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We study the disproportionate impact of the lockdown as a result of the COVID-19 outbreak on female and male academics' research productivity in social science. We collect data from the largest open-access preprint repository for social science on 41,858 research preprints in 18 disciplines produced by 76,832 authors across 25 countries in a span of two years. We find that during the 10 weeks after the lockdown in the United States, although the total research productivity increased by 35%, female academics' productivity dropped by 13.9% relative to that of male academics. We also show that several disciplines drive such gender inequality. Finally, we find that this intensified productivity gap is more pronounced for academics in top-ranked universities, and the effect exists in six other countries.

Key words: Gender inequality, research productivity, COVID-19

1. Introduction

The Coronavirus 2019 (COVID-19) pandemic has significantly changed the way people live and work. We study how this pandemic shock affected academics' research productivity using data from the largest open-access repositories for social science in the world—Social Science Research Network (SSRN).[1] We provide evidence that female researchers' productivity significantly dropped relative to that of male researchers as a result of the lockdown in the United States.

In response to the pandemic, the US and many other countries have mandated their citizens to stay at home. As a result, many people had to carry out both work and household duties at home. Most countries have closed their schools and daycare centers, which has massively increased childcare needs. Given that the childcare provided by grandparents and friends is limited due to the social distancing protocol, most families have to take care of the children themselves. In addition, restaurants have been either closed or do not allowed dine-ins, which has increased the need for

[1] `https://en.wikipedia.org/wiki/Social_Science_Research_Network`, accessed June 2020.

food preparation at home. Given that women, on average, are burdened with disproportionately more child care, domestic labor, and household responsibilities (Bianchi et al. 2012), they are likely to be more affected than men during the lockdown.

The lockdown has also disrupted how academics carry out their activities. Many countries have closed their universities, so faculties have to conduct research and teaching at home. Concentration is critical for creative thinking. Conducting scientific research often requires a quiet and interruption-free environment. The unequal distribution of domestic duties[2] means that female faculties are likely to be disproportionately affected compared with their male colleagues.

Anecdotal evidence provides mixed support (Dolan and Lawless 2020). Several journal editors have noticed that while there is a 20-30% increase in submissions as a result of the pandemic, most of this increase can be attributed to male academics (Beck 2020). Amano-Patiño et al. (2020) find that a particularly large number of senior male economists, instead of mid-career economists, have been exploring research questions arising from the COVID-19 shock. Others have seen no change or are receiving comparatively more submissions from women since the lockdown (Kitchener 2020). However, there is dearth of systematic evidence on whether and to what extent the shock affects gender inequality in the academia.

In this paper, we use a large dataset on female and male academics' production of new research papers to systematically study whether COVID-19 has a disproportionate effect on female academics' productivity. We also identify the disciplines, universities, and countries in which this inequality is intensified. We collect the data on *all* research papers uploaded to SSRN in 18 disciplines from December 2018 to May 2019 and from December 2019 to May 2020. We extract information on paper titles, author names, author affiliations, and author addresses. We use such information to identify the authors' countries and institutions. We also use their names and their faculty pages to identify their gender. The final dataset includes 41,858 papers written by 76,832 authors from 25 countries. Our main analysis focuses on academics in the US, and we then perform the same analysis for other countries.

We take a difference-in-differences (DID) approach to estimate the effect. We compute the number of papers produced by female and male academics in each week. We then compare the variations in women and men's research productivity gap before and after the start of the lockdown, and show

[2] Women spend almost twice as much time on housework and childcare in the US (Bianchi et al. 2012). There are 8.5 million more single mothers than single fathers in the US (Alon et al. 2020). Even in the gender-egalitarian countries of northern Europe, women do almost two-thirds of the unpaid work (The European Commission 2016). Among heterosexual couples with female breadwinners, women still do most of the care work (Chesley and Flood 2017). The same pattern exists in the academia (Schiebinger and Gilmartin 2010, Andersen et al. 2020). Women professors spend more time doing housework and carework than men professors across various ranks, for example, 34.1 hours versus 27.6 hours per week for lecturers, 29.6 hours versus 25.1 hours per week for assistant professors, and 37.7 hours versus 24.5 hours per week for associate professors (Misra et al. 2012).

that the gap increased after the start of the lockdown. We also show that female and male authors' preprint volume followed the parallel time trend before the lockdown, and we find no significant changes in the research productivity gap in 2019 during the same time of the year. Taken together, these results suggest that the intensified disparity is primarily driven by the pandemic shock.

We find that during the 10 weeks since the lockdown began, female academics' research productivity dropped by 13.9% compared to that of male academics in the US. The effect persists as we varied the time window since the pandemic outbreak in the analysis. Our findings lend empirical credence to the argument that when female and male academics face a short-term reorganization of care and work time, women become significantly less productive. We also find that the effect is more pronounced in top-ranked research universities. We further show that this effect exists in six other countries.

While gender inequality has been long documented for academics in terms of tenure evaluation (Antecol et al. 2018), coauthoring choices (Sarsons 2017), and citations received (Ghiasi et al. 2015), the COVID-19 pandemic brings this issue to the forefront. Our study is among the first to rigorously quantify such inequality in research productivity as a result of the pandemic, and our results highlight that this disruption exacerbated gender inequality in the academic world. There are concerns that because all academics will participate together in open competitions for promotions and positions, these short-term changes in productivity will affect long-term career outcomes (Minello 2020). Thus, institutions should take this inequality into consideration when evaluating faculty members.

