event.

Timing of patenting. In Figure 10 we focus on women who are inventors pre birth, meaning that they already submitted a patent application before the first child is born. Then we look at two categories, inventors who have at least another patent after birth and those that never patent again. We find that there are differences in behavior of returning to work, the child penalty in participation rate is 20 percent smaller for women inventors that patent again. However, the child penalty for both wages and earnings is similar for both of these categories, around 50 percent.

In comparison to other categories of workers. To understand how the child

penalties of women inventors compare to other occupations we look at child penalties for female workers in STEM, managers and the average women in our sample as shown in Figure 11. We chose STEM workers and managers as are both occupations that are more comparable with inventors in terms of requiring long working hours and dedication. Even though penalties for women inventors are big and long lasting, they are smaller than for all the other three categories. Five years after giving birth, managers have a 43 percent penalty on wages, 60 percent penalty on earnings and 39 percent penalty on participation rates. STEM workers experience a 50 percent penalty on wages, 65 percent penalty on earnings and 41 percent penalty on participation rates. In addition STEM workers with a university degree have similar penalty as inventors. For the average women in our sample we find similar results as Kleven et al. (2019b) who estimate child penalties in Germany for total sample of female workers. They find that in the fifth year after a first child is born, the child penalty on earnings is 63 percent and 40 percent in terms of participation rates.

Regional differences. In Figure 12 we look at child penalties for women inventors working in East and for those working in West Germany. Gender norms are substantially different for East and West Germany due to historical and cultural reasons. In East gender norms are more egalitarian and women are more likely to return to work after becoming mothers while in West women are less likely to return to work Boelmann et al. (2021). We find that while for inventors working in the West the child penalties are large and persistent over time, for those working in the East the child penalties disappear over time. In the fifth year, the earnings and wage penalties are insignificant as mothers fully return to work in East Germany.

Recent critics of the child penalties, Melentyeva and Riedel (2023) argue that the methodology suffers from "forbidden comparisons" and "contamination bias". Forbidden comparisons happens in the case when the outcomes of mothers who gave birth act as the counterfactual part in the case of no birth. While the contamination bias happens when the estimate for each relative time period around the event can be "contaminated" by the treatment effects from all other periods. Accounting for these biases, they find even bigger earnings penalty for Germany. In our next steps we aim to use their methodology to check the robustness of our results.

5 Conclusions

We present first evidence on the child penalty experienced by women inventors. As innovation and R&D are the main drivers of economic growth, gender-specific child penalties do not only lead to inferior career paths for women but might also restrain the potential for increased economic prosperity more generally. We study the consequences of having kids on the wages, labor force participation, and earnings of women inventors, and compare

women inventors with and without kids around the time of their first birth. In contrast to female inventors without kids, those with kids face a substantial 50 percent long-term earnings gap, driven nearly equally by declines in labor force participation and wage rates. Furthermore, there is a 40 percent long-term penalty in overall patent citations, a key indicator of patent quality.

While child penalties explain much of the variation between women with and without children, they do not fully account for the broader gaps observed between men and women. The life cycle analysis reveals significant gender disparities in career outcomes among inventors. While men experience steady growth in wages, managerial roles, and patenting through their mid-thirties, women particularly those with children experience a decline starting around age 30. Women with children face steeper drops in participation, earnings, and patenting activity, although these trends begin to improve after age 40. Women are also more likely than men to switch occupations, firms, or industries, with this trend persisting even among women without children.

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Tables and Figures

Table 1: Individual characteristics, 1999-2011

	Male inventor	Female inventor		Female STEM worker	
		with kids	without kids	with kids	without kids
Daily gross wages	279.99	150.20	178.18	70.09	77.78
	(178.54)	(108.02)	(135.52)	(47.36)	(54.73)
Annual earnings	94,059	44,764	56,883	22,246	24,974
	(67,232)	(40,018)	(49,442)	(17,294)	(20,250)
Participation rate	0.92	0.83	0.88	0.97	0.96
	(0.27)	(0.38)	(0.33)	(0.17)	(0.19)
Part-time	0.06	0.37	0.18	0.36	0.25
	(0.23)	(0.48)	(0.38)	(0.48)	(0.43)
Age	41.93	35.68	37.76	34.49	42.99
	(9.68)	(6.63)	(9.35)	(7.68)	(11.36)
East Germany	0.09	0.15	0.15	0.18	0.22
	(0.28)	(0.35)	(0.36)	(0.39)	(0.42)
Education:					
Low education	0.03	0.05	0.06	0.14	0.22
	(0.18)	(0.21)	(0.24)	(0.35)	(0.41)
Vocational training	0.23	0.25	0.29	0.69	0.64
	(0.42)	(0.43)	(0.45)	(0.46)	(0.48)
University degree	0.74	0.70	0.65	0.17	0.14
	(0.44)	(0.46)	(0.48)	(0.37)	(0.35)
Number of obs.	1,709,655	34,094	99,126	105,325	291,302

Notes: Participation takes a value of one if the individual works either part-time or full-time and zero otherwise. The variable East Germany takes value one if the inventor works in East Germany. We have reliable information for this variable only after 1993 due to the introduction of the employment notification procedure. Low education is defined as no vocational training nor university degree.

