The Impact of the COVID-19 Pandemic on PhD Education: An Empirical Analysis of a Large Comprehensive European University*

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Abstract

The COVID-19 pandemic has profoundly disrupted higher education, yet the specific impact on PhD students (ISCED level 8) remains understudied. This study investigates the relationship between the pandemic and various aspects of PhD education, including the duration of doctoral studies, diploma attainment, dropout rates, and the enrollment of new PhD students. Using a panel dataset from 2010 to 2023, which includes 19,565 PhD students and 2,126 supervisors from a top-50 ranked European university (Times Higher Education), a difference-in-differences and supervisor fixed effects model is applied to control for both observed and unobserved supervisor characteristics. The results show a 3.5% decrease in the probability of graduation in 2020, followed by a rebound in 2021 and a further 4.6% decline in 2022. Additionally, the average time to graduation increased by 2 months in 2021 and by 1.4 months in 2022, with signs of recovery in 2023. In 2020, there was also an 18.5% reduction in scholarship discontinuations, though these figures returned to pre-pandemic levels thereafter. It is argued that university closures allowed professors to allocate more time to research, resulting in an increase in successful funding applications. Consequently, PhD enrollment remained stable in 2020 and surged by 19% in 2021. Further analysis reveals that the pandemic's effects were most pronounced in the field of Biomedical Sciences, where graduates faced an average delay of approximately 4 months compared to those in other research fields.

Keywords: COVID-19; PhD education; University closures; Academic development; Research productivity; ISCED level 8.
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1 Introduction

The higher education landscape has undergone significant transformations in recent decades, driven by rapid technological advancements, increasing internationalization, and evolving student demographics. Among these developments, the COVID-19 pandemic has emerged as a critical disruptor, posing unprecedented challenges to universities, faculty, and students worldwide. The abrupt closure of academic institutions and the shift to remote learning affected educational outcomes at all levels, but the impact on doctoral education remains relatively underexplored. While existing research has extensively examined the effects of the pandemic on primary and secondary education (e.g. De Witte & François, 2022; Betthäuser, Bach-Mortensen, & Engzell, 2023; Patrinos, Vegas, & Carter-Rau, 2022), limited attention has been given to how the pandemic influenced the trajectories of graduate / PhD students (ISCED level 8).

Given the central role that doctoral education plays in driving innovation and advancing research, understanding the specific challenges and long-term consequences PhD students faced during the COVID-19 pandemic remains highly relevant, even in non-pandemic times. This paper fills a critical gap by providing a quantitative analysis of the pandemic's impact on key aspects of doctoral education, such as time to graduation, dropout rates, and the overall progression of PhD candidates across various disciplines. Although four years have passed, examining the effects of the health crisis offers insights that are pertinent not only for current academic practices but also for future preparedness. By analyzing this extreme situation, this article highlights the indispensable nature of in-person research for doctoral students and underscores the lasting effects that periods of confinement can have on academic trajectories.

The closure of universities worldwide as a preventive measure against the spread of COVID-19 has had a profound impact on the higher education sector, particularly disrupting the research activities and academic progression of PhD students. Myers et al. (2020) discovered that research time experienced an average decrease of 24.4%, with a more substantial decline of 30-40% observed among biomedical scientists. Furthermore, Cui, Ding, and Zhu (2022) noted a 13% reduction in productive time, as measured by the number of publications, specifically among women. This suggests that the pandemic has exacerbated pre-existing gender disparities within academia, particularly due to university closures. Considering the impact on senior researchers, it is plausible that the effects of the pandemic may be even more pronounced among young, unprepared scientists, including PhD students, leading to potential consequences for their academic trajectory and career prospects.

The present study contributes to the literature in three significant ways. First, it provides a quantitative assessment of the (long-term) consequences of university closures on PhD candidates. This evaluation encompasses four crucial indicators of PhD progress, namely, dropout rates, diploma attainment, time to graduation, and the number of starting PhDs. Furthermore, it aims to provide a causal relation between the impact of COVID-19 on the time to graduation by using a quasi-experimental identification strategy. Second, recognizing the diverse requirements for onsite research, such as laboratory work, this paper explores the heterogeneity among three distinct research fields: Biomedical Sciences, Humanities and Social Sciences, and Sciences, Engineering, and Technology. This analysis aims to uncover variations in the impact of COVID-19 across these fields. Third, extending beyond the scope of the pandemic, our study delves into specific factors that influence the doctoral process. These factors include the student's birthplace (EU versus non-EU), gender, and the presence of a co-supervisor. To the best of our knowledge, this is the first quantitative paper on the drivers of success and failure in doctoral programs while considering the impact of the pandemic on PhD education.

The analysis focuses on a Times Higher Education (THE) top-50 ranked large comprehensive European university. We are using the universe of all 19,565 PhD students who graduated between 2010 and 2023, and their of 2,126 supervisors. Our main identification strategy relies on a Difference-in-Differences (DiD) framework, which includes supervisor-fixed effects. In addition to analyses with data at the PhD level, we explore the impact of the health crisis by employing a panel data OLS regression model with supervisor-fixed effects on data aggregated at the supervisor level. As such, next to time-varying variables (e.g. share of women in a research group, supervisor's years of experience, etc.), we take into account observed (e.g. gender[1], school[2] , etc.) and unobserved (e.g. support provided[3], salary, etc.) supervisor heterogeneity.

The remainder of the paper unfolds as follows. Section 2 provides a review of prior research findings and section 3 discusses the setting. Section 5 presents the data used in our analysis after section 4 details our empirical specification. The main results and heterogeneity analyses are reported and discussed in sections 6 and 7. Finally, some robustness checks are conducted in section 8 before the paper concludes.

[1]More about the gender influence in academia can be found in Corbera, Anguelovski, Honey-Rosés, and Ruiz-Mallén (2020), Cui et al. (2022), Mata and Samimi (2022), Minello (2020), Myers et al. (2020) and Rodrigues, Silva, and Franco (2021).

[2]More about the differences across schools can be found in Aydemir and Ulusu (2020) and Börgeson et al. (2021).

[3]See, e.g., Börgeson et al. (2021), Dohaney, de Róiste, Salmon, and Sutherland (2020) and Rodrigues et al. (2021).

2 Literature Review and Hypotheses

The impact of university closures on PhD progress has been a topic of interest since the beginning of the COVID-19 pandemic. While quantitative studies on the subject are limited, there is qualitative evidence that certain fields, such as medical and biomedical sciences, have been heavily impacted due to their reliance on university laboratories (Aydemir & Ulusu, 2020; Börgeson et al., 2021). Meanwhile, Communication Sciences and Disorders (CSD) have also seen a negative influence on PhD progress, as noted by Covington and Jordan (2022). However, the general conclusions regarding the pandemic's impact on PhD students are mixed. As an illustration, a qualitative analysis conducted by Guest et al. (2021) involved 12 PhD students in the Education faculty at the University of Ottawa. The findings revealed conflicting perspectives, with 40% of respondents considering the pandemic as a positive experience and 20% perceiving it as neutral. Despite this, the authors also observed an increase in anxiety and uncertainty among PhD students. On the other hand, Covington and Jordan (2022) found that the majority of 160 PhD students in CSD experienced negative impacts and increased anxiety, along with reduced support from their supervisor. In contrast, Börgeson et al. (2021) studied 254 PhD students in biomedical sciences and found that 185 students reported increased support from their mentor, which was associated with improved well-being and better supervision. Dohaney et al. (2020) explored the factors that could mitigate the impact of a crisis on mental health, concluding that strong community, peer support, and leadership are crucial mitigators during pandemic times on learning and teaching. The authors highlight the need for students to have interactions and meetings, possibly face-to-face, with their supervisor. Rodrigues et al. (2021) went even further, emphasizing the need for academic institutions to provide more conciliation, such as deadline adjustments and supervisor support.

Beyond PhD education, a significant body of the literature has focused on research productivity during the pandemic and found mixed results. On the one hand, Cui et al. (2022) estimated a difference-in-differences analysis on the number of publications written by nearly 77,000 authors from 25 countries. The dataset they utilized spans the initial wave of the pandemic, spanning from December 2019 to May 2020. Their findings indicate a 35% increase in research productivity during this period. Moreover, the study observed no noteworthy decline in productivity for PhD students when compared to other academic positions, including assistant or full professor. On the other hand, Myers et al. (2020) reached opposing conclusions. Based on a quantitative analysis of 4,535 academic surveys from the EU and the USA, the authors observed that the average work hours declined from 61.4 hours to 54.4. Additionally, the results of a LASSO regression indicated a 24.4% decrease in the average total hours dedicated to research, although there was significant variability in this outcome. The greatest decline in research time was found in the field of biomedical sciences, with a drop ranging from 30% to 40%. Conversely, fields that require less equipment such as statistics or social sciences saw only an average drop of 10%. The findings of Myers et al. (2020) are supported by other studies on productivity outside the academic realm. For instance, Bloom, Bunn, Mizen, Smietanka, and Thwaites (2020) evaluated the Total Productivity Factor (TPF) of 2,900 companies in the United Kingdom and found a 5% decrease in TPF in 2020 and a decrease in working hours in the private sector. In an earlier interview, Nicholas Bloom attributed the decrease in productivity to the difficulties encountered in establishing an appropriate work environment at home (Gorlick, 2020). Many workers were forced to work with children present, which greatly impacted their ability to concentrate.

Still, when focusing on the medium to long run, Bloom et al. (2020) paint a relatively positive picture in their forecast of the lasting impacts of the pandemic. They assert that the "medium-run impact of COVID-19 implies only a small negative effect on productivity" (Bloom et al., 2020, p.4). This view is also echoed by Wigginton et al. (2020) who highlight that educational institutions in the USA and EU were already planning for the re-opening of their facilities and the resumption of academic work during the first wave of the pandemic. This proactive approach, they argue, would enhance the resilience of universities and mitigate the lasting impact of the pandemic in the medium to long term.

Individual characteristics such as gender, for instance, might also be a mechanism underlying COVID-19's influence. This is not new as a gender gap was present in the academic world prior to the health crisis, as supported by numerous studies that have documented gender inequality (Corbera et al., 2020; Mata & Samimi, 2022; Minello, 2020; Rodrigues et al., 2021). These studies attribute the differences between men and women to the fact that women typically take on a greater share of childcare and household responsibilities, even among highly educated couples. Following the university closure, this phenomenon seems to have been exacerbated. Indeed, despite their contrasting results on the impact of the pandemic on research productivity, both Cui et al. (2022) and Myers et al. (2020) agreed that the pandemic widened the gender gap in research. Cui et al. (2022) observed a decrease of 13% in women's research productivity, even as overall productivity rose by 35%. Myers et al. (2020) found that women's time fully dedicated to research declined by 4.2% more than men's.

Based on the previous findings, it is now possible to anticipate the effects of the university closure on PhD students. Following the decrease in productivity due to the lockdown, as a first hypothesis, we expect a decline in

the number of graduated PhD during the pandemic years. Second, if fewer students complete their program, one could think that either more students dropped out or that their graduation had to be postponed. In the latter case, we would observe an extended time to graduation. Nonetheless, as projected by Bloom et al. (2020), the adverse impacts of the pandemic are expected to be temporary. As a third hypothesis, we anticipate a significant resurgence post-pandemic, including an increase in the overall number of new PhD candidates. Fourth, based on the greater impact of the university closure on biomedical research fields, the previously formulated hypotheses are expected to be more pronounced among biomedical PhD students (Aydemir & Ulusu, 2020; Börgeson et al., 2021). Fifth, the role of strong support from a supervisor as well as resilience factors such as community support and avoiding social isolation were identified as critical to avoiding mental health problems. Therefore, as a final hypothesis, we expect that the presence of a co-supervisor and supportive peer effects result in a more successful graduation probability for students.

3 Setting

This section provides insights into the typical trajectory of a PhD curriculum at the examined university. Next, it describes how the examined university faced the COVID-19 crisis among the staff and the students.

3.1 The PhD track

Graduate students have the option to pursue a PhD in one of three primary research fields: "Humanities and Social Sciences" (HSS), "Biomedical Sciences" (BS), or "Science, Engineering and Technology" (SET). The HSS doctoral school is composed of multiple subjects divided into schools, including economics, arts, law, philosophy, theology, and others. The BS doctoral school encompasses various departments such as biology, cellular research, pharmaceuticals, and more. Finally, the SET field is also organized into departments, such as mathematics, computer science, architecture, and chemistry. In the remainder of the paper, we will focus on the research field rather than the specific school or department.

In the PhD program, regardless of the research field, students have two choices to embark on their doctoral path: either by applying for an open position or by presenting their own research proposal. Opting for the latter option requires the student to independently find a supervisor who can assist in securing funding for their project. The specific requirements to begin a PhD may vary depending on the circumstances under which the student applies. However, as a general principle, students are typically expected to have graduated with at least cum laude honors.[4] In certain departments, PhD students who have only completed a master's degree in their field may be required to fulfill additional prerequisites before commencing their doctoral studies. These prerequisites could include the completion of a research master's program or a pre-doctoral program. The duration of these programs typically ranges from 1 to 2 years, providing students with the necessary background and skills for their PhD research.

Upon acceptance, the student is typically committed to a 4-year, full-time research program, which is the standard length of time required to complete a doctoral program. During this period, the student is responsible for conducting and presenting their research, attending seminars and conferences, and may also be required to complete evaluated coursework. In certain cases, these additional courses may be incorporated into a research or pre-doctoral program that can be pursued alongside the PhD studies. It is worth noting that PhD students may also have educational obligations, such as providing tutoring, supervising master's theses, and invigilating exams. It is important to mention that, at the evaluated university, professors of any rank can serve as supervisors for PhD students. This means that an assistant professor, for instance, can supervise a doctoral student just as a full professor can. The only restriction is that postdoctoral researchers are not eligible to be supervisors of doctoral students.

In addition to meeting several milestones throughout the 4-year program, the PhD student is required to write a doctoral thesis. It might be either paper-based or a comprehensive explanation of the research conducted during the program and its significance to the scientific community. After writing the thesis, the PhD candidate must defend his/her work in front of an examination committee, priorly constituted by the supervisory team. The defense is a formal discussion lasting up to three hours, to elucidate the content and contribution of the work to both faculty members and external jury participants, encompassing both experts and non-experts. During the defense, the PhD candidate has to demonstrate that he/she effectively masters the content through active discussion and answering questions.

[4] Graduating with cum laude or with distinction means being graduated with a weighted grade point average of at least 14 out of 20.

The PhD student receives a scholarship, corresponding to a monthly fee free of any charge that was around 2 000€net at the time of the pandemic. Note that a PhD student does not pay any personal taxes but is subject to the social security contribution.[5] In some cases, the scholarship is funded by research agencies, and not directly by the university. Consequently, part of the supervisor's job is to elaborate research projects and to participate in competitive research bids, that ultimately fund new PhD students. Approximately 25% of the PhD students are not financially supported and are required to secure their own funding. These individuals often engage in their research while simultaneously holding another job or employment. They are commonly referred to as 'part-time' PhD students, as they balance their doctoral studies alongside their other professional commitments.

In the event that a student is unable to complete their doctoral program within the standard 4-year timeframe, the student can continue the research without a scholarship or the supervisor can hire the student as a (more expensive) research or teaching assistant. As a result, these individuals may require more or less time beyond the standard 4-year program length to obtain their doctoral degree.

3.2 The research university dealing with the COVID-19 health crisis

In an effort to contain the spread of the pandemic throughout the academic year 2019-2020, the university administration opted to transition to exclusively online teaching, commencing on March 11. This measure remained in effect until the end of the term, resulting in a total closure of the university for approximately 9 weeks. Consequently, the administration announced a suspension of all non-essential on-campus research activities for PhD students and also canceled any new research projects that necessitated the use of on-campus facilities. Despite the interruption of non-essential on-campus research activities, ongoing studies involving cell structures or lab animals, which were difficult to interrupt, were allowed to continue. In addition, labs working on COVID-19 research were also permitted to continue their investigations. However, the impact of these measures was primarily felt by biomedical sciences researchers working with labs and regular manipulations, while researchers in other fields were able to continue their research remotely, albeit with the difficulties that it entailed.