2. Data and Summary Statistics

We collect data from SSRN, a repository of preprints with the objective to rapidly disseminate scholarly research in social science. We gather data on *all* social science preprints submitted from December 2018 to May 2019 and from December 2019 to May 2020. We extract information on paper titles, author names, author affiliations, and author addresses. We use the authors' addresses to identify their countries. The COVID-19 outbreak began at different time points across countries, so we collect each country's start date of lockdown from news sources and the United Nations' report.[3] We drop authors without addresses or with addresses in more than one country because we cannot determine when these authors were affected by the lockdown. We also drop countries without a sufficient number of authors in our data set. The final data consist of a total of 41,858 papers in 18 disciplines produced by 76,832 authors from 25 countries.

To identify the authors' genders, we first use a database called *Genderize*,[4] which predicts the genders based on their first names with a confidence level. About 78% of the authors' genders were

[3] `https://en.unesco.org/covid19/educationresponse`, accessed June 2020

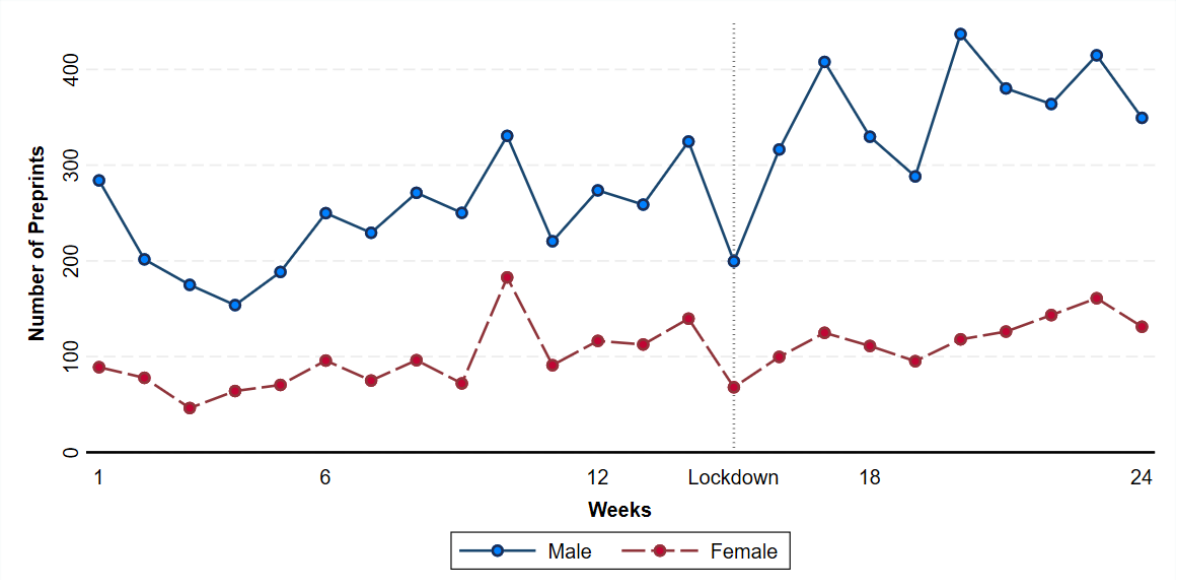
[4] `https://genderize.io/`, accessed June 2020

identified with over 80% confidence levels. For the remaining authors, we use Amazon Mechanical Turk to manually search for their professional webpages based on names and affiliations and then infer their genders from their profile photos. Our dataset contains a total of 21,733 female academics and 55,099 male academics.

We aggregate the number of new preprints at the weekly level. We then count the number of papers uploaded by each author in each week. To measure the *effective* productivity for preprints with multiple authors, when a preprint has n authors, each author gets a publication count of $1/n$.[5] Finally, we aggregate the effective number of papers to the gender level: in each week, we count the total number of papers produced by male and female authors separately in each social science discipline.

Figure 1 plots the time trend of preprints in aggregation from December 3, 2019 to May 19, 2020 in the US. The vertical line represents the week of March 11, 2020, which is the start of the implementation of the nationwide lockdown measures in the US.[6] We can observe that male academics, on average, have submitted more preprints than female academics, and that female and male academics' research productivity evolved in parallel before the lockdown. After the lockdown started, however, male academics significantly boosted their productivity, whereas female academics' productivity did not change much, indicating an increased productivity gap.

Figure 1 Time Trends of US Preprints from December 2019 to May 2020



This graph plots the time trend of the number of preprints for female academics and male academics. The vertical line represents the start of the lockdown due to COVID-19 in the US.

[5] Note that in many social science disciplines, author names are listed in alphabetical order.

[6] Most universities were closed in the week of March 11, 2020. Source: `https://gist.github.com/jessejanderson/09155afe313914498a32baa477584fae?from=singlemessage&isappinstalled=0`, accessed June 2020.

To ensure that our results are not driven by seasonality, we plot the time trend of preprints during the same time window in 2019 in Appendix Figure A.1. We observe a similar pattern before the week of March 11, 2019, but there is no significant change in productivity gap after that week.

We use the authors' affiliations to identify their universities. To ascertain whether the productivity gap becomes intensified or weakened across top-ranked and lower-ranked research universities, we collect social science research rankings from three sources: QS University Ranking,[7] Times Higher Education,[8] and Academic Ranking of World University.[9] We then use these data to rank US universities.