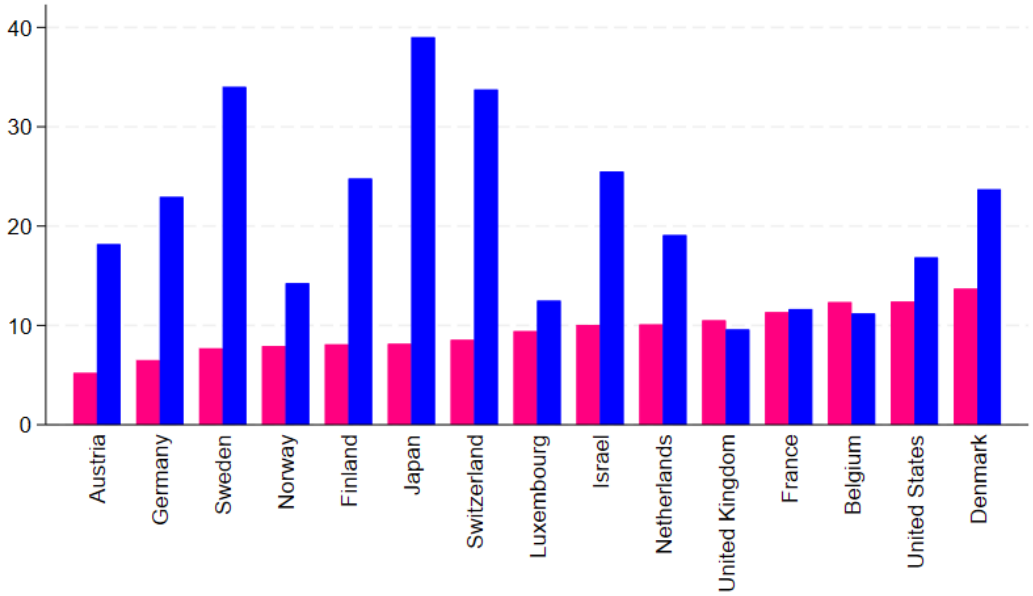
Table 2: Firm and team characteristics, 1999-2011

	Male inventor	Female inventor with kids	Female inventor without kids
Firm characteristics:			
Size of the firm	3135	2945	2568
	(7098)	(6337)	(5899)
Mean wage	153.61	148.72	145.13
	(61.42)	(56.92)	(52.34)
Likelihood of switching:			
Occupation	0.11	0.12	0.11
	(0.31)	(0.32)	(0.31)
Firm	0.10	0.12	0.11
	(0.30)	(0.33)	(0.32)
Sector	0.07	0.09	0.08
	(0.26)	(0.29)	(0.27)
Number of obs.	1,709,655	34,094	99,126
Team characteristics:			
Number of inventors	4.60	5.48	5.48
	(3.05)	(3.64)	(4.07)
Number of foreign inventors	0.16	0.20	0.20
	(0.37)	(0.40)	(0.40)
Number of obs.	179,605	3,458	10,052

Table 3: Patent outcomes, 1999-2011

	Male inventor	Female inventor with kids	Female inventor without kids
Number of lifetime patents:			
Applications	3.15	2.28	2.24
	(6.99)	(5.15)	(5.43)
Granted	1.28	0.83	0.79
	(2.86)	(1.89)	(1.91)
Likelihood of a patent in a year:			
Applications	0.23	0.17	0.17
	(0.42)	(0.37)	(0.38)
Granted	0.11	0.08	0.08
	(0.32)	(0.27)	(0.27)
Age at first patenting:			
Application	39.66	33.98	36.06
	(8.73)	(5.66)	(8.20)
Granted	40.09	34.19	36.64
	(8.67)	(5.68)	(8.18)
Citations:			
Overall citations of past ten years	3.72	3.30	3.02
	(17.47)	(19.08)	(15.07)
Originality score	0.07	0.06	0.06
	(0.18)	(0.17)	(0.17)
Generality score	0.05	0.04	0.04
	(0.14)	(0.14)	(0.14)
Number of obs.	1,709,655	34,094	99,126

Figure 1: Share of women inventors and number of patents by 10 mil. inhabitants.



Note: The figure plots the share of women inventors (pink) and the number of patents by 10 million inhabitants (blue) in 2019 for high-innovation countries (defined as countries with 10 or more patents by 10 mil. inhabitants).*Source:* OECD.

