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Has Covid-19 increased gender inequalities in professional advancement? Cross-country evidence on productivity differences between male and female software developers

Lena Hipp[1,2] and Markus Konrad[1]

[1] WZB Berlin Social Science Center, [2] University of Potsdam

Address correspondence to: Lena Hipp, WZB Berlin Social Science Center, Reichpietschufer 50, 10785 Berlin (Germany).
Email: lena.hipp@wzb.eu

Abstract

Objective: This article analyzed gender differences in professional advancement following the outbreak of the Covid-19 pandemic based on data from open-source software developers in 37 countries.

Background: Men and women may have been affected differently from the social distancing measures implemented to contain the Covid-19 pandemic. Given that men and women tend to work in different jobs and that they have been unequally involved in childcare duties, school and workplace closings may have impacted men's and women's professional lives unequally.

Method: We analyzed original data from the world's largest social coding community, GitHub. We first estimated a Holt-Winters forecast model to compare the predicted and the observed average weekly productivity of a random sample of male and female developers (N=177,480) during the first lockdown period in 2020. To explain the cross-country variation in the gendered effects of the Covid-19 pandemic on software developers' productivity, we estimated two-way fixed effects models with different lockdown measures as predictors – school and workplace closures, in particular.

Results: In most countries, both male and female developers were, on average, more productive than predicted, and productivity increased for both genders with increasing lockdown stringency. When examining the effects of the most relevant types of lockdown measures separately, we found that stay-at-home restrictions increased both men's and women's productivity and that workplace closures also increased the number of weekly contributions on average – but for women, only when schools were open.

Conclusion: Having found gender differences in the effect of workplace closures contingent on school and daycare closures within a population that is relatively young and unlikely to have children (software developers), we conclude that the Covid-19 pandemic may indeed have contributed to increased gender inequalities in professional advancement.

Key words: gender, Covid-19, inequality, productivity, international comparison, GitHub

1. Introduction

Have the social distancing measures implemented to contain the Covid-19 pandemic – school and workplace closures, in particular – affected men's and women's professional advancement differently? From a theoretical point of view, two main factors could explain potentially unequal effects of the pandemic on men's and women's professional activities. First, men and women tend to work in different occupations, organizations, economic sectors, and perform different types of tasks and may therefore have been unequally affected by contact restrictions and firm closures (Alon et al. 2020; Kleinert et al. 2020 for the United States and Germany). Second, given the unequal distribution of unpaid care work, the additional childcare duties arising from school and daycare closures may have also interfered with men's and women's paid work to different degrees (Collins et al. 2020; Hank & Steinbach 2020; Kreyenfeld et al. 2020; Landivar et al. 2020; Heggeness 2020; Globisch & Osiander 2020; Zinn et al. 2020; Zoch et al. 2020 for the United States and Germany).

However, the empirical evidence on the pandemic's effect on gender inequalities thus far is mixed (Grasso et al. 2021). Some survey studies have found that women were more likely than men to reduce their working hours or stop working after the start of the nationwide lockdowns (e.g., Collins et al. 2020; Farré et al. 2020; Hipp & Bünning 2020 for the United States, Spain, and Germany). Others, by contrast, have found that men were more likely than women to stop working (Witteveen 2020 for the UK). In addition, survey evidence from Germany and the United States suggests that the additional childcare burdens were, at least initially, equally distributed between men and women and that men increased the time they spent on childcare even more than women did (Globisch & Osiander 2020; Hank & Steinbach 2020; Kreyenfeld et al. 2020; Zoch et al. 2020 for Germany and Sevilla & Smith 2020 for the United States).

Studies based on observational data, most of which analyzed patterns of submissions to academic journals and preprint platforms, have found an increase in gender inequalities during the initial lockdown phase: Women were found either to submit fewer manuscripts after the outbreak of the pandemic than they had in previous years or to submit fewer manuscripts than men, who appeared to be more productive after the outbreak of the pandemic (Amano-Patiño et al. 2020; Bell & Fong 2021; Cui et al. 2020; Frederickson 2020; Inno et al. 2020; Minello 2020; Muric et al. 2020; Squazzoni et al. 2020).These differential submission rates indeed indicate detrimental effects of the Covid-19 pandemic on gender inequality, but they are, admittedly, also a coarse indicator: Rather than reflecting instantaneous productivity, submissions to academic journals are the product of months – if not years – of work.

This study seeks to shed further light on the gendered labor market effects of the pandemic arising from an unequal distribution of increased childcare duties following school and daycare closures by analyzing data on contributions to software projects from the online platform GitHub. GitHub is the world's largest online source code repository, with more than 50 million users who contribute to the platform by creating and modifying

code ("commits") and providing responses to discussions ("issues") in more than 200 million professional and leisure-time projects ("repositories").[1]

GitHub contributions are superior to many other types of data for assessing the pandemic's effects on men's and women's professional advancement. First, GitHub contributions reflect individuals' instantaneous productivity and are therefore an ideal measure to examine potential labor market inequalities. Second, the analysis of GitHub data provides us with a conservative and lower-bound estimate of potential gender differences due to increased childcare burdens, as GitHub users tend to be young and childless (Stack Overflow 2017-2020) Third, potential gender differences found with GitHub data are not confounded by gender differences in occupational choices and job types, as all GitHub users perform similar tasks and both male and female developers are equally experienced in working remotely (Stack Overflow, 2017-2020).

In our analyses, we used contribution data from a random sample of 177,480 GitHub public user accounts in a total of 37 countries. We first estimated a Holt-Winter forecast model (Holt, 2004; Winters, 1960) to predict the weekly contribution rates for the counterfactual scenario that the pandemic did not occur. The comparison of the differences between the predicted and the observed contribution rates shows that male software developers in most countries were more productive than expected during the initial phase of the pandemic; only in Bangladesh, China, Taiwan, and Russia did men's productivity patterns follow the predicted path or lag behind expectations. Women's productivity, by contrast, varied considerably between countries. In some countries, women were more productive than the predictions of our Holt-Winters forecast models suggest (e.g., Australia, Canada, Ireland, Romania, the Philippines, and Taiwan), whereas in others, female software developers' actual productivity was below predictions after the Covid-19 outbreak (e.g., Indonesia and Belgium). In still other countries, women's average number of contributions was not affected (e.g., Austria, Germany, Ukraine, Mexico, and Bangladesh).