Table 1 reports the summary statistics for the weekly number of preprints by gender and discipline, as well as split sample statistics prior to or after the lockdown from December 3, 2019 to May 19, 2020, spanning 24 weeks. This sample includes 9,943 preprints produced by 15,494 authors in the US and 21,065 preprints produced by 37,997 authors across all countries. The average number of submissions per week is 444.6 in the US and 877.7 across 25 countries. Notably, while the total research productivity in the US was boosted by 35% after the lockdown, male authors seem to be the main contributors to this increase.

About 78% of the preprints fall under multiple disciplines.[10] Note that when computing the total preprints, we count the paper only once when aggregating across disciplines to avoid multiple counting. When computing the number of preprints in each discipline, we separately count all of the papers classified under each one. We observe substantial variations across disciplines. Among 18 disciplines, Political Science, Economics, and Law received the most submissions, whereas Geography, Criminal Justice and Education received the fewest submissions. While there is a large increase in productivity in several disciplines, such as Economics, Political Science, Finance, Health Economics, and Sustainability, after the COVID-19 outbreak, other disciplines showed no obvious increase. A few disciplines, such as Anthropology, Cognitive, and Information Systems, even experienced a decline.

3. Empirical Results

In this section, we identify the effect of the COVID-19 outbreak on research productivity. We first elaborate our identification methodology that leverages the exogenous pandemic shock by using a DID regression. We then report the estimation results of gender inequality in the US, across universities, and across countries.

[7] Available at `https://www.topuniversities.com/university-rankings/university-subject-rankings/2020/social-sciences-management`, accessed June 2020.

[8] Available at `https://www.timeshighereducation.com/world-university-rankings/2020/subject-ranking/social-sciences#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats`, accessed June 2020.

[9] Available at `http://www.shanghairanking.com/FieldSOC2016.html`, accessed June 2020.

[10] Authors self-classify their own preprints into disciplines when they upload their papers. SSRN reviews and approves these classifications.

Table 1 Summary Statistics

		All observations					Before Lockdown		After Lockdown	
Level	Weekly no. of preprints	Mean	Std. dev	Max	Min	Total	Mean	Std. dev	Mean	Std. dev
All Disciplines (US only)	All	444.6	109.4	617	224	9,934	378.8	88.0	511.4	86.0
	Female authors	111.3	30.8	186	47	2,493	103.4	36.2	119.3	21.4
	Male authors	333.3	85.3	180	161	7,441	275.4	55.4	392.1	68.6
By Discipline (US only)	Accounting	19.5	7.2	40	9	468	17.9	6.3	21.8	8.2
	Anthropology	85.0	21.5	141	63	2,040	93.9	24.0	72.5	6.9
	Cognitive	11.3	9.2	31	1	271	14.1	11.1	7.4	3.2
	Corporate	14.1	6.5	27	3	339	12.2	6.5	16.8	5.8
	Criminal	15.4	6.7	27	4	370	12.8	6.7	19.1	4.9
	Economics	133.2	54.2	237	37	3,197	106.6	39.1	170.5	51.6
	Education	17.9	7.0	36	7	429	16.9	7.4	19.2	6.7
	Entrepreneurship	9.9	5.3	22	2	238	10.2	4.9	9.5	5.9
	Finance	91.7	34.5	139	25	2,201	78.5	35.5	110.2	24.0
	Geography	8.2	3.3	17	3	196	7.5	2.7	9.1	4.0
	Health Economics	8.4	10.1	47	0	202	3.0	2.1	16.0	12.1
	Information Systems	15.6	7.3	39	7	374	17.4	8.6	13.1	4.2
	Law	98.5	24.3	142	44	2,365	94.1	26.7	104.7	20.1
	Management	33.4	11.4	56	12	802	33.4	13.3	33.4	8.6
	Organization	20.5	11.5	44	3	491	16.9	10.2	25.5	11.7
	Political Science	167.9	50.5	255	85	4,030	142.1	39.0	204.1	42.8
	Sustainability	22.8	11.9	66	8	546	18.1	5.9	29.3	15.1
	Women/Gender	18.0	4.7	28	10	431	17.2	4.4	19.0	5.2
All countries	All	877.7	199.3	1,175	487	21,065	779.1	177.5	1015.8	140.4
	Female authors	246.5	53.9	347	165	5,916	231.0	57.0	268.2	42.9
	Male authors	631.2	152.0	866	322	15,149	548.1	124.4	747.6	104.3

The table summarizes the weekly number of papers from December 2019 to May 2020. The sample includes 15,494 authors from the United States and 37,997 authors across all countries. In total, there are 9,934 preprints produced by US authors, 2,493 of which are produced by 3,877 female researchers and 7,441 are produced by 11,617 male researchers. We gather the country-specific lockdown time to split our sample to before and after the lockdown for each country.

3.1. Identification

Our identification exploits the lockdown as a result of the COVID-19 outbreak as an exogenous shock that has caused substantial disruptions on academic activities, requiring academics to conduct research, teach, and carry out household duties at home. The validity of our approach resides in the assumption that the shock is exogenous with respect to the researchers' anticipated responses. If a particular gender group of researchers anticipated and strategically prepared for the shock by accelerating the wrap-up of their current research papers, among others, this could confound the treatment effect. In reality, this possibility is unlikely because of the rapid development of the situation.[11] We adopt the DID methodology, a common approach used to evaluate people's or organizations' responses to natural shocks (Seamans and Zhu 2013, Cui et al. 2019, Calvo et al. 2019). We perform the DID analysis using outcome variables in two levels: the total number of preprints aggregated across all disciplines and the number of preprints in each discipline.