Figure 2: Sector share of inventors by gender

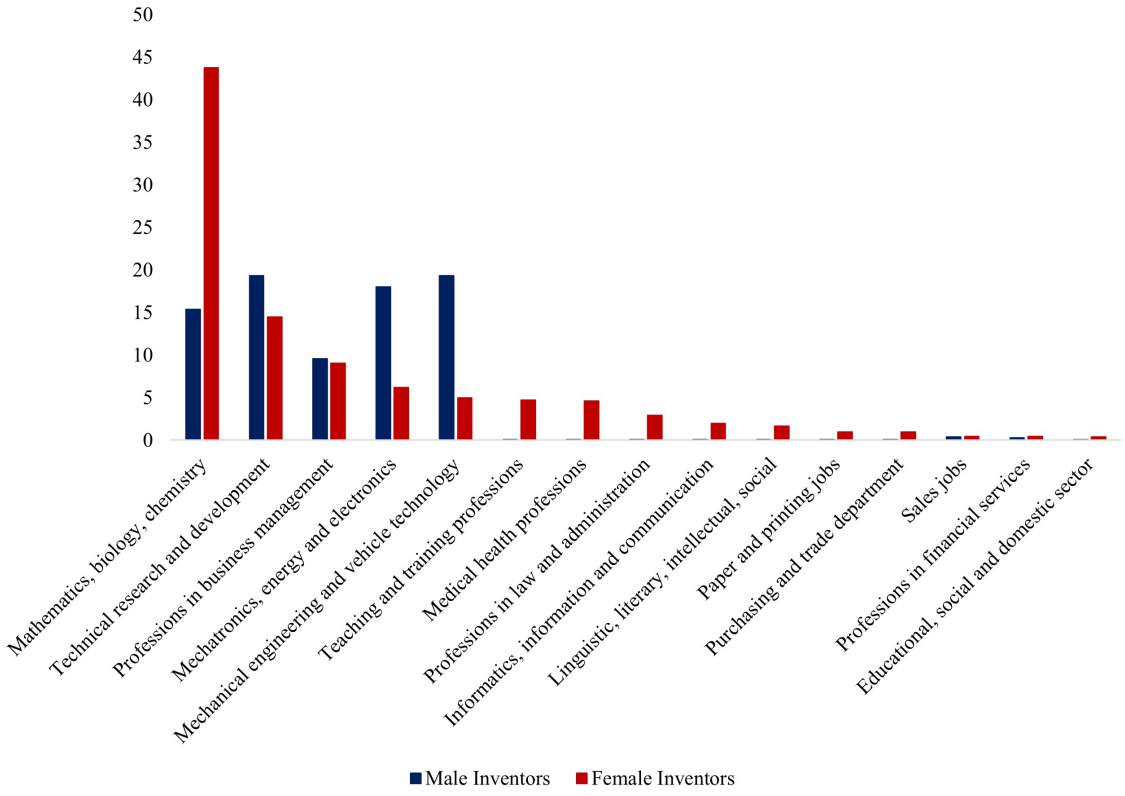
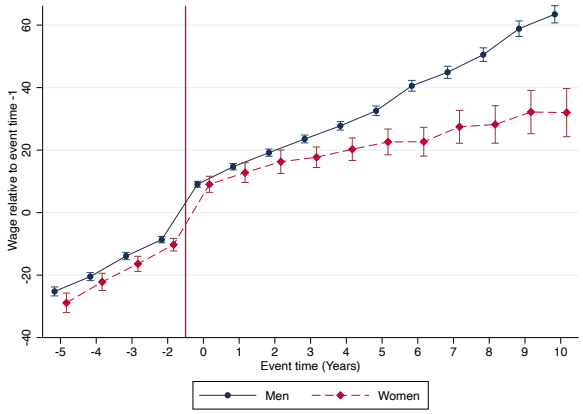
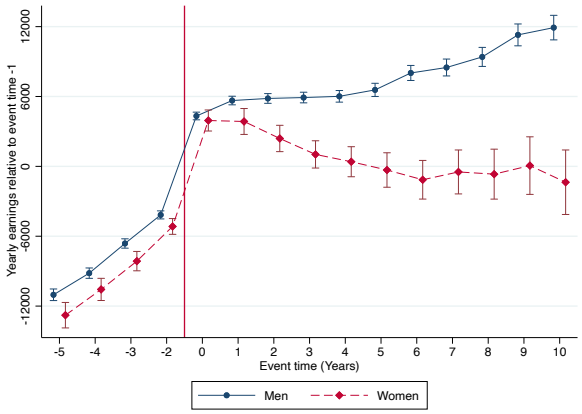