To assess the degree to which school and daycare closures contributed to the observed variation in productivity by gender and country, we merged the average weekly deviations between the predicted and the observed number of GitHub contributions to country-level policy information on different lockdown measures and estimated 2–way fixed-effects models. In these analyses, we used both a composite measure capturing the overall stringency of lockdown measures as well as separate measures for school and workplace closures and stay-at-home restrictions (policy information stems from the Oxford Covid-19 Government Response Tracker; see Hale et al. 2020). The analyses with the composite measure show that both men's and women's GitHub activities increased with increasing lockdown stringency on average but that there was great variation across countries. The findings from the analyses with the separate indicators show some remarkable differences between men and women. Going from no restrictions or non-binding recommendations to mandatory restrictions for each of the three specific policy measures increased men's weekly contributions considerably (between .08 and .18 depending on the measure and the model specification). Given that the average number of weekly contributions by men in 2019 – the year preceding the pandemic – was 2.61, this corresponds to an average

1 See https://github.com/search?q=type:user&type=Users and https://github.com/search.

productivity increase of between 3 and 7 %. Women's productivity also increased when governments issued stay-at-home restrictions, but we also found that the productivity-enhancing effect of workplace closures among women was contingent on school openings. While men's productivity increased when workplaces were closed independent of school closures, we only found a positive effect of workplace closures for women when schools were open. As school closures play out differently in a population that is unlikely to have childcare responsibilities, the findings of our study provide evidence of the unequal effects of the Covid-19 pandemic on men's and women's professional advancement. In the case of software developers, women's productivity increased less following workplace closures than men's.

2. Gender inequalities and the Covid-19 pandemic

Covid-19 and the various policy measure to contain the pandemic seem to have affected men's and women's economic activities differently. Studies on the initial lockdown phase found that in many countries, women, and in particular mothers, were more likely than men to stop working or to reduce their working hours and hence to forfeit significant amounts of labor market experience (e.g., Collins et al. 2020; Farré et al. 2020; Bünning et al. 2020; Reichelt et al. 2020; Landivar et al. 2020; Heggeness, 2020; Dias et al. 2020; Kristal & Yaish 2020; Qian & Fuller 2020 for the United States, Canada, Germany, Singapore, Spain and Israel; for the United Kingdom, by contrast, Witteveen 2020 found men to have a higher probability of being put on temporary leave or dismissed).

The two most important explanations for the pandemic's unequal gender effects are differences in men's and women's employment situations and the additional care duties arising from school and daycare closures. In contrast to previous economic crises, in which men were more likely to lose their jobs or reduce their working hours because they worked in less recession-proof sectors, the economic crisis accompanying the Covid-19 pandemic has also severely affected female-dominated sectors (Alon et al. 2020). Adams-Prassl et al. (2020) found that in both the United States and the United Kingdom, the workers who were most likely to have lost their jobs during the pandemic were those in the female-dominated "food preparation and serving" and "personal care and service" sectors. Workers in male-dominated sectors, such as "computer and mathematical" occupations and "architecture and engineering", by contrast, were most likely to have kept their jobs. The pandemic's detrimental economic effects on men and women are therefore likely to be larger between than within occupations and sectors.

Moreover, the additional care responsibilities that arose from pandemic-related school and daycare closures placed an additional burden on working parents, mothers in particular. In addition to benefiting less from the productivity-enhancing effects of remote work (Bloom et al. 2014), parents tended to have less time to dedicate to paid work due to homeschooling and care responsibilities. Studies from Germany, the United Kingdom, and the United States, for instance, found that the unequal pre-pandemic distribution of housework remained largely unchanged during the initial lockdown phase between March and July 2020 (Hank & Steinbach 2020; Kohlrausch & Zucco 2020; Kreyenfeld et al. 2020;

Kulic et al. 2020; Sevilla & Smith 2020; Zamberlan et al. 2021). Likewise, a study on dual-earner couples in Australia found that the gender gap in unpaid work has remained constant during the pandemic due to similar increases in the amount of time spent on housework by both women and men (Craig & Churchill 2020). In a qualitative study from Hungary, Fodor et al. (2021), moreover, found that in highly educated couples, mothers and fathers increased the time spent on childcare to equal extents, but that the gender gap in the division of childcare still increased in the absolute number of hours due to the inequality that was in place before the pandemic.

In addition, several studies have reported gender differences in well-being following the Covid-19 outbreak (e.g., Zhou et al. 2020 for the United Kingdom and Bünning et al. 2020; Möhring et al. 2020 for Germany). For the United States and Australia, Ruppanner et al. (2021) found increased sleep problems and anxiety levels among parents, particularly among mothers in the United States. Czymara et al. (2020), moreover, documented increases in the mental load associated with reproductive work during the pandemic when analyzing open-text entries in a survey conducted in Germany. All of these psychologically detrimental consequences of the pandemic may also impair productivity at work and hence contribute to an increase in gender inequalities in professional advancement.

Studies on inequalities in academic manuscript submission rates help to disentangle these care-related explanations from sectoral explanations. Overall, women in academia seem to have been hit harder by measures to contain the pandemic than men. Some studies have shown that female researchers submitted fewer papers and preprints after the outbreak of the pandemic than before (Cui et al. 2020; Inno et al. 2020; Muric et al. 2020), whereas others have shown that submission rates increased overall but that women's submissions lagged behind men's (Bell & Fong 2021; Frederickson 2020; Squazzoni et al. 2020). Part of these inequalities seem to be driven by men's and women's unequal participation in Covid-19-related studies, which has become a major publication field since the outbreak (Pinho-Gomes et al. 2020). Most importantly, however, it is men's and women's unequal involvement in childcare responsibilities that seems to be driving these inequalities (e.g., Minello 2020 for Italy; Krukowski et al. 2021 for the United States; Staniscuaski et al. 2020 for Brazil). Although differences in the submission of scholarly work to journals and preprint archives are a solid indication of the potentially unequal effects of the Covid-19 pandemic on gender inequality, it needs to be noted that academic manuscripts are most likely not a reflection of instantaneous productivity. Instead, they are the product of months (if not years) of work preceding the submission.

3. The case of open-source software development

By analyzing contributions from software developers before and after the outbreak of the Covid-19 pandemic, this study sought to overcome measurement problems associated with productivity assessments in form of journal publications. More specifically, we analyzed contributions to the open source software development and project management platform GitHub, which allows its users to host and collaborate on code. The platform was founded in 2008 and has since become an essential part of the software development process for many individuals and companies. GitHub has more than 50 million users in

43 countries[2], many of whom register with their real names, as the platform is an important showcase for developers' work and professional advancement. GitHub is characterized by low selectivity among software developers, and all work published on the platform is non-proprietary and hence accessible for research without jeopardizing privacy and data protection rules.[3]

Investigating gender differences among software developers is particularly enlightening, as it is very unlikely to find a differential impact of the pandemic on male and female developers. Software developers tend to be relatively young and unlikely to have children (see Stack Overflow 2017-2020 data presented below). In contrast to other labor market segments both male and female software developers are used to working remotely and do so to equal degrees across countries (Stack Overflow 2017-2020). Finally, software developers are overwhelmingly male (e.g., BLS 2020); women who work as software developers are therefore presumably very committed to what they do and feel strongly about their work.