[11] COVID-19 was regarded as low risk and not a threat to the US in late January (Moreno 2020) and no significant actions had been taken other than travel warnings issued for four countries until late February (Franck 2020). It quickly turned into a global pandemic after the declaration of the World Health Organization on March 11, 2020 followed by the nationwide shelter-in-place orders within a week. Source: `https://www.cdc.gov/nchs/data/icd/Announcement-New-ICD-code-for-coronavirus-3-18-2020.pdf`, accessed June 2020.

We first compare the productivity gap between female and male researchers prior to and after the pandemic outbreak using the following model specification with the aggregate-level data:

$$log(Preprints_{gt}) = c + Female_g + \beta Female_g \times Lockdown_t + \gamma_t + \epsilon_{gt}, \quad (1)$$

where g denotes the gender, t denotes the week, $log(Preprints_{gt})$ represents the logged number of preprints uploaded for gender g during week t, γ_t is the time fixed effect, and ϵ_t is the error term. The time fixed-effect γ_t includes a set of weekly time dummies that control for time trends. The dummy variable $Female_g$ equals 1 if gender g is a female academics, and 0 otherwise. The dummy variable $Lockdown_t$ equals 1 if week t occurs after the lockdown measure was adopted (i.e., the week of March 11, 2020), and 0 otherwise. Its main effect is absorbed by the time fixed effects. The coefficient β estimates the effect of lockdown on female academics' research productivity relative to male academics' productivity.

We also use the discipline-level panel data to estimate the effect with the following DID specification:

$$log(Preprints_{igt}) = c + Female_g + \beta Female_g \times Lockdown_t + \gamma_t + \delta_i + \epsilon_{igt}, \quad (2)$$

where i denotes each discipline, δ_i is the discipline fixed effect that captures the time-invariant characteristics of discipline i, $log(Preprints_{igt})$ represents the logged number of preprints uploaded to discipline i for gender g during week t, and ϵ_{igt} is the error term. As before, we include the time fixed effect γ_t.

3.2. Results

Table 2 reports the estimated effect of the pandemic shock on research productivity at the aggregate level using Equation (1). Table 3 reports the estimated effect at the discipline level using Equation (2). In each analysis, we use 14 weeks before the lockdown as the pre-treatment period and 6 weeks, 7 weeks, ... and 10 weeks after the lockdown as the post-treatment periods. The analyses yield consistent results. First, consistent with our summary statistics, the results show that fewer preprints are produced by female academics than male academics in general. Second, since the lockdown began, there has been a significant reduction in female academics' productivity relative to their male colleagues', indicating an exacerbated productivity gap in gender. The coefficient of the interacted term in Column (1) of Table 2 suggests a reduction of 17.9% in females' productivity over the six-week period after the lockdown relative to the males', and the coefficient of the interacted term in Column (5) suggests an average reduction of 13.9%.[12]

We then repeat the analysis as in Table 2 for each discipline separately. Table 4 reports the coefficients of the interacted term, $Female_g \times Lockdown_t$, for each discipline. We find that the gender

Table 2 Impact of Lockdown on Gender Inequality

	Dependent variable: No. of preprints (in logarithm) in aggregation				
	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
Variables	(1)	(2)	(3)	(4)	(5)
Female	−1.013***	−1.013***	−1.013***	−1.013***	−1.013***
	(0.054)	(0.054)	(0.053)	(0.053)	(0.053)
Female × *Lockdown*	−0.197**	−0.199***	−0.173**	−0.159**	−0.150**
	(0.068)	(0.064)	(0.067)	(0.066)	(0.064)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	40	42	44	46	48
R^2	0.981	0.982	0.982	0.982	0.983

This table reports the estimated coefficients and robust standard errors (in parentheses) in Equation (1). The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 3 Impact of Lockdown on Gender Inequality at the Discipline Level

	Dependent variable: No. of preprints (in logarithm) by discipline				
	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
Variables	(1)	(2)	(3)	(4)	(5)
Female	−0.791***	−0.791***	−0.791***	−0.791***	−0.791***
	(0.042)	(0.042)	(0.042)	(0.042)	(0.042)
Female × *Lockdown*	−0.140*	−0.148**	−0.162**	−0.157**	−0.142**
	(0.076)	(0.072)	(0.068)	(0.065)	(0.063)
Discipline Fixed Effects	Yes	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	720	756	792	828	864
R^2	0.837	0.836	0.839	0.841	0.841

This table reports the estimated coefficients and robust standard errors (in parentheses) in Equation (2). The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

differences significantly intensified in several disciplines, namely, Criminal, Economics, Finance, Health Economics, Political Science, and Sustainability.

Table 5 replicates the DID analysis using Equation (2) for a subset of academics based on the rankings of their affiliated universities.[13] Due to our focus on social science, we use the 2020 QS World University Ranking for social sciences and management as the main analysis. We separately analyze academics in universities ranked in the top 10, 20,..., and 100. The results show that the COVID-19 effect is more pronounced in top-tier universities and that this effect in general decreases and becomes less significant as we include more lower-ranked universities. We find similar results when using the two other rankings, as shown in Appendix Table A.1.