During the examination period, PhD students were required to participate in some on-campus activities, such as invigilating or taking exams. However, aside from these activities, the majority of staff and researchers continued to work from home.

During the summer of 2020, the situation regarding exams was a hybrid one, with approximately 86% of exams being conducted on-campus as the pace of the pandemic had slowed down. This allowed for more staff members and PhD students to gradually return to campus, albeit with strict adherence to safety protocols. It's crucial to highlight that the exact count of individuals present on campus at any specific moment is unknown, necessitating us to make inferences. Although staff members were not explicitly forbidden from using their offices, they were strongly encouraged to work from home whenever feasible, prioritizing remote work arrangements.

The following academic year, 2020-2021, began in a similar mixed situation with lecture halls being occupied at a capacity ranging from 20% to 50%. On-campus research was allowed, but there were restrictions on a maximum number of researchers per room. Consequently, many PhD students continued working from home in the first term. Academic activities, such as doctoral defenses, were allowed to be conducted on-campus, albeit with a limited number of attendees in a single room, and individuals were advised to work from home if experiencing any symptoms of illness. The expansion of on-campus activities was largely motivated by the aim to offer the optimal educational experience for new students. However, social gatherings were strictly regulated, with a limited number of individuals allowed.

The aforementioned circumstances were not sustained, as all campuses were again closed from November 3, 2020 onwards. This persisted until March 5, 2021, after which the situation gradually improved and returned to normal by the end of the academic year. Overall, on top of the 9 weeks in 2020, the university was closed for a total of 14.5 weeks in 2021.

The series of transitions from complete closure to partial reopening posed significant challenges for biomedical scientists and their PhD students, who often required several months to initiate new research activities. Conversely, researchers in other fields were able to conduct their work either on-campus or remotely from home. As a result, these researchers experienced comparatively fewer disruptions than their counterparts in the biomedical sciences.

[5] The contribution to social security covers 13% of the gross wage. In the end, if a PhD student earns monthly a net wage of 2 000€, the gross wage is therefore around 2 298€.

4 Methodology

To offer an understanding of the effects of the COVID-19 pandemic on PhD education, our analysis delves into the effects of the pandemic at the student level. Looking at individual data points allows examining the heterogeneous impact of the pandemic. This approach enables the identification of individual-level factors that may have affected PhD progress and success during the pandemic, such as student demographics. Furthermore, the latter perspective allows us to raise a causal link between the pandemic and the graduation probability as well as the time spent in a doctoral program. On the other hand, clustering data at the supervisor level allows us to capture common (un)observed effects that may be missed when looking at individual data from the student level (e.g. a supervisor has a common approach to advice all of his/her PhD students). Additionally, it can reduce the potential for bias due to unobserved heterogeneity among students. The findings from the supervisor level are presented in Appendix B.

The primary model, inspired by Bostwick and Weinberg (2022), employs a Difference-in-Differences (DiD) methodology to investigate the effects of graduating during and post-pandemic years, specifically from 2020 to 2023, on the total number of months enrolled in the PhD program in comparison to the remaining years within the sample period (2010-2019). As variables of interest, we focus on five dummies: $COVID_2020$ to $COVID_2023$ and T_{it}. The first variable equals 1 for ending the PhD (i.e., graduating or dropping out) in the year 2020 only, while the following ones are set to 1 for graduation or dropout in respectively 2021, 2022 and 2023.[6] T_{it} is a dummy equal to one when an individual is 'treated', with the 'treatment' depending on the model (see below). The regression is as follows :

$$\begin{aligned} y_{i,t} =& \alpha + \beta_1 COVID_2020_i + \beta_2 COVID_2021_i + \beta_3 COVID_2022_i + \beta_4 COVID_2023_i + \beta_5 T_{i,t} \\ &+ \beta_6 COVID_2020_i \times T_{i,t} + \beta_7 COVID_2021_i \times T_{i,t} + \beta_8 COVID_2022_i \times T_{i,t} \\ &+ \beta_9 COVID_2023_i \times T_{i,t} + \theta X_i + \lambda Trend_{i,t} + \delta_j + \epsilon_{j,t} \end{aligned} \tag{1}$$

Consider first the analysis of the COVID-19 impacts on the time spent in the doctoral program. The total number of months spent by student i in the PhD program in his/her last year observed t is denoted by $y_{i,t}$. The first four estimates, β_1 to β_4, capture the overall effects of ending the PhD (i.e. graduating or dropping out) during and post-COVID-19 relative to the 2010-2019 time period on the outcome variables. The former focuses on the changes that occurred immediately in the aftermath of the initial wave of university closures, the next ones examine the impact years later. β_5 captures the effect of the "treatment" on the outcome variables, namely $T_{i,t}$ is a dummy variable equal to 1 if student i graduates in his/her last year observed, t. Coefficients β_6 to β_9 present the interaction effects between being graduated in respectively 2020 to 2023 on the total number of month spent by student i in the PhD program.[7] The linear $Trend$ coefficient captures the variations over time, such as the increasing seniority of the supervisor or the increased professionalism of doctoral schools, for instance. Student characteristics such as the European Union (EU) citizenship, gender, and the number of supervisors guiding the students are captured by $X_{i,t}$. A supervisor fixed effects, δ_j, capture observed (e.g. gender, school, etc.) and unobserved (e.g. support provided, supervisory style, etc.) heterogeneity at supervisor j level. Finally, we cluster the standard errors $\epsilon_{j,t}$ at the supervisor level.

Second, the model specification exploring the graduation probability is almost identical to equation (1). In this case, $y_{i,t}$ is a dummy equal to 1 if student i graduated during his/her last year observed t. The treatment, $T_{i,t}$, is another dummy variable equal to 1 if a student i is completing the fourth year of PhD in year t. Given that PhD contracts are set for 4 years, students are not expected to complete their studies ahead of this timeframe.[8] Hence, β_5 estimates the effect of being "eligible" to graduate on the probability of graduation. Coefficients β_6 to β_9 capture the impact of being eligible to graduate during and post-COVID-19 years in comparison to 2010-2019 on the global probability of graduation. The model aims to evaluate the effect of being eligible to graduate on the probability of graduation at different moment in time on top of disentangling students who are at the end of the program and more likely to be impacted by the health crisis from the others.

The data structure in this latter model differs significantly from the one of the PhD length. So far, one observation in the sample covers one student for whom the year of starting the PhD as well as the last year in the program is observed. The cross-sectional structure avoids giving greater weight in the regression to the students who remain enrolled in the program longer, unlike panel data. Nonetheless, the current data structure prevents us from properly evaluating the graduation probability of a student. The COVID-19 variables capture only two

[6] Note that we only observe the year when the PhD was achieved or started, not the specific dates.

[7] The inclusion of the all the years at our disposal as interest variables in the model is motivated by investigating the long run effect of the COVID-19, specifically on individuals who started their program during or just before a lockdown.

[8] Less 0.75% of the students still managed to graduate before 3 years of PhD.

options, i.e. graduating or dropping out in 2020 to 2023, which is correct for students observed last from 2020 to 2022 , but it misses a third option for those last observed in 2023 (the last year in our sample) : continuing in the program. Hence, equation 1 entails a selection bias as there is a significant number of students observed and eligible to graduate in 2023, but not considered by the current construction of the variable $COVID_2023$. This is solved by applying the same model, but turning the cross-sectional sample into a panel data one. In more detail, the number of observations available for each student is now defined by the number of years each of them spent in the PhD program until they leave it. Regarding the graduation probability or the treatment dummy (e.g., being eligible to graduate), these variables remain equal to zero until respectively the year of graduation or after completing 3 years of PhD. This construction avoids the selection bias as, each year, all students either graduate, drop out or keep going on the program.[9] In the end, equation 1 regardless of the data structure allows us to evaluate the effect of a treatment and its variations during and outside the health crisis.

Our identification strategy depends on the fact that the health crisis is, in essence, unexpected and therefore exogenous. The latter implies independence between the dependent variables and the COVID-19 crisis, which prevents our analysis from any reverse causality concern. In addition, it should be noted that most unobserved heterogeneity is taken into account by our econometric framework and the supervisor fixed effects. Lastly, there is no selection made to construct our sample as it covers every PhD student in the university since 2010.

To delve deeper into the fundamental mechanisms influencing the causal effects of COVID-19 on the duration of PhD studies and the likelihood of graduation, we carry out additional panel data fixed effects OLS models, utilizing data aggregated at the supervisor level. At this level, we examine the impact of COVID-19 pandemic on the number of PhD candidates who successfully obtained their diploma in a given year, the annual number of PhD candidates who dropped out of the program, and the annual number of new PhD candidates supervised by the professor. In addition, the mean time to graduation[10] is also considered. As variables of interest, we focus on the same four dummy variables, $COVID_2020$ to $COVID_2023$. The OLS model takes the following form:

$$\begin{aligned} y_{j,t} =& \alpha + \beta_1 COVID_2020_{j,t} + \beta_2 COVID_2021_{j,t} + \beta_3 COVID_2022_{j,t} + \beta_4 COVID_2023_{j,t} \\ &+ \lambda Trend_t + \theta X_{j,t} + \delta_j + \epsilon_{j,t} \end{aligned} \tag{2}$$

where $y_{j,t}$ denotes the outcome variables by year t and supervisor j. Relatively to the 2010-2019 time period, the effect of COVID-19 is captured by β_1 to β_4. The linear $Trend$ coefficient captures the variations over time. Time-varying controls[11] (e.g., the number of students in the research group, the share of women, share of non-EU students or share of students with more than one supervisor) are captured by the variable $X_{j,t}$. We control for observed and unobserved heterogeneity at the supervisor level by using a supervisor fixed effects, δ_j. Finally, we cluster the standard errors $\epsilon_{i,t}$ at the supervisor level. As a final remark, note that the same OLS fixed effects model is applied using individual-level data to evaluate the effect of the pandemic on the dropout probability. The above methodology is employed for this outcome variable as it was impossible to derive a treatment effect on the dropping out probability.

5 Data

Panel B of Table 1 describes information at the supervisor level and aggregates the data from panel A, which details the PhD student level. Let us focus firstly on panel A, gathering cross-sectional information for all 19,565 students. It shows that half of our sample graduated while 16% left the program. The average time enrolled in the PhD program (the outcome variable) is 51 months when including all students, while only graduated PhDs spend 59.5 months. These high values are due to observations for long-time PhD's who graduated, which increases the mean. Our sample consists of 44% of women and 28.5% of the PhD candidates are born outside the EU borders. Finally, most of the doctoral candidates have less than 2 (co)supervisors. One would note that some individuals graduated before their fourth year of PhD considering the minimum value of 24 months in the time to graduation. These are minor situations covering 1.6% of the sample, that may happen.

[9] Note that although the selection bias is a problem when looking at the graduation probability, it is not the case when focusing on the PhD length. In this latter model, we balance the effects of graduating in 2020 to 2023 with those of completing the PhD in the remaining years of the sample. In other words, it focuses on PhD student leaving the program. Hence, the selection bias at work in 2023 does not matter since it concerns students who do not graduate nor dropout. Still, we present three robustness checks in section 8. Students who keep going in 2023 are removed and another one presents the same model applied to a panel data sample. Finally, we also remove the long-run PhD students to avoid the overweight they might cause in the panel data model.

[10] This variable is the average of the time to graduation of the graduate PhD students supervised by supervisor j in year t .

[11] While dummies were used at the students' level, these controls become now shares at the supervisor level. For instance, the share of women is computed by the total number of women in the research group divided by the total number of students in the group.

The data of the 2,126 supervisors who were active during the period spanning 2010 to 2023 is presented in panel B. The supervisors are observed from either 2010 or the year of their appointment at the university, until either 2023 or the year in which they retired or left the university. As observed, the average supervisor has one graduated student every two years (value 0.54), and a new PhD student starts under his/her supervision about every year and three months (value 0.86). Considerable variations underlie these means, with certain supervisors overseeing as many as 11 graduates annually and initiating the supervision of 15 new PhD students, while others may have none. About every 6 to 7 years, a supervisor experiences that a student leaves the PhD program, although there are also supervisors with 5 students who left in a given year. The large variation in the data is also present from the research group size, which has on average 4 PhD students but a similar standard deviation. About a quarter of the supervisors are female. The average supervisor has 11.8 years of seniority. Furthermore, panel B demonstrates that 18.6% of PhDs have more than one supervisor. Comparing panel A and panel B indicates similar findings about the time to graduation with respectively 59.5 and 59.2 months. Moreover, it shows that the average age difference between a PhD student and their supervisor is about 20 years.

The sample includes information from 53 departments gathered in three main research fields. The "Humanities and Social Sciences" (HSS) field accounts for 27.76% of the observations, followed by "Biomedical Sciences" (BS) with 25.26% and "Science, Engineering and Technology" (SET) with 46.86%.[12] Additionally, the year in which the supervisor was hired is also known. Any student who graduated, started, or dropped out of their PhD with a supervisor who was hired after these events are removed from the observations, as these limited situations may occur when a professor comes from another university or was a postdoc before becoming a full professor.

It should be noted that the variation in the number of observations in panel B is attributed to the nature of the observed data. For example, the time to graduation is recorded solely when there is at least one graduation in a given year and research group. Then, we included the missing observation number of graduated/started/dropped out PhD when a supervisor has not any student to supervise, which explains the lower number of observations related to these variables.[13]

Table 1: Summary statistics

	Mean	SD	Min	Max	N
Panel A. Sample at student level					
Diploma attainment	0.527	0.499	0	1	19 565
Dropped out PhD	0.160	0.366	0	1	19 565
Time spent in the PhD program	50.662	28.015	1	300	19 565
Time to graduation	59.540	17.764	24	236	10 308
Eligible	0.582	0.493	0	1	19 565
PhD gender (female = 1)	0.443	0.497	0	1	19 565
EU citizenship (non-EU = 1)	0.285	0.451	0	1	19 565
Shared supervision	1.801	0.860	1	8	19 565
PhD birth year	1987.731	7.861	1923	2003	19 565
Panel B. Sample at supervisor level					
Diploma attainment	0.536	0.918	0	11	18 424
Dropped out PhD	0.162	0.434	0	5	18 424
Started PhD	0.858	1.167	0	15	18 424
Time to graduation	59.205	15.575	24	236	6484
Share of Diploma attainment with a co-supervisor	0.186	0.376	0	1	21 247
Research group size	3.922	4.280	0	71	21 247
Supervisor gender (female = 1)	0.274	0.446	0	1	21 247
Supervisor birth year	1968.168	9.220	1944	1992	21 247
Seniority	11.851	8.476	0	37	21 247

In a preliminary exploration of the sample, Figures A1-A2 in Appendix A illustrate the number of supervisors and students over the years. The figures present a parallel tendency, as it can be seen that the number of PhD

[12] 0.12% of the observations are missing. Furthermore, the supervisor level presents more equal frequencies with 33.9%, 35.6% and 30.3% (0.2% missing) for respectively HSS, BS and SET.

[13] We assume that, if a supervisor has no student the outcome variables would take the value zero, which would deteriorate the true effect of the pandemic on the outcomes.

students has been steadily increasing, with a jump in 2021, the year after the first pandemic wave. Similarly, the total number of (co-)supervisors has been constantly increasing, with a minor dip in 2019. Given the common trends, the latter suggests a rather constant ratio between the number of PhD students managed by supervisors. As observed in the data, the average ratio of PhD students by supervisor moved slightly from 3.90 in 2010 to 4.4 in 2023.

According to Figure A3, the annual trend in the overall count of PhD graduates exhibited a reduction in the first year of the pandemic, followed by a resurgence in 2021 and massive jump in 2023. Remarkably, the decline observed in 2020 was also evident one year earlier in 2019. Moreover, Figure A4 depicts a comparable pattern, with a decrease in the number of PhD dropouts in 2020 and a substantial escalation in 2021 and 2022. The latter graph seems much more volatile compared to the others, particularly in comparison to the constant growth of started PhDs since 2014, as shown in Figure A5. Despite a slight dip in 2020, there has been a significant increase in 2021 in the number of started PhDs. On the other hand, the average time to graduation, as depicted in Figure A6, remains relatively stable over time, hovering around 59 months. However, a decrease in length was observed in 2020, followed by an increase to over 61.5 months in 2021.