Figure 3: Event study outcomes after first patent application by inventor gender

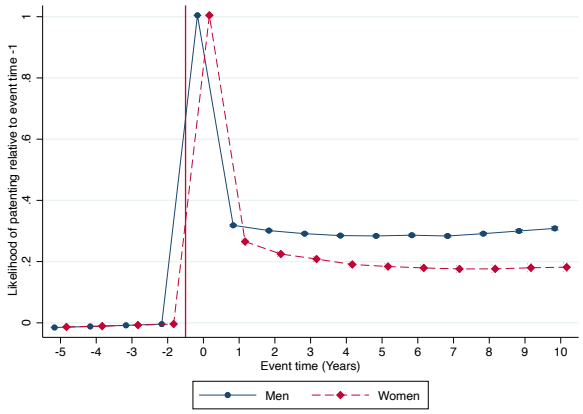
(a) Daily gross wages



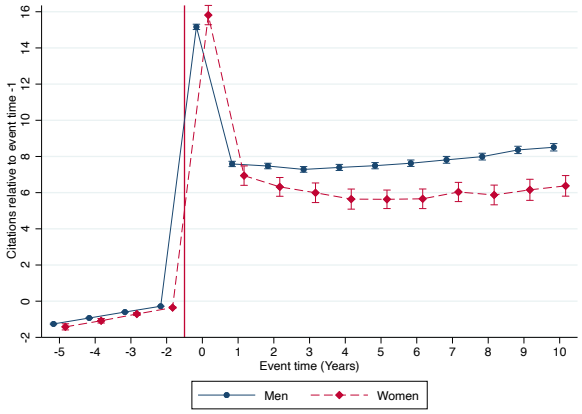
(b) Annual earnings



(c) Likelihood of further patenting

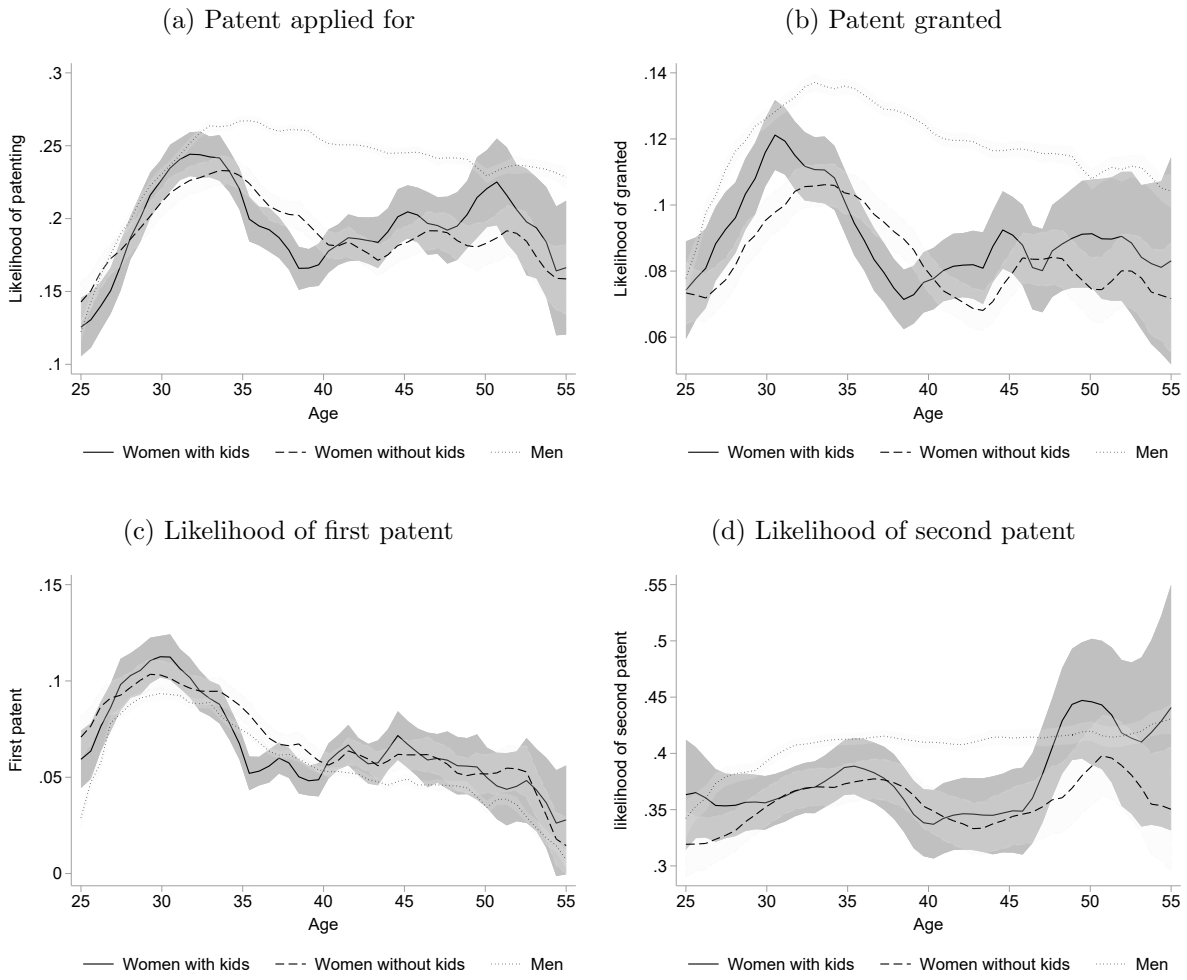


(d) Citations



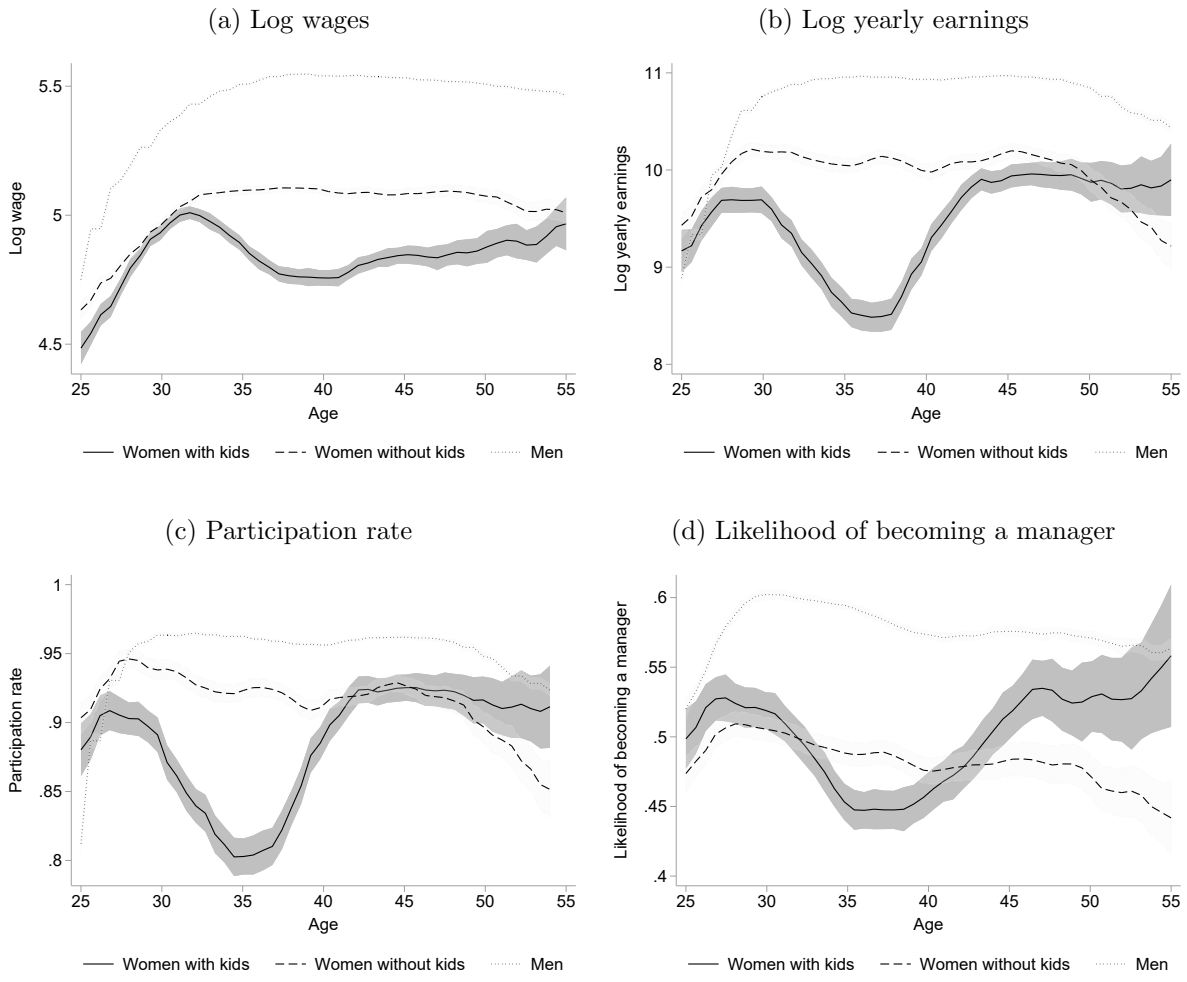
Notes: The figures plot the coefficients relative to the event of the first patent application in period -1, controlling for year and inventor age fixed effects. Outcomes are displayed for male and female inventors from five years before to 10 years after their first patent.

