Publish or Procreate: The Effect of Motherhood on Academic Performance

ABSTRACT

Women are underrepresented in science and representation deficits are even greater for more senior positions and in the STEM fields. The dominant explanation is that male and female scientists, even within the same field, publish at unequal rates.

Prior studies on select fields suggest that the gender gap in academic productivity reflects differential effects of childbearing on men and women, as women face tensions between the two greedy institutions of family and academia. We study the universe of STEM academics in Denmark and investigate parenthood penalties on scientific productivity of mothers and fathers, who are active in research before the birth of their first child. We employ an event-study on annual research publications, an outcome especially relevant in the science domain, and rely on a unique combination of Danish registers and granular bibliometric data on publications from the database Scopus.

We find that, on average, the first childbirth results in an annual penalty of 23 percent on scientific productivity of mothers across STEM fields relative to fathers in years 2 to 6 after birth. The penalty reflects a drop in annual research publications of mothers relative to their own pre-birth productivity. Our results are robust to attrition. The penalty is unchanged when conditioning on research activity after birth. Hence, unequal impacts of parenthood may be an important driver of gender inequality in science.

We find that the productivity constraint on mothers is closely linked to the characteristics of their research field and household. Motherhood penalties are particularly large in bench fields, which require laboratory presence and depend on research infrastructure and in households with traditional gender norms and/or lacking access to informal help. Moreover, having a flexible partner who is receptive to the demands of research mitigates penalties on mothers.

1. INTRODUCTION

Women continue to be underrepresented in the scientific profession, particularly in the fields of science, technology, engineering and mathematics (STEM), and representation deficits are even greater in academia's highest echelons (Wolfinger, Mason, & Goulden, 2008). Across their careers, female scientists tend to earn fewer promotions (Ginther & Hayes, 1999; Ginther & Kahn, 2006) receive less funding (Witteman et al. 2017; Witteman et al., 2019) and win fewer prestigious prizes than their male peers (Meho, 2021)

This inefficient allocation and underutilization of female talent generates a loss to our society because we fail to take full advantage of the available talent pool. Apart from reducing the overall idea production, less diversity in the pool of innovators tends to reduce the breadth of scientific advances. Fewer topics are studied and a smaller variety of products are developed (Koning et. al. 2021). Finally, the future generations of young girls are missing out on important role models in science (Bettinger & Long 2005; Shannon et al., 2019; Porter & Serra, 2020).

One particular aspect of the gender gap in science stands out, namely the productivity puzzle. Numerous contributions have highlighted the fact that male and female researchers, even within the same research field, publish at unequal rates (Cole & Zuckerman, 1984; West et al., 2013; Mairesse & Pezzoni, 2015; Harriet Zuckerman, 1993; Xie & Shauman, 1998). This specific gender gap is particularly problematic because scientific productivity is one – if not the most – most important factor explaining access to funding resources, career progress, and, more broadly, scientific success among individual researchers (Huang et al., 2020; Stephan, 2012; Bentley & Adamson, 2003).

Prior studies suggest that the gender productivity gap in academia may reflect differential effects of childbearing and parenthood on male and female academics because women face heightened tensions between the two greedy institutions of family and research. While the gender productivity gaps in science may have decreased over time, having children still seems to represent one of the main factors explaining them (Xie & Shauman, 1998). Gaining a better understanding of the potentially differential effects of parenthood on scientists is thus central to a discussion of equality and inclusion in science.

While a number of studies focus on the effect of childbearing on the likelihood of tenure, promotion, and survival in science for women (Wolfinger, Mason, & Goulden, 2008; Ginther & Kahn, 2006; Huang et al., 2020; Cech & Blair-Loy, 2019; Van Anders, 2004; Cheng, 2020; Wolfinger et al., 2009, Mairesse et al., 2019), there are also some studies prior to ours that have documented the negative effect of childbirth on mothers' academic productivity. The general validity of very early studies is limited due to the use of cross-sectional data (Zuckerman, 1993; Fox, 1981; Frank et al., 1985; Long & McGinnis, 1993), while later studies on self-reported longitudinal data and a cleaner identification tend to focus on select fields with one particular characteristic in common (Mairesse et al. 2021, Morgan et al. 2021, Stack, 2004). Particularly, they focus on researchers in desk fields that do not require presence in the workplace. For three such fields (computer science, history and business), Morgan et al. (2021) find that over time childbearing plays a diminishing role for productivity gaps in US and Canada. To our knowledge, there is only one contribution on gender gaps and childbearing for the universe of STEM scientists. The study by Kim and Moser (WP, 2020) suggests that childbearing was an important driver of gender gaps in scientific productivity among scientists with childbearing during the baby-boom of the 1950s. However, their study suffers from selection on survival and lacks actual data on childbearing.

In our study, we focus on the full population of STEM scientists in Denmark in the period from 1990 to 2018 and investigate parenthood effects on the scientific productivity of mothers as compared to fathers around the birth of their first child. In particular, we are interested in understanding how different time constraints, both on the workplace and at home, contribute to the “motherhood penalty” in scientific production. Due to the combination of detailed register data on family dynamics and granular bibliometric data, we are able to precisely identify the effect of childbirth of scientists’ productivity within the universe of STEM academics employed in Denmark, thus avoiding the issues of selection or representativeness that were present in earlier studies. The event-study method we employ is well-established in the labor literature (Kleven et al. 2018) and relies on quasi-random variation in timing of birth conditional on age, year and career-stage.

This study makes several contributions to our current understanding of gender gaps in science, and is closely related to the labor literature on child penalties among knowledge-intensive workers.

First, we offer a precise identification of the motherhood penalty on scientific output in the full population of STEM academics affiliated in a single country over a period of 28 years, overcoming the focus on single discipline or institutions of previous studies. We find that, on average, the first childbirth results in an annual penalty of 23 percent on scientific productivity of mothers across STEM fields relative to fathers in the first 2 to 6 years after birth. The penalty reflects a drop in annual research publications of mothers relative to their own pre-birth productivity. Our results are robust to attrition. The results are practically identical when conditioning on research activity after birth.

Additionally, we find that productivity constraints on mothers are closely linked to the characteristics of their research field and household, pointing to the differential effects of time constraints. Motherhood penalties are particularly large in bench fields that require laboratory presence and depend on extensive research infrastructure and in households with traditional gender norms and/or lacking access to informal care. Moreover, having a flexible partner, who is receptive to the demands of research is found to mitigate penalties on mothers. These results resonate with the conclusions from Myers et al. (2020) on constraints on research activity during the Covid-19 pandemic. The authors identify larger drops in research activity for individual researchers with care responsibilities and occupied in the bench-fields.

Finally, by leveraging our findings, we suggest possible unintended consequences of current parental leave arrangements.

Our findings contribute to the general literature on labor market penalties in the knowledge-intensive fields. (Bütikofer et al., 2018) The STEM fields are often praised for having a higher degree of gender equality due to lower wage penalties on mothers than, e.g., business and law. Our results emphasize that individual mothers in research do face lower wage penalties relative to the population average (10% vs. 20%), but in addition, they pay a high price in terms of academic productivity, recognition and impact. This in turn may have societal costs in the form of foregone innovation.

2. DATA AND METHODS

Data

We rely on two data sources, namely the Danish administrative registers and bibliometric data on publications from the Scopus database. The data sources are matched on researchers' name by Statistic's Denmark, such that bibliometric Scopus data on scientific publications are linked to a unique id in the Danish registers.[1] The registers we rely on contain high-quality administrative data on education (UDDA and PhD-register), demographics (BEF), occupational status (AKM) workplace, income (IND), family status and parental status (FAM), e.g. year of becoming a parent. We study granular bibliometric data on individual researchers' publications form SCOPUS, including citations, Journal Impact Factor, year of publication, affiliation, and author order.

Sample

Our full sample consists of the population of STEM scientists in Denmark in the period from 1990 to 2018. We include researchers in all STEM fields, including in Human and Veterinary Medicine, while excluding researchers in Economics, Business, Management and Accounting, Social Sciences, Psychology, and Arts and Humanities. Our field restriction is motivated by significant differences in publishing traditions. In STEM fields, annual publication output is a direct proxy – albeit imperfect - for annual productivity based on inputs of research time. This

[1] We remove a subset of 25 researchers, where the matching is unconvincing, as reflected in productivity levels very far from the rest of the distribution over the 10 year period. This is likely reflecting that some Danish researchers with very common names have been merged.

connection between annual time input and research output is less direct in other scientific fields, where publications are either infrequent or consist of monologues.

We focus on academics based in Denmark around the birth of their first child. A majority of academics in our sample (close to 70%) are PhD students or PhD graduates, who were working as researchers at a public research institution in Denmark, such as a university or a university hospital, one year before and in the exact year of birth of their first child. By conditioning on being employed at a Danish research institution around childbirth, we ensure that individual academics face a similar institutional setting with regard to child leave entitlements and job security at the time of childbirth.

We select individuals, who were active in publishing their research before the birth of their first child. Specifically, individuals in our sample are required to have published in a STEM journal at least once in the 3 years before their first childbirth. We follow their research publication activity from 1990 to 2018.

Researchers in our sample become parents for the first time in the period from 1993 to 2011.[2] This ensures that we can compare their pre- and post-birth publication levels. Particularly, we follow their academic productivity from 3 years before and up to 8 years after the event of having a first child.

For our sample 2, we introduce a further requirement of research activity in the years after birth. This allows us to focus on survivors in science, and ensure that differential publication levels are not an artefact of attrition. Specifically, we require that individual researchers

[2] Following conventions in the literature, if a child is born in November or December, we change their birth year to the following year. We count twins as one birth.

continue to publish no later than in years 5 to 8 after the birth of their first child. However, we do allow for temporary breaks in publishing activity around childbirth (years 0 to 5). Individuals in our sample may have left Denmark for some time prior to birth or go on to leave Denmark in the period after birth. However, our data on publications allow us to continuously track their individual research activity. The only caveat is that we may not observe additional childbirths taking place outside Denmark, unless the individual returns to Denmark, and thus reappears in the registers.