Regardless of the variations within each variable, a common feature can be highlighted: in 2021, the likelihood of observing a student who had graduated, started, or dropped out their PhD was higher than in previous years. This suggests that, during or post-pandemic, there has been a growing number of students completing or starting their PhD, but also a higher number of students choosing to discontinue their studies. These overall increases in 2021 could be linked to the steady rise in the number of students, which mechanically results in potentially larger values for each variable. Furthermore, the higher number of graduated and discontinued PhDs could be the cause of the decrease in student numbers in 2021. Therefore, the following section will evaluate whether or not this conclusion remains true through the light of our econometric framework that accounts for a trend and (un)observed heterogeneity.

Finally, Figure A7 presents by research field the average time to graduation by year. With an average of 61.9 months, it shows that graduates in HSS doctoral programs took more time to graduate than BS and SET students who respectively took on an average of 59.9 months and 58 months to graduate. In line with our hypothesis about the larger pandemic influence among BS, the greatest increase in time to completion was observed in the BS field in 2021, although the average length is lower than in HSS. This pattern might be explained by the larger amount of part-time PhDs in the HSS research field.

6 Results

Table 2 presents the impact of the COVID-19 pandemic on the time enrolled in a PhD program and the probability of graduation using respectively cross-sectional and panel data structure at the student level. These findings are based on our main identification strategy presented in equation (1). Corresponding analyses at the supervisor level are detailed in Appendix B. It also provides insights into the outcomes pertaining to the number of dropouts and initiated PhDs.[14]

Column 1 of Table 2 outlines the findings concerning the duration of time spent in the PhD program. For non-graduates only, the COVID-19 effects are not significantly different from zero except in 2023, highlighting the restricted impact on time spent in the program for those students. The 5.4 months increase in 2023 seems the results of students dropping out of doctoral studies later than in previous years. Out of pandemic periods, students who do not graduate leave the program 19 months earlier than students who eventually graduate (coefficient of 19.34). Examination of the interaction terms indicates that graduating during the initial year of the pandemic leads to a relatively modest increase of 17.7 months in the time to graduation, which subsequently escalates to 20.4 months one year later.[15] Taking all these coefficients together with the constant shows that the graduation in 2020, 2021, 2022 and 2023 respectively were around 58.8, 61.6, 59.4 and 61 months. In relation to the global average, the first pandemic wave saw a small decrease in the graduation time (-0.7 months), before showing a slowdown in 2021 with a 2 months increase. Similarly, the year 2022 is closer to the mean while 2023 again presents a 1.4-months increase.[16] Lastly, from 2020 to 2021, the time to graduation for PhD candidates increased by 2.8 months, by 2 weeks in comparison to 2022, and by 2 months in 2023.

The student-level analysis provides interesting information on the control variables. Over time, the *Trend* coefficient suggests that the PhD duration increases by about 1 month per year. The coefficient for $Non - EU$

[14] In addition, Table E1 in the appendix presents the same results, without supervisor-fixed effects.

[15] A multiple hypothesis test certifies the difference between the 2021 coefficient (20.4 months) and the PhDs graduating in non-pandemic periods (19.34 months) as well as remaining years at the 1% level.

[16] As a reminder, the average time needed to graduate by focusing only on graduated students is around 59.54 months.

is statistically significant and negative, indicating that being born outside the EU correlates with a decrease in PhD length by 3.8 months. The latter corresponds to a 6.4% reduction compared to the mean duration. Similarly, being a woman decreases the time of the PhD significantly by around 2 months. Lastly, increasing the number of supervisors by one does significantly alter the average time to graduation by 2 months.

Column 2 reveals our findings regarding the probability of graduation. We focus immediately on the interaction terms. For students eligible to graduate, the initial year of the pandemic resulted in a 3.5% decline in graduation probability, signifying statistical significance at the 1% level. A year later, the lingering impact of the pandemic persisted, as graduation rates in 2021 remained lower compared to earlier periods, but not statistically significant. Similarly, graduation probability is 4.6% significantly lower in 2022, while 2023 indicates almost no change. Moreover, being eligible for graduation raises the likelihood of actual graduation by 33%, excluding periods of the pandemic. In the broader context, the probability of graduation remains constant over time, as indicated by the *Trend* coefficient, while the *Research group size* suggests a slight uptick in graduation with each additional student in the group. The characteristics of the students show limited evidence of heterogeneity in the probability of graduation.[17]

Table 2: Main results

	Time spent in the PhD program	Diploma attainment
COVID_2020	-1.020	0.000955
	(2.269)	(0.00360)
COVID_2021	-1.430	-0.00810*
	(2.228)	(0.00391)
COVID_2022	-2.236	-0.00563
	(2.140)	(0.00429)
COVID_2023	5.391*	-0.00295
	(2.448)	(0.00514)
Treatment	19.34***	0.330***
	(0.725)	(0.00537)
Treatment×COVID_2020	17.68***	-0.0348**
	(0.786)	(0.0112)
Treatment×COVID_2021	20.39***	-0.0177
	(0.765)	(0.0106)
Treatment×COVID_2022	18.21***	-0.0461***
	(0.786)	(0.00982)
Treatment×COVID_2023	19.82***	-0.0000871
	(0.740)	(0.0105)
Time trend	1.139***	0.0000108
	(0.0866)	(0.000497)
Research group size		0.00208**
		(0.000732)
Non-EU	-3.778***	0.00547*
	(0.498)	(0.00277)
Female	-1.920***	0.000837
	(0.427)	(0.00228)
Shared supervision	1.907***	-0.00360*
	(0.276)	(0.00148)
Constant	21.82***	0.00852
	(1.567)	(0.00971)
Supervisor fixed effects	✓	✓
Adjusted within R2	0.121	0.195
N	19 565	85 094

Note: The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman.

To identify the mechanisms at the root of the above tendencies, Table B1 in Appendix B presents also the above outcomes variables (columns 1 and 2) completed with the probability and number of dropouts (column 5 and 3) and new PhD students (column 4) using the OLS FE model developed in equation (2). Due to multicollinearity, we could not include the size of the research group as a time-varying control. As it can be observed, columns (1) and (2) present very similar tendencies regarding the variable of interest, although the results are globally less significant. However, compared to Table 2, students graduating in 2021 took 2.49 months longer (i.e., an increase of 4.2% to the average of 59.20 months, significant at the 5% level) to complete the PhD. The latter figures are in

[17]The *Research group size* variable was not included as a control when studying the time spent in the PhD as it led to collinearity issues.

line with the tendencies raised under the DiD identification. Likewise, the number of graduations exhibits a notable decline significant at 10% in 2020 (-7.7% compared to the mean number of graduations of Table 1), succeeded by a recovery the following two years and an important jump in 2023 (equivalent to a 19.4% increase). The use of the eligibility to graduation as a treatment in equation 1 is at the root of those differences between Table 2 and B1. The latter captures the changes in the raw number of graduation, while the former looks at the probability of graduation when being eligible for it. Hence, when considering the eligibility, there is a recovery in 2023, but not that high because there is way more eligible students that year. The control variables reveal results consistent with those in Table 2. It appears that having more than one supervisor reduces the number of graduates by 4.7% (coefficient of 0.025).

Moreover, employing the OLS FE methodology and aggregating data at the supervisor level enables us to explore the impact of the health crisis on the number of dropouts (column 3) and new PhD students (column 4). Column 3 reveals an 18.5% decrease compared to the mean in the number of interrupted PhD programs in 2020 (coefficient of 0.03), while there is no statistically significant change in column 4. However, one year later, both variables present a recovery, notably the statistically significant increase of 0.16 new students per supervisor, equating to an 19% rise. Although coefficients are not significant, the number of dropout keeps on going higher in 2022, before reducing in 2023. Finally, the number of starting PhDs show limited changes in 2022-2023. The 2021-2022 resumption in the number of dropouts translates to a 3.6% increase in individual's dropout probability from 2020 to 2021, and 4.6% from 2021 to 2022.[18] As underlying mechanisms, during the university closures dropping out of the PhD program was less attractive as the outside options became less attractive (due to the restrictions in the general economy). Hence, PhD students might have experienced more opportunities to re-focus on their research. Furthermore, the rise in the number of PhD students commencing their studies in 2021 could be clarified by the additional time university professors had during the closures. They utilized this time to draft research funding proposals, leading to the subsequent recruitment of new PhD students (in line with Wigginton et al., 2020; Myers et al., 2020). Consequently, due to the slowdown in the number of new PhDs in 2020, some supervisors may have "saved" their funds to use them one year later. Hence, this larger amount of money allowed them to hire more students in 2021.

To understand the overall long-term repercussions of the health crisis, we consider the coefficients of interest from each model collectively. Assuming that COVID-19 led to a slowdown in the progress of all PhD students, regardless of the specific phase of their program during the pandemic, the results can be interpreted as follows: Following the first wave of the pandemic in 2019-2020, students who were eligible to graduate in 2020 postponed their graduation, resulting in a 3.5% decrease in the probability of timely graduation. However, those who did graduate in 2020 completed their program slightly faster than expected, with a reduction of 0.7 months in their time to completion [19] The postponement of graduation for students eligible in 2020 led to an increase in the probability of graduation in 2021. However, PhD candidates originally eligible to graduate in 2021 may have also experienced delays, resulting in a reduced probability of graduation that year. These two effects essentially offset each other, leading to no significant overall change in graduation rates for 2021. When focusing specifically on those who did graduate in 2021, the data show an average delay of two months, reflecting the deferral of their graduation from 2020 to 2021.

The year 2022 is different. As most of the delayed PhDs of 2020 graduated in 2021, it remains the 2021-eligible students who delayed to 2022 and the 2022-eligible students who delayed to 2023. Nonetheless, there are no cancelling effects in 2022 as the graduation probability falls by 4.6%. This is the result of a combination of three effects. (a) Only 20.4% of the 2021-eligible students delayed their graduation to 2022, leading to a weaker increase in the graduation probability of 2022 compared to the remaining years (22.6% delayed to the next year in 2020 and 24.5% in 2022, respectively). (b) Only 28.3% of the 2022-eligible individuals graduate in 2022, which further reduces the probability of graduation. In comparison, the latter share was 30% for both years 2020 and 2021.[20] (c) Finally, the share of 2022-eligible students postponing their graduation to 2023 is larger than before (24.5% in 2022, against 22.6% and 20.4% respectively in 2020 and 2021), which is again reducing the graduation probability. The larger share of dropouts among eligible students in 2022 for unknown reasons may also play a role in the graduation fall. Lastly, the year 2023 corresponds to 2021. Eligible students who were delayed in 2022 graduated in 2023, while there might still be eligible students affected by the health crisis leading to no changes in the graduation probability for the year 2023. Graduated students are composed of delayed eligible students from 2022, resulting in a 1.4-month increase in time to graduation. Globally, these coefficients seem to highlight the

[18] A hypothesis test certified the significant difference between the coefficients of the COVID-19 of column 5.

[19] As an underlying mechanism, the decline in time to graduation in 2020 might be explained by part-time PhD students, who combine their education with a position in companies and industry. Due to the general restrictions during the pandemic, this group of students might have made more progress in their research, and hence graduated more quickly. Although we do not observe whether a student takes the program full or part-time, we explore this mechanism more in detail in section 8.

[20] As further evidence of the effects of the pandemic, the share eligible students in year t graduating t reached on average 34% over the period 2010-2019.

long-lasting effects of the health crisis, although the effects become smaller as time runs.[21]

7 Heterogeneity analyses

This section explores the heterogeneity in the data by focusing on the research field, gender, being born outside the EU, and additional supervision by multiple supervisors or co-supervisors. The results in Table 3 focus on the time spent in the doctoral program using the DiD identification, but alternative heterogeneity analyses for other outcomes variables and models are presented in Appendix C.

First, consider the heterogeneity among research fields. The findings from section 6 are mainly driven by the field of Biomedical Sciences (column 1). Taking together the graduation dummy and the interaction term shows an increase in time spent on the PhD by almost 4.87 months in 2021 compared to the average graduation time in "Biomedical Sciences" (BS). On the contrary, schools of "humanities and social sciences" (HSS) and "Science, Engineering and Technology" (SET) present respectively an increase of only 0.27 and 1.39 months.[22] Furthermore, biomedical researchers present the largest time gap between 2020 to 2021 with 4.36 months, while SET and HSS differ by more or less 2 months. As an underlying mechanism, the intensive use of specialized laboratories in biomedical sciences might explain such a large increase in the PhD duration. As these were closed, (PhD) research is more at risk of delay compared to the remaining research fields, which can more easily work remotely. Table C1 (Appendix C) presents almost identical results using data aggregated at the supervisor level. BS scientists seem to have raised their time to graduation by 5.3 months in 2021, while there is no significant change in 2021 among the HSS and SET schools.[23]

Second, our attention is directed towards EU versus non-EU students individually (columns 4 and 5). At first sight, the interaction terms reveal an extended duration to graduation among EU students. The latter fact might be explained by the tendency of EU students to graduate later than non-EU ones. This is illustrated mostly by the constant term, reporting 6 months longer average PhD length among EU students only. Nevertheless, from the interaction terms of Table C2, non-EU students present a significantly lower probability of graduation in the year 2021, which remains lower in 2022, while EU students recover and seem less affected. This suggests that the effect on mental well-being is more outspoken for non-EU students.[24] As an illustration, the prolonged restriction on intercontinental travel and a comparatively weaker social network for non-EU individuals could potentially contribute to increased anxiety and depression, potentially impacting their progress in the PhD program.[25] On the contrary, the peer effects among non-EU shows a larger probability of graduation (5.8%), in line with the tendency of a quicker graduation.

Third, at first sight, columns 6 and 7 indicate an increase in the gender gap, as the coefficients of the interaction terms seem to be larger among women. However, taken together, the health crisis might have been even more harmful among men, as opposed to earlier findings in the literature. The sum of the coefficients for women in 2020 presents a PhD length of 60.5 months, raising to 62.2 months in 2021. For men, it moves from 55.9 months in 2020 to 60.4 months one year later.[26] In other words, the bigger increase for men illustrates a more severe impact of the pandemic, while the larger coefficients reported for women come from their tendency to graduate later than men. The latter fact is illustrated by the graduation dummy. Furthermore, Appendix C3 shows larger number of dropouts among men, although the differences are not statistically significant. Lastly, Table C3 (Appendix C) present almost identical findings. The latter outcomes go against any increase in the gender gap presented earlier in the literature. As underlying mechanism, PhD women of our sample are most likely not to be mothers during the PhD, which may explain the absence of gender gap evidence.[27]

Our final heterogeneity analysis is about differences between PhD students with more than one supervisor and those with only one. Columns 8 and 9 indicate that the prolonged effects on time to graduation in 2021

[21] To certify the validity of the above interpretation, a robustness check is conducted in Section 8, where eligible students in the years 2020 and 2022 who delayed their graduation are removed from the analysis. More details will be provided in the designated section.

[22] The mean time to graduation are 59.92, 61.85 and 58.04 months for respectively the BS, HSS and SET schools.

[23] A multiple hypotheses test certifies the difference of COVID-19 effects in 2021 for the biomedical scientists compared to the remaining ones at the 1% level.

[24] A hypothesis test certifies the difference between EU and non-EU students in effects of COVID-19 on the graduation probability for the year 2021 at the 10% level.

[25] As further evidence of this statement, Table C3 (Appendix C) reports larger and significant increases in the probability of dropout among non-EU students from 2020 to 2023 compared to EU ones. A hypothesis test confirms the difference in the $COVID_2021$ coefficients between EU and non-Eu students.

[26] However, the hypothesis test does not certify the difference between men and women in 2021 (pvalue ≈ 0.12).