Table 1, which pools information from the StackOverflow Annual Developer Survey for the years 2017 to 2020, shows that software developers on average tend to be in their mid-twenties to early thirties and that a low proportion of them have children. As few as six percent of female developers in Spain and as many as 35 percent of male developers in Pakistan stated in the survey (2018/2019) that they were parents.[4] Third, there are no substantial gender differences in how male and female software developers work (Column 3, Table 1, pooled data for the years 2017 and 2019). Even in the countries with the highest proportion of software developers who say that they work remotely, only 14 percent of men (Argentina) and 13 percent of women (Ukraine) say that they spend at least half of their working hours at a location other than their employer. Last but not least, software developers seem to have a high intrinsic motivation. During the pre-pandemic period, the majority of both male and female software developers also coded in their leisure time as the pooled StackOverflow data show – between 44 percent of women in Ireland and 78 percent of women in Taiwan and between 74 percent of men in Colombia and 88 percent of men in Denmark.

2 See https://github.com/search?q=type:user&type=Users

3 GitHub's general terms and conditions state that it requires users to allow others to copy and analyze all content they produce and only prohibits spamming or commercial use (See https://docs.github.com/en/free-pro-team@latest/github/site-policy/github-terms-of-service, section D and H in particular.

4 As not all variables are included in all StackOverflow surveys, Table 1 combines different surveys for the different variables (https://insights.stackoverflow.com/survey). As sample sizes for women tend to be very small, we pooled data from different years when the information on a particular variable was collected, that is, 2017/18 for information on remote work, 2018/19 on children, 2017– early 2020 for leisure coding.

Table 1: Characteristics of male and female software developers

	mean age		% w/ kids		% remote work		% leisure coding	
	M	F	M	F	M	F	M	F
Americas								
AR	31	31	19	12	14	10	77	61
BR	29	27	16	7	7	7	76	60
CA	32	30	19	10	8	7	81	61
CO	29	NA	18	NA	13	NA	74	69
MX	29	29	21	12	10	5	79	75
US	33	32	23	14	10	10	83	62
Eastern Europe/ Central Asia								
PL	29	27	20	11	10	9	87	73
RO	30	27	17	12	8	6	82	60
RU	30	28	24	15	11	7	79	66
TR	29	27	21	15	6	4	77	61
UA	29	26	26	18	13	13	77	64
Western Europe								
BE	31	29	18	11	4	NA	84	70
AT	30	31	15	8	6	6	87	61
CH	31	28	17	10	4	3	84	53
DE	30	30	17	12	5	5	86	65
DK	33	30	25	19	4	NA	88	66
ES	32	31	17	6	8	7	80	67
FI	33	32	20	11	8	NA	84	62
FR	30	29	15	8	6	5	83	66
GB	33	31	17	8	7	6	82	63
IE	33	31	18	8	7	2	81	44
IT	32	30	17	14	8	7	77	56
NL	31	32	17	10	5	3	87	72
NO	33	31	25	14	4	NA	86	67
PT	31	29	16	13	7	NA	76	58
East Asia/Pacific								
AU	33	33	24	11	7	6	83	68
CN	27	26	30	28	4	NA	85	76
ID	26	NA	25	23	10	NA	84	72
KR	30	NA	17	NA	6	NA	77	53
NZ	33	29	22	10	7	8	82	65
PH	26	26	23	20	10	4	77	57
TW	30	NA	21	NA	6	NA	83	78
South Asia								
BD	27	NA	31	31	9	NA	78	73
IN	26	25	30	24	5	5	81	72
PK	26	25	35	22	10	5	78	67
Middle East/Africa								
EG	26	27	25	22	9	NA	78	58
ZA	32	30	24	15	7	8	81	63
SG	29	27	25	9	4	NA	82	57
IL	33	30	30	24	5	7	79	58
VN	26	NA	24	NA	6	NA	87	NA
CL	31	NA	21	NA	10	NA	79	67
CZ	30	29	20	18	10	5	88	68
NG	26	24	26	22	12	NA	81	73

Note: Pooled StackOverflow Annual Developer Survey 2017-2020; country estimates were replaced with NA if N < 30.

GitHub data are ideally suited to the analysis of changes in productivity in response to the Covid-19 pandemic. First, in contrast to scholarly article submissions, GitHub contributions are an indicator of immediate productivity and not of work done in the past that is counted as productivity at the time of submission. Second, academic work is often produced in collaboration with others, and conventions regarding author order vary widely across fields and sub-disciplines (Burrows & Moore 2011). Contributions to GitHub, by contrast, are made by individuals. Although GitHub users also work collaboratively, we can nonetheless clearly identify individual productivity as all code "commits," "issues," and "pull requests" are directly attributed to the person who published them. Third, the sheer amount of available data allows us to collect sufficient information on both male and female developers and to take general time trends into account (Melo et al. 2019). These advantages outweigh some of the obvious limitations that GitHub data have – namely, the limited individual-level information that can be retrieved about the developers (most importantly, we lack information about developers' parental status) and the high selectivity of this population, which limits the conclusions we can draw for the general population.

4. Empirical predictions

Based on the available information about software developers' demographic characteristics and the fact that large proportions of developers also code as a hobby, it is unlikely to observe either declines in productivity or different productivity developments between male and female developers following the outbreak of the Covid-19 pandemic. With the restrictions on public life, software developers may have increased their coding activities given the extra time available to them and the opportunity and need to develop code in response to the pandemic. This paper therefore tested the prediction that the increasing stringency of lockdown measures led to an increase in both male and female developers' coding activities. In particular, we expected that stay-at-home restrictions and workplace closures had a positive effect on productivity, as they provided coders with the opportunity either to work on personal coding projects or to work from home, thus eliminating commuting time and reducing distractions (Bloom et al. 2014).

However, given the unequal distribution of childcare responsibilities by gender, we also examined gender differences in this effect as well as interactions between workplace closures and school closures. While it is indeed unlikely that female developers were affected differently by the lockdown measures due to their low average age and their low likelihood of having children, it might nonetheless be that additional care responsibilities and mental load that arose from school and daycare closures were shouldered primarily by women rather than men. Hence, we expected women's productivity to increase to a lesser degree than men's with increasing levels of lockdown stringency. We also expected differences between male and female developers' to be particularly pronounced when schools and daycare facilities were closed.