Summary statistics

Our sample consists of 2395 individual researchers, of which 1517 are male and 878 are female. Characteristics of individuals in our sample are summarized in **Table 1** on Publication Activity**,** in **Table 2** on Family Characteristics, and in **Table 3** on Distribution into Publication Fields.

From **Table 1,** we see that 93% of individuals in our sample achieved at least a Master's Degree prior to the birth of their first child, while close to 70% were either PhD graduates or PhD-students at first birth. It is very common junior researchers, including PhD-students, in Denmark to start a family as their employment contracts offer the same benefits as those of other contracts. The PhD-age of mothers and fathers at first birth differs by more than one year, indicating that women pursue family formation slightly earlier in their career, while men tend to delay parenthood to after PhD-graduation. Therefore, male academics achieve somewhat higher cumulative publications relative to female academics prior to having their first child. The average PhD age at first birth is 0.5 years for fathers and -0.9 years for mothers.

Men and women in our sample start publishing at similar ages, namely around age 29, and close to ¾ of individuals have published in the year before birth.

Regarding childbearing, women are slightly younger at 33 years of age than men at 34 years at first birth. Over the period of observation, males and females in our sample have a similar number of children on average. Within the 8 years after first birth, 82-83% of individuals go on to have another child. More than half of the individuals in our sample end up having 2 children, while 1/6 have 1 child, and 1/4 have 3 or more during the period of observation. At first birth, women take leave of 36 weeks on average, while men take leave of 7 weeks. Almost half of the researchers have a retired mother or mother in law, which we take as a proxy for access to informal help. The matching behavior of academics appears to be relatively traditional. Female researchers tend to match with older partners, who have a relatively higher income than they do in the year prior to birth, and a similar level of education. The opposite is true for male researchers. Male academics marry younger, less educated partners with lower earnings than themselves in the year prior to birth. Finally, significantly more women (29 %) than men (20%) have a partner who is active in research or has pursued a PhD.

Table 3 shows that the shares of male and female academics differ substantially across publication fields. Males publish almost equally across medical, laboratory and theoretical desk fields such as computer science and physics, while almost half of the women publish in medical journals, and only 1/6 publish in the desk fields. Finally, close to 2/5 of women in our sample publish in the laboratory fields, e.g. biology and chemistry.

Empirical Strategy

Our empirical strategy follows the event study methodology of Kleven et al. (2019). The event is the birth of the researcher's first child. The event is not exogenous, but following Kleven et al. (2019) and a large literature on child penalties in the labor market, we claim that timing of birth is quasi-random, when conditioning on year, age and career-age fixed effects. We expect the event, i.e. the birth of a first child, to cause a sharp change in the academic productivity measured as number of yearly publications. The inclusion of PhD-age fixed effects, allows us to control for any trend in scientific productivity over career that may influence the decision of when to have a child.

We index all years in relation to the year of the birth of the first child: $t = 0$. This implies that the year before the childbirth is denoted $t = -1$ and the year after is denoted $t = 1$. Individual researchers are observed from 3 years before the birth of the first child to 8 years after.

Model. We denote the number of yearly publications as U_{ist}^{g}, where i is the individual, s is the calendar year, g is the gender, m is the PhD-age and t is the time relative to the event time. We run the following regression to measure the impact of children on academic productivity relative to the year just before the event of having the first child.

$$U_{ist}^{g} = \sum_{j \neq -1} \alpha_j^{g} * \mathbb{1}[\mathrm{j} = \mathrm{t}] + \sum_{\mathrm{k}} \beta_k^{g} * \mathbb{1}[k = age_{is}] + \sum_{u} \gamma_u^{g} * \mathbb{1}[u = s] + \sum_{m} \delta_m^{g} * \mathbb{1}[m = PhDage_{is}] + v_{ist}^{g} \qquad (1)$$

Hence, we regress number of publications on a full set of dummies for age, calendar year, PhD age (number of years since finishing the PhD, negative if the researcher is a PhD student) and time relative to event, leaving out as reference category the event time dummy for $t = -1$, to ensure that α estimates the impact of childbirth relative to the year before entering parenthood conditional on age, calendar year and PhD-age. We predict number of publications in the absence of childbirth by omitting the contributions from the event time dummies as:

$$\tilde{U}_{ist}^{g} = \sum_{k} \hat{\beta}_{k}^{g} * \mathbb{1}\,[k = age_{is}] + \sum_{u} \hat{\gamma}_{u}^{g} * \mathbb{1}[u = s] + \sum_{m} \hat{\delta}_{m}^{g} * \mathbb{1}[m = PhDage_{is}]$$

Next, we use the estimated level effects to calculate the year-relative-to-event effect of the first child as a percentage of the predicted academic productivity in the absence of children. Particularly, the gender specific impacts of children on academic productivity are calculated as:

$$P_{t}^{g} = \frac{\hat{\alpha}_{t}^{g}}{E[\tilde{U}_{ist}^{g}|t]} \quad (2)$$

These gender specific P_t are the estimates we plot in the main **Figures** of the paper.

Next, we define the child penalty on females relative to males as:

$$P_{t} = P_{t}^{w} - P_{t}^{m} \qquad (3)$$

P_t measures how many percentage points female researchers' academic productivity falls behind their male counterparts' due to children at a time relative to the event of having a first child (Kleven et al., 2021). Long run penalties will include the effects of later children, unless the individual has only one child. In the analysis we report the average P_t over years 2 to 6 after birth, i.e. the average annual penalty from year 2 to year 6.

3. RESULTS

Across STEM fields, we find that mothers, on average, suffer an annual child penalty on scientific productivity of 23 percent (*p=0.001*) relative to fathers in years 2 to 6 after birth, when measuring productivity by annual number of research publications, cf. **Figure 1**.

The child penalty on mothers' productivity relative to fathers' is equivalent to a loss of 2.4 articles, when measuring the productivity penalty relative to own estimated productivity of 12.1 articles in the absence of children. Annual productivity losses of mothers relative to fathers in the first years after birth result in substantial cumulative productivity losses over time (cf. **Appendix A.1, Figure 9)**. As childbirth tends to happen in the early stages of women's academic career, a period that is central to her future career progression, mothers face a substantial long-term disadvantage compared to their male peers with children. A back of the envelope calculation suggests that society foregoes around 350 papers annually from female researchers with children below school age, or more than 2000 research articles in total from the women in our sample over the first 6 years of motherhood.

From **Figure 1,** we see that the gender gap in annual scientific productivity widens around year 2 after first childbirth and remains large until year 5-6. From years 6-7 after birth, annual productivity of female academics relative to own pre-birth productivity starts to converge back, seemingly reaching the pre-birth productivity level some time after year 8. This is in line with findings by Kim and Moser (2020) on historical data on patents and publications among US researchers in the 1950s. The authors find that conditional on survival in science, female academics with children experience productivity peaks much later than those of other scientists and eventually, after being married for 15 years, experience large and persistent increases in scientific output.(Kim & Moser, 2020)

However, convergence in productivity does not imply that female scientists on average catch up with their male peers in regards of rank, publications or other objective success criteria. They remain at a disadvantage throughout their careers as they fail to recover the ground lost around childbirth.

One mechanism that may contribute to motherhood penalties on academic output is attrition out of scientific publishing. **Figure 2.A** shows the impact of childbirth on participation in academic research, defined as having had at least one publication in the last four years among male and female researchers working in Denmark around the birth of their first child. Focusing only on individuals who obtain a PhD, We find that 8 years after birth, 13% of male PhDs and 19% of female PhDs are no longer active in research. Hence, survival in research is affected differentially for men and women. The average annual penalty is estimated between 5% (PhDs) and 7% (MA). Figure 2.B shows the impact of childbirth on participation at a Danish research institution, defined as having a Danish University or University Hospital as one's employer. While, the motherhood penalty on participation at a Danish research institution is statistically insignificant and small at 3%, we find that 8 years after birth, 45% of mothers have left their position, while this is true for 40% of men.

Given slightly higher attrition among women, we proceed to estimate the impact of childbirth on academic productivity only for those individuals, who survive in research, i.e. on the sample of researchers with publication activity before *and after* birth. Figures 3.A-3.B show the impact of childbirth on academic productivity. When focusing only on survivors, the penalty on scientific output varies between 18% and 23%. Hence, it is only 1/6 of the child penalty that may be explained by lower survival rates of women. However, the lion's share of penalties is not due to differential attrition.

In the remaining part of the paper, we therefore focus only on survivors in research, and try to disentangle factors that mitigate or exacerbate penalties for this group.

Before we move to the potential mechanisms, we first consider another aspect of scientific productivity. Until now, we focused on a relatively narrow measure of productivity, namely number of papers published, while we did not take into account the quality of such output. If the after-birth scientific contributions of female scientists are on average more comprehensive or innovative than those of males, analyzing scientific quality rather than quantity may deliver new insights on the gender gap in science. This may also reflect a deliberate strategy of women who, facing increased time constraints after childbirth, decide to focus on a smaller number of highly promising projects. Therefore, we investigate whether women are simply changing their publishing strategy from producing many articles before birth to producing fewer articles, but of higher quality, after having children. **Figures 4.A-4.D** show the impact of childbirth on frequency, quality and impact of publications among surviving researchers working in Denmark. We find that the average annual motherhood penalty on the probability of publishing in a given year is 12% in years 2 to 6 after birth. This indicates that the post-birth drop in productivity reflects both external and internal productivity margins. Considering now the quality of publications, **Figure 4.B** shows that among PhDs, the child penalty on annual average quality-adjusted publications (20%**) is very close to the penalty on the raw publication counts (18%), where the quality-adjusted annual count of articles is found by multiplying each publication by (1 + Journal Impact Factor), and summarizing within each year. Similarly, **Figure 4.C** shows that the penalty on publications in Q1-ranked journal is 21%**. Our results indicate that the quality per publication is unchanged after birth for women relative to men. Results on average quality per publication across mothers and fathers, conditional on publishing confirm this conclusion. When considering citation metrics as proxies for research impact, **Figure 4.D** shows that the penalty on annual scientific impact as proxied by 3-year citations to publications from year t, is noisy, but large at 30%*, though the average penalty on 3-year citations per article is lower and insignificant at 15%. Our results indicate that after birth publications of female researchers are of similar quality as before birth publications, while they appear to obtain lower scientific impact, perhaps due to reduced visibility and more limited attendance to conferences and workshops.