[27] The average age of women who graduated in our sample is 31.1 years, while the age of mothers at birth is 31 years old, on average in 2021 in Belgium (Statbel, 2021). This suggests that female PhD students are most likely not to be mothers (or only at the end of their program), implying less effect of the gender gap (Mata & Samimi, 2022).

is mainly driven by students without co-supervisor. From 2020 to 2021, the gap in graduation time is of 4.8 months compared to 2.2 for students with co-supervisor.[28] Moreover, additional findings in Appendix C2 reveal that students with a single supervisor encountered a notably reduced probability of graduation (-5%) in 2020, by examining our interaction variables. Conversely, students with more than one supervisor are not significantly affected.[29] As a result, co-supervisors seem to help the students to keep on track during the pandemic, which was already highlighted by Dohaney et al. (2020). The dropout heterogeneity analysis from Table C3 provides further evidence of this positive impact. Having co-supervisor(s) show lower dropout probability compared to the others. A multiple hypothesis test confirms the significant difference of the variables $COVID_2020$ to $COVID_2023$ between students with and without co-supervisor(s) at the 1% level of significance.

[28] Compared to the respective average time to graduation, scholars with more than one supervisor present a raise of 5.2 months in 2021 (mean time of 59.85 months) while individuals with only one supervisor increase by 4.3 months (mean time of 59.06 months).

[29] Yet, a hypothesis test does not guarantee the significant difference in graduation probability for the year 2020.

Table 3: Heterogeneity analyses in the time spent in the PhD program – Data at individual level

	Biomedical Sciences	Humanities and Social Sciences	Science, Engineering and Technology	EU students only	Non-EU students only	Women only	Men only	Students without co-supervisor	Students with co-supervisor(s)
COVID_2020	-7.567*	1.834	1.517	-1.558	0.874	-1.586	-0.410	-7.409	3.824
	(3.518)	(5.373)	(3.066)	(2.690)	(4.324)	(3.537)	(3.196)	(4.126)	(2.918)
COVID_2021	-5.609	-2.602	1.561	-1.763	-2.458	-2.933	-0.306	-2.155	-0.879
	(4.217)	(3.816)	(3.388)	(2.826)	(3.345)	(3.157)	(3.275)	(3.218)	(2.980)
COVID_2022	2.541	-5.011	-2.723	-2.062	-1.208	1.056	-3.788	-5.154	2.678
	(4.616)	(4.899)	(2.753)	(2.602)	(3.993)	(3.734)	(2.900)	(3.377)	(3.159)
COVID_2023	-5.436	7.682	8.674*	5.553	3.157	1.555	8.851*	2.143	8.672**
	(3.782)	(5.085)	(3.494)	(2.926)	(5.016)	(3.319)	(4.065)	(4.036)	(3.206)
Treatment	26.47***	11.90***	20.54***	19.47***	19.79***	22.63***	17.06***	18.20***	20.27***
	(1.246)	(1.556)	(0.911)	(0.881)	(1.345)	(0.986)	(1.034)	(1.082)	(0.956)
Treatment×COVID_2020	20.13***	15.64***	17.93***	17.72***	16.84***	19.62***	15.82***	16.17***	18.36***
	(1.408)	(1.825)	(1.060)	(0.983)	(1.469)	(1.186)	(1.140)	(1.363)	(0.983)
Treatment×COVID_2021	24.49***	17.52***	20.13***	20.41***	20.21***	21.32***	20.30***	20.95***	20.59***
	(1.384)	(1.944)	(0.937)	(1.021)	(1.323)	(1.140)	(1.071)	(1.219)	(0.978)
Treatment×COVID_2022	20.89***	12.65***	19.62***	17.89***	19.94***	19.65***	16.51***	18.33***	17.66***
	(1.342)	(2.025)	(1.012)	(0.935)	(1.482)	(1.169)	(1.094)	(1.317)	(0.990)
Treatment×COVID_2023	21.96***	16.28***	20.58***	20.10***	20.29***	22.83***	17.68***	19.30***	19.71***
	(1.362)	(1.825)	(0.944)	(0.873)	(1.340)	(1.121)	(1.002)	(1.312)	(0.918)
Time trend	1.460***	1.030***	1.115***	1.104***	1.211***	1.141***	1.118***	1.167***	1.240***
	(0.136)	(0.187)	(0.120)	(0.0989)	(0.169)	(0.114)	(0.120)	(0.138)	(0.116)
Non-EU	-3.507**	-2.604*	-4.510***			-1.036	-5.512***	-3.743***	-4.297***
	(1.119)	(1.244)	(0.572)			(0.825)	(0.626)	(0.842)	(0.615)
Female	-2.115**	-1.660	-1.766***	-3.379***	0.721			-1.086	-2.388***
	(0.702)	(1.092)	(0.514)	(0.542)	(0.761)			(0.770)	(0.507)
Shared supervision	1.655**	0.830	2.333***	1.880***	2.026***	1.849***	2.159***		
	(0.502)	(0.684)	(0.364)	(0.307)	(0.577)	(0.396)	(0.388)		
Constant	13.83***	32.70***	18.76***	22.92***	15.78***	18.24***	23.00***	24.24***	24.19***
	(2.479)	(3.458)	(2.137)	(1.772)	(3.058)	(1.987)	(2.170)	(2.295)	(1.995)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.207	0.050	0.155	0.118	0.129	0.151	0.106	0.104	0.125
N	4 942	5 431	9 168	13 988	5 577	8 665	10 900	8 344	11 221

Note: The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy indicating the graduation. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman.

8 Robustness checks

To assess the robustness of the results, seven additional analyses are performed. First, as previously discussed, two mechanisms influence graduation probability: (a) students who experienced the pandemic delayed their graduation each year from 2020 to 2023, and (b) a recovery mechanism occurred in 2021, 2022, and 2023, as these delayed students graduated in subsequent years, boosting graduation rates for those years. However, the recovery effect in 2022 was weak, as fewer students deferred graduation from 2021 to 2022 compared to the delays from 2022 to 2023, leaving room for a 4.6% drop in graduation probability. To test this interpretation, we excluded from the dataset students eligible to graduate but who deferred in 2020 and 2022, effectively removing the recovery mechanism for 2021 and 2023. Only these years were adjusted since the recovery effect in 2021 and 2023 obscures the decline in graduation probability caused by mechanism (a).

The decline in probabilities shown in column 1 of Table D1 for 2021 and 2023 supports the presence of the first mechanism and confirms the robustness of our interpretations. Additionally, column 2 presents results for the full sample with student fixed effects applied. The coefficients for the interactions between the treatment and the pandemic years align with the conclusions outlined in Section 6.[30]

Second, we change the model specifications and the type of sample in Table D2. Column 1 uses the panel data sample at the student level rather than the cross-sectional one to evaluate the time enrolled in the PhD program. The PhD length variable becomes thus continuous and increases as the scholar takes time to complete the PhD. Then, columns 2 to 5 reveal findings when using equation 2 to evaluate the robustness of all our outcome variables, again using the panel data sample. Finally, columns 6 and 7 both use the cross-section sample by respectively applying equation 2 and 1, but without scholars who keep going in 2023 (we keep students who graduate or dropout only). Overall, the tendencies depicted by the interactions terms from 2020 to 2023 are in line with those of Table 2, although the overall values are larger. For instance, column 1 indicates a 8.6-months increase in graduation time for the year 2021 compared to the mean. Findings in columns 2 and 5 are also in line with Table 2, despite the small reduction in magnitude and significance of the pandemic coefficients. The drop in time to graduation in $COVID_2020$ will be explained in the third test. Column 3 indicates that students were significantly 1.1% to 1.5% less likely to graduate in 2020-2022, which increases when focusing only on eligible students (between -4.6% and -6.1%). However, the fluctuations in graduation probability are still present in both columns 3 and 5, which aligns with Table 2 and D1. Column 4 evaluates the dropout probability and presents weaker effects of the pandemic, but align with the findings in Table B1. The smaller magnitude might be following the additional observations per year that mechanically arises when turning a cross-section sample to a panel data one, which mitigates any effects. Finally, columns 6 and 7 align with Table 2 in terms of tendencies, especially column 7 indicating stronger coefficients of interactions.

Third, 5% of the outlying observations are dropped, encompassing individuals with a PhD duration of 95 months or more. These extended PhD studies could be attributed to individuals who integrate their PhD pursuits with other responsibilities (e.g., part-time students). The results in Table D3 (Appendix 8) show the same tendencies as those raised in section 6, except in columns 1 and 2. The former indicates a larger increase in the time to graduation from 2020 to 2023, while the latter shows a larger drop in the graduation probability. These outcomes emphasize the impact of the health crisis on full-time PhD candidates. Focusing on the time to graduation (columns 1 and 4), the decrease in time for the year 2020 observed in Table 2 (-0.7 months), now turns to an increase of 6 months in column 1 and a coefficient twice as small in column 4. In other words, by removing "part-time" PhD students, we remove individuals acting as outliers on the PhD length and who took advantage of the pandemic to graduate, resulting in stronger effects for full-time PhDs.[31]

As a fourth robustness test, we focus only on research groups with at least two PhD students to ensure that our findings are not driven by research groups composed of one student, which could shift estimators when these individuals graduate, drop out, or start the curriculum. Consequently, we removed more than 35% of the supervisors' sample, and 6% of the students in the student sample. The results in Table D4 show the robustness of our earlier findings.

Next, we conduct a falsification test by considering all our models, but with dummies for the years 2017 and 2018 in place of the pandemic years. The lack of significance for those variables highlights the robustness and the accuracy of the health crisis' consequences on PhDs.

[30] The decrease in the number of observations in column 2 of Table D1 compared to Table 2 is due to the inclusion of controls. Unlike Table 2, which uses absolute values, column 2 of Table D1 presents data as the share of individuals, similar to the supervisor-level analysis, resulting in some missing values.

[31] As a further support to this statement, note that as we increase the limit of the PhD length (e.g., a maximum of 65 months) the coefficient of the first pandemic year loses significance and gets closer to zero in columns 4, while column 1 again presents larger coefficients.

Sixth, both models at the supervisor and student level are considered, but including a time dummy instead of a linear time trend. Coefficients presented in Table D6 are almost identical to those of Tables 2 and B1, which emphasizes the validity of our conclusions.

At the student level only, equation 1 is conducted by replacing the treatment with an ordered dummy for the "Phase" in which a student is observed during a certain year.[32] The Table D7 aims to highlight the differences in the effects of the pandemic depending on the student's cohort rather than specific years. One would expect that ending or starting PhDs may have been differently affected by the health crisis. Column 1 shows that, compared to Phase 1 students outside of the pandemic period, only phase 5 students increased their PhD length by 1.79 months from 2020 to 2021.[33] Although the latter fact is in line with Table 2, the difference is smaller and below the average time increase reported out of pandemic times (coefficient of 59.51 months). This issue is caused by the selection bias inherent to the cross-sectional dataset, developed in Section 4. The $COVID_2023$ is wrongly coded as it does not capture phase 5 students who neither graduate or dropout in 2023, but keep going. However, these students fall in the phase 5 dummy. In addition, the latter dummy also captures the effect of every part-time PhDs who graduated before 2020, i.e., all outliers with a very long time to graduation of the period 2010-2019. As a result, more outliers or long-term PhDs are captured by the phase 5 dummy than by the COVID-19 dummies, leading to biased results. Column 2 removes this bias by focusing only on graduate students. It reveals results more in line with Table 2. In addition, the same analysis is conducted on our panel data sample as it avoids the selection bias without removing observations. The latter findings highlight the robustness of our conclusions as the year 2021 presents a 2.5 months increase in the graduation time, which keeps on growing in 2022 and 2023. In terms of dropout probability, column 3 goes in the sense of Table B1 with an overall parallel tendency with those raised in Table B1. Finally, the graduation probability in column 4 also depicts a similar pattern to our main findings.

A last test specific to the student level analysis consists of applying equation 2 with a new outcome variable following Bostwick and Weinberg (2022). In more detail, the probability of being graduated within 5 or 6 years is evaluated using the cross-section sample in Table D8. However, we limit the sample to student cohorts that are observed at least 5 years (resp. 6 years), implying to focus on the cohorts starting the program between 2010 and 2018 (resp. 2017) to avoid any selection bias.[34] The significant drops in probability of graduating from a doctoral program within 5 or 6 years from 2020 to 2021 by respectively 4.5% and 1.9%, followed by a significant reduction of 12.4% and 25.5% in 2023 go in the sense of our findings.

Additionally, we also conduct a test specific to the supervisor level, in which we recode the $COVID_2020$ dummy to 1 in 2020 until 2023, such that the $COVID_2021$ to $COVID_2023$ dummies present an indicator for resiliency after the pandemic.[35] The results, presented in Table D9, suggest that the findings remain largely unchanged, except for the number of graduation. The estimates indicate that since the pandemic, the time to graduation was stable, but increased in 2021 and 2023 by about 3.56 and 2.42 months. Nevertheless, the results in terms of graduation number show less significance, although they retain similar magnitudes.

Finally, it is also worth noting that we implemented the Romano-Wolf (RW) multiple hypothesis correction[36] on our variables of interest to further investigate the significance of the analysis at the supervisor level. From Table D10, the closeness of the adjusted p-values with our main model confirms the significance of our findings. Since the RW correction does not fit our main models at the student level, the latter has been re-conducted with more conservative standard errors (e.g. by doctoral school and the professor's department in Table D11). Once again, the lack of difference strengthens our findings.

9 Conclusion

This paper aims to evaluate the impacts of the COVID-19 pandemic on the progress of PhD students' education. Furthermore, we investigate the influence of individual characteristics, including gender, nationality, and the pres-

[32] The "Phase" indicates in which year of the program is a student. It goes from 1 to 5, with Phase 1 capturing PhDs of less than a year and Phase 5 for researchers who are completing their 4 years of PhD or more, i.e. these are allowed to graduate.

[33] A series of t-tests confirmed that only phase 5 students present significantly different coefficients in year 2020 compared to 2021.

[34] This outcome variable is considered only as a robustness test because it limits drastically the sample (51.3% of observations are dropped) and because causality cannot be claimed under equation 2, while the lack of a treatment variable prevents us to rely on equation 1.

[35] This cannot be observed at the individual level as, when students drop out or graduate, they are not observed. This prevents us from deriving an indicator of resiliency with individual-level data.

[36] The RW multiple hypothesis correction controls for the familywise error rate (i.e., the probability of rejecting at least one hypothesis s in a set of hypotheses S) by considering the dependence among the tested p-values. This is achieved by the use of a bootstrap resampling method to gain statistical power and account for the potential correlation across each test statistic for a given level of significance (α). Unfortunately, the correction does not allow interactions between independent variables, which prevents us from applying this correction to our main identification strategy. See Clarke, Romano, and Wolf (2020) for more insights.

ence of support from a co-supervisor or peers, on these effects. To fulfill this objective, we utilized a methodology grounded in a Difference-in-Differences model and supervisor fixed effect regressions to probe into the causal relationships between the health crisis and the duration of time spent in a doctoral program, as well as the likelihood of graduation. We relied on the universe of 19,565 doctoral candidates from a large comprehensive European university ranked in the top 50.