5. Data and measures

In our analyses, we used the average number of weekly GitHub contributions by country and gender to approximate productivity differences between men and women after the outbreak of the pandemic in the year 2020. Our sample consisted of a random draw of 177,480 GitHub user accounts with almost 103 million contributions (around 99M contributions by male and 4M by female developers) from 37 countries. GitHub profile data were collected using the GitHub API; individual contribution counts were collected via webscraping.

We first used the GitHub search API to fetch all accounts that matched the following three criteria: (1) the account had to have at least one public repository, (2) the account was created on one of 100 randomly chosen days between April 2008 (launch date of GitHub) and December 2019 (the last month before the pandemic's official outbreak in China), and (3) the account contained a country-specific keyword in its "location" field, i.e., the country name or the name of one of the biggest cities in that country.[5] Next, we drew a random sample from these data that included a sufficiently large number of women. We removed all user accounts for which no contribution data could be fetched (55 out of 195,299 user accounts, which were probably deleted between selection and the fetching of the contribution data). To deal with bots or "bulk commits" that automatically submit large numbers of contributions to GitHub, we filtered out days where individual contributions exceeded 30.

We obtained all daily contribution counts within our observation period, 2014 to mid-2020, for all sampled user accounts. We used the mean number of weekly contributions by men and women for each country to predict the mean weekly contributions for the counterfactual scenario that the pandemic did not happen by fitting a forecast model. The difference between the predicted and actual weekly mean contribution rate is our dependent variable. Positive values mean that GitHub users in a given week produced more code than predicted and negative values that they produced less than predicted.

We decided to analyze the aggregate rather than individual-level data due to the following two restrictions: First, high numbers of users do not regularly commit contributions on a weekly basis. In 2019, 53 percent of users did not make any contribution 90 percent of the time, i.e., in 47 out of the 52 weeks. Changes in contribution behavior therefore only become visible when we consider the aggregate level. Second, while it would theoretically be possible to estimate zero-inflated Poisson or negative binomial regressions, the hierarchical structure of the data (individuals are nested in both countries and weeks) makes these models computationally highly intensive in practice. Using the weekly aggregates, by contrast, allows us to estimate linear models without violating any OLS assumptions.

5 There is no other way to select accounts that are likely to be in our countries of interest from the over 50M existing GitHub accounts.

Table 2: Overview on national-level lockdown intensity (# of weeks/mean stringency)

	school closing				workplace closings				curfews				overall stringency	
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**M**	**(sd)**
Americas														
AR	2	0	0	19	2	0	8	11	2	0	13	6	.84	(.24)
BR	2	0	0	20	3	0	5	14	3	7	12	0	.69	(.23)
CA	2	0	0	19	2	0	5	14	2	19	0	0	.64	(.19)
CO	5	0	0	19	2	4	12	6	6	0	18	0	.7	(.31)
MX	2	0	0	18	2	0	8	10	3	0	17	0	.69	(.23)
US	2	0	0	21	4	0	6	13	4	1	18	0	.61	(.23)
Eastern Europe/ Central Asia														
PL	2	0	9	11	3	0	19	0	13	8	1	0	.59	(.23)
RO	2	0	6	14	2	6	14	0	7	7	8	0	.61	(.23)
RU	4	1	5	13	4	0	13	6	2	0	12	9	.66	(.25)
TR	3	0	0	19	3	8	11	0	2	2	18	0	.62	(.18)
UA	2	0	9	11	3	5	14	0	3	19	0	0	.64	(.29)
Western Europe														
AT	11	2	2	7	2	3	13	4	15	0	7	0	.54	(.24)
BE	2	4	14	0	2	0	11	7	9	0	11	0	.63	(.2)
CH	2	7	4	8	2	7	6	6	7	14	0	0	.56	(.16)
DE	2	3	9	10	6	0	18	0	16	2	6	0	.56	(.21)
DK	4	0	15	4	3	1	19	0	2	21	0	0	.58	(.2)
ES	2	0	9	11	5	3	6	8	5	5	12	0	.63	(.22)
FI	3	11	8	0	2	7	13	0	11	11	0	0	.45	(.14)
FR	7	0	6	10	4	5	6	8	4	11	8	0	.66	(.23)
GB	2	0	0	19	2	1	8	10	2	12	7	0	.66	(.21)
IE	3	0	4	15	2	7	6	7	9	6	7	0	.63	(.28)
IT	2	0	0	22	2	2	10	10	2	12	7	3	.67	(.2)
NL	2	7	5	8	3	0	11	8	2	13	7	0	.58	(.24)
NO	13	0	3	6	2	8	12	0	22	0	0	0	.49	(.21)
PT	2	0	11	9	2	0	13	7	3	7	12	0	.67	(.21)
East Asia/Pacific														
AU	4	0	10	6	2	6	12	0	6	3	10	1	.62	(.14)
CN	3	0	2	24	3	0	5	21	2	7	0	20	.69	(.21)
ID	2	0	4	21	8	4	7	8	12	0	15	0	.53	(.21)
KR	2	0	2	23	5	4	16	2	11	12	4	0	.5	(.19)
NZ	13	0	2	5	13	0	2	5	13	0	7	0	.51	(.32)
PH	2	0	0	20	3	0	8	11	3	2	5	12	.82	(.23)
TW	24	0	0	3	27	0	0	0	27	0	0	0	.24	(.04)
South Asia														
BD	2	0	0	19	2	6	2	11	2	5	14	0	.75	(.23)
IN	7	0	2	19	9	5	10	4	2	8	12	6	.6	(.36)
PK	2	0	0	21	6	0	14	3	6	2	15	0	.66	(.27)
Middle East/Africa														
EG	2	0	7	12	2	0	19	0	3	7	11	0	.67	(.26)
ZA	2	0	7	12	3	0	12	6	3	6	12	0	.74	(.22)

Note: 0–no measures in effect, 1–recommended measurs, 2–required measures w/ exceptions, 3–required measures w/o or w/ minimal exceptions; data from the Oxford COVID-19 Government Response Tracker (https://github.com/OxCGRT).