4. HETEROGENEITY

In the following section, we investigate household characteristics and research environment specific factors that may aggravate or mitigate the effects of childbirth on productivity of mothers.

The role of partners and of immediate family

At the onset of parenthood, both fathers and mothers may feel time constrained. Providing care for a newborn requires both time and effort, while making progress in research depends crucially on the same ingredients. The intra-household division of child-related tasks after birth is therefore likely to influence the individual academics' trade-off between engaging in research and care work. In particular, having a partner that takes leave with the baby, a partner with flexible employment, or a partner that understands the challenges of doing research, may have a positive impact on the individual researcher's productivity after birth. (Sonnert & Holton, 1996) Particularly, having a partner in academia could mitigate the constraints from inflexible childcare due to both a flexible work-schedule and a greater understanding of inherent challenges, while having a partner outside academia may exacerbate the impact of childbirth on the scientific productivity of female academics.

In addition, the partner's relative education, age and earnings are likely to influence bargaining over who will take leave or reduce their work hours after childbirth, and as such may, on average, result in unequal outcomes between mothers and fathers in academia. These ideas motivate splitting our sample into subgroups by having a partner who is active in research or holds a PhD (alternatively is engaged in PhD-studies) versus having a partner without a PhD-degree. In our sample 29 percent of female academics have their first child with an academic partner, while this is true for 20 percent of male academics. **Panel B** in **Figure 5** document that child penalties on productivity among mothers in academia are driven by individuals with a partner outside of academia, i.e. a partner without a PhD degree or research activity, while we find no significant gender differences in productivity trends around birth, when both parents are academics, cf. **Panel A in Figure 5.** This suggests that having an academic partner may alleviate some of the time pressure mothers experience in academia, resulting in improved scientific productivity.

In a similar vein, having access to informal networks that can provide extra or emergency care, for example when children fall ill or have to taken to the doctor, is likely to reduce the impact of having children on one's productivity at work. In order to test this, we look at the presence of immediate family who could provide such extra care, in particular retired grandmothers.

From **Figures 5.C-5.D,** we see that women with no access to help from a retired grandmother are more likely to experience large and protracted penalties, while women with access to retired grandmothers experience lower penalties.

Hence, partner's occupation affects male and female academics asymmetrically. This is likely to reflect the wife's relative education and income, as well as gender norms on division of childcare and housework, and entitlements to and division of child leave among parents. Therefore, we next consider the role of household gender norms as proxied by leave-taking by the focal researcher above or below median leave-taking (by gender). **Figures 6.A-6.B** show that female researchers living in gender progressive households, as proxied by shorter leave of the focal female researchers (and longer leave of the focal male researcher), experience half as large motherhood penalties as focal researchers with traditional leave-taking (15-16% vs. 28-31%***), which are driven by larger drops in the productivity of traditional mothers. In very gender progressive households, the penalty on women is more muted as seen in **Figure 6.C**. This reflects mainly that fathers in very progressive households also experience a post-birth productivity drop. Finally, mothers in very traditional households face statistically significant penalties as large as 45%***, cf. **Figure 6.D**, reflecting both a productivity premium on traditional fathers, and a large productivity penalty on traditional mothers. It is important to note that the aggregated household impact on productivity of two progressive partners (e.g. a couple of academics), appears to be smaller than the aggregated household impact on productivity of two traditional partners (where perhaps only the mother is active in research). Hence, our evidence supports the story that child penalties are not per se a zero-sum game. The premise that someone has to pay the price of parenthood is false, as the price paid by the household is likely to be smaller when leave-taking and other household responsibilities are shared between mothers and fathers.

Family size

The fact that the initial productivity gap continues to widen after the birth of the first child is likely to reflect continued family formation. Indeed, the arrival of a second child in years 2 to 4 after the first birth is likely to exacerbate the child penalties experienced by mothers.

As seen from **Figure 11 in Appendix A.1**, the annual child penalty on productivity of female academics relative to males is much higher at 31% *($p<0.001$)* in years 2 to 6 after childbirth among individuals who have more than one child during the observation period than among individuals with only 1 child. However, a majority of researchers (5/6) have more than one child.

Research environment

Researchers in different academic fields are likely to experience different working conditions and to rely on different research methods. Particularly, the so-called “wet fields”, such as chemistry and biology, rely heavily on applied methods, e.g. conducting experiments in laboratories and using large and expensive research infrastructure. Pursuing research in these "bench" fields typically depends on actual presence of researchers at research facilities (or "at the bench"). This lack of flexibility due to the need for regular presence at the workplace is likely to influence the size of child penalties experienced by mothers working in those fields. Therefore, we split the sample by publication fields, and consider subgroup results for 1) researchers in laboratory-intensive fields, excluding medicine, 2) researchers in theoretical "dry" fields, and 3) researcher in clinical fields, i.e. medicine.

In **Figures 7.A-7.D,** we present results on motherhood penalties across fields. We find that the motherhood penalty on female academics relative to males is larger among researchers, who depend on laboratory presence for conducting their research, relative to researchers in other fields. Female academics in laboratory-intensive fields face average annual penalties of 37 percent (*p=0.001*) in year 2 to 6 after birth, while female academics in the dry and clinical fields face much lower penalties (12-19%), which are not statistically significant. This implies that the laboratory-intensity of research field has a significant impact on the severity of penalties. The fact that medical researchers fare so well may reflect a higher degree of regulation and organization of work hours at the hospital and a culture of substitutability at the workplace, as doctors frequently divide responsibilities for the care of patients.

Considering career stage, we find that both late-career and early-career researchers in laboratory intensive fields suffer large penalties, though in general early career researcher face larger penalties (34%, insign.) than researchers who are later in their career at child birth. (19%, insig.), cf. Figures 8.A-8.B. When considering research team responsibilities, we find that very few researchers have last author responsibilities prior to birth, especially women, we therefore focus on publications as mid-authors and first-authors. From Figures 8.C-8.D, we see that motherhood penalties are large and significant for mid-author publications (26%). This could be a reflection of reduced work-place presence making it harder to stay in the loop and become involved in projects of colleagues. Meanwhile penalties on first and last-author publications are smaller and imprecisely estimated (17% to 19%), indicating that these publications are perhaps given higher priority by focal researchers.

5. DISCUSSION

Despite considerable gender convergence in the general labor market and reduced gender gaps in science in the last few decades, at the current speed many fields are looking at extended time horizons to achieve gender equality. This calls for attention and action from policy makers, grants agencies, university administrators and the science community at large. From a policy perspective, disentangling the mechanisms driving the persistence of gender inequality in science is important, as it can inform the design of effective interventions to mitigate the current gender gap.

Our study contributes to the on-going debate on gender inequality in science by suggesting that the disproportionate impact of parenthood on male and female academics may be an important driver of such inequality. This is unsurprising as mothers continue to take the lion's share of parental leave and childcare responsibilities at home compared to fathers. Up until today parental leave entitlements for women have been much more generous than those for men in Denmark, substantially creating inequality in the allocation of leave between parents and reinforcing gender stereotypes on task allocation in households. Parental leave entitlements targeted specifically at mothers may be a two-edged sword. On one hand, they provide income and job security for the individual, while ensuring that a child can enjoy the intimate care of a parent during infancy. On the other hand, the effects of leave-taking in scientific and other knowledge-intensive professions may be detrimental for one's career, given the idiosyncratic characteristics of such professions. Being successful in science requires continuous engagement in research and with scientific networks (for example by participating in international scientific conferences), making investments in updating one's frontier-knowledge, and applying for funding at a regular basis. All these activities require active presence and investments in terms of time, elements, which are lacking, while individuals are on parental leave. A child, no doubt, needs close care during the first year of life, but a mother and a father are equally disposed to provide it. Hence, policies ensuring equal and earmarked child leave entitlements across genders represent a low-hanging fruit to level the playing field in academia as well as in other knowledge-intensive professions. Moreover, public policies send a strong signal of societal expectations to parents in terms of a more equal division of work in the household. However, attention to detail is crucial, as gender equal tenure-clock stopping policies in the US are found to have very unequal effects across genders due to differential time allocations of mothers and fathers during tenure extensions.(Antecol, Bedard, & Stearns, 2018; Manchester, Leslie, & Kramer, 2013) Hence, symmetrical policies may have an asymmetric impact across genders.

In addition, when a parent returns to work after parental leave, specific actions may be needed to reinsert the researcher in the scientific work loop. In order to re-start their pipeline, new parents need to devote a large share of their time to research and applying for funding (which are activities idiosyncratic to them as individual researchers), rather than to administration and teaching, which are more fungible and therefore can be covered by other faculty members. However, policies alleviating new parents of their teaching responsibilities may also have gender-specific effects, if teaching obligations are exchanged for either childcare or research engagement according to gender. Additionally, quota policies may have a backlash on productivity, if each scientific committee needs a token female member, resulting in burdening female faculty with extensive faculty services.