Compared with previous years, the progress of doctoral students has slowed down overall among those who have experienced the pandemic, regardless of the phase of their doctorate during which they experienced it. As a result, we observe long-lasting impact of the health crisis until 2023. More specifically, two mechanisms emerge: (a) scholars who experienced the health crisis delayed their graduation in 2020 to 2023. (b) as a consequence of (a), a recovery mechanism occurs during the years 2021 to 2023. Students who deferred their graduation in 2020 (resp. 2021 or 2022), graduated a year later in 2021 (resp. 2022 or 2023), which increased the graduation probability for those year. Yet, mechanism (a) is still at work in 2021 (resp. 2022 or 2023), implying a decrease in the graduation probability. Altogether, it reflects a drop in graduation probability by 3.5% in 2020, leading to more graduations and a longer time to graduation of 2 months in 2021. Similarly, graduations were delayed in 2022 with a fall of 4.6%, but they came back in 2023 with an average longer time to graduation of 1.4 months. Additionally, we observe an 18.5% decline in the number of students discontinuing their scholarships before rebounding in the following years, which translates to a 3.6% increase in individuals' dropout probability from 2020 to 2021 and 8.2% (resp. 4.4%) from 2020 to 2022 (resp. 2023). We argued that the university closure of 2020 gave more time to professors to prepare research proposals and slowed down the hiring growth of new PhD students, which allowed them to save funding during this year. These two phenomena resulted in a 19% increase in the number of new PhD students in 2021. Overall, the post-crisis situation appears to still suffer from the consequences of the COVID-19 pandemic, although its effects have become smaller. A back-of-the-envelope calculation indicates that the HR-related cost of the pandemic due to study delay amounts to about 4.23m €.[37] Our heterogeneity analysis reveals that the effects were mainly driven by PhD students in the field of biomedical sciences. For these students, the time to graduation increased by almost 4 months more compared to the remaining schools.

The examination of an extreme event like the COVID-19 pandemic highlights the critical importance of in-person research and education for doctoral scholars, as well as the long-lasting effects of the crisis, which are still evident. Given the central role of PhD students in academia and research, our findings offer valuable insights into the doctoral process, both for the present and in preparing for future challenges the world may face.

Our findings align with previous qualitative research, particularly in regard to the impact of the health crisis and the influence of peer effects (Aydemir & Ulusu, 2020; Bloom et al., 2020; Börgeson et al., 2021; Dohaney et al., 2020; Myers et al., 2020). However, we observe that students born outside the EU are likely to finish their program 4 up to more than 7 months sooner compared to other students during non-pandemic times, which is a new pattern. During the COVID-19 pandemic, it appears that non-EU students have experienced greater challenges compared to their EU counterparts. Contrary to previous literature, our analysis did not uncover evidence of an increasing gender gap as a result of the health crisis (Corbera et al., 2020; Cui et al., 2022; Mata & Samimi, 2022; Minello, 2020; Rodrigues et al., 2021).

This paper presents several avenues for further research. First, in this study, we gauge the progress of PhD students by examining their time to graduation, as well as the number of completed, discontinued, and initiated PhDs. While we acknowledge that PhD progress is not solely indicated by these factors, future research could explore the quality as well as the number of (withdrawn) publications as an additional proxy. Secondly, while providing insights into the gender gap among PhD students, further research should delve more profoundly into this aspect. The literature predicted an added value of having a co-supervisor on top of the main supervisor. Our findings revealed mixed evidence of the co-supervisor influence since it seems to slow down the PhD progress, but it reduces the dropout probability and helps to improve the graduation probability. Still, nothing is known about the mental health of the students during the lockdown and the potential positive link with the support of a (co-) supervisor suggested by Börgeson et al. (2021) and Dohaney et al. (2020). Therefore, further research could evaluate the link between the presence of a co-supervisor and mental health in times of crisis. Finally, in contrast with full-time students, our investigations indicate that the research productivity of "long term" or "part-time" PhD students increased during the first wave of the pandemic in 2020. Nonetheless, we did not manage to test and confirm this pattern, which could be also a subject for further studies.

[37] This corresponds to the sum of 475 PhD students who are delayed from 2020 to 2021 by 2.01 months, 483 from 2021 to 2022 without any effects on the time to graduation and 617 from 2022 to 2023 by 1.44 months of increase. Assuming a monthly gross wage of 2 298€, the calculation becomes (2.01*475*2298)+(0)+(1,44*617*2298) ≈ 4,233,000.