Finally, we examine how the estimated gender inequality varies across countries by replicating the analysis for academics in each country. Figure 2 illustrates the impact on the productivity gap graphically by plotting the estimates of the interacted term with 90% and 95% confidence intervals, of which a negative value represents a drop in female academics' research productivity relative

[12] Because the outcome variable is logged, the percentage change in the outcome variable is computed as $e^{\text{coefficient}} - 1$.

[13] It is possible that some authors are affiliated with more than one academic institutions. We use the highest ranked institution as their affiliation in such cases.

Table 4 Impact of Lockdown on Gender Inequality in Each Discipline

	Dependent variable: No. of preprints (in logarithm) by discipline				
	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
Discipline	(1)	(2)	(3)	(4)	(5)
Accounting	−0.282	−0.311*	−0.248	−0.213	−0.192
Anthropology	−0.015	0.049	0.123	0.112	0.127
Cognitive	−0.184	−0.091	−0.166	−0.200	−0.131
Corporate	−0.021	−0.091	−0.285	−0.380	−0.324
Criminal	−0.395**	−0.350*	−0.417**	−0.295	−0.296
Economics	−0.248***	−0.248***	−0.212**	−0.208**	−0.181**
Education	−0.146	−0.088	−0.102	−0.010	0.082
Entrepreneurship	−0.138	−0.085	−0.108	−0.105	−0.136
Finance	−0.401*	−0.404**	−0.391**	−0.391**	−0.387**
Geography	−0.266	−0.246	−0.298	−0.314	−0.189
Health Economics	−0.767**	−0.784***	−0.890***	−0.870***	−0.786***
Information Systems	0.033	0.042	0.070	0.070	0.060
Law	0.081	0.088	0.097	0.140	0.149
Management	−0.056	−0.011	−0.075	−0.013	−0.019
Organization	0.069	0.169	0.157	0.148	0.115
Political Science	−0.262***	−0.252***	−0.233***	−0.232***	−0.221***
Sustainability	−0.687**	−0.673***	−0.644***	−0.637***	−0.589***
Women/Gender	−0.238	−0.090	−0.139	−0.103	−0.072
Observations	40	42	44	46	48

This table reports the estimated coefficients based on Equation (1) for each discipline. The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Time fixed effects at the weekly level are included in all regressions. Standard errors and estimates of other variables are omitted for brevity. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 5 Impact of Lockdown on Gender Inequality by University Ranking

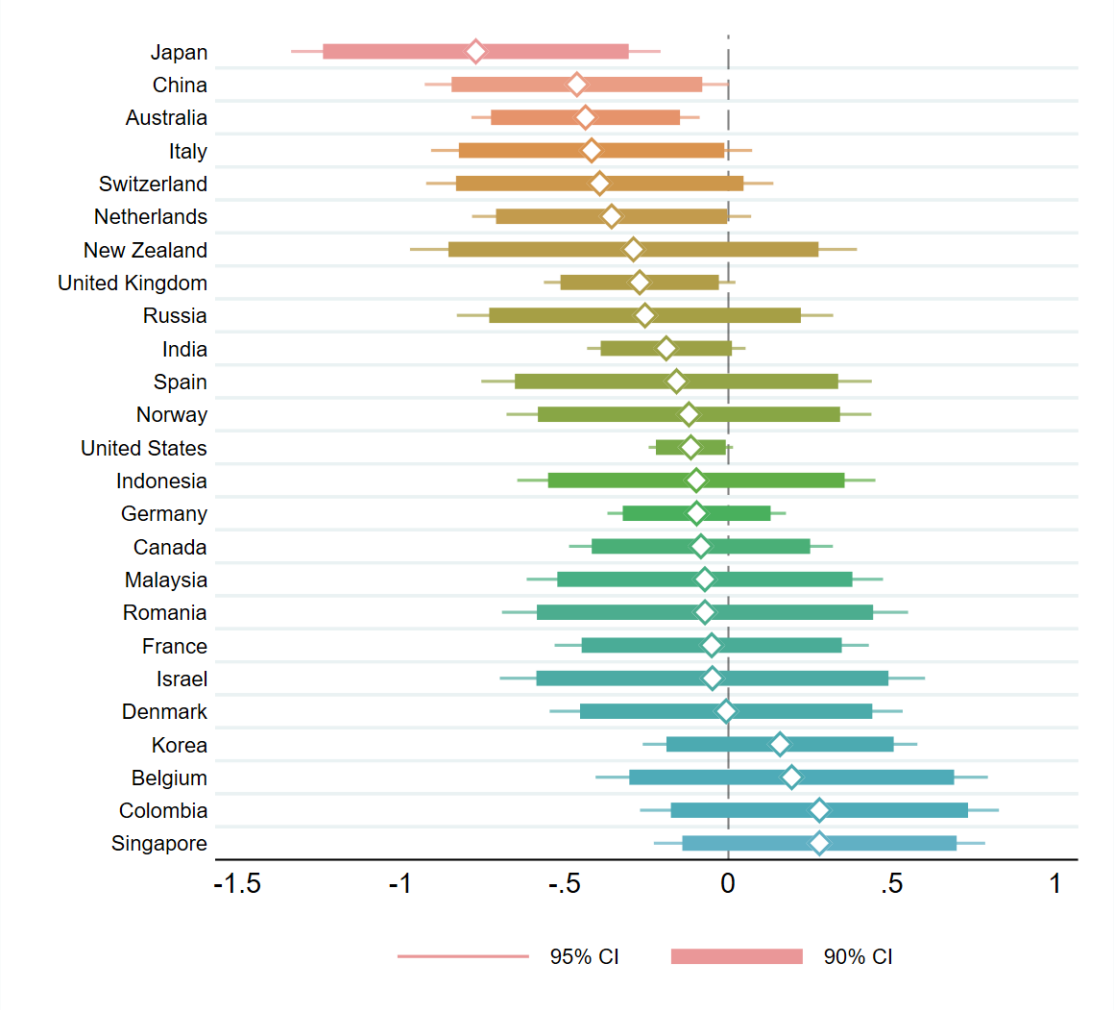
	Dependent variable: No. of preprints (in logarithm) by discipline				
Universities	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
by QS Ranking	(1)	(2)	(3)	(4)	(5)
Top 10	−0.169**	−0.199***	−0.158**	−0.153**	−0.165**
Top 20	−0.181**	−0.215***	−0.183**	−0.179***	−0.183***
Top 30	−0.189**	−0.210**	−0.167**	−0.168**	−0.170**
Top 40	−0.218***	−0.238***	−0.200***	−0.191***	−0.194***
Top 50	−0.197**	−0.214***	−0.180***	−0.179***	−0.182***
Top 60	−0.138*	−0.163*	−0.145*	−0.143**	−0.155**
Top 70	−0.142*	−0.155*	−0.132*	−0.122*	−0.127*
Top 80	−0.139*	−0.149**	−0.130*	−0.123*	−0.126*
Top 90	−0.118	−0.124*	−0.101	−0.097	−0.097
Top 100	−0.100	−0.102	−0.083	−0.082	−0.090
Observations	720	756	792	828	864