One potential limitation of our work is that we are studying a very specific context, which may not generalize to other countries. Indeed, Scandinavian countries are often praised for their high rate of female participation in the labor force and their generous policies in support of families. However, we believe that our results are of interest to the broader scientific community for at least two reasons. First, as we are analyzing a context where families enjoy relatively generous support, we would expect our results to underestimate the actual penalty in terms of scientific productivity that academic mothers would face in countries where such support is lower or non-existent. Second, while gender norms are generally perceived to be more egalitarian in Scandinavia than elsewhere, it appears that in reality gender attitudes in Denmark are quite traditional, when it comes to the labor supply of women after having children (ISSP Research Group, 2016), and in line with prevalent values in countries such as the UK or the US. This suggest that Danish female researchers face similar pressures at home in terms of disproportionate allocation of childcare duties.

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1 Tables

Table 1: Descriptive Statistics on Publication Activity

	Male			Female		
	N	Mean	Std.	N	Mean	Std.
Completed education at birth						
Master	1517	0.93	0.26	878	0.91	0.28
PhD	1517	0.69	0.46	878	0.67	0.47
Career stage at birth						
PhD student at first birth	1517	0.28	0.45	878	0.34	0.47
Phd graduate at first birth	1517	0.30	0.46	878	0.24	0.43
Master age at first birth	1409	5.72	4.43	801	4.86	3.47
PhD age at first birth	1042	0.50	4.37	591	-0.85	3.80
Publication age						
Age at first publication	1517	28.83	3.68	878	28.81	3.13
Age at last publication	1517	44.54	8.48	878	41.14	7.67
Productivity in year before birth						
Publications	1517	1.91	2.12	878	1.35	1.45
Any publication	1517	0.75	0.43	878	0.72	0.45
First author publications	1517	0.70	1.01	878	0.54	0.82
Last author publications	1517	0.31	0.90	878	0.10	0.35
Mid author publications	1517	0.78	1.36	878	0.61	1.01
3-year citations per publication	1143	11.07	22.78	631	13.26	21.50
3-year citations to publications	1517	21.26	43.88	878	18.04	39.63
5-year citations to publications	1517	35.63	72.64	878	30.32	67.46
Publications in q1-journal	1517	0.82	1.39	878	0.70	1.11
Any publication in q1-journal	1517	0.40	0.49	878	0.41	0.49
Any publications w/ top-quarter citations	1517	0.48	0.92	878	0.37	0.75
Any publication w/ top-decile citations	1517	0.20	0.54	878	0.16	0.47
Total publications	1517	8.69	11.85	878	5.10	6.69
Post-birth productivity						
Annual publications (year 5 after birth)	1517	2.36	2.88	878	1.21	1.98
Total publications (year 5 after birth)	1517	21.61	20.25	878	12.59	13.87
Total publication (year 8 after birth)	1517	28.24	25.99	878	16.10	17.37
Total productivity						
Total publications (observed in Scopus)	1517	45.76	53.43	878	24.51	33.94

Note: Summary statistics are shown for the full sample of male and female researchers with at least one publication prior to first birth.

Table 2: Family Characteristics

	Male			Female		
	N	Mean	Std.	N	Mean	Std.
Focal researcher						
Breadwinner	1517	0.75	0.43	878	0.44	0.50
Secondary earner	1517	0.23	0.42	878	0.54	0.50
Danish	1517	0.82	0.38	878	0.80	0.40
Partner characteristics						
Partner BA or less	1517	0.30	0.46	878	0.30	0.46
Partner Master	1517	0.47	0.50	878	0.40	0.49
Partner PhD	1517	0.14	0.35	878	0.20	0.40
Partner active in research	1517	0.13	0.34	878	0.22	0.42
Partner research or PhD	1517	0.20	0.40	878	0.29	0.46
Younger partner	1502	0.64	0.48	845	0.21	0.41
Same age partner	1502	0.14	0.34	845	0.15	0.36
Older partner	1502	0.22	0.42	845	0.64	0.48
Childbearing						
Age at first birth	1517	33.81	4.69	878	32.61	3.58
Age of partner at first birth	1502	31.58	3.84	845	34.59	5.28
1 child	1517	0.17	0.38	878	0.18	0.38
2 children	1517	0.56	0.50	878	0.56	0.50
3 children or more	1517	0.27	0.44	878	0.26	0.44
Child leave (weeks)	1405	6.84	7.65	825	35.74	18.61
Partner leave (weeks)	1288	5.75	11.76	752	5.61	11.38
Retired grandmother	1510	0.43	0.61	869	0.50	0.67

Note: Summary statistics are shown for the full sample of male and female researchers with at least one publication prior to first birth.

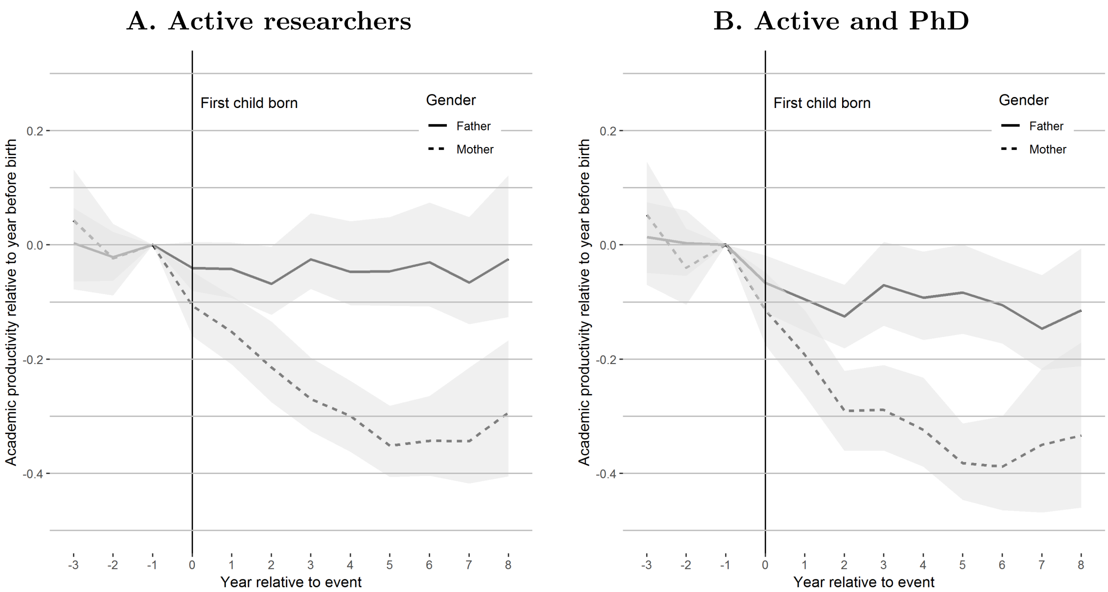
Table 3: Distribution on Publication Fields

	Active pre-birth			Active pre- and post birth		
	Total	Men	Women	Total	Men	Women
Share in:						
1. Laboratory fields	**0.32**	**0.30**	**0.37**	**0.32**	**0.30**	**0.37**
Agricultural and Biological Sciences	0.06	0.06	0.07	0.07	0.07	0.08
Biochemistry, Genetics and Molecular Biology	0.18	0.16	0.21	0.18	0.16	0.20
Chemical Engineering	NA	NA	NA	NA	NA	NA
Chemistry	0.04	0.04	0.03	0.03	0.03	0.02
Immunology and Microbiology	0.02	0.01	0.03	0.02	0.02	0.04
Neuroscience	0.02	0.01	0.02	0.01	0.01	0.02
Pharmacology, Toxicology and Pharmaceutics	0.01	0.01	0.01	0.01	0.01	0.01
2. Desk fields	**0.26**	**0.33**	**0.15**	**0.27**	**0.32**	**0.16**
Computer Science	0.05	0.07	0.03	0.05	0.07	0.03
Earth and Planetary Sciences	0.04	0.04	0.03	0.04	0.04	0.03
Engineering	0.03	0.04	0.01	0.03	0.04	0.01
Materials Science	0.02	0.03	0.01	0.02	0.03	0.02
Physics and Astronomy	0.05	0.07	0.02	0.05	0.07	0.01
Decision Science	NA	NA	NA	NA	NA	NA
Mathematics	0.01	0.01	NA	0.01	0.01	NA
Energy	0.01	0.01	NA	0.01	0.01	NA
Environmental Science	0.04	0.04	0.04	0.05	0.05	0.05
3. Medical fields	**0.41**	**0.38**	**0.48**	**0.41**	**0.38**	**0.47**
Observations	**2395**	**1517**	**878**	**1873**	**1248**	**625**

Note: Fields with less than 1% of sample have been marked by NA. The medical fields contain primarily medical doctors (99%), and very few nurses and dentists.