Country and gender information for the user accounts was inferred from the profile entries in the “location" and “full name" fields. We used the Google Maps geocoding API to identify the country from the location information. Users’ gender was identified with country-specific lookups of the given name using the Genderize API (genderize.io). Only accounts with 80% probability of correct gender identification (as provided by the Genderize API) entered our sample. We also removed all user accounts for which the automated location geocoding was ambiguous (i.e., produced more than one result). For 6 out of 43 countries, we obtained fewer than 100 female accounts and therefore excluded these countries from our analytic sample. In our analytic sample, 13,476 out of 177,480 users accounts belonged to women, i.e., around 8%, which is low but consistent with other estimates (see Finley 2017, for example). The overall average number of weekly contributions before the Covid-19 outbreak (i.e., in 2019) was around 2.6 for men (s.d. of 9) and 1.7 for women (s.d. of 7).

6. Country-level Covid-19 countermeasures

To assess the country and time-specific stringency of the lockdown measures, we drew on information provided by the Oxford Covid-19 Government Response Tracker (Hale et al. 2020), which we obtained through the Covid-19 Data Hub project (https://github.com/OxCGRT). In addition to using a composite measure that captures the overall stringency of nine containment measures, including school closures, workplace closures, and travel bans, we also used school closures (C1), workplace closures (C2), and stay-at-home restrictions (curfews) (C6) as separate indicators in our analyses.

The overall Covid-19 stringency measure can take on values between 0 and 100; higher values indicate more severe restrictions. If policies vary at the subnational level, the index takes on the level of the strictest sub-region. This means that in our empirical analyses, we may have underestimated the actual effect of both the overall lockdown stringency as well as effects of the separate lockdown measures on software developers’ productivity when the implementation of these measures differed at lower administrative levels, e.g., region or municipality. Empirically, this applies in particular to large countries and countries with wide differences in infection rates at the local level, e.g., the United States (McDonald et al. 2020).

To improve the readability of our tables, we re-scaled the overall stringency indicator to range from 0 to 1. For instance, a value of around 73 (or .73 in the rescaled version used in our analyses), which reflects the situation in the United States in mid-April 2020, corresponds to school and workplace closures at all levels (with the exception of all essential tasks), the cancellation of public events, restrictions on social gatherings to 10 people or fewer, and travel restrictions (international travel bans, restrictions on domestic travel, curfews with few exceptions, and recommendations to close public transportation).[6]

6 Illustrations of stringency levels of Covid-19 government responses can be found at https://covidtracker.bsg.ox.ac.uk/stringency-map; for the example above, data from September 7, 2020, were used.

The three separate indicators for school closures, workplace closures, and stay-at-home restrictions, which we also used in our analyses, were originally measured on four levels: (0) no restrictions; (1) non-binding recommendations; (2) partial restrictions with exceptions; and (3) mandatory and enforced restrictions with no/only few exceptions. Table 2 provides an overview of the number of weeks during which each measure was implemented—along with the mean of the overall Covid-19 stringency index and its standard deviation. As most countries did not have all levels of each lockdown measure implemented during our observation period, we collapsed the categories and used a dichotomous variable in our multivariable analyses (0 – no restrictions / non-binding recommendations; 1 – partially enforced restrictions / mandatory restrictions with few/no exceptions).

We also used the implementation of these countermeasures to specify the country-specific time of the pandemic's outbreak. That is, we defined the manifest outbreak of the pandemic if any of the policy measures "school closures,'' "workplace closures," or "stay-at-home restrictions" took on a value above zero (i.e., if the government at least recommended restrictions).[7]

7. Analytic strategy

To assess whether, and to what degree, the outbreak of the Covid-19 pandemic affected the productivity of male and female software developers differently, we proceeded in two steps. In a first step, we used the data from the beginning of our observation period (2014) up to the country-specific onset of Covid-19 countermeasures to train a Holt-Winters forecast model (Holt 2004; Winters 1960). The Holt-Winters model is appropriate to forecast "seasonal" data series and is used to make a counterfactual prediction of the weekly mean GitHub contributions if the pandemic had not occurred. That is, for the time after each country had started to implement any type of countermeasure to fight the pandemic, we can compare the predicted mean weekly contributions with the observed mean weekly contributions. The counterfactual scenarios are estimated separately by country and gender. In the following, we refer to the difference between the predicted and the observed weekly contribution as the estimated "productivity gap". Positive values indicate an upward deviation from the predicted productivity and negative values a downward deviation. In addition to graphically displaying this productivity gap for a select number of countries, we also seek to systematically describe the productivity gap for all countries in our study by presenting the stylized results of country-specific OLS regressions (separated by gender).

In a second step, we estimated two-way fixed effects models to explain the variation in the observed productivity gap between genders and countries with the stringency of the country-specific safety measures to contain the pandemic. In these analyses, we restricted our sample to the period between the country-specific implementation of the first measures to counteract the pandemic in any given country and the end of July 2020. We

7 Replication materials available at https://github.com/WZBSocialScienceCenter/github_covid_gender_jfr

estimated robust standard errors clustered at the country level. Our models take on the following form:

$$(1) \qquad y_{jt} = \alpha + \beta_1 x_{sjt} + \mu_j + \gamma_t + \epsilon_{jt}$$