This table reports the estimated coefficients based on Equation (1) for universities within each rank group. The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Time fixed effects at the weekly level are included in each regression. Standard errors and estimates of other variables are omitted for brevity. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

to male academics'. We can observe that most countries—21 out of 25 countries—experienced a decline in female researchers' productivity. In addition to the US, six countries have shown statistically significant declines, namely, Japan, China, Australia, Italy, the Netherlands, and the United Kingdom. Note that because SSRN is a repository primarily used by US researchers, SSRN's preprints for other countries might be limited in number, which might weaken our ability to detect changes.

In short, we find that the lockdown has adversely affected female researchers' productivity relative to that of male researchers. We also find a large heterogeneity of such gender inequality across disciplines, universities, and countries.

Figure 2 Impact of Lockdown on Gender Inequality across Countries



This graph plots the estimates of the interacted term with 90% and 95% confidence intervals in each country. The negative values represent female academics' research productivity drop relative to male academics' across countries.

4. Robustness Checks

In this section, we report several robustness tests. Specifically, we check the parallel trends assumption and conduct falsification tests to ensure that our estimated effects are not idiosyncratic.

Parallel trends. The key identification assumption for the DID estimation is the parallel trends assumption: before the COVID-19 shock, female and male researchers' productivity would follow the same time trend. In Appendix Figure A.1, which presents the time trends of preprints in 2019, the visual inspection shows two gender groups' parallel evolving before the shock. We then test

this assumption by performing a similar analysis to Seamans and Zhu (2013), Cui et al. (2019) and Calvo et al. (2019), where we expand Equation (1) to estimate the treatment effect week by week before the shock. Specifically, we replace $Lockdown_t$ in Equations (1) with dummy variables $Time^t_\tau$, where $\tau \in \{-14, -13, ..., -2, -1, 0\}$ and $Time^t_\tau = 1$ if $\tau = t$ and 0 otherwise, indicating the relative τth week to the outbreak,

$$log(Paper_{it}) = c + Female_i + \sum_{\tau=-14}^{-1} Time^t_\tau + \sum_{\tau=-14}^{-1} \beta_\tau Female_i \times Time^t_\tau + \epsilon_{it}. \quad (3)$$

The benchmark group is the week of the pandemic outbreak. The coefficients β_{-14} to β_{-1} identify any week-by-week pre-treatment difference between the female and the male researchers, which we expect to be insignificant. We then repeat the same analysis with our discipline-level data.

Appendix Table A.2 presents the estimation results. The test results show no pre-treatment differences in the research productivity trends between female and male academics, which support the parallel trends assumption.

Falsification test. To show that our estimate effects are not an artifact of seasonality, we test whether such decline in female productivity also existed in 2019. Appendix Table A.3 reports the summary statistics in 2019. We repeat the same analysis specified in Equation (1) for the same time window in 2019. If our results simply capture seasonality, we would be able to find significant effects in 2019. Appendix Table A.4 reports the falsification test results. The placebo-treated average treatment effects are insignificant, implying that women's productivity did not decline significantly in the previous year.

5. Conclusions

Our paper adds to the long-standing literature on gender equality, an important topic in social science. For example, the literature has shown evidence of fairness in parental leaves (Lundquist et al. 2012); inequality in tenure evaluation (Sarsons 2017, Antecol et al. 2018), recognition received (Ghiasi et al. 2015), compensation (Newton and Simutin 2015), job hiring (Fernandez-Mateo and Fernandez 2016), and initial salary received (Sterling and Fernandez 2018); and underrepresentation of women in science (Penner 2015). The COVID-19 crisis brings a long existing issue to the forefront—the limitations faced by women who often contribute more in child care and housework. Recent research has predicted that the shock will severely decrease female employment opportunities, and that the effects are likely to outlast the actual epidemic (Alon et al. 2020, Adams-Prassl et al. 2020). We contribute to the literature by providing direct tests on the impact of the pandemic shock on gender inequality in the academia.