Figure 4: Likelihood of patents over the life cycle



Notes: Results are estimated separately for male inventors and for female inventors with and without children. Controls include cohorts, education, 1-digit occupation and 2-digit sector at the time of first patent.

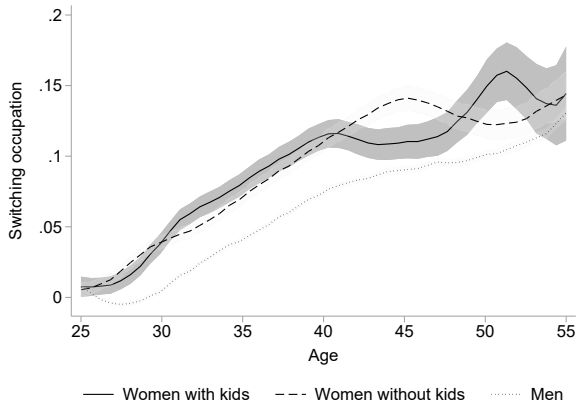
Figure 5: Labor market outcomes over the life cycle



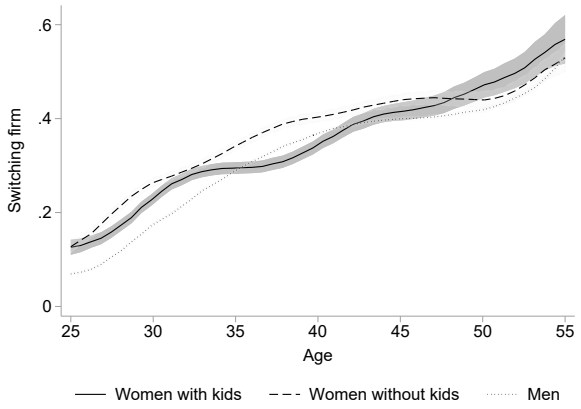
Notes: Results are estimated separately for male inventors and for female inventors with and without children. Controls include cohorts, education, 1-digit occupation and 2-digit sector at the time of first patent.