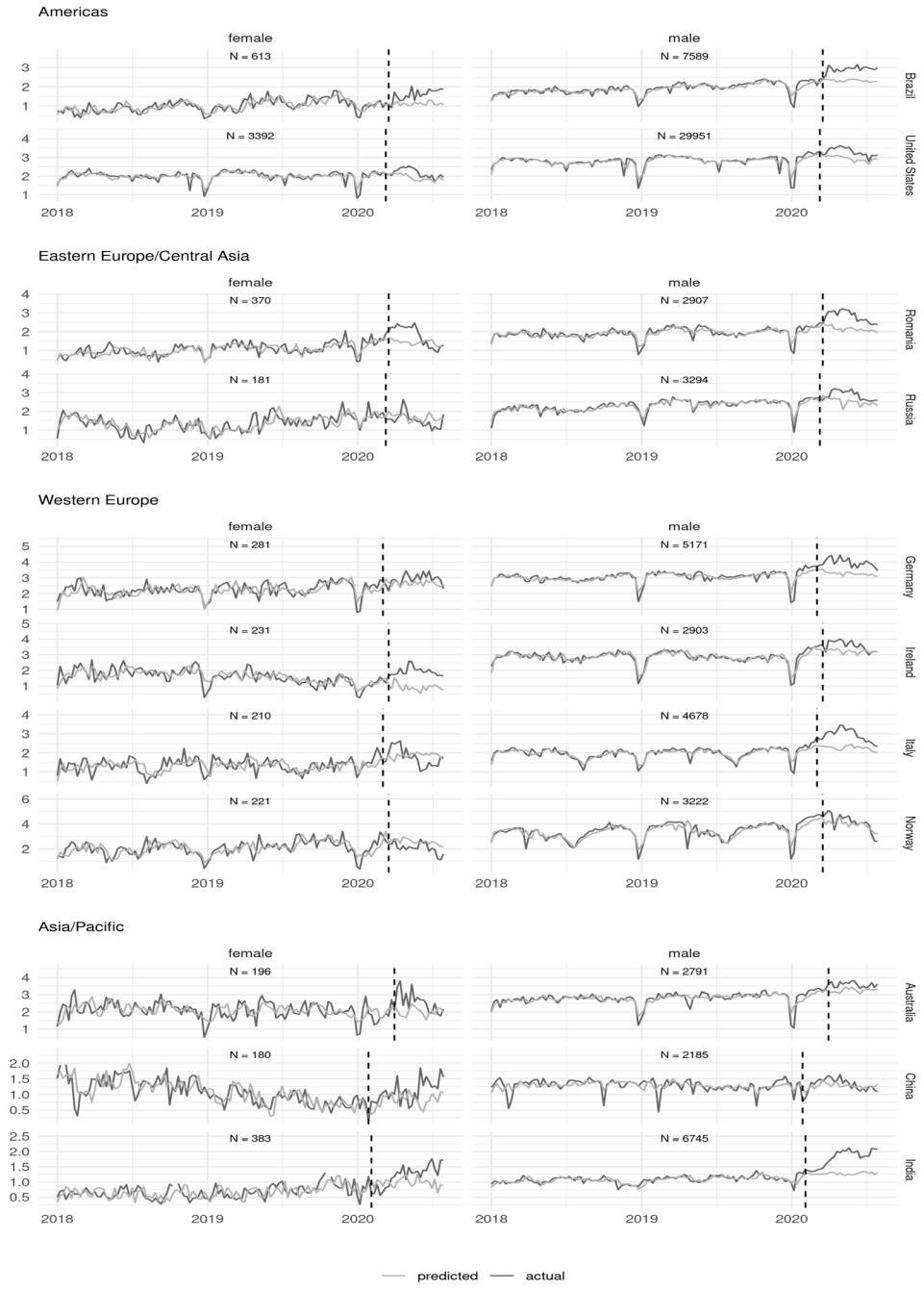
$$(2) \qquad y_{jt} = \alpha + \beta_1 x_{1jt} + \beta_2 x_{2jt} + \beta_3 x_{3jt} + \beta_4 x_{1jt} x_{2jt} + \mu_j + \gamma_t + \epsilon_{jt}$$

Male and female software developers' average deviations between the predicted and observed number of weekly GitHub contributions y_{jt} in *country j* in *week t* are explained by the exogenous variable *stringency of lockdown measures* x_{sjt} (Model 1) and alternatively by the variables *school closures* x_{1jt}, *workplace closures* x_{2jt}, and *stay-at-home restrictions/curfews* x_{3jt} at the country-week level as well as an *interaction effect between school and workplace closures* $x_{1jt}x_{2jt}$ (Model 2). We included this interaction effect because working from home when schools and daycare facilities are closed tremendously decreases the benefits from remote work for individuals who have to take care of children or do homeschooling. With the country fixed effects μ_j, we sought to rule out time-invariant unobserved confounders that may affect the average number of contributions by software developers to GitHub, such as the health care system or political majorities in national governments. With the time fixed effects γ_t, measured in weeks since implementation of initial countermeasures, we took account of the fact that software developers' average weekly productivity is likely to vary with the duration of the pandemic. α is the overall intercept for all countries for the time at which the first countermeasures were implemented, β_{1-3} are the parameters of interest, and ϵ_{jt} is the error term. The underlying assumption of this specification is that variation in the stringency of the different lockdown measures x_{sjt} and x_{1-3jt} is exogenous and conditional on a general time trend γ_t. This two-way fixed effects specification can be interpreted as a generalized difference-in-differences approach. The estimated parameters β_1 to β_3 can therefore be interpreted causally.

8. Findings

Figure 1 displays the difference between the observed and the predicted number of average weekly contributions for a select number of countries from different regional clusters. A graph that juxtaposes the predicted and the actual number of weekly contributions by gender for all the countries in our sample is provided in the supplementary online materials. Within each of the four geographic regions, we see some variation in the deviation patterns for male and female developers. In the majority of countries shown in Figure 1, men were constantly more productive than expected after the country-specific lockdown measures were implemented (indicated by the dashed vertical line). For women, by contrast, there was great variation. Women in Romania and Ireland were considerably more productive than expected. For Brazil, India and the United States, the upward deviation was similar, though less pronounced. Other countries show mixed patterns or even a decrease in productivity compared to the prediction (Norway, Russia).

Figure 1: Actual vs. predicted number of weekly contributions by country and gender



Note: GitHub data, 2014 to August 2020, own calculations. Please note the differences in the scale of the y-axis to account for baseline productivity differences between countries.

In addition to indicating the differential effect of the lockdown measures on men's vs. women's productivity, Figure 1 also shows that—due to the considerably smaller sample sizes for women—the forecasts based on the Holt-Winters model tend to be more accurate for men than for women. In the pre-pandemic phase, the line for observed productivity and the line for predicted productivity overlap to a large degree for men but to a smaller degree for women. This potential imprecision needs to be kept in mind when interpreting the results for those countries in which no differences in the productivity gap were observed, in particular among women.

Table 3 provides a summary of the statistically significant upward and downward deviations from the prediction by gender and country by drawing on the results from country-specific, linear OLS regressions. The arrows in the "intercept" column indicate whether men's and women's initial productivity increases (↑) or initial decreases (↓) were statistically significant or whether there was no statistically significant deviation from the prediction (→). The arrows in the "slope" column indicate the time trend over the observation time (between the country-specific outbreak and the end of July 2020). Here again, only statistically significant ($p < 0.05$) increases and decreases are marked with upward and downward arrows; intercepts and slopes that are not statistically significant were assigned constant values (→). While this stylized summary of the development captures neither the size of the productivity gap across countries and genders nor nonlinear time trends, it provides a comprehensive overview of all countries in our sample.

Overall, Table 3 shows that the observed productivity exceeded the predicted number of average weekly contributions for women in a total of 10 countries and for men in a total of 31 countries (combinations of intercept and slope with at least one positive component and no negative component). A total of 25 countries for women and six countries for men showed mixed patterns or followed the expected path in terms of observed productivity. Productivity was below the predictions in two countries for women ($p < 0.05$) but not in a single one for men (combinations of intercept and slope with at least one negative component and no positive component).