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A Graphical analyses

Figure A.1: Total number of supervisors

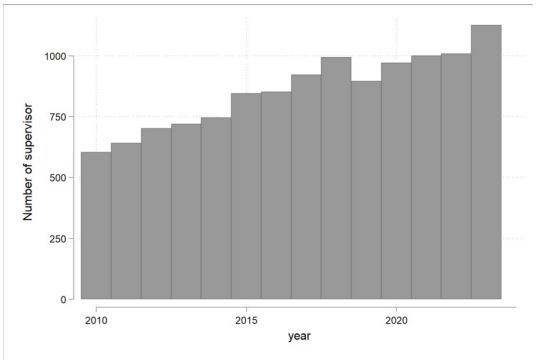


Figure A.2: Total number of students

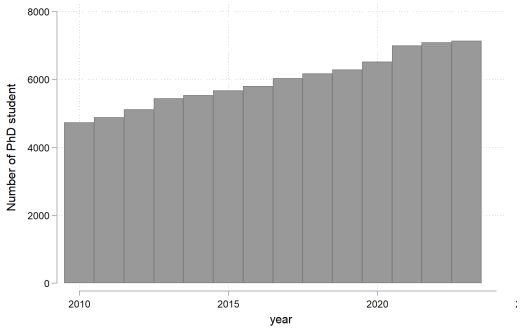


Figure A.3: Graduated PhDs

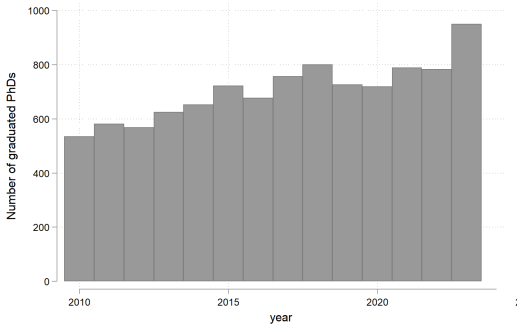


Figure A.4: Dropped out PhDs

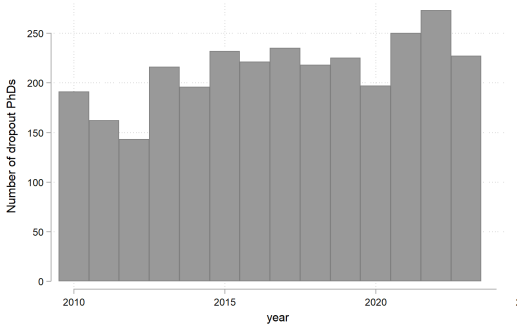


Figure A.5: Newly started PhDs

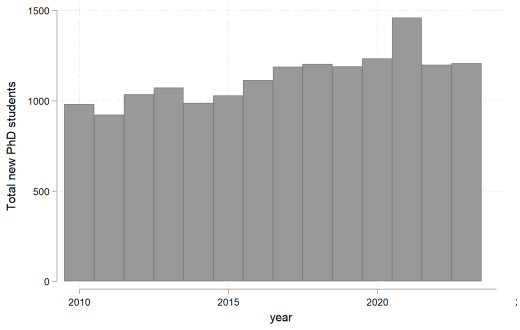


Figure A.6: Average time to graduation

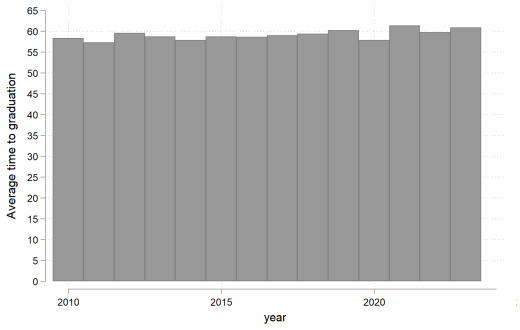


Figure A.7: Average time by research field

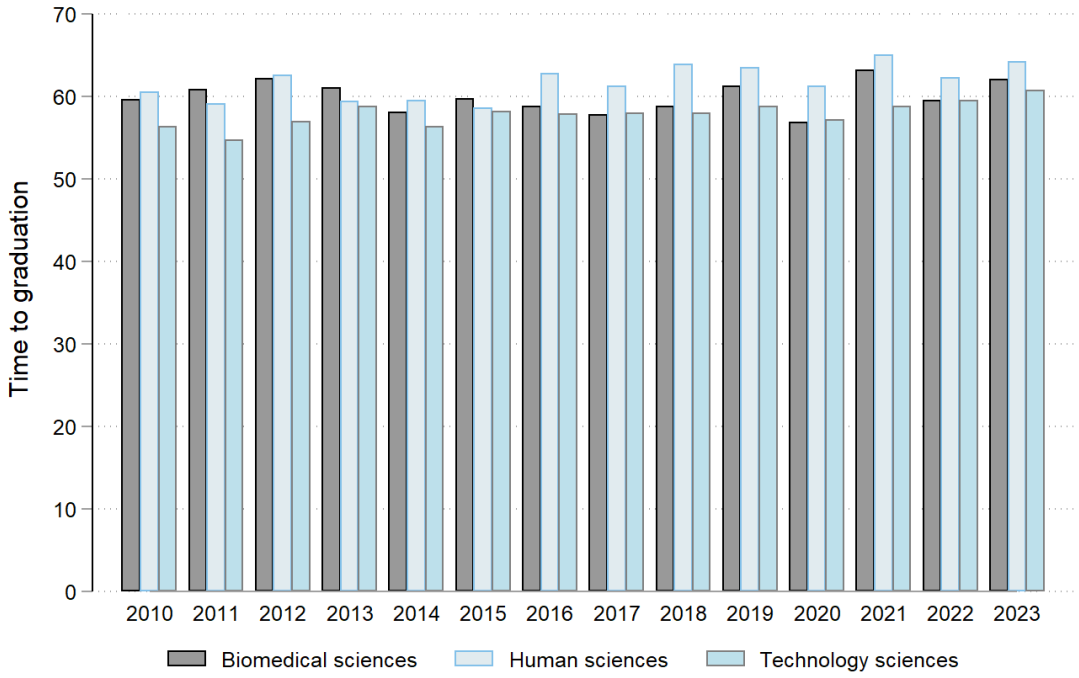


Figure A.8: Yearly average number of initiated PhDs by seniority of supervisor

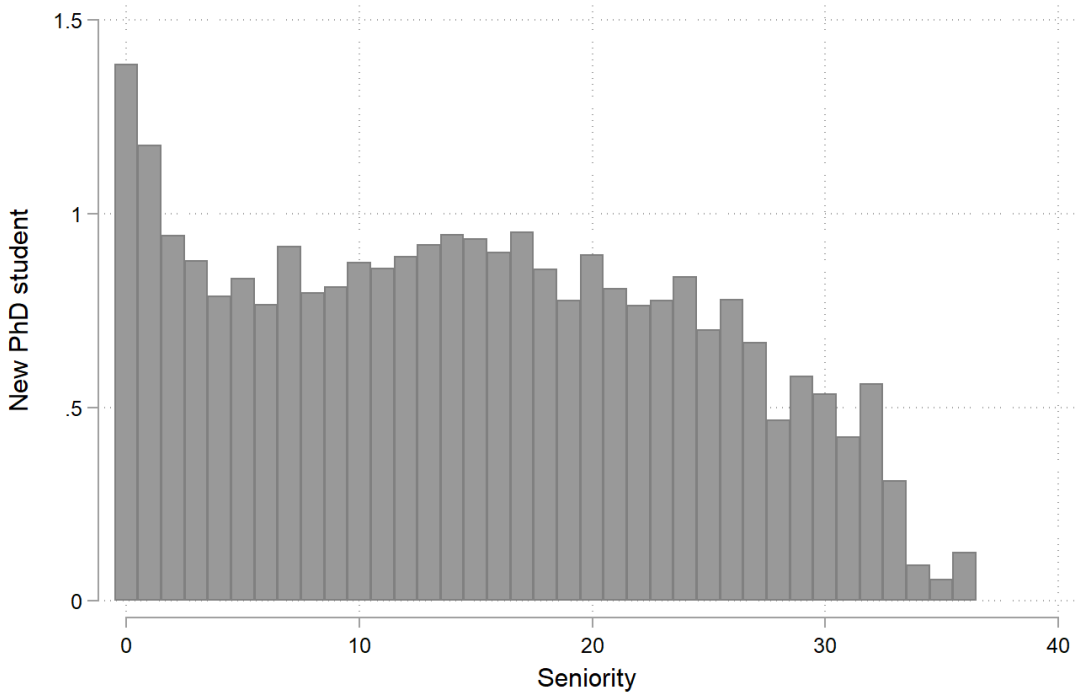


Figure A.9: Share of graduated PhDs by EU citizenship

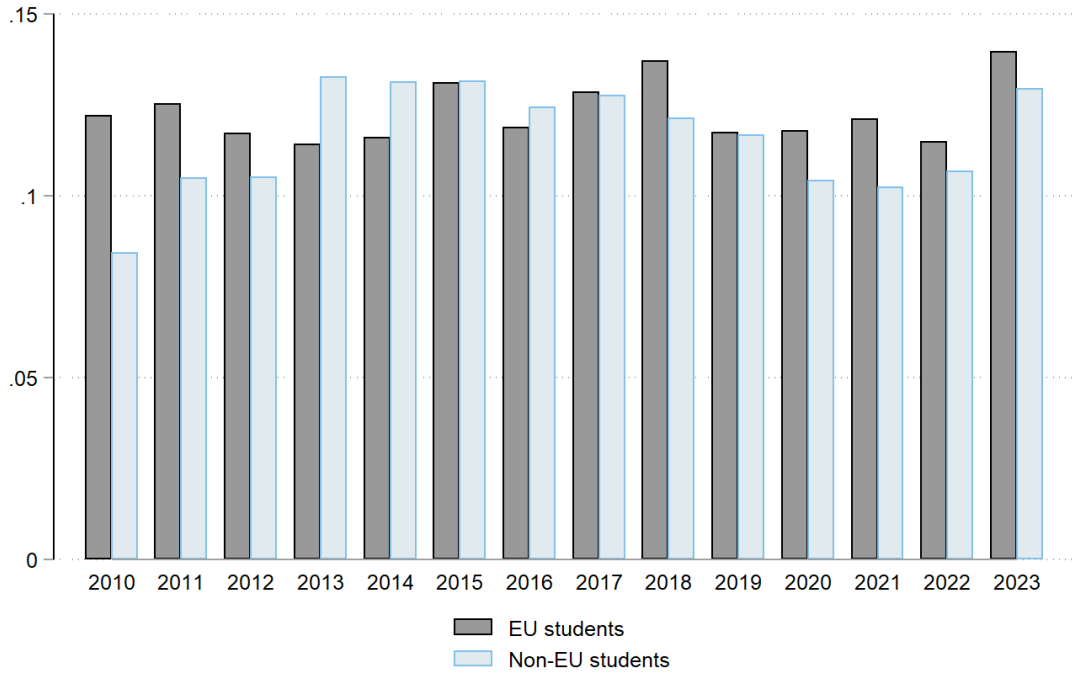


Figure A.10: Share of discontinued PhDs by EU citizenship

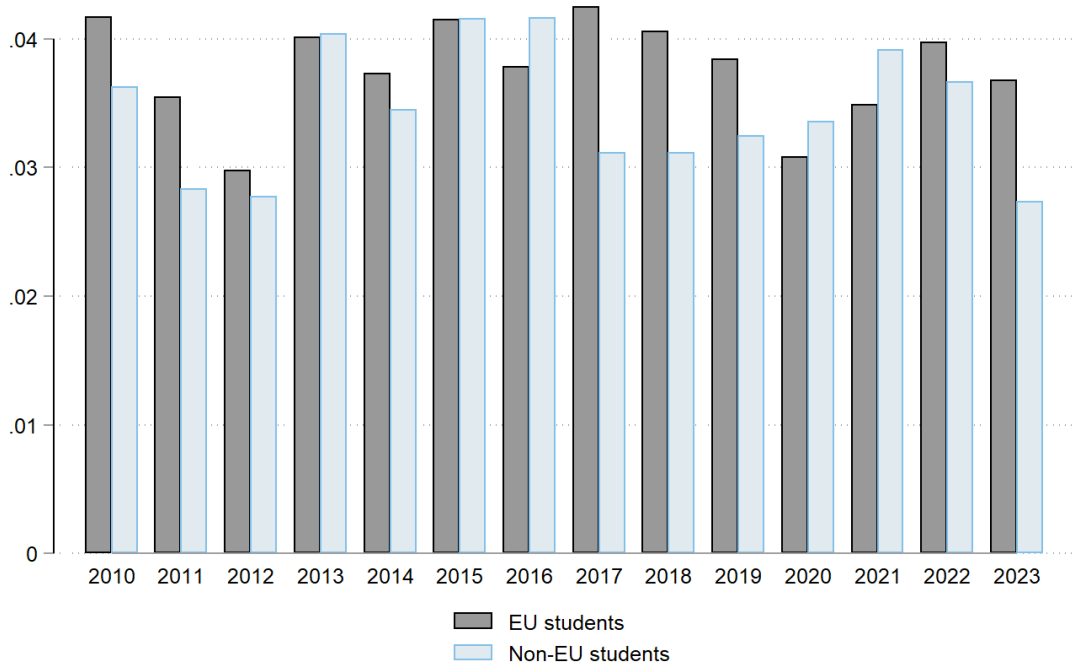


Figure A.11: Share of graduated PhDs by the number of supervisors

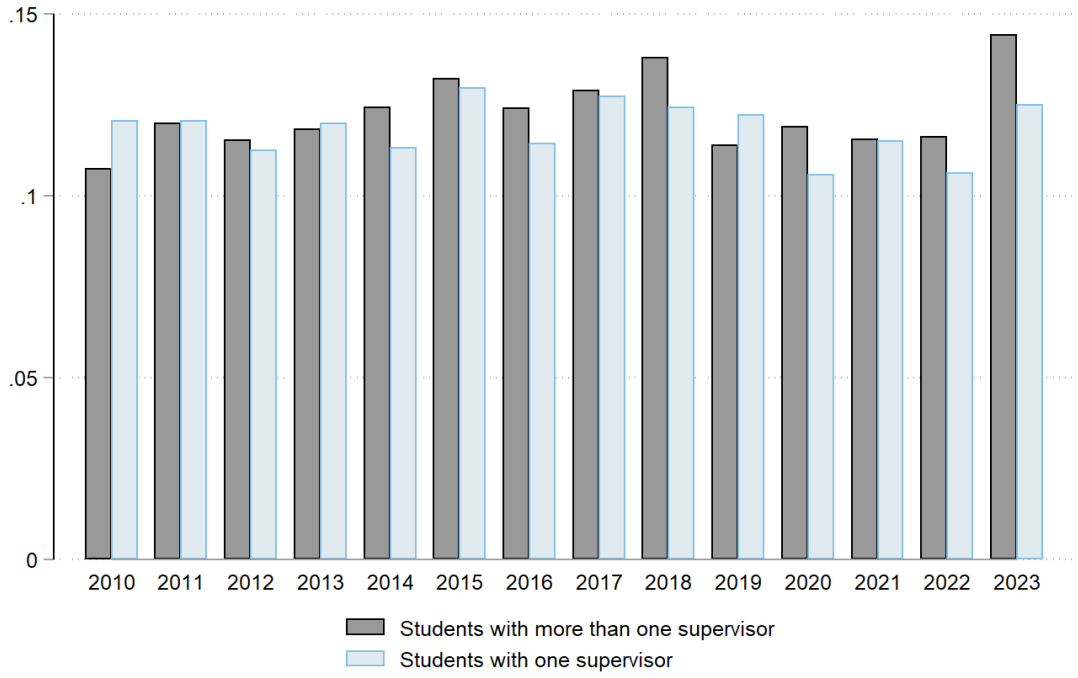
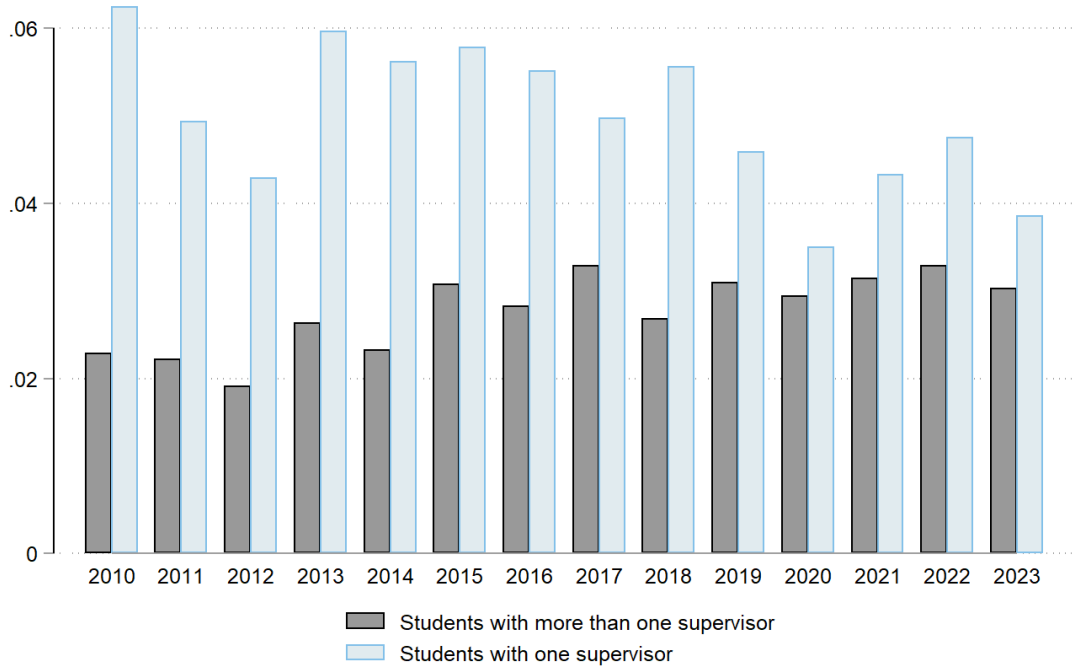


Figure A.12: Share of discontinued PhDsby having a co-supervisor



B Main results - Data aggregated at supervisor level

Table B1: Main results

	Panel A. Data aggregated at supervisor level				Panel B. Data at student level
	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD	Dropped out PhD
COVID_2020	-1.073	-0.0412	-0.0282*	0.0322	0.124***
	(0.841)	(0.0233)	(0.0123)	(0.0301)	(0.0135)
COVID_2021	2.487*	-0.00731	0.00204	0.163***	0.160***
	(0.990)	(0.0273)	(0.0138)	(0.0333)	(0.0132)
COVID_2022	0.692	-0.0156	0.0188	-0.00198	0.206***
	(0.976)	(0.0291)	(0.0158)	(0.0353)	(0.0141)
COVID_2023	1.347	0.104**	-0.00634	0.0295	0.168***
	(0.989)	(0.0328)	(0.0160)	(0.0378)	(0.0121)
Time trend	0.503***	0.0277***	0.00401**	-0.0408***	-0.0238***
	(0.0942)	(0.00306)	(0.00148)	(0.00349)	(0.000862)
Non-EU	-1.769**	-0.0450	-0.0451**	0.149***	-0.00504
	(0.677)	(0.0334)	(0.0168)	(0.0452)	(0.00671)
Female	-0.00186	-0.0392	0.0292*	0.0640*	0.0112
	(0.666)	(0.0245)	(0.0123)	(0.0304)	(0.00607)
Shared supervision	0.544	-0.0254***	-0.00821***	-0.0321***	-0.0459***
	(0.573)	(0.00104)	(0.000445)	(0.00138)	(0.00357)
Constant	51.53***	0.443***	0.181***	1.538***	0.560***
	(1.268)	(0.0358)	(0.0172)	(0.0423)	(0.0145)
Supervisor fixed effects	✓	✓	✓	✓	✓
Adjusted within R2	0.028	0.060	0.016	0.054 0.076	
N	6 484	18 424	18 424	18 424	19 565

Note: The above results are based on equation 2. Columns 1 to 4 use data aggregated at the supervisor level, while column 5 is from the cross-sectional data structure of the PhD student level. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at supervisor level. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'Shared supervision' stands for the share of students that are guided by more than one supervisor.

C Heterogeneity analyses - Further results

Table C1: Heterogeneity analyses in time to graduation by doctoral school - Supervisor level

	Biomedical Sciences	Humanity and Social Sciences	Sciences, Engineering and Technology
COVID_2020	-2.112	-1.851	0.0592
	(1.458)	(2.196)	(1.015)
COVID_2021	5.284**	1.268	1.592
	(1.955)	(2.264)	(1.168)
COVID_2022	1.767	-2.395	1.996
	(1.592)	(2.438)	(1.233)
COVID_2023	2.539	0.557	1.254
	(1.695)	(2.407)	(1.223)
Time trend	0.230	0.786***	0.503***
	(0.174)	(0.212)	(0.119)
Non-EU	-4.218**	1.067	-2.274**
	(1.445)	(1.695)	(0.753)
Female	-2.676**	1.685	0.700
	(0.966)	(1.623)	(0.747)
Shared supervision	2.456*	-2.053	1.537*
	(1.102)	(1.186)	(0.741)
Constant	56.33***	49.13***	49.09***
	(2.334)	(2.837)	(1.639)
Supervisor fixed effects	✓	✓	✓
Adjusted within R2	0.044	0.025	0.041
N	1 902	1 919	2 653

Note: The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at supervisor level. The variable 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor.

Table C2: Heterogeneity analyses in diploma attainment - Student level

	EU students only	NonEU students only	Women only	Men only	Student with co-supervisor(s)	Student without co-supervisor
COVID_2020	0.00290	-0.00663	0.00210	-0.00177	-0.000265	0.00199
	(0.00437)	(0.00680)	(0.00507)	(0.00495)	(0.00414)	(0.00644)
COVID_2021	-0.00808	-0.0139	-0.00674	-0.0126*	-0.00815	-0.00818
	(0.00416)	(0.00816)	(0.00540)	(0.00524)	(0.00453)	(0.00673)
COVID_2022	-0.00408	-0.0154	-0.00729	-0.00872	-0.00440	-0.00854
	(0.00475)	(0.00830)	(0.00609)	(0.00589)	(0.00548)	(0.00703)
COVID_2023	-0.00242	-0.0139	-0.00971	-0.00297	-0.00464	-0.00408
	(0.00565)	(0.00964)	(0.00677)	(0.00673)	(0.00612)	(0.00831)
Treatment	0.336***	0.336***	0.350***	0.326***	0.352***	0.312***
	(0.00582)	(0.00909)	(0.00717)	(0.00649)	(0.00617)	(0.00795)
Treatment×COVID_2020	-0.0311*	-0.0430	-0.0380*	-0.0310*	-0.0248	-0.0540**
	(0.0127)	(0.0222)	(0.0167)	(0.0151)	(0.0146)	(0.0174)
Treatment×COVID_2021	-0.00636	-0.0448*	-0.0248	-0.0105	-0.0249	-0.0117
	(0.0124)	(0.0199)	(0.0157)	(0.0141)	(0.0134)	(0.0178)
Treatment×COVID_2022	-0.0442***	-0.0521**	-0.0394**	-0.0488***	-0.0539***	-0.0396*
	(0.0118)	(0.0196)	(0.0150)	(0.0131)	(0.0125)	(0.0161)
Treatment×COVID_2023	0.00265	-0.00297	-0.00788	0.00964	-0.00328	0.00442
	(0.0121)	(0.0193)	(0.0154)	(0.0140)	(0.0132)	(0.0168)
Time trend	0.000205	0.00157	0.000990	0.000436	0.000226	0.000870
	(0.000563)	(0.001000)	(0.000719)	(0.000655)	(0.000624)	(0.000827)
Research group size	0.00117	0.00187*	0.00253**	0.000768	0.00144	0.00262***
	(0.000668)	(0.000903)	(0.000918)	(0.000628)	(0.000908)	(0.000714)
Non-EU			-0.0139**	0.0159***	0.00991**	0.00167
			(0.00460)	(0.00361)	(0.00362)	(0.00446)
Female	0.0108***	-0.0184***			0.00342	-0.00249
	(0.00285)	(0.00445)			(0.00300)	(0.00400)
Shared supervision	-0.00494**	-0.000540	-0.00367	-0.00407		
	(0.00164)	(0.00296)	(0.00225)	(0.00210)		
Peer effect among EU students	0.0389***					
	(0.00856)					
Peer effect among non-EU students		0.0577***				
		(0.0169)				
Peer effect among women			0.0241*			
			(0.0109)			
Peer effect among men				0.0667***		
				(0.0107)		
Constant	-0.0134	-0.0219	-0.0149	-0.0217*	-0.00253	-0.00949
	(0.00943)	(0.0158)	(0.0108)	(0.0108)	(0.0109)	(0.0112)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.205	0.188	0.218	0.189	0.220	0.170
N	61 562	23 532	37 091	48 003	50 698	34 396

Note: The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy indicating the eligibility for graduation. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman.

Table C3: Heterogeneity analyses in dropout - Student level

	EU students only	Non-EU students only	Women only	Men only	Students without co-supervisor	Students with co-supervisor(s)
COVID_2020	0.113***	0.135***	0.118***	0.128***	0.105***	0.130***
	(0.0161)	(0.0293)	(0.0212)	(0.0182)	(0.0238)	(0.0176)
COVID_2021	0.133***	0.208***	0.147***	0.160***	0.170***	0.147***
	(0.0157)	(0.0295)	(0.0198)	(0.0186)	(0.0229)	(0.0171)
COVID_2022	0.194***	0.203***	0.176***	0.217***	0.237***	0.176***
	(0.0170)	(0.0264)	(0.0211)	(0.0195)	(0.0245)	(0.0178)
COVID_2023	0.169***	0.174***	0.169***	0.151***	0.208***	0.129***
	(0.0147)	(0.0228)	(0.0191)	(0.0163)	(0.0202)	(0.0152)
Time trend	-0.0228***	-0.0256***	-0.0250***	-0.0222***	-0.0307***	-0.0184***
	(0.000976)	(0.00171)	(0.00128)	(0.00112)	(0.00152)	(0.00102)
Non-EU			-0.00667	0.00122	-0.00333	-0.00619
			(0.0101)	(0.00923)	(0.0106)	(0.00818)
Female	0.0144*	-0.0000301			0.0114	0.00887
	(0.00716)	(0.0119)			(0.0100)	(0.00773)
Research group size	-0.0471***	-0.0420***	-0.0477***	-0.0431***		
	(0.00427)	(0.00750)	(0.00583)	(0.00476)		
Constant	0.552***	0.569***	0.587***	0.536***	0.624***	0.369***
	(0.0167)	(0.0300)	(0.0203)	(0.0195)	(0.0226)	(0.0152)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.069	0.087	0.079	0.069	0.085	0.051
N	13 988	5 577	8 665	10 900	8 344	11 221

Note: The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman.

D Robustness checks

Table D1: Panel data sample - Student level

	Diploma attainment	Diploma attainment
Treatment	0.341***	0.257***
	(0.00550)	(0.00692)
COVID_2020	-0.0105*	-0.00418
	(0.00411)	(0.00435)
COVID_2021	-0.0226***	-0.0175**
	(0.00433)	(0.00612)
COVID_2022	-0.0242***	-0.0344***
	(0.00465)	(0.00763)
COVID_2023	-0.0226***	-0.0605***
	(0.00553)	(0.00987)
Treatment×COVID_2020	0.0815***	-0.0538***
	(0.0138)	(0.0121)
Treatment×COVID_2021	-0.174***	-0.0362**
	(0.0102)	(0.0122)
Treatment×COVID_2022	0.0425***	-0.0450***
	(0.0115)	(0.0119)
Treatment×COVID_2023	-0.206***	0.0292*
	(0.00952)	(0.0129)
Time trend	0.00191***	0.0473***
	(0.000537)	(0.00175)
Research group size	0.00223**	0.00156
	(0.000752)	(0.00130)
Non-EU	0.00639*	0.0163
	(0.00301)	(0.0155)
Female	0.00178	-0.0237
	(0.00243)	(0.0133)
Shared supervision	-0.00395*	0.000617
	(0.00161)	(0.000612)
Constant	-0.0119	-0.291***
	(0.0103)	(0.0197)
Supervisor fixed effects	✓	×
Student fixed effects	×	✓
Adjusted within R2	0.207	0.2778
N	77 557	83 327

Note: This table presents our main analyses of the graduation probability from equation 1, but with a limited sample in column 1 and a student fixed in column 2. In the first column, students who were eligible to graduate but did not in 2020 and 2022 are removed, so that the recovery mechanism at work in 2021 and 2023 disappears. The purpose is to test the robustness of the interpretation of our results presented in Section 6. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor, while the student fixed effects control for observed and unobserved heterogeneity at the level of the student. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy indicating the eligibility for graduation. The 'shared supervision' captures the number of supervisors guiding the students, Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman.