Figure 6: Switching compared to the time of the first patent application

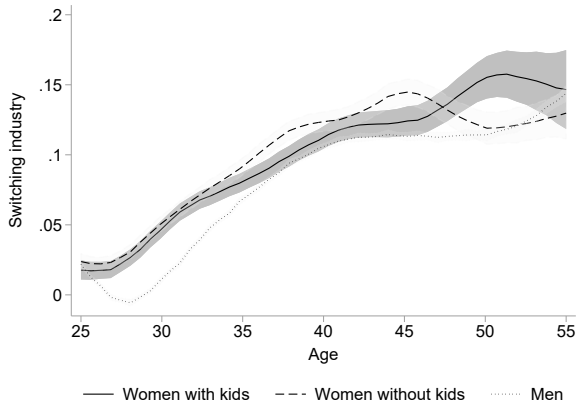
(a) Switching occupation



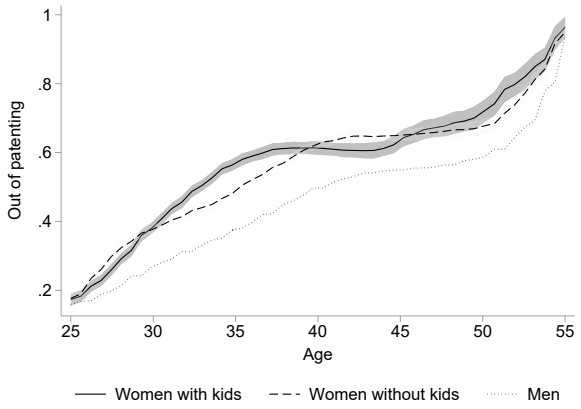
(b) Switching firm



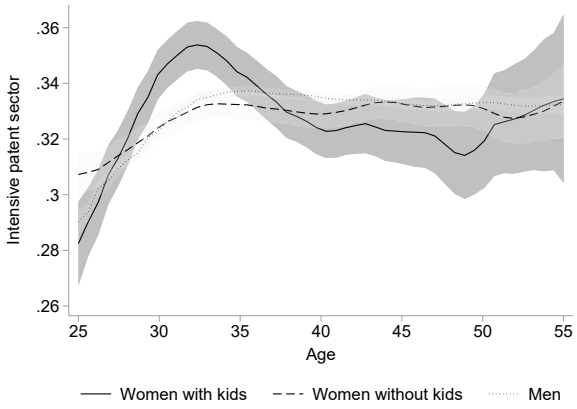
(c) Switching industry



(d) Switching out of patenting



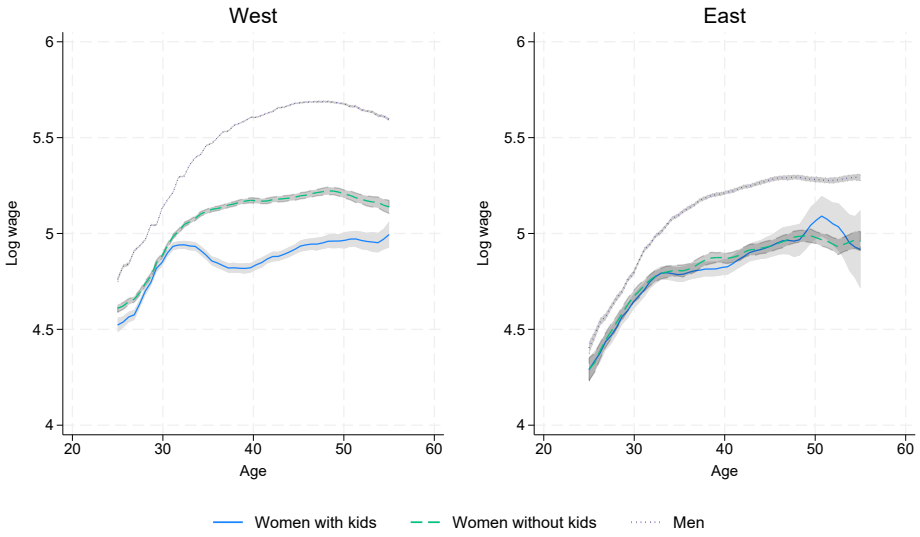
(e) Out of a patent-intensive industry



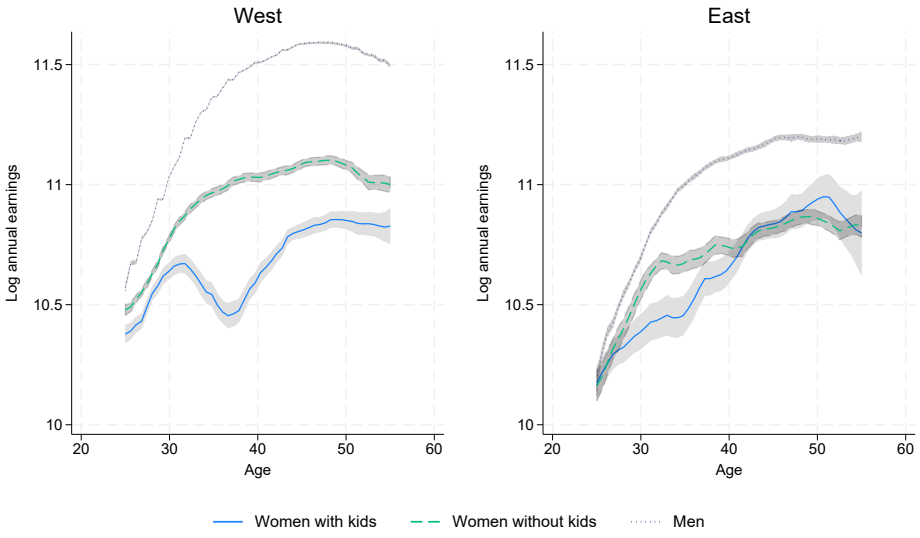
Notes: Results are estimated separately for male inventors and for female inventors with and without children. Controls include cohorts, education, 1-digit occupation and 2-digit sector at the time of the first patent.

Figure 7: West Germany vs East Germany

(a) Log wages



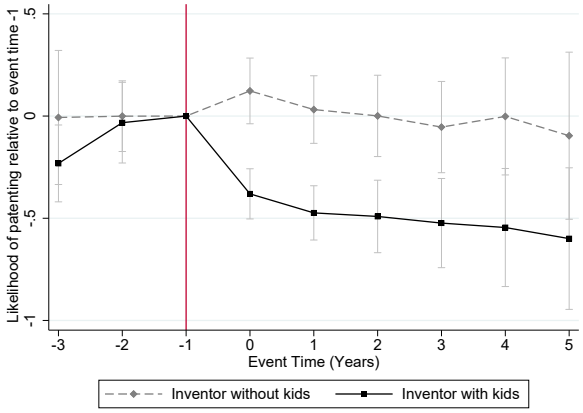
(b) Log yearly earnings



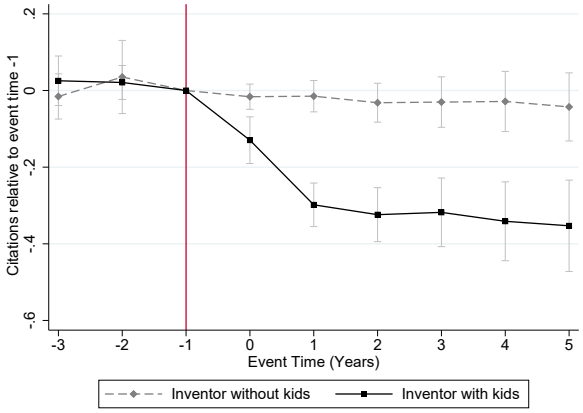
Notes: Results are estimated separately for male inventors and for female inventors with and without children for West vs East Germany. Controls include cohorts, education, 1-digit occupation and 2-digit sector at the time of first patent.