The lockdown measure has disrupted how academics conduct research. We show that since the lockdown began, women have produced 13.9%–17.9% less research papers compared to men in the

US. We also find that the effect significantly exists in several disciplines and among top-ranked universities. Finally, we find that the increase in productivity inequality exists in seven countries.

Our findings suggest that if the lockdown is kept in place for too long, female academics in certain disciplines at top-ranked universities are likely to be significantly disadvantaged. Thus, universities thus need to take this potential gender inequality into account as they implement policies such as tenure clock extensions to the faculty in response to the pandemic.

Our study has a few limitations. First, our study focuses on social science disciplines and, thus, the findings may not be generalizable to other disciplines. Second, we have limited information about the researchers in our dataset. Future research could collect additional information such as their parental status to directly test the mechanism underlying the observed empirical patterns.

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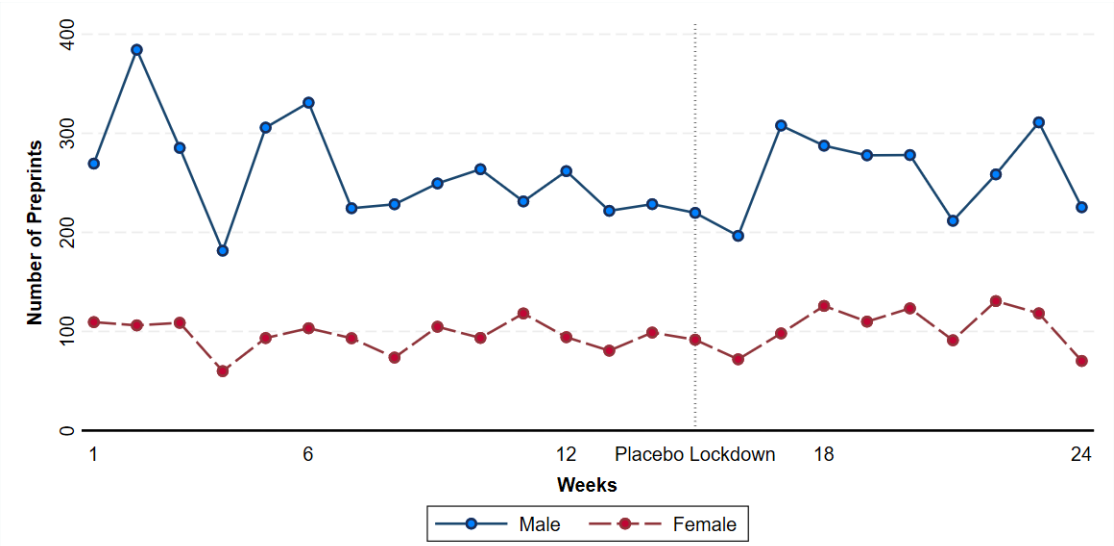
Appendix

Figure A.1 Time Trends of US Preprints from December 2018 to May 2019



This graph plots the time trend of the number of preprints for female academics and male academics. The vertical line represents the placebo lockdown week (the week of March 11) in 2019.

Table A.1 Robustness to Different University Rankings

	Dependent variable: No. of preprints (in logarithm) by discipline				
Universities	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
by Times ranking	(1)	(2)	(3)	(4)	(5)
Top 10	−0.209***	−0.230***	−0.198***	−0.185***	−0.181***
Top 20	−0.177**	−0.222***	−0.205***	−0.204***	−0.214***
Top 30	−0.227***	−0.253***	−0.228***	−0.228***	−0.228***
Top 40	−0.157**	−0.211***	−0.196***	−0.196***	−0.202***
Top 50	−0.114	−0.147**	−0.130*	−0.138**	−0.146**
Top 60	−0.126*	−0.143*	−0.131*	−0.137**	−0.147**
Top 70	−0.142*	−0.157**	−0.141**	−0.143**	−0.143**
Top 80	−0.139*	−0.154**	−0.140**	−0.131*	−0.130**
Top 90	−0.134*	−0.146**	−0.137**	−0.133*	−0.135**
Top 100	−0.124	−0.129*	−0.125*	−0.118*	−0.118*
Observations	720	756	792	828	864
	Dependent variable: No. of preprints (in logarithm) by discipline				
Universities	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
by ARWU ranking	(1)	(2)	(3)	(4)	(5)
Top 10	−0.232***	−0.255***	−0.233***	−0.214***	−0.222***
Top 20	−0.259**	−0.297***	−0.271***	−0.260***	−0.256***
Top 30	−0.261***	−0.305***	−0.268***	−0.264***	−0.259***
Top 40	−0.136*	−0.188**	−0.171**	−0.176***	−0.171***
Top 50	−0.104	−0.156**	−0.132*	−0.133**	−0.139**
Top 60	−0.171**	−0.154***	−0.154***	−0.143***	−0.114*
Top 70	−0.080	−0.125*	−0.109	−0.113*	−0.120*
Top 80	−0.123	−0.128*	−0.117*	−0.118*	−0.120*
Top 90	−0.099	−0.105	−0.095	−0.093	−0.096
Top 100	−0.090	−0.094	−0.086	−0.084	−0.089
Observations	720	756	792	828	864