2 Figures

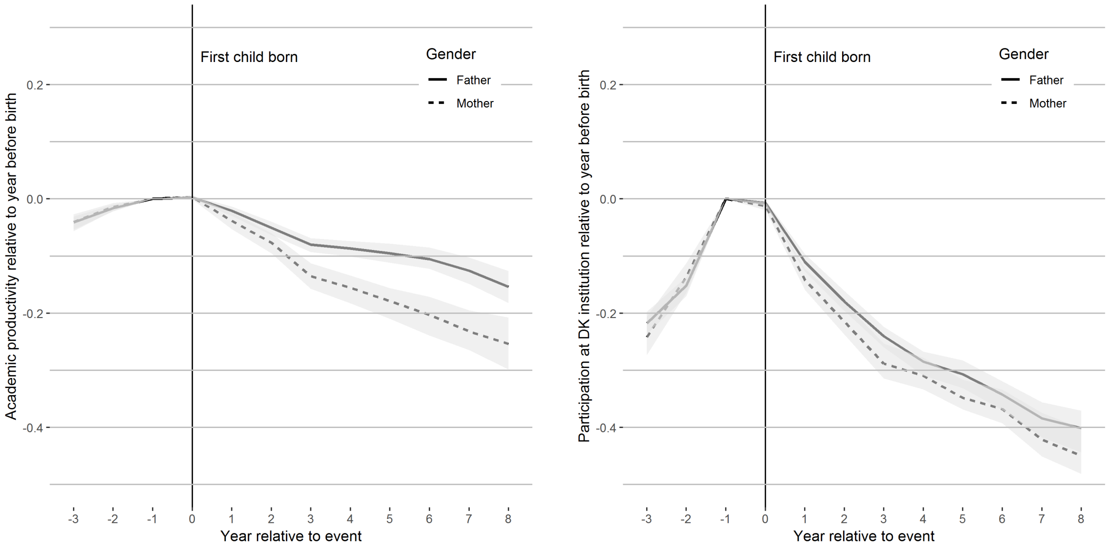
Figure 1: Impact of childbirth on the scientific productivity of researchers in STEM



Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. In Figure A, the estimated average annual child penalty is 23 percent ($p = 0.001$) over years 2 to 6 after birth. The sample of Figure A consists of all STEM researchers, who published prior to birth, including 878 women and 1517 men. In Figure B, the estimated average annual child penalty is 21 percent ($p = 0.012$) over years 2 to 6 after birth. The sample of Figure C consists of all STEM researchers, who published prior to birth and completed a PhD, including 591 women and 1042 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

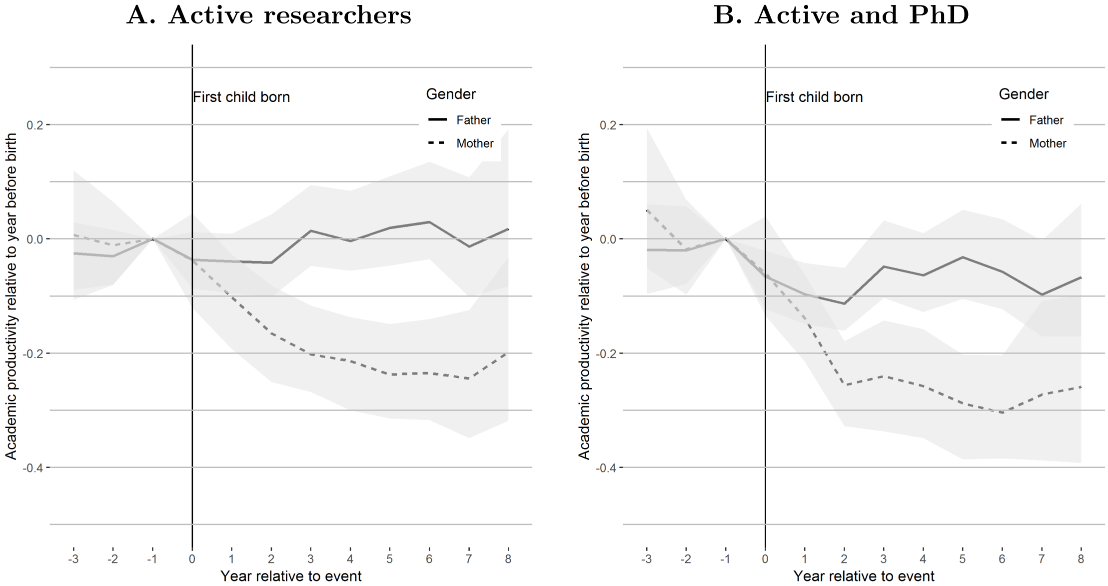
Figure 2: Impact of childbirth on researcher participation in STEM

A. Participation in Publishing **B. Participation at Danish Institution**



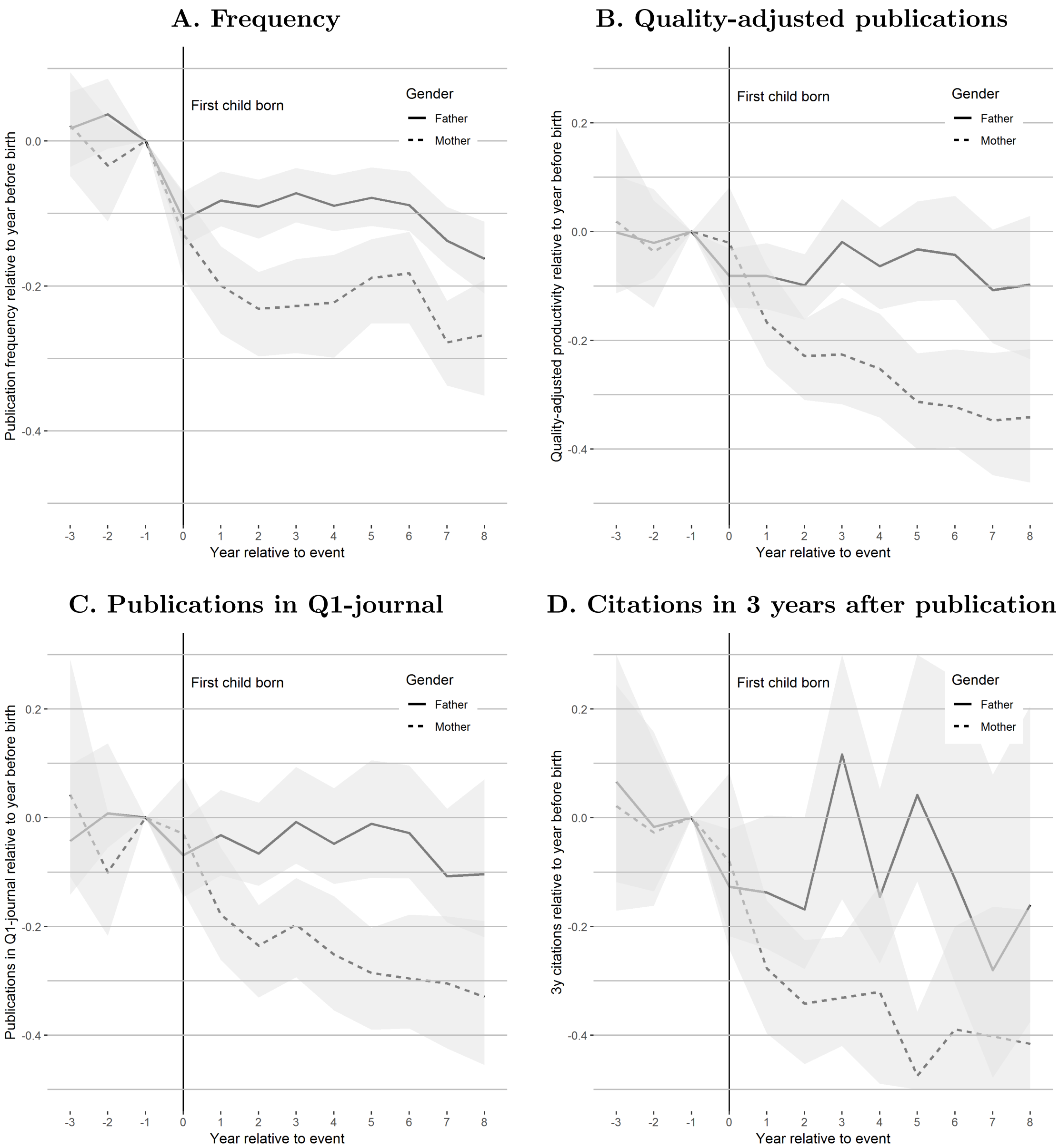
Note: The figure A show the impact of childbirth on participation in academic research (P_t) defined as having had at least one publication in the last 4 four years of male and female researchers working in Denmark around the birth of their first child. Figure B shows the impact of childbirth on participation at a Danish research institution, defined as having a Danish University or University Hospital as one's employer. In Figure A, the estimated average annual child penalty is 7 percent ($p = 0.001$) over years 2 to 6 after birth. The sample of Figure A consists of all STEM researchers, who published prior to birth, including 878 women and 1517 men. In Figure B, the estimated average annual child penalty is 3 percent ($p = 0.173$) over years 2 to 6 after birth. The sample of Figure B consists of all STEM researchers, who published prior to birth and completed at least a Master's degree, including 801 women and 1409 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 3: Impact of childbirth on the scientific productivity of active researchers in STEM