Figure 8: The effect of childbirth on patent outcomes for women inventors

(a) Likelihood of a patent application



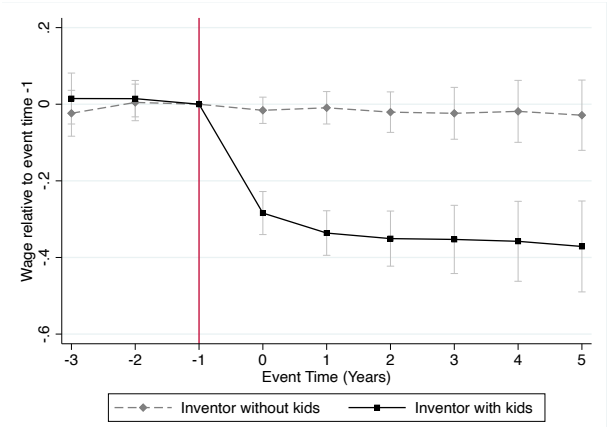
(b) Overall citations



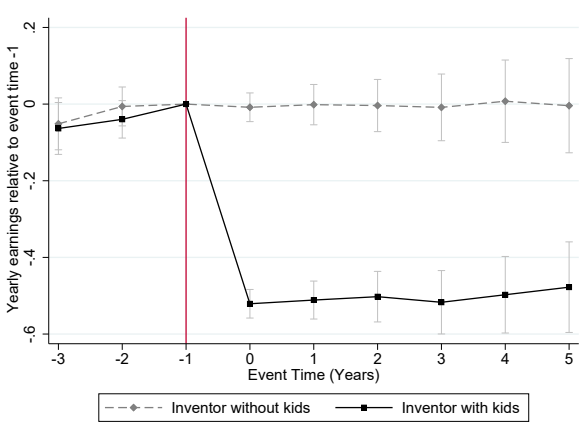
Notes: The figures show the effect of having a first child on outcomes. The child penalty in percentages is measured as event time coefficients that are calculated as explained in equation (1) divided by the counterfactual outcomes predicted by running equation (2), which calculates predicted outcomes in case the event of giving birth did not happen. In the treated group are female inventors who have the first childbirth between 2002 and 2009, while in the control group are female inventors who never have kids in our sample, whose birth event time is determined by assigning placebo births. The sample used for these graphs is a balanced sample of inventors, who are in our data three years before and five years after the first childbirth. 95 percent confidence intervals are based on standard errors that are clustered at the individual level.

Figure 9: The effects of childbirth on labor market outcomes for women inventors

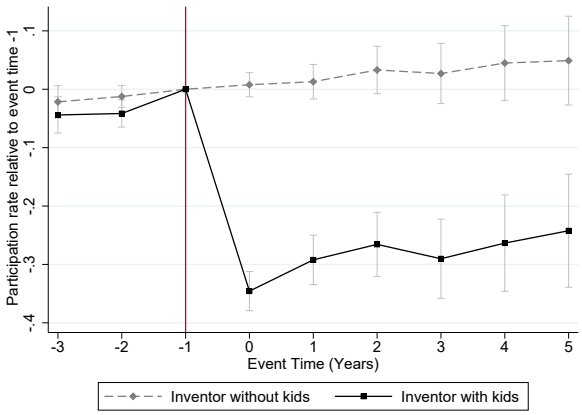
(a) Daily gross wages



(b) Annual earnings



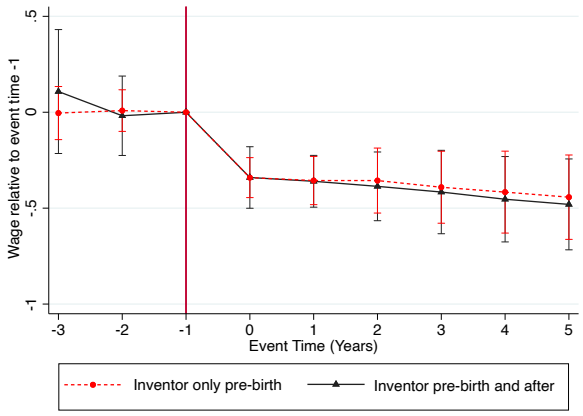
(c) Participation rate



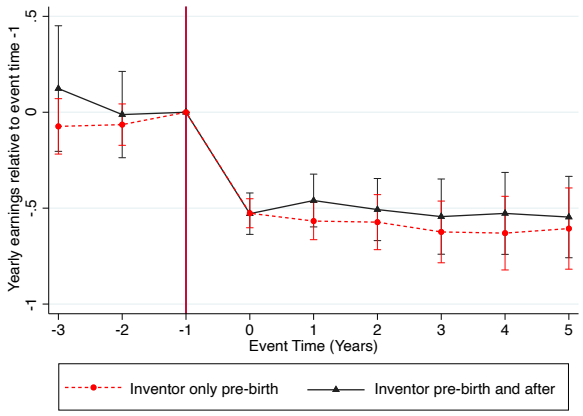
Notes: The figures show the effect of having a first child on outcomes. The child penalty in percentages is measured as event time coefficients that are calculated as explained in equation (1) divided by the counterfactual outcomes predicted by running equation (2), which calculates predicted outcomes in case the event of giving birth did not happen. In the treated group are female inventors who have the first childbirth between 2002 and 2009, while in the control group are female inventors who never have kids in our sample, whose birth event time is determined by assigning placebo births. The sample used for these graphs is a balanced sample of inventors, who are in our data three years before and five years after the first childbirth. 95 percent confidence intervals are based on standard errors that are clustered at the individual level.

Figure 10: The child penalty for women inventors, based on the timing of patenting