Table D2: Various OLS FE model - Student level

	Panel data sample					Cross-section data sample	
	Time spent in the PhD program	Time to graduation	Diploma attainment	Dropped out PhD	Diploma attainment (eligible students only)	Time spent in the PhD program	Time spent in the PhD program (ended PhD only)
COVID_2020	2.081***	-1.596*	-0.0131**	-0.00946***	-0.0456***	6.878***	0.739
	(0.391)	(0.733)	(0.00497)	(0.00282)	(0.0122)	(0.820)	(2.404)
COVID_2021	3.019***	1.968*	-0.0114*	-0.00679*	-0.0376**	10.09***	0.513
	(0.500)	(0.869)	(0.00552)	(0.00293)	(0.0130)	(0.805)	(2.609)
COVID_2022	5.526***	0.702	-0.0153*	-0.00519	-0.0613***	9.206***	-0.428
	(0.596)	(0.891)	(0.00608)	(0.00337)	(0.0143)	(0.865)	(2.642)
COVID_2023	7.452***	1.611	0.00773	-0.0112**	-0.00203	14.61***	7.073*
	(0.695)	(0.908)	(0.00654)	(0.00350)	(0.0152)	(0.788)	(3.000)
Treatment	28.12***						19.20***
	(0.288)						(0.928)
Treatment×COVID_2020	24.58***						17.45***
	(0.661)						(1.194)
Treatment×COVID_2021	27.04***						20.66***
	(0.668)						(1.307)
Treatment×COVID_2022	24.97***						19.10***
	(0.779)						(1.318)
Treatment×COVID_2023	25.76***						19.90***
	(0.824)						(1.375)
Research group size	-0.508***	-0.288**	0.000606	0.000778*	0.00421*		
	(0.102)	(0.0882)	(0.000618)	(0.000322)	(0.00175)		
Non-EU	-3.484***	-3.258***	-0.0132***	-0.00523**	0.00583	-3.849***	-3.800***
	(0.516)	(0.498)	(0.00233)	(0.00179)	(0.00765)	(0.525)	(0.549)
Female	-1.494**	-0.00671	-0.00344	0.00375*	0.0128	-2.352***	-1.923***
	(0.464)	(0.442)	(0.00200)	(0.00164)	(0.00666)	(0.448)	(0.472)
Shared supervision	0.232	0.686*	-0.00193	-0.0155***	0.00216	3.016***	1.518***
	(0.290)	(0.271)	(0.00138)	(0.000958)	(0.00417)	(0.290)	(0.294)
Time trend	1.739***	0.596***	0.00778***	0.00181***	0.00200	-0.201*	1.012***
	(0.0863)	(0.0896)	(0.000582)	(0.000308)	(0.00143)	(0.0828)	(0.107)
Constant	12.97***	52.06***	0.0205*	0.0365***	0.258***	48.04***	23.77***
	(1.497)	(1.694)	(0.00884)	(0.00457)	(0.0309)	(1.304)	(1.677)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.194	0.0343	0.0062	0.00432	0.00214	0.04241	0.149
N	85 094	10 308	85 094	85 094	26 718	19 565	13 434

Note: Column 1 uses the panel data sample rather than the cross-sectional one to evaluate the time enrolled in the PhD program. Columns 2 to 5 reveal findings when using equation 2 to evaluate the robustness of all our outcome variables, using still the panel data sample. Finally, columns 6 and 7 both use the cross-section sample by respectively applying equation 2 and 1, but without scholars who keep going in 2023 (we keep students who graduate or dropout only). The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in columns 1 and 7. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman. The'research group size' captures the number of PhD scholars within the research group.

Table D3: Main results - Top 5% deleted

	Data at individual level			Data aggregated at supervisor level			
	Time spent in the PhD program	Diploma attainment	Dropped out PhD	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
COVID_2020	0.371	-0.00476	0.118***	-0.673	-0.0313	-0.0158	0.0121
	(1.851)	(0.00350)	(0.0137)	(0.636)	(0.0247)	(0.0128)	(0.0319)
COVID_2021	-5.781***	-0.0148***	0.150***	1.405*	-0.0163	-0.0000395	0.133***
	(1.498)	(0.00379)	(0.0135)	(0.676)	(0.0284)	(0.0139)	(0.0353)
COVID_2022	-6.248***	-0.0141***	0.196***	1.057	-0.0217	0.0207	-0.0404
	(1.284)	(0.00407)	(0.0142)	(0.763)	(0.0304)	(0.0159)	(0.0375)
COVID_2023	-0.568	-0.0127**	0.156***	1.577*	0.0926**	0.00298	-0.0251
	(1.645)	(0.00487)	(0.0124)	(0.762)	(0.0342)	(0.0166)	(0.0398)
Treatment	23.82***	0.415***					
	(0.489)	(0.00472)					
Treatment×COVID_2020	21.60***	-0.0439**					
	(0.594)	(0.0140)					
Treatment×COVID_2021	23.18***	-0.0539***					
	(0.537)	(0.0126)					
Treatment×COVID_2022	22.05***	-0.0963***					
	(0.554)	(0.0114)					
Treatment×.COVID_2023	22.96***	-0.0615***					
	(0.522)	(0.0117)					
Time trend	0.797***	0.00207***	-0.0240***	0.353***	0.0292***	0.00163	-0.0294***
	(0.0575)	(0.000500)	(0.000884)	(0.0714)	(0.00330)	(0.00154)	(0.00363)
Research group size		0.000847					
		(0.000637)					
Non-EU	-2.312***	0.00425	-0.00161	-1.557***	-0.0563	-0.0323	0.161***
	(0.328)	(0.00249)	(0.00688)	(0.458)	(0.0343)	(0.0175)	(0.0472)
Female	-0.982***	-0.00162	0.0147*	0.966*	-0.0437	0.0299*	0.0714*
	(0.283)	(0.00203)	(0.00624)	(0.428)	(0.0252)	(0.0127)	(0.0309)
Shared supervision	1.815***	-0.00450***	-0.0450***	0.899	-0.0246***	-0.00816***	-0.0322***
	(0.193)	(0.00131)	(0.00364)	(0.460)	(0.00113)	(0.000477)	(0.00149)
Constant	20.17***	0.00352	0.546***	50.89***	0.435***	0.193***	1.399***
	(1.015)	(0.00832)	(0.0145)	(0.969)	(0.0372)	(0.0175)	(0.0417)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.292	0.256	0.076	0.0328	0.0579	0.0153	0.0471
N	18 531	76 133	18 531	5 863	16 551	16 551	16 551

Note: The table presents our main results at both the student and the supervisor level from equation 1 and 2, but with a restricted sample where the top 5% of the distribution of the time to graduation are removed. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor. In the estimations at individual level, these variables correspond to individual characteristics of the PhD student. As a result, 'shared supervision' captures the number of supervisors guiding the student. The'research group size' captures the number of PhD scholars within the research group.

Table D4: Main results – Focus on research groups with at least two students

	Data at individual level			Data aggregated at supervisor level			
	Time spent in the PhD	Diploma attainment	Dropped out PhD	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
COVID_2020	-0.820	-0.00100	0.124***	-1.080	-0.0712*	-0.0259	0.0200
	(2.359)	(0.00365)	(0.0141)	(0.864)	(0.0296)	(0.0156)	(0.0384)
COVID_2021	-1.811	-0.00845*	0.159***	2.361*	-0.0168	0.0122	0.195***
	(2.298)	(0.00404)	(0.0134)	(1.022)	(0.0347)	(0.0175)	(0.0426)
COVID_2022	-2.596	-0.00693	0.209***	0.487	-0.0294	0.0350	0.0121
	(2.218)	(0.00440)	(0.0145)	(1.012)	(0.0368)	(0.0200)	(0.0449)
COVID_2023	4.935	-0.00338	0.165***	1.354	0.145***	-0.00243	0.0526
	(2.538)	(0.00530)	(0.0124)	(1.013)	(0.0415)	(0.0200)	(0.0478)
Treatment	19.37***	0.329***					
	(0.744)	(0.00560)					
Treatment×COVID_2020	17.82***	-0.0355**					
	(0.805)	(0.0116)					
Treatment×COVID_2021	20.22***	-0.0165					
	(0.782)	(0.0110)					
Treatment×COVID_2022	18.02***	-0.0479***					
	(0.811)	(0.0101)					
Treatment×COVID_2023	19.79***	0.000760					
	(0.748)	(0.0109)					
Time trend	1.139***	0.000290	-0.0236***	0.541***	0.0302***	0.00358*	-0.0435***
	(0.0897)	(0.000515)	(0.000888)	(0.0972)	(0.00367)	(0.00178)	(0.00422)
Research group size		0.00194**					
		(0.000721)					
Non-EU	-3.772***	0.00553*	-0.00402	-1.833**	-0.0524	-0.0524*	0.174**
	(0.509)	(0.00281)	(0.00678)	(0.702)	(0.0430)	(0.0210)	(0.0582)
Female	-1.903***	0.000827	0.00999	-0.0721	-0.0395	0.0187	0.0748
	(0.433)	(0.00231)	(0.00618)	(0.699)	(0.0344)	(0.0168)	(0.0436)
Shared supervision	1.920***	-0.00338*	-0.0460***	0.496	-0.0260***	-0.00816***	-0.0330***
	(0.284)	(0.00152)	(0.00365)	(0.590)	(0.00113)	(0.000472)	(0.00153)
Constant	21.60***	0.00548	0.558***	51.17***	0.551***	0.227***	1.784***
	(1.624)	(0.0100)	(0.0150)	(1.324)	(0.0455)	(0.0217)	(0.0536)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.121	0.195	0.074	0.0301	0.063	0.0162	0.055
N	18 474	80 112	18 474	5 737	13 663	13 663	13 663

Note: The table presents our main results at both the student and the supervisor level from equation 1 and 2, but with a sample focusing on research group with more than 2 PhD researchers. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor. In the estimations at individual level, these variables correspond to individual characteristics of the PhD student. As a result, 'shared supervision' captures the number of supervisors guiding the student. The'research group size' captures the number of PhD scholars within the research group.

Table D5: Main results - Falsification test

	Data at individual level			Data aggregated at supervisor level			
	Time spent in the PhD	Diploma attainment	Dropped out PhD	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
2017	0.250	0.00199	0.0465***	-0.588	0.00718	0.00711	0.00754
	(2.458)	(0.00300)	(0.0138)	(0.713)	(0.0213)	(0.0119)	(0.0270)
2018	7.659**	0.000104	0.0445***	-1.139	0.0245	-0.0103	-0.000715
	(2.584)	(0.00277)	(0.0132)	(0.746)	(0.0220)	(0.0109)	(0.0249)
Treatment	19.65***	0.319***					
	(0.546)	(0.00492)					
Treatment×2017	18.88***	0.0345**					
	(0.813)	(0.0113)					
Treatment×2018	18.94***	0.00742					
	(0.803)	(0.0105)					
Time trend	1.162***	-0.00113***	-0.0171***	0.607***	0.0297***	0.00396***	-0.0361***
	(0.0705)	(0.000335)	(0.000856)	(0.0604)	(0.00202)	(0.000949)	(0.00248)
Research group size		0.00219**					
		(0.000731)					
Non-EU	-3.775***	0.00547*	-0.00757	-1.793**	-0.0419	-0.0446**	0.150***
	(0.501)	(0.00277)	(0.00686)	(0.683)	(0.0335)	(0.0168)	(0.0453)
Female	-1.914***	0.000879	0.0103	0.0185	-0.0364	0.0293*	0.0652*
	(0.426)	(0.00228)	(0.00624)	(0.664)	(0.0246)	(0.0123)	(0.0304)
Shared supervision	1.921***	-0.00378*	-0.0450***	0.528	-0.0254***	-0.00824***	-0.0321***
	(0.276)	(0.00149)	(0.00358)	(0.573)	(0.00104)	(0.000446)	(0.00139)
Constant	21.21***	0.0218**	0.492***	50.43***	0.418***	0.181***	1.499***
	(1.291)	(0.00807)	(0.0146)	(0.962)	(0.0295)	(0.0139)	(0.0370)
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.121	0.194	0.044	0.025	0.0583	0.016	0.0525
N	19 565	85 094	19 565	6 484	18 424	18 424	18 424

Note: The table presents our main results at both the student and the supervisor level from equation 1 and 2, but with the COVID-19 dummies replaced by two dummies for the two years preceding the health crisis. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor. In the estimations at individual level, these variables correspond to individual characteristics of the PhD student. As a result, 'shared supervision' captures the number of supervisors guiding the student. The'research group size' captures the number of PhD scholars within the research group.

Table D6: Main results - Time dummy indicator

	Data at individual level			Data aggregated at supervisor level			
	Time spent in the PhD	Diploma attainment	Dropped out PhD	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
COVID_2020	-0.525	0.00709	0.118***	-1.215	-0.0777***	-0.0299*	0.0474
	(2.256)	(0.00533)	(0.0135)	(0.832)	(0.0230)	(0.0124)	(0.0300)
COVID_2021	-0.950	-0.00196	0.151***	2.098*	-0.0552*	-0.00188	0.181***
	(2.202)	(0.00523)	(0.0129)	(1.000)	(0.0267)	(0.0138)	(0.0332)
COVID_2022	-1.867	0.000513	0.198***	0.117	-0.0687*	0.0119	0.0394
	(2.139)	(0.00547)	(0.0137)	(0.993)	(0.0281)	(0.0158)	(0.0354)
COVID_2023	4.610	0.00323	0.173***	0.625	0.0333	-0.0141	0.0854*
	(2.421)	(0.00572)	(0.0121)	(0.996)	(0.0319)	(0.0160)	(0.0376)
Treatment	18.48***	0.330***					
	(0.726)	(0.00537)					
Treatment×COVID_2020	17.31***	-0.0347**					
	(0.805)	(0.0112)					
Treatment×COVID_2021	20.22***	-0.0176					
	(0.771)	(0.0106)					
Treatment×COVID_2022	17.95***	-0.0459***					
	(0.792)	(0.00982)					
Treatment×COVID_2023	19.43***	-0.0000272					
	(0.749)	(0.0105)					
Research group size		0.00207**					
		(0.000735)					
Non-EU	-3.720***	0.00546*	-0.00513	-1.760**	-0.0300	-0.0432*	0.148**
	(0.493)	(0.00277)	(0.00652)	(0.678)	(0.0314)	(0.0168)	(0.0471)
Female	-1.826***	0.000859	0.00912	-0.00635	-0.0398	0.0301*	0.0521
	(0.416)	(0.00228)	(0.00588)	(0.660)	(0.0236)	(0.0122)	(0.0310)
Shared supervision	1.828***	-0.00365*	-0.0451***	0.403	-0.0202***	-0.00733***	-0.0368***
	(0.273)	(0.00148)	(0.00348)	(0.563)	(0.00107)	(0.000476)	(0.00164)
Constant	-7.063	0.00266	1.240***	21.50***	0.272***	0.106***	2.193***
	(7.190)	(0.00861)	(0.0663)	(1.647)	(0.0375)	(0.0193)	(0.0639)
Dummy time indicator	✓	✓	✓	✓	✓	✓	✓
Supervisor fixed effects	✓	✓	✓	✓	✓	✓	✓
Adjusted within R2	0.1376	0.195	0.115	0.0481	0.086	0.0168	0.0703
N	19 565	85 094	19 565	6 484	18 424	18 424	18 424

Note: The table presents our main results at both the student and the supervisor level from equation 1 and 2, but with an ordered dummy for the time instead of a time trend. The coefficients related to each year were not included for clarity concerns. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor. In the estimations at individual level, these variables correspond to individual characteristics of the PhD student. As a result, 'shared supervision' captures the number of supervisors guiding the student. The'research group size' captures the number of PhD scholars within the research group.