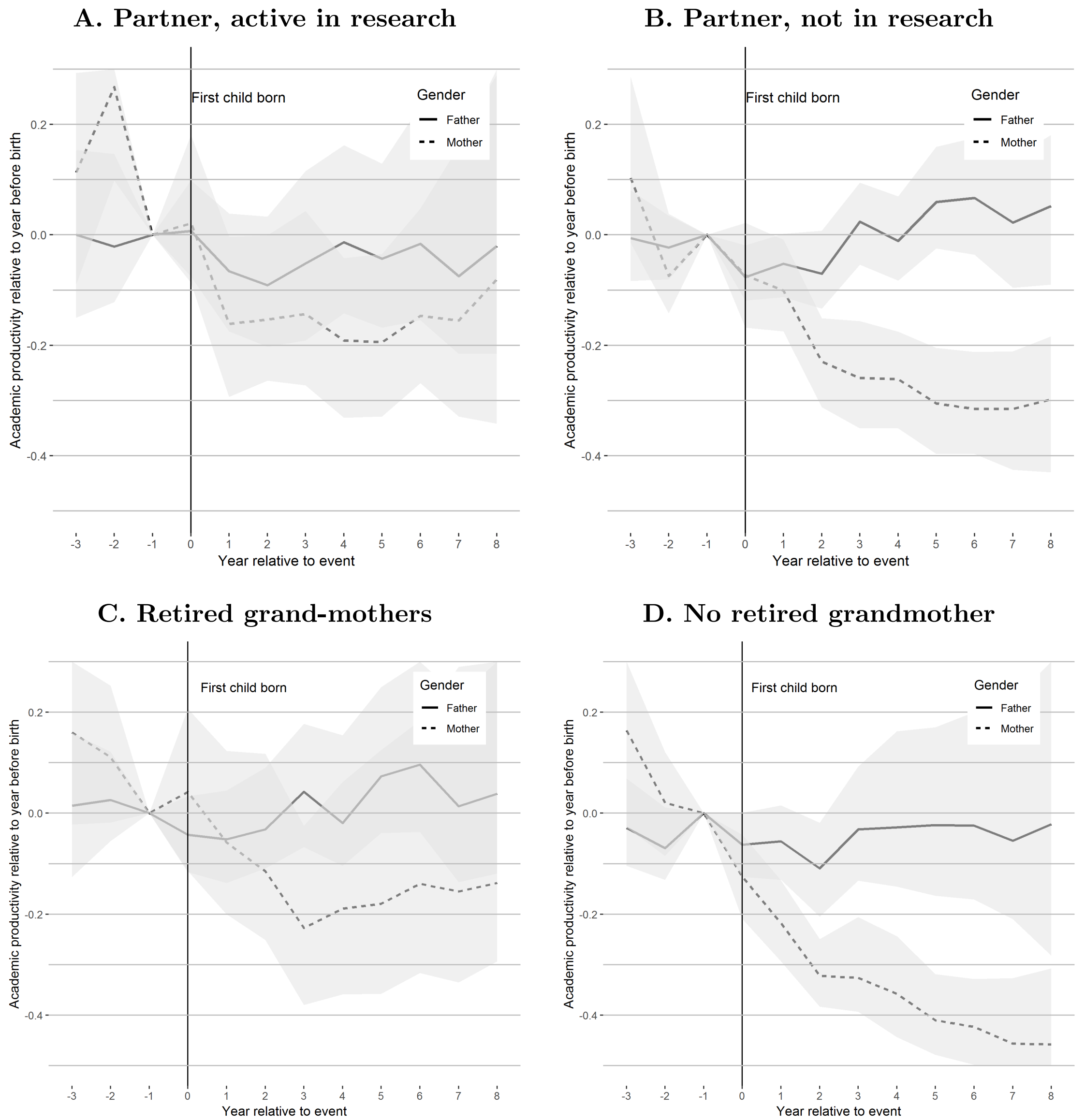
Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. In Figure A, the estimated average annual child penalty is 21 percent ($p = 0.006$) over years 2 to 6 after birth. The sample of Figure A consists of all STEM researchers, who published prior to and after birth, including 625 women and 1248 men. In Figure B, the estimated average annual child penalty is 18 percent ($p = 0.025$) over years 2 to 6 after birth. The sample of Figure C consists of all STEM researchers, who published prior to and after birth and completed a PhD, including 591 women and 1042 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 4: Impact of childbirth on frequency, quality and impact of publications



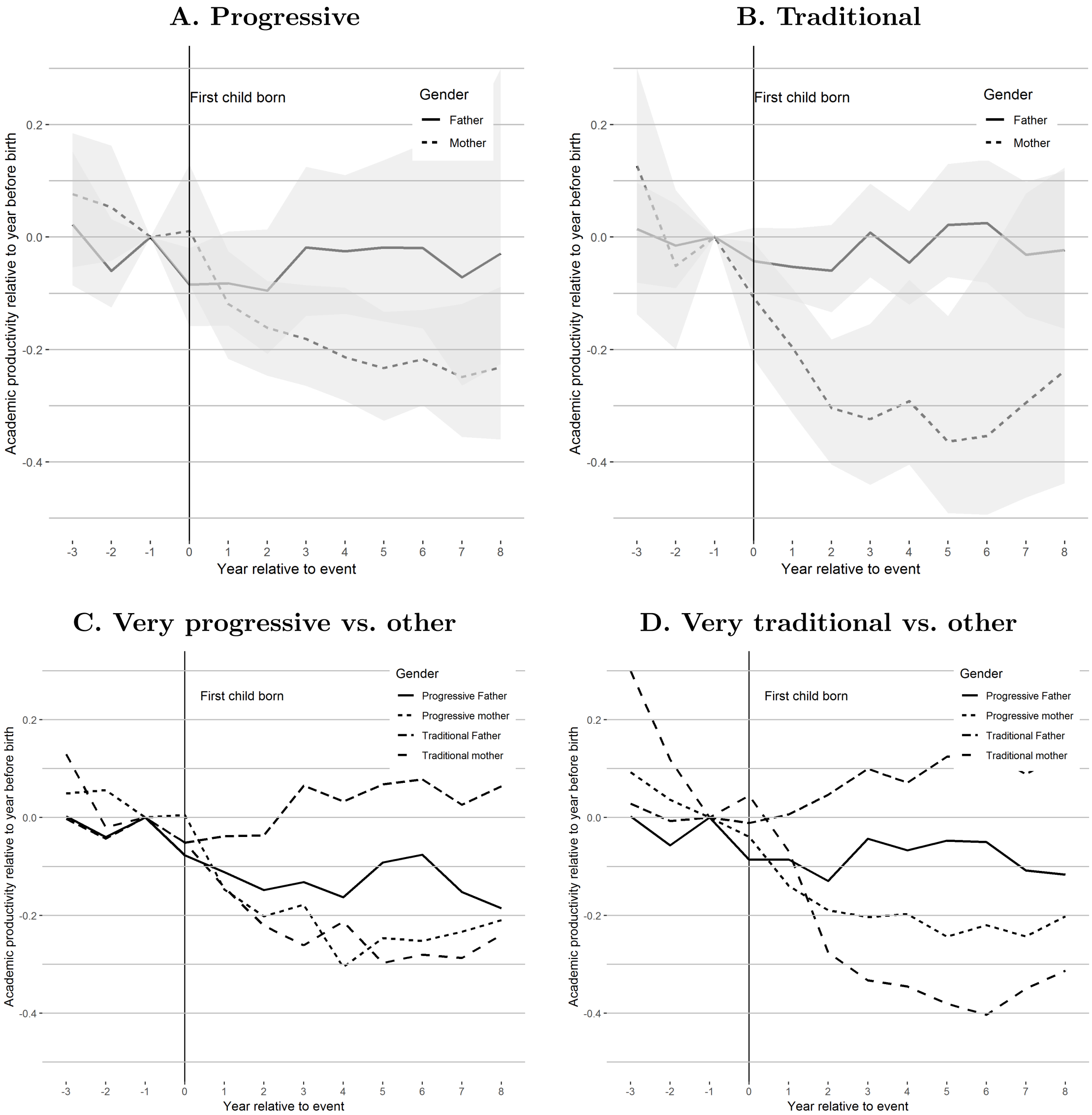
Note: Figure A show the impact of childbirth on frequency of publication, defined as a dummy equal to 1 in years with one or more publications (P_t) of male and female researchers working in Denmark around the birth of their first child. In Figure A, the estimated average annual child penalty is 12 percent ($p = 0.008$) over years 2 to 6 after birth. Figure B shows the impact of childbirth on quality-adjusted publications. Within a year, quality-adjusted publications are found by multiplying each publication with (1 + journal impact factor), and summing contributions within year. In Figure B, the average annual child penalty is 20 percent ($p = 0.018$) over years 2 to 6 after birth. Figure C shows impact of childbirth on number of publications in Q1-ranked journals. The estimated average annual child penalty is 21 percent ($p = 0.014$) over years 2 to 6 after birth. Figure D shows impact on citations to publications from a given year, accrued over a 3 year window. The estimated average annual child penalty is 30 percent ($p = 0.098$) over years 2 to 6 after birth.The sample of Figure A, B, C and D consists of STEM researchers, who published prior to and after birth and completed a PhD, including 461 women and 887 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 5: Partners and grandmothers: Impact of childbirth on scientific productivity