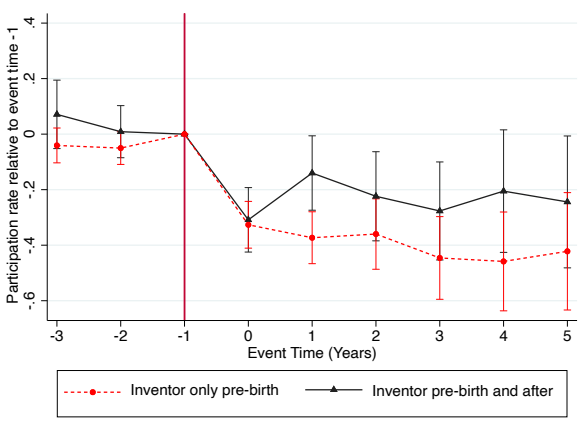
(a) Daily gross wages



(b) Annual earnings



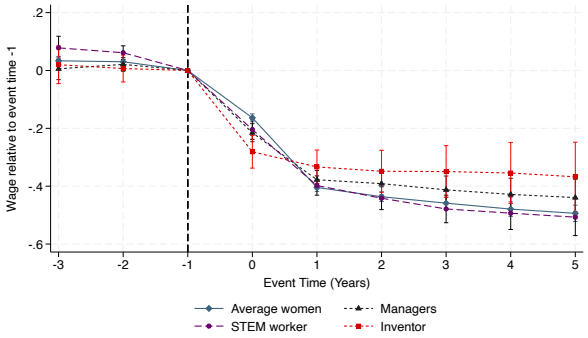
(c) Participation rates



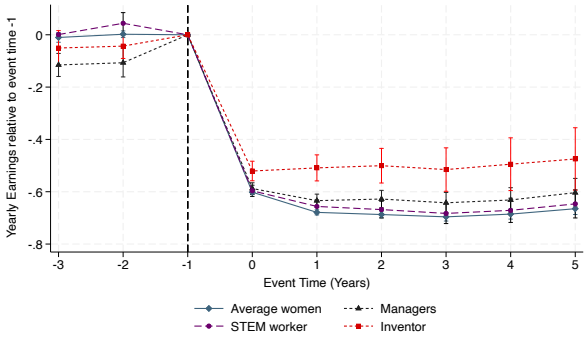
Notes: The figures show the effect of having a first child on outcomes. The child penalty in percentages is measured as event time coefficients that are calculated as explained in equation (1) divided by the counterfactual outcomes predicted by running equation (2), which calculates predicted outcomes in case the event of giving birth did not happen. In the treated group are female inventors who have the first childbirth between 2002 and 2009, while in the control group are female inventors who never have kids in our sample, whose birth event time is determined by assigning placebo births. The sample used for these graphs is a balanced sample of inventors, who are in our data three years before and five years after the first childbirth. 95 percent confidence intervals are based on standard errors that are clustered at the individual level.

Figure 11: Childbirth effects for different types of women

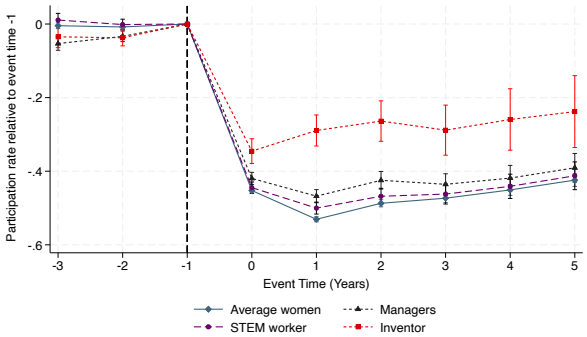
(a) Daily gross wages



(b) Annual earnings



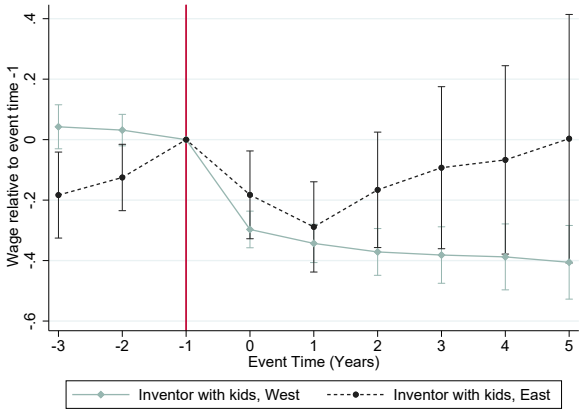
(c) Participation rate



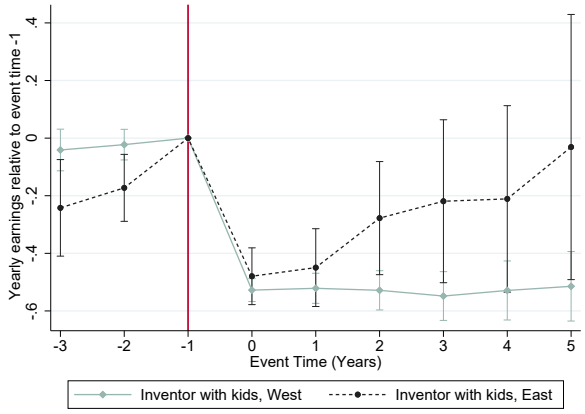
Notes: The figures show the effect of having a first child on outcomes. The child penalty in percentages is measured as event time coefficients that are calculated as explained in equation (1) divided by the counterfactual outcomes predicted by running equation (2), which calculates predicted outcomes in case the event of giving birth did not happen. In the treated group are female inventors who have the first childbirth between 2002 and 2009, while in the control group are female inventors who never have kids in our sample, whose birth event time is determined by assigning placebo births. The groups shown are female inventors, female STEM workers, female managers and the average female with kids in our sample who have the first childbirth between 2002 and 2009. The sample used for these graphs is a balanced sample of inventors, who are in our data three years before and five years after the first childbirth. 95 percent confidence intervals are based on standard errors that are clustered at the individual level.

Figure 12: The effect of childbirth for women inventors in East vs. West Germany

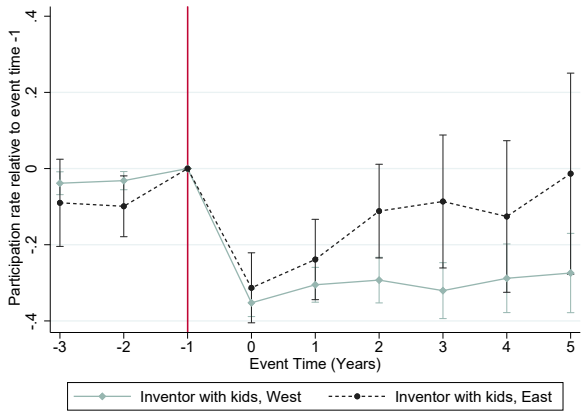
(a) Daily gross wages



(b) Annual earnings



(c) Participation rate



Notes: The figures show the effect of having a first child on outcomes. The child penalty in percentages is measured as event time coefficients that are calculated as explained in equation (1) divided by the counterfactual outcomes predicted by running equation (2), which calculates predicted outcomes in case the event of giving birth did not happen. In the treated group are female inventors who have the first childbirth between 2002 and 2009, while in the control group are female inventors who never have kids in our sample, whose birth event time is determined by assigning placebo births. The sample used for these graphs is a balanced sample of inventors, who are in our data three years before and five years after the first childbirth. 95 percent confidence intervals are based on standard errors that are clustered at the individual level.