Next we turn to the findings from our multivariable analyses. Table 4 shows the results for our two-way fixed effects analyses and confirms the impression provided by our descriptive findings. Both men's and women's average deviations from the predicted number of contributions increased after national governments implemented countermeasures to fight the pandemic (intercepts of 0.31 for men and 0.35 for women in M0). The variation in this overall effect, however, is slightly greater for women than for men (95%CI around the intercept in M0, which only includes time and country fixed effects, ranges from 0.17 to 0.54 for women and from 0.21 to 0.42 for men).

Model 1 in Table 4 shows that more stringent lockdown measures increased both men and women's productivity to almost equal degrees. Men's average number of contributions increased by .061 and women's by .057 for every 10 percentage point increase in the stringency of the lockdown measures. In other words, the more social contact was restricted, the more code software developers—both male and female—wrote and shared on average across countries. One explanation for this overall increase in number of weekly contributions relates to the fact that software developers presumably had more time on their hands when public life had come to a standstill. Another

explanation may be that software developers were responding to the virus and the necessity to answer questions with code. In contrast to men and women in other fields, software developers do not seem to have suffered a productivity decrease, as most developers did not have care obligations at that time.

With Model 2 in Table 4, we sought to examine how school and workplace closures as well as stay-at-home restrictions affected men's and women's coding productivity. Going from no or recommended school closures to mandatory school closures with few/no exceptions increased men's mean number of GitHub commits across all countries by .12 (M2(M)), whereas this effect was negative and close to zero for women (-.03)(M2(F)). Workplace closures, by contrast, seem to have positively affected both men's and women's productivity, although the coefficient for men (.14) was twice the size of that for women (.07), which—in addition—had a very large 95%CI (-.12 to .53). In substantive terms, this means that going from open to closed workplaces increased men's productivity on average by 5% when we used the value of men's average number of weekly contributions from 2019, i.e., the year preceding the pandemic, as a baseline level. We also observed productivity increases following the implementation of stay-at-home restrictions for both men and women; here, by contrast, the increases were much greater for women (0.15) than for men (0.08).

As the possibilities to work from home are severely constrained by care and homeschooling responsibilities, in Model 3 we further examined whether the observed productivity effects for men and women following workplace closures were affected by school closures. Examining this interaction effect is crucially important, as governments in most countries implemented school and workplace closures simultaneously at the outset of the pandemic in 2020. Once we accounted for this co-occurrence of school and workplace closures (which appeared in 719 out of our 838 country-weeks), the positive effects of workplace closures on women's GitHub contributions essentially disappeared, whereas the positive effect for men was unaffected by school closures.[8]

8 The results from a three-way interaction between all three country-level policies did not alter the substantial conclusions based on Model 3; please see replication files for a graphical display of the joint effects of all three measures.

Table 3: Actual vs. predicted number of weekly contributions by country and gender

Women		Men		Country
intercept	**slope**	**intercept**	**slope**	
→	↗	↑	→	Argentina
↑	→	↑	→	Australia
→	→	↑	→	Austria
→	→	→	↗	Bangladesh
→	↘	↑	→	Belgium
→	↗	↑	↗	Brazil
↑	→	↑	→	Canada
→	↗	→	→	China
↑	↘	↑	↗	Colombia
→	→	↑	→	Denmark
→	→	↑	→	Egypt
↑	↘	↑	→	Finland
↑	↘	↑	→	France
→	→	↑	→	Germany
↓	↗	→	↗	India
↓	→	→	↗	Indonesia
↑	→	↑	→	Ireland
↑	↘	↑	→	Italy
→	→	↑	↗	Mexico
→	→	↑	→	Netherlands
↑	↘	↑	→	New Zealand
→	→	↑	↘	Norway
→	↗	→	↗	Pakistan
↑	→	→	→	Philippines
↑	→	↑	→	Poland
→	→	↑	→	Portugal
↑	↘	↑	→	Romania
→	→	→	→	Russia
→	→	↑	→	South Africa
↑	↘	↑	→	South Korea
→	→	↑	↘	Spain
→	→	↑	→	Switzerland
→	↗	→	↗	Taiwan
↑	↘	↑	→	Turkey
→	→	↑	↘	Ukraine
↓	↗	↑	→	United Kingdom
→	→	↑	→	United States

Note: Summary of the overall deviation patterns by gender and countries based on the results from country-specific OLS regressions; arrows in the "intercept" column indicate whether men's and women's productivity initially increased (↑), decreased (↓), or stayed the same (→) after the first lockdown measures were implemented; arrows in the "slope" column indicate the time trend over the observation time.

Table 4: Results of 2-way fixed-effects regressions (DV = deviation from the predicted productivity)

	M0(M)	M0(F)	M1(M)	M1(F)	M2(M)	M2(F)	M3(M)	M3(F)
Overall lockdown stringency			0.61*** [0.46,0.75]	0.57** [0.17,0.96]				
School closings (1=yes)					0.12** [0.04,0.20]	-0.03 [-0.29,0.23]	0.14* [0.02,0.27]	0.04 [-0.31,0.38]
Workplace closings (1=yes)					0.14** [0.06,0.22]	0.07 [-0.12,0.26]	0.18** [0.06,0.30]	0.20 [-0.12,0.53]
Curfews (1=yes)					0.08* [0.02,0.15]	0.15* [0.02,0.29]	0.09* [0.02,0.16]	0.16* [0.02,0.31]
Interaction: Work x School closings							-0.05 [-0.19,0.09]	-0.17 [-0.57,0.23]
Constant	0.31*** [0.21,0.42]	0.35*** [0.17,0.53]	0.12* [0.01,0.23]	0.16 [-0.02,0.34]	0.23*** [0.13,0.33]	0.27** [0.09,0.44]	0.23*** [0.13,0.33]	0.27** [0.09,0.44]
Observations	839	837	839	837	839	837	839	837
Adjusted R^2	0.486	0.284	0.551	0.307	0.550	0.298	0.549	0.299

*Note: Results are based on models that include both country and time (weeks since outbreak) fixed-effects * p < 0.05, ** p < 0.01, *** p < 0.001.*

9. Limitations

Before concluding the paper, we need to mention several issues that warrant further research. First, the selectivity of the GitHub population—particularly their age and the fact that developers in most countries tend to be childless—prohibits us from drawing general conclusions about the extent to which the pandemic may have affected men's and women's professional advancement in general. Our findings should therefore be interpreted cautiously as a lower-bound estimate of the pandemic's gendered effects.