Table D7: Main results by cohorts of student - Student level

	Cross-section data sample			Panel data sample	
	Time spent in the PhD program	Time to graduation (Graduates only)	Dropped out PhD	Diploma attainment	Time spent in the PhD program
1.Phase×COVID_2020	-1.031		0.647***	0.00623*	1.618***
	(1.314)		(0.0215)	(0.00304)	(0.275)
1.Phase×COVID_2021	-1.603*		0.694***	0.000797	1.602***
	(0.801)		(0.0213)	(0.00361)	(0.317)
1.Phase×COVID_2022	-0.827		0.730***	0.00126	1.407***
	(0.686)		(0.0174)	(0.00409)	(0.356)
1.Phase×COVID_2023	-2.025*		0.780***	-0.000635	1.338***
	(0.881)		(0.0193)	(0.00470)	(0.391)
2.Phase	9.391***		0.00805	0.00216***	11.22***
	(0.267)		(0.0137)	(0.000432)	(0.0375)
2.Phase×COVID_2020	8.839***		0.660***	0.00336	12.05***
	(0.898)		(0.0196)	(0.00292)	(0.250)
2.Phase×COVID_2021	9.448***		0.672***	0.00535	12.32***
	(0.777)		(0.0194)	(0.00351)	(0.306)
2.Phase×COVID_2022	8.328***		0.745***	0.000878	12.52***
	(0.664)		(0.0155)	(0.00403)	(0.350)
2.Phase×COVID_2023	5.714***		0.779***	0.00242	11.71***
	(1.075)		(0.0189)	(0.00456)	(0.416)
3.Phase	21.78***	0	-0.126***	0.0236***	22.76***
	(0.275)	(.)	(0.0145)	(0.00187)	(0.0640)
3.Phase×COVID_2020	20.88***	1.125	0.171*	0.0300***	22.47***
	(0.727)	(1.274)	(0.0680)	(0.00589)	(0.237)
3.Phase×COVID_2021	20.70***	2.545	0.348***	0.0196***	23.63***
	(0.926)	(1.689)	(0.0624)	(0.00493)	(0.291)
3.Phase×COVID_2022	18.38***	-1.234	0.467***	0.0170***	23.84***
	(1.341)	(2.643)	(0.0603)	(0.00505)	(0.357)
3.Phase×COVID_2023	17.43***	-3.146	0.429***	0.0159**	24.11***
	(1.097)	(2.711)	(0.0703)	(0.00599)	(0.396)
4.Phase	35.46***	14.25***	-0.286***	0.106***	34.72***
	(0.290)	(0.702)	(0.0140)	(0.00413)	(0.0975)
4.Phase×COVID_2020	34.26***	13.31***	-0.164***	0.0872***	33.79***
	(0.832)	(1.182)	(0.0405)	(0.00875)	(0.235)
4.Phase×COVID_2021	34.15***	12.80***	-0.0289	0.0674***	34.14***
	(0.645)	(1.093)	(0.0469)	(0.00935)	(0.288)
4.Phase×COVID_2022	32.53***	12.81***	0.00551	0.0781***	35.17***
	(0.695)	(1.082)	(0.0430)	(0.00864)	(0.335)
4.Phase×COVID_2023	34.00***	14.19***	-0.0348	0.0781***	35.53***
	(0.607)	(1.153)	(0.0377)	(0.00919)	(0.411)
5.Phase	59.51***	31.33***	-0.378***	0.363***	59.32***
	(0.477)	(0.720)	(0.0138)	(0.00548)	(0.384)
5.Phase×COVID_2020	54.53***	30.01***	-0.232***	0.330***	61.16***
	(0.680)	(0.934)	(0.0175)	(0.0113)	(0.539)
5.Phase×COVID_2021	56.32***	32.88***	-0.218***	0.338***	61.78***
	(0.746)	(1.033)	(0.0161)	(0.0106)	(0.564)
5.Phase×COVID_2022	55.01***	31.99***	-0.184***	0.312***	62.70***
	(0.759)	(1.006)	(0.0164)	(0.0105)	(0.558)
5.Phase×COVID_2023	55.46***	32.69***	-0.144***	0.361***	65.03***
	(0.687)	(1.083)	(0.0156)	(0.0109)	(0.614)
Time trend	1.063***	0.475***	-0.0316***	-0.000628	0.721***
	(0.0599)	(0.0777)	(0.000797)	(0.000485)	(0.0475)
Research group size				0.00192**	-0.306***
				(0.000697)	(0.0605)
Non-EU	-1.736***	-1.834***	-0.0203***	0.00665*	-0.990***
	(0.349)	(0.435)	(0.00561)	(0.00277)	(0.297)
Female	-0.937**	-0.624	-0.00119	0.00158	-0.703*
	(0.308)	(0.398)	(0.00497)	(0.00227)	(0.288)
Shared supervision	-0.357	-0.00342	-0.0158***	-0.00414**	-0.376*
	(0.206)	(0.232)	(0.00312)	(0.00148)	(0.162)
Constant	-5.897***	24.46***	0.886***	-0.0123	-0.759
	(1.040)	(1.384)	(0.0183)	(0.00925)	(0.722)
Supervisor fixed effect	✓	✓	✓	✓	✓
Adjusted within R2	0.575	0.223	0.317	0.205	0.738
N	19 565	10 308	19 565	85 094	85 094

Note: The table presents our main results at the student level from equation 1, but with an interaction term between the phase of the students and the COVID-19 years. Column 1 presents the results for the full sample, while column 2 focuses only on graduated students. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'Treatment' is a dummy for the graduation in column 1, 2 and 5, while it indicates eligibility for graduation in column 4. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman. The'research group size' captures the number of PhD scholars within the research group.

Table D8: Graduation probability in time - Student level

	Diploma attainment within 5 years	Diploma attainment within 6 years
COVID_2020	0.114***	0.169***
	(0.0198)	(0.0204)
COVID_2021	0.0691**	0.150***
	(0.0214)	(0.0229)
COVID_2022	0.0827***	0.103***
	(0.0222)	(0.0285)
COVID_2023	-0.124***	-0.255***
	(0.0218)	(0.0318)
Time trend	-0.0122***	-0.0163***
	(0.00283)	(0.00355)
Non-EU	0.0463**	0.00772
	(0.0142)	(0.0135)
Female	-0.0144	-0.00296
	(0.0117)	(0.0119)
Shared supervision	0.0172*	0.0426***
	(0.00703)	(0.00743)
Constant	0.458***	0.580***
	(0.0178)	(0.0184)
Supervisor fixed effect	✓	✓
Adjusted within R2	0.0181	0.0386
N	9 533	8 331

Note: The table presents our findings with two additional outcome variables : the probability of being graduated within 5 (column 1) or 6 years (column 2) using the cross-section sample. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at the supervisor level. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman. The'research group size' captures the number of PhD scholars within the research group.

Table D9: Main results - Resiliency analysis

	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
COVID_2020	-1.073	-0.0412	-0.0282*	0.0322
	(0.841)	(0.0233)	(0.0123)	(0.0301)
COVID_2021	3.560***	0.0339	0.0303*	0.130***
	(0.994)	(0.0268)	(0.0147)	(0.0346)
COVID_2022	1.765	0.0255	0.0470**	-0.0342
	(0.988)	(0.0273)	(0.0153)	(0.0337)
COVID_2023	2.420*	0.145***	0.0219	-0.00275
	(0.953)	(0.0302)	(0.0155)	(0.0364)
Time trend	0.503***	0.0277***	0.00401**	-0.0408***
	(0.0942)	(0.00306)	(0.00148)	(0.00349)
Non-EU	-1.769**	-0.0450	-0.0451**	0.149***
	(0.677)	(0.0334)	(0.0168)	(0.0452)
Female	-0.00186	-0.0392	0.0292*	0.0640*
	(0.666)	(0.0245)	(0.0123)	(0.0304)
Shared supervision	0.544	-0.0254***	-0.00821***	-0.0321***
	(0.573)	(0.00104)	(0.000445)	(0.00138)
Constant	51.53***	0.443***	0.181***	1.538***
	(1.268)	(0.0358)	(0.0172)	(0.0423)
Supervisor fixed effect	✓	✓	✓	✓
Adjusted within R2	0.0275	0.060	0.0164	0.0543
N	6 484	18 424	18 424	18 424

Note: The above results are based on equation 2 at the supervisor level, but the $COVID_2020$ dummy is set to 1 in 2020 until 2023, such that the $COVID_2021$ to $COVID_2023$ dummies present an indicator for resiliency after the pandemic. The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. Standard errors are clustered at supervisor level. The 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'Shared supervision' stands for the share of students that are guided by more than one supervisor.

Table D10: Romano-Wolf Multiple Hypothesis

	Data aggregated at supervisor level		
	Model pvalue	Resample pvalue	RomanoWolf pvalue
Time to graduation			
COVID_2020	0.2025	0.0889	0.4336
COVID_2021	0.0003	0.001	0.001
COVID_2022	0.0743	0.01	0.1508
COVID_2023	0.0112	0.001	0.004
Diploma attainment			
COVID_2020	0.0771	0.016	0.1558
COVID_2021	0.2057	0.0659	0.4336
COVID_2022	0.3494	0.1878	0.5754
COVID_2023	0.000	0.001	0.001
Dropped out PhD			
COVID_2020	0.0214	0.003	0.017
COVID_2021	0.0397	0.004	0.0509
COVID_2022	0.0022	0.001	0.001
COVID_2023	0.1583	0.049	0.3716
Started PhD			
COVID_2020	0.2844	0.1279	0.5574
COVID_2021	0.0002	0.001	0.001
COVID_2022	0.3105	0.1758	0.5654
COVID_2023	0.9396	0.9081	0.991

Note: Column 1 of the above table presents the p-values of the variable of interests estimated in our baseline model from Table B1. Column 2 presents the same p-values, but as average of a 1000 replications bootstrap. Finally, column 3 shows again the same p-values, but corrected by to the Romano-Wolf algorithm.

Table D11: More conservative standard errors - Research field × department

	Time spent in the PhD program	Diploma attainment	Dropped out PhD
COVID_2020	-1.020	0.000955	0.124***
	(2.206)	(0.00367)	(0.0141)
COVID_2021	-1.430	-0.00810	0.160***
	(2.491)	(0.00547)	(0.0147)
COVID_2022	-2.236	-0.00563	0.206***
	(1.771)	(0.00508)	(0.0141)
COVID_2023	5.391	-0.00295	0.168***
	(3.022)	(0.00714)	(0.0137)
Treatment	19.34***	0.330***	
	(1.442)	(0.0143)	
Treatment×COVID_2020	17.68***	-0.0348***	
	(1.238)	(0.00916)	
Treatment×COVID_2021	20.39***	-0.0177	
	(1.021)	(0.0136)	
Treatment×COVID_2022	18.21***	-0.0461***	
	(1.057)	(0.00981)	
Treatment×COVID_2023	19.82***	-0.0000871	
	(0.929)	(0.0100)	
Time trend	1.139***	0.0000108	-0.0238***
	(0.103)	(0.000679)	(0.00145)
Research group size		0.00208*	
		(0.000891)	
Non-EU	-3.778***	0.00547	-0.00504
	(0.702)	(0.00336)	(0.00778)
Female	-1.920***	0.000837	0.0112
	(0.467)	(0.00229)	(0.00694)
Shared supervision	1.907***	-0.00360*	-0.0459***
	(0.316)	(0.00169)	(0.00394)
Constant	21.82***	0.00852	0.560***
	(1.998)	(0.0119)	(0.0249)
Supervisor fixed effect	✓	✓	✓
Adjusted within R2	0.122	0.195	0.0754
N	19 565	85 094	19 565

Note: The table presents our main results from the student-level analysis with more conservative standard errors (e.g. by doctoral school and professor's department). The supervisor fixed effects control for observed and unobserved heterogeneity at the level of the supervisor. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. The 'shared supervision' captures the number of supervisors guiding the student. Non-EU and Female are dummies indicating respectively whether the student was born outside the EU and is a woman. The'research group size' captures the number of PhD scholars within the research group.

E OLS without fixed effects

Table E1: Main results without supervisor's fixed effect

	Data at individual level			Data aggregated at supervisor level			
	Time spent in the PhD program	Diploma attainment	Dropped out PhD	Time to graduation	Diploma attainment	Dropped out PhD	Started PhD
COVID_2020	1.293	-0.00192	0.0830***	-0.787	-0.0734***	-0.0388***	-0.0523
	(2.356)	(0.00265)	(0.0137)	(0.686)	(0.0202)	(0.0105)	(0.0271)
COVID_2021	-1.067	-0.0107***	0.104***	2.490**	-0.0462*	-0.0109	0.0699*
	(2.201)	(0.00248)	(0.0132)	(0.756)	(0.0218)	(0.0110)	(0.0296)
COVID_2022	-2.400	-0.00881***	0.123***	0.880	-0.0611**	0.00117	-0.101***
	(2.166)	(0.00234)	(0.0141)	(0.675)	(0.0227)	(0.0123)	(0.0296)
COVID_2023	4.472	-0.00589*	0.0646***	1.993**	0.0500*	-0.0293*	-0.0778*
	(2.425)	(0.00275)	(0.0120)	(0.621)	(0.0253)	(0.0117)	(0.0311)
Treatment	17.11***	0.306***					
	(0.537)	(0.00528)					
Treatment×COVID_2023	19.24***	0.00124					
	(0.770)	(0.0104)					
Treatment×COVID_2022	17.77***	-0.0431***					
	(0.779)	(0.00991)					
Treatment×COVID_2021	18.94***	-0.0154					
	(0.791)	(0.0107)					
Treatment×COVID_2020	16.08***	-0.0328**					
	(0.765)	(0.0113)					
Time trend	0.907***	-0.000226	-0.00111**	0.371***	0.0259***	0.00570***	-0.0100***
	(0.0439)	(0.000216)	(0.00046)	(0.0344)	(0.00149)	(0.000573)	(0.00185)
Research group size	-0.268***	0.000510	-0.000296				
	(0.0811)	(0.000340)	(0.000704)				
Non-EU	-3.176***	0.00518	-0.0284***	-1.645**	0.205***	0.0403***	0.387***
	(0.494)	(0.00282)	(0.0061)	(0.584)	(0.0361)	(0.0122)	(0.0524)
Female	-1.818***	0.00122	0.00615	0.816	-0.0937**	-0.0210*	-0.168***
	(0.405)	(0.00239)	(0.00564)	(0.473)	(0.0285)	(0.0103)	(0.0378)
Shared supervision	1.033***	-0.0000486	-0.0469***	0.326	-0.00700***	-0.00430***	-0.0108***
	(0.276)	(0.00154)	(0.00318)	(0.496)	(0.00100)	(0.000363)	(0.00125)
Constant	29.91***	0.0268***	0.248***	53.13***	0.290***	0.136***	1.072***
	(0.915)	(0.00467)	(0.0111)	(0.630)	(0.0222)	(0.00879)	(0.0334)
Supervisor fixed effects	×	×	×	×	×	×	×
Adjusted within R2	0.181	0.179	0.0234	0.0351	0.0641	0.0182	0.0268
N	19 565	85 094	19 565	6 484	18 424	18 424	18 424

Note: The table presents our main results at both the student and the supervisor level from equation 1 and 2, but without any fixed effects. The 'Treatment' is a dummy for the graduation in column 1, while it indicates eligibility for graduation in column 2. In the data aggregated at supervisor level, 'Non-EU' denotes the share of non-EU students supervised by the professor, 'Female' the share of females supervised by the professor, 'shared supervision' stands for the share of students that are guided by more than one supervisor. In the estimations at individual level, these variables correspond to individual characteristics of the PhD student. As a result, 'shared supervision' captures the number of supervisors guiding the student. The'research group size' captures the number of PhD scholars within the research group.