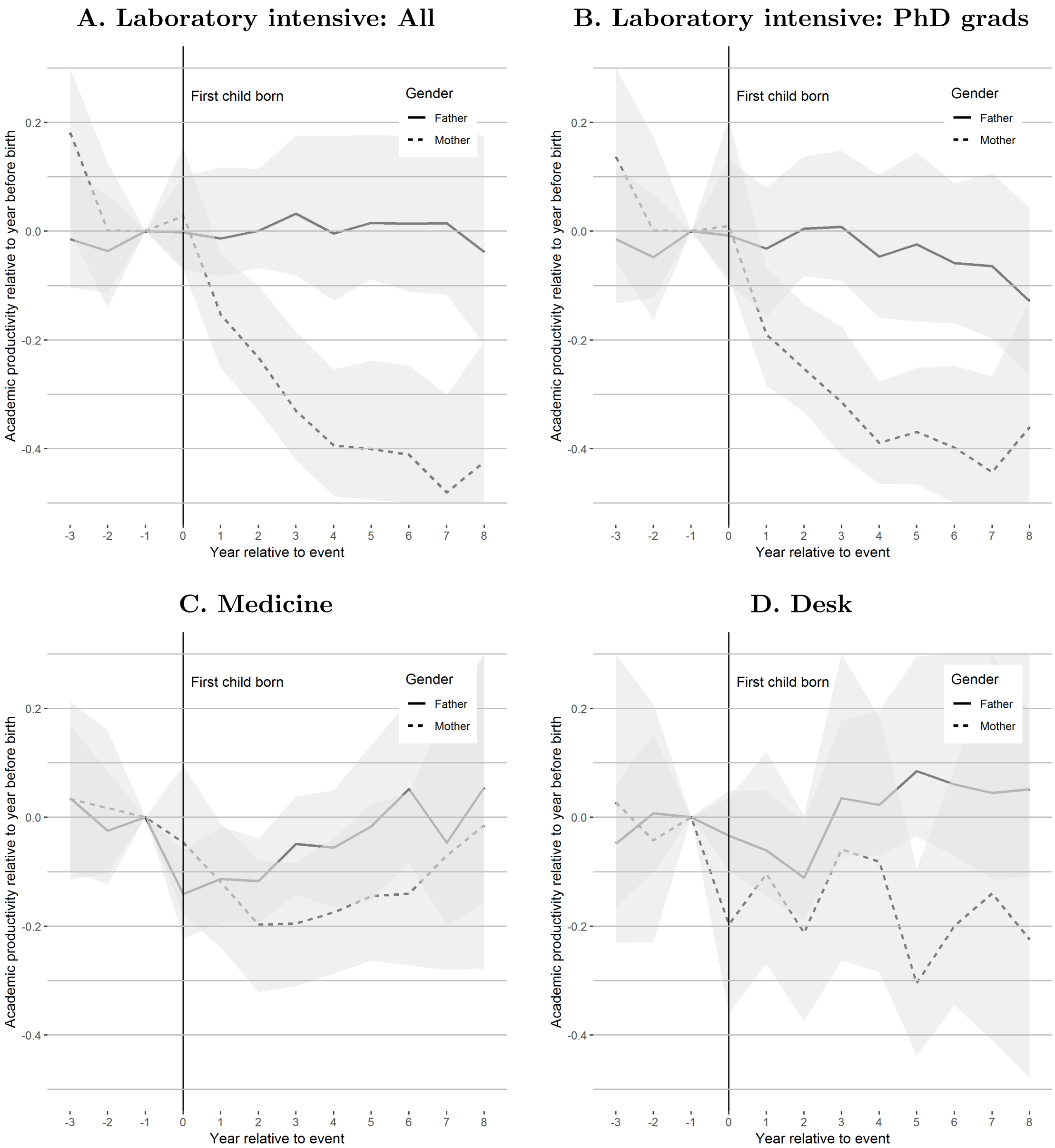
Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. Individuals are active in research before and after birth, and they have completed at least a Master's degree. We split the sample into couples where the partner is also active in reseach, i.e. has a publication or a PhD, and into couples where the focal researcher is the breadwinner. In Figure A, the estimated average annual child penalty is 10 percent ($p = 0.507$) over years 2 to 6 after birth, for 170 women and 253 men. In Figure B, the estimated average annual child penalty is 29 percent ($p = 0.000$) over years 2 to 6 after birth for 398 women and 905 men. In Figure C, the estimated average annual child penalty is 16 percent ($p = 0.231$) over years 2 to 6 after birth, for 222 women and 428 men. In Figure D, the estimated average annual child penalty is 27 percent ($p = 0.001$) over years 2 to 6 after birth for 342 women and 725 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 6: Gender norms: Impact of childbirth on scientific productivity



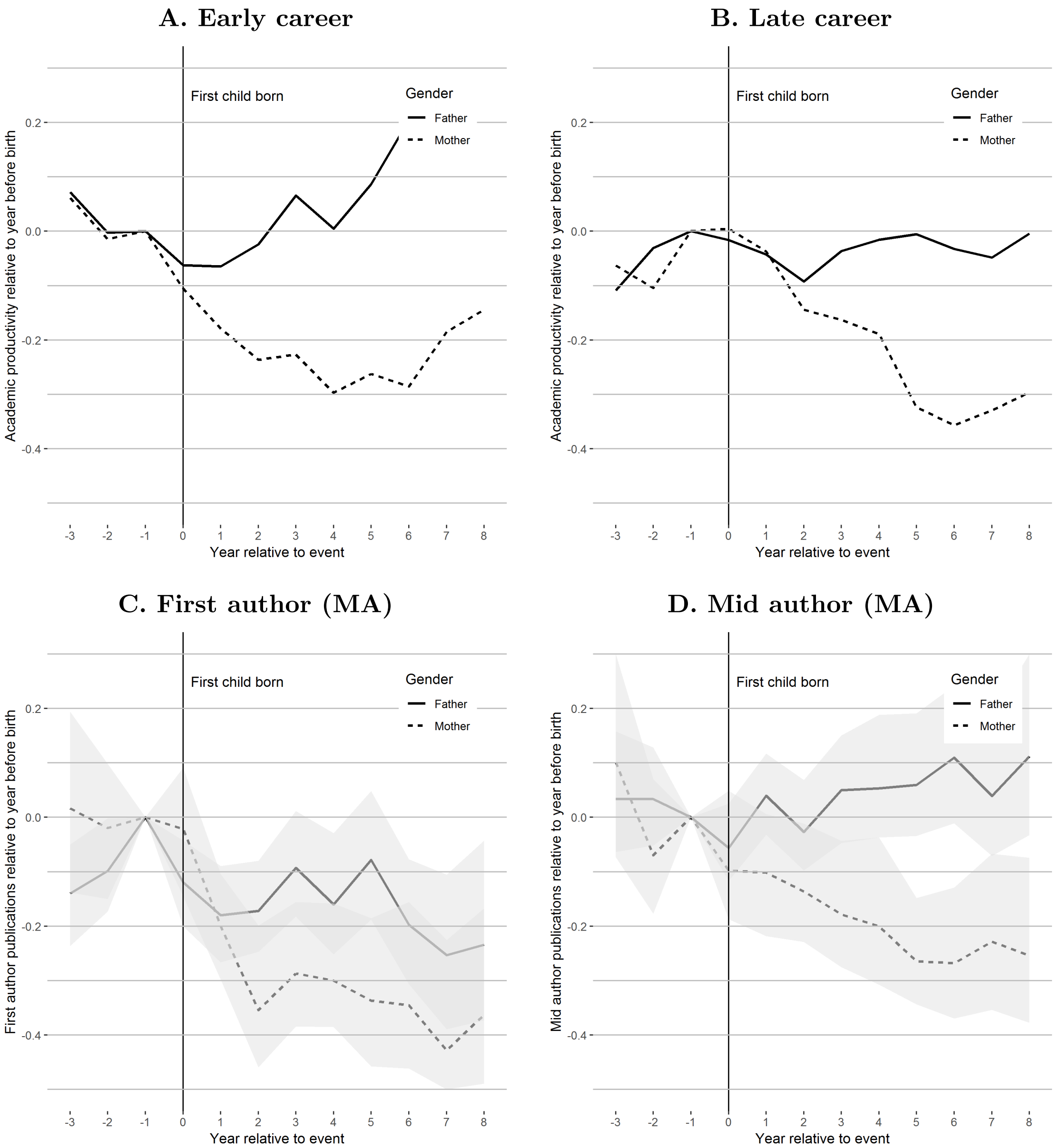
Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. Individuals are active in research before and after birth, and they have completed at least a Master's degree. We split the sample by leave-taking of the focal researcher as a proxy for household gender norms. In Figure A we split by median leave taking, and define progressive households as those where mothers take less than median leave and fathers take more than median leave. Similarly in Figure B, we define traditional households at those where mothers take more than median leave, and fathers take less than median. In figure C we compare very progressive households (mother¡Q1, father¿Q3) to other residual households, while in figure D we compare very traditional households (mother¿Q1, father¡Q1) to other residual households. The penalty on progressive households in figure A is 16 percent ($p = .191$) for 314 women and 412 men. The penalty on traditional households in figure B is 31 percent ($p = .008$) for 220 women and 665 men. The penalty on very progressive households in figure C is 15 percent ($p = .441$) for 196 women and 217 men, while for other households it is 28 percent ($p = .001$) for 338 women and 860 men. Finally, the penalty on very traditional households in figure D is 45 percent ($p = .000$) for 136 women and 491 men, while for residual households it is 12 percent ($p = .214$) for 398 women and 586 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 7: Publishing field: Impact of childbirth on scientific productivity



Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. Individuals are active in research before and after birth, and have completed at least a Master's degree. We split the sample into three subgroups based on their main field of publication: Laboratory-intensive, desk fields and medical fields. In Figure A for laboratory intensive fields, we estimate a child penalty of 37% ($p = 0.001$). The subgroup consists of 198 women and 345 men. In Figure B, the estimated average annual child penalty is 51 percent ($p = 0.001$) over years 2 to 6 after birth. The sample of Figure B consists of all PhDs in laboratory intensive fields, who graduated prior to birth, including 71 women and 155 men. In Figure A for medicine, we estimate a child penalty of 12% ($p = 0.355$). The subgroup consists of 283 women and 458 men. In Figure B for desk fields we estimate a child penalty of 19% ($p = 0.248$). The subgroup consists of 87 women and 355 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event

Figure 8: Career stage and author order: Impact of childbirth on scientific productivity



Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. Individuals are active in research before and after birth. In figures A and B, we split the sample by PhD-graduation after birth, PhD-students, and PhD-graduation before birth, PhD-graduates. The child penalty of students is estimated to 34 percent ($p = 0.22$) and the penalty of graduates is estimated to 19 percent ($p = 0.23$). The sample in A consists of 299 women and 423 men, while the sample in B consists of 210 women and 462 men. For figures C and D, we have divided publications into first, last and mid-author publications. In Figure C, the estimated average annual child penalty is 17 percent ($p = 0.134$) over years 2 to 6 after birth. In Figure D, the estimated average annual child penalty is 26 percent ($p = 0.004$) over years 2 to 6 after birth. The sample of Figures C and D consists of individuals who completed a Master's degree, and includes 568 women and 1158 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