Second, as the data in our analyses did not include individual-level information on parenthood, current work status, or use of remote work options, we cannot clearly attribute the observed gender differences to an unequal distribution of childcare duties between men and women.[9] By using aggregated data only in our analyses, moreover, we may have missed out on the heterogeneity that exists among women (and men)—even among those of similar age, as is the case for the software developers in our study. This concern applies, in particular, to those countries for which we observed no large differences between the observed and the predicted mean weekly number of contributions. While some groups of women may have reduced their coding activities due to childcare duties or firm closures, others may have used the additional time to code—either as part of their job or for their private enjoyment and enhancement of their human capital. Such opposing trends would cancel each other out, but unfortunately cannot be assessed in our analyses.

Third, our analyses were limited to the initial period after the outbreak of the Covid-19 pandemic. Expanding the time frame would certainly provide additional insights, as the time gained from workplace closures or curfews that people might have used for extra coding activities may (or may not) have levelled out over time. The predictions of our forecast model, however, become more unreliable with an increase in the span of time for which the predictions are made. Likewise, in our analyses, we could not adjust for the uncertainty associated with our forecast model. Given the considerably smaller number of GitHub accounts held by female software developers, this uncertainty may even be greater for women than for men.

10. Discussion and conclusion

This paper sought to examine whether the Covid-19 pandemic and, in particular, the measures implemented to contain the spread of the virus, affected men's and women's work-related productivity to different degrees. To do so, we drew on data that we collected on the social coding platform GitHub. In a first step, we compared the number of actual mean contributions by country and gender to the predicted contributions that we assessed based on data from 2014 to the beginning of 2020 as if the Covid-19 pandemic had not

9 We must also acknowledge that female developers are less likely than male developers to register on GitHub with their real names. See Terrell et al. (2017)and Nafus (2011) for recent evidence of differential treatment of male and female developers on GitHub. Similar concerns may apply to the geocoding information that software developers provide.

happened. The results from a Holt-Winter forecast model show that in most countries, both male and female developers submitted more contributions than predicted during the first few months of the pandemic. However, the upward deviations for women were less pronounced than for men, and for a considerable number of countries, the descriptive display of the deviations even suggests that women—at least for some time during the first lockdown in 2020—contributed less than predicted.

To shed light on the underlying reasons for the greater variation in women's productivity, we combined the GitHub data with country-level information on lockdown stringency. The results of our two-way fixed effects analyses confirm the findings from the descriptive analyses. Both men's and women's productivity increased with increasing levels of lockdown stringency. Our analyses also show that when governments imposed stay-at-home restrictions, on average, both male and female software developers increased the number of contributions they made to GitHub. In addition, we found that men's productivity increased when workplaces were closed—independent of whether schools were closed or open. For women, however, we only observed such a productivity-enhancing effect of workplace closures when schools were open.

With these insights, we seek to contribute to the ongoing debate on the pandemic's social and economic consequences for men and women. In contrast to previous work on the topic, our study was able to draw on "hard" data, which are more likely than survey data to lead to reliable results. Moreover, our use of contributions to coding projects provides an instantaneous indication of productivity and therefore likely also a more accurate reflection of productivity than submissions to academic journals and preprint outlets.

Although GitHub users are not a random sample of the population, this finding nonetheless has important implications for our understanding of the pandemic's gendered impacts on men's and women's professional advancement. Given that software development is a least-likely case for observing gender differences in productivity following the outbreak of the Covid-19 pandemic due to the demographic characteristics of our population, our finding provides some indication of the unequal effects of the pandemic on men's and women's professional advancement depending on potential care responsibilities.

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Information in German

Deutscher Titel

Hat Covid-19 geschlechtsspezifische Arbeitsmarktungleichheiten verstärkt? Produktivitätsunterschiede zwischen männlichen und weiblichen Softwareentwicklern in 37 Ländern

Zusammenfassung

Fragestellung: In diesem Artikel untersuchen wir anhand von Open Source-Softwareentwicklern Produktivitätsunterschiede zwischen Männern und Frauen in Folge der Covid-19-Pandemie für insgesamt 37 Länder.

Hintergrund: Die Maßnahmen, die zur Eindämmung der Covid-19 Pandemie getroffen wurden, hatten möglicherweise unterschiedliche Auswirkungen auf das berufliche Fortkommen von Männern und Frauen. Wie haben sich insbesondere die Schließungen von Arbeitsstätten, Schulen und Kitas ausgewirkt?

Methode: Grundlage der Analysen sind Daten der weltweit größten Social Coding Community GitHub. In einem ersten Schritt schätzen wir Holt-Winters-Vorhersagemodelle, um die tatsächliche Produktivität mit der vorhergesagten Produktivität von männlichen und weiblichen Softwareentwicklern während des ersten Lockdowns im Jahr 2020 zu vergleichen (N=177.480). In einem zweiten Schritt schätzen wir two-way fixed-effects Modelle, um Unterschiede in den geschlechtsspezifischen Auswirkungen der Covid-19-Pandemie auf die Produktivität von Softwareentwicklern anhand verschiedener Lockdownmaßnahmen zu erklären, insbesondere der Schließung von Schulen und Arbeitsstätten.

Ergebnisse: In den meisten Ländern waren sowohl männliche als auch weibliche Entwickler im Durchschnitt produktiver als erwartet. Diese Produktivitätszuwächse stiegen bei beiden Geschlechtern mit zunehmender Lockdownintensität. Eine getrennte Betrachtung der verschiedenen Maßnahmen zeigt, dass Ausgangssperren mit einer höheren Produktivität bei Männern und Frauen einhergingen. Gleiches gilt für die Schließung von Arbeitsstätten – bei Frauen jedoch nur dann, wenn die Schulen gleichzeitig geöffnet waren.

Schlussfolgerung: Angesichts der Tatsache, dass unsere Untersuchungspopulation relativ jung und in der Tendenz kinderlos ist, wir aber dennoch in Abhängigkeit von Schul- und Kitaschließungen geschlechtsspezifische Unterschiede in den Auswirkungen geschlossener Arbeitsstätten finden, kommen wir zu dem Schluss, dass die Covid-19-Pandemie in der Tat zu größeren Ungleichheiten zwischen den Geschlechtern beim beruflichen Aufstieg beigetragen haben könnte.

Schlagwörter: Geschlecht, Covid-19, Ungleichheit, Produktivität, Internationaler Vergleich, GitHub

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Lena Hipp: https://orcid.org/0000-0002-1535-8748

Markus Konrad: https://orcid.org/0000-0002-9796-7538