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The heterogeneous effects of teacher turnover on student achievement: Evidence from a centralized teacher allocation system

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Abstract

This paper contributes to the literature on the effect of teacher turnover on student achievement. We study an educational system characterized by a centralized teacher allocation model and estimate the causal effects of teacher turnover on students' exam scores. A small but statistically significant negative effect is found, which is mainly attributed to organizational disruption at the school level and seems to persist for up to two years. We find heterogeneous effects, with students from lower socioeconomic backgrounds and with lower previous achievement being more negatively affected. We conclude that students in lower-achieving and socially disadvantaged schools are more exposed to teacher turnover, and this turnover penalizes these students more. We also find that it is the turnover among short-term contract teachers that drives the negative effects.

JEL Classification: I21, I28

Keywords: Education, Teacher turnover, Student achievement, Schools

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1 Introduction

Teacher turnover is an increasingly relevant topic in education policy. Although there are potential benefits associated with teacher turnover, as new teachers may bring new ideas, gain new experiences, and be more motivated, the general assumption is that high turnover rates impose a cost on students' learning processes and may create organizational disruption in schools. The few empirical studies on this topic are either from the UK or the USA, which have decentralized and flexible teacher recruitment systems that allow schools autonomy in the hiring process[1]. These studies have