A Appendix

A.1 Additional Figures and Tables

Figure 9: Cumulative publications around child birth

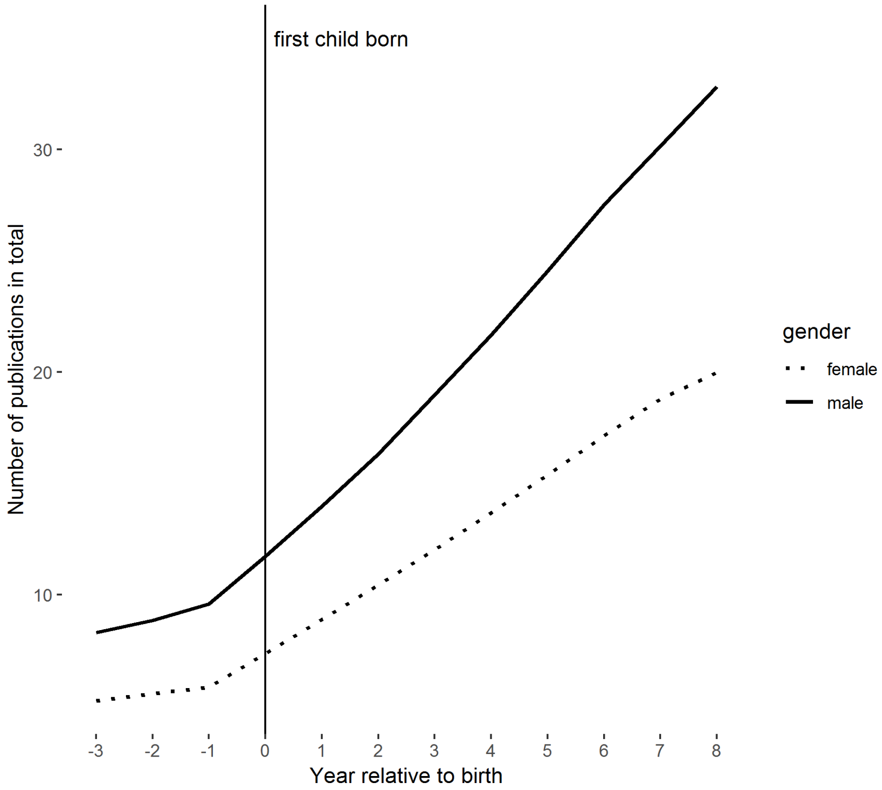
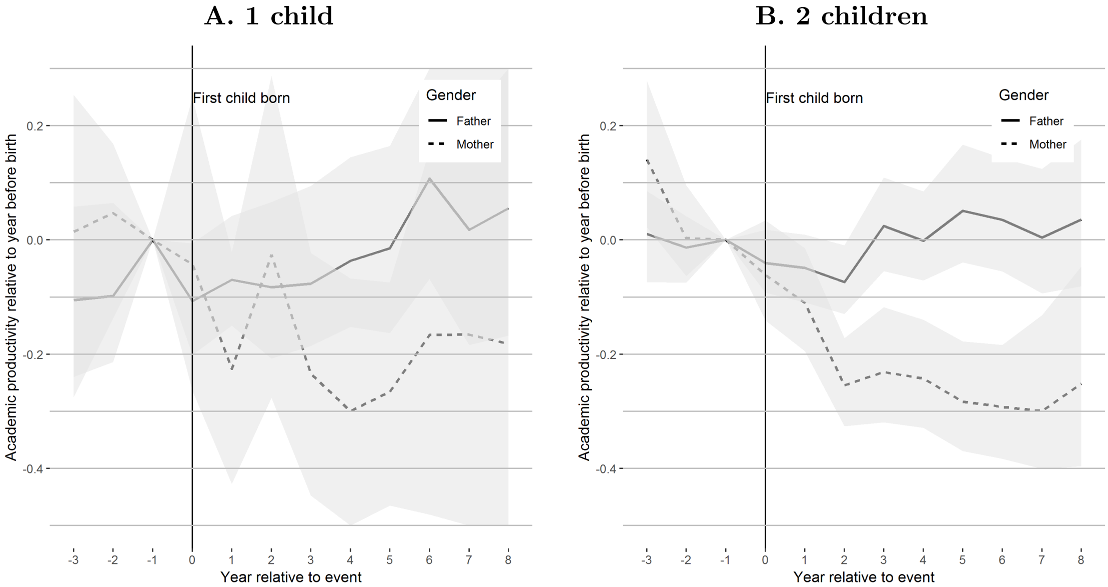
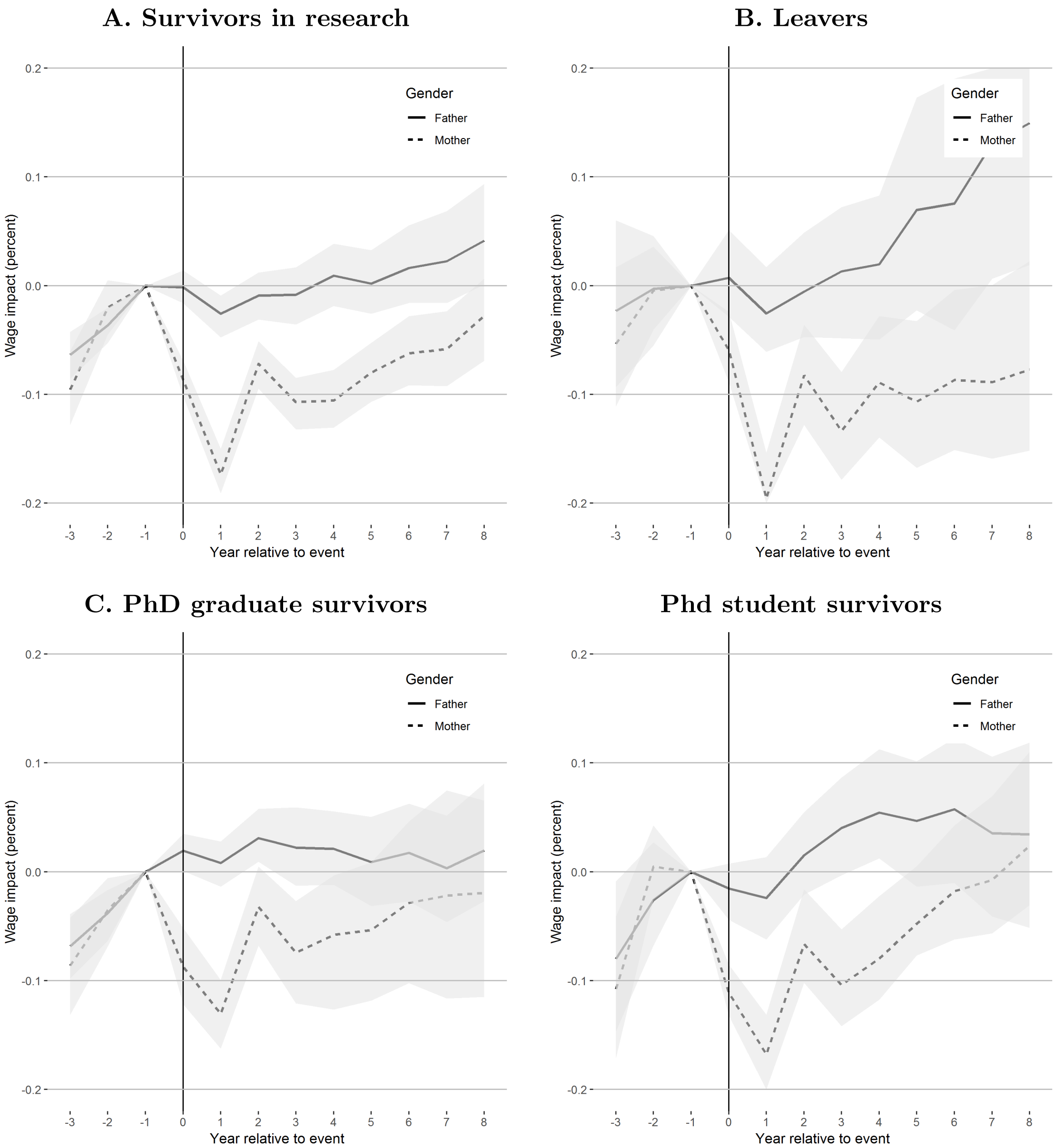


Figure 10: Family size: Impact of childbirth on scientific productivity



Note: The figures show the impact of childbirth on academic productivity (P_t) of male and female researchers working in Denmark around the birth of their first child. We split the sample by family size. In Figure A, the estimated average annual child penalty is 16 percent ($p = 0.433$) over years 2 to 6 after birth for 96 women and 190 men. In Figure B, the estimated average annual child penalty is 27 percent ($p = 0.002$) over years 2 to 6 after birth for 470 women and 961 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.

Figure 11: Impact of childbirth on annual wages of STEM researchers



Note: The figures show the impact of childbirth on annual wage earnings (P_t) of male and female researchers working in Denmark around the birth of their first child. Individuals in figures A, C and D are active in research before and after birth. Individuals in figure B are active in research before birth. The sample is limited to individuals who remained in Denmark, such that their earnings are available from the registers in the full period of observation. In Figure A, the estimated average annual child penalty is 10 percent ($p = 0.0.000$) over years 2 to 6 after birth. The sample consists of individuals with a Master's degree and includes 546 women and 1048 men. In Figure B, the estimated average annual child penalty is 14 percent ($p = 0.008$) over years 2 to 6 after birth. Individuals in the sample left academic research after birth, and it includes 227 women and 233 men. In Figure C, the estimated average annual child penalty is 0.09 percent ($p = 0.008$) over years 2 to 6 after birth. The sample consists of individuals who completed their PhD prior to birth, and includes 150 women and 355 men. In Figure D, the estimated average annual child penalty is 12 percent ($p = 0.002$) over years 2 to 6 after birth. The sample consists of individuals who were PhD students at birth, and includes 212 women and 308 men. In all figures 90%-confidence intervals are based on bootstrapped standard errors (1000 replications). In all estimations we include fixed effects for age, time, year, and graduation age (Master or PhD) or work experience relative to event.