This table reports the estimated coefficients in Equation (1) across universities with different rankings. The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Time fixed effects at the weekly level are included in all regressions. Note that we omit reporting standard errors and estimates of other variables for brevity. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.2 Parallel Trends Test

Variables	No. of preprints (in logarithm) in aggregation (1)	No. of preprints (in logarithm) by discipline (2)
$Female \times Time_{-14}$	−0.231	−0.189
	(0.430)	(0.352)
$Female \times Time_{-13}$	−0.013	0.157
	(0.430)	(0.335)
$Female \times Time_{-12}$	−0.377	−0.202
	(0.430)	(0.309)
$Female \times Time_{-11}$	0.060	0.219
	(0.430)	(0.302)
$Female \times Time_{-10}$	−0.030	−0.054
	(0.430)	(0.210)
$Female \times Time_{-9}$	−0.028	−0.213
	(0.430)	(0.243)
$Female \times Time_{-8}$	−0.144	−0.146
	(0.430)	(0.258)
$Female \times Time_{-7}$	−0.101	−0.031
	(0.430)	(0.234)
$Female \times Time_{-6}$	−0.363	−0.413**
	(0.430)	(0.250)
$Female \times Time_{-5}$	0.355	0.314*
	(0.430)	(0.214)
$Female \times Time_{-4}$	0.130	0.063
	(0.430)	(0.224)
$Female \times Time_{-3}$	0.098	−0.051
	(0.430)	(0.218)
$Female \times Time_{-2}$	0.069	0.056
	(0.430)	(0.239)
$Female \times Time_{-1}$	0.092	0.190
	(0.430)	(0.219)
Observations	24	540
R^2	0.894	0.808

This table reports the estimated coefficients of the interacted term, Female × Time, in Equation (3). The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Note that we omit reporting estimates of other variables for brevity. Time fixed effects at the weekly level are included in all regressions. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.3 Summary Statistics for December 2018 - May 2019

		All observations					Before March 2019		After March 2019	
Level	Weekly no. of preprints	Mean	Std. dev	Max	Min	Total	Mean	Std. dev	Mean	Std. dev
All Disciplines (US only)	All	401.0	69.6	535	267	9,333	406.4	75.8	393.3	58.9
	Female author	103.0	17.2	131	62	2,413	102.1	15.1	104.4	19.7
	Male authors	298.0	57.9	424	205	6,920	304.3	65.7	288.9	42.7
By Discipline (US only)	Accounting	21.0	6.3	34	10	505	21.9	6.6	19.9	6.2
	Anthropology	76.3	19.9	115	41	1,832	69.4	20.9	86.1	14.0
	Cognitive	17.0	7.7	38	7	407	20.5	7.9	12.0	3.7
	Corporate	17.5	5.9	30	8	420	17.2	5.6	17.9	6.4
	Criminal	16.3	5.6	32	6	390	14.9	6.4	18.2	3.8
	Economics	212.0	50.9	348	133	5,089	225.7	55.7	192.9	37.9
	Education	15.3	5.2	29	6	366	15.3	5.2	15.2	5.6
	Entrepreneurship	16.1	5.6	28	8	387	18.7	5.3	12.5	3.6
	Finance	89.7	21.3	148	66	2,153	95.0	25.2	82.3	11.8
	Geography	13.6	6.3	29	5	327	11.9	4.9	16.0	7.5
	Health Economics	4.3	4.2	22	0	104	3.3	1.7	5.8	6.1
	Information Systems	20.2	5.8	36	10	485	22.0	6.4	17.7	3.9
	Law	143.1	32.6	211	76	3,434	135.4	36.3	153.8	24.4
	Management	32.4	11.8	57	8	778	34.7	11.1	29.2	12.5
	Organization	24.8	7.8	43	15	594	27.2	8.4	21.3	5.7
	Political Science	166.3	28.3	225	124	3,991	172.5	30.9	157.6	22.8
	Sustainability	38.8	23.9	105	14	930	34.1	16.7	45.2	31.3
	Women/Gender	19.4	8.4	40	4	466	20.9	9.9	17.4	5.8

The table summarizes the weekly number of papers from December 2018 to May 2019. In total, there are 9,333 preprints produced by 14,767 US authors, 2,413 of which are produced by 3,876 female researchers and 6,920 are produced by 10,891 male researchers. We gather the country-specific lockdown time to split our sample to before and after the lockdown for each country.

Table A.4 Falsification Test

	Dependent variable: No. of preprints (in logarithm) in aggregation				
	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
	(1)	(2)	(3)	(4)	(5)
Female × *Lockdown*	0.042	0.061	0.088	0.080	0.057
Observations	40	42	44	46	48
R^2	0.980	0.980	0.979	0.980	0.980
	Dependent variable: No. of preprints (in logarithm) by discipline				
Female × *Lockdown*	0.092	0.094	0.103*	0.085	0.070
Observations	720	756	792	828	864
R^2	0.877	0.877	0.871	0.873	0.873

This table reports the estimated coefficients of the interacted term, Female × Lockdown, in Equation (1). The coefficients for 6, 7, 8, 9 and 10 weeks since the lockdown are presented in columns (1)–(5), respectively. Note that we omit reporting estimates of other variables for brevity. Time fixed effects at the weekly level are included in all regressions. Significance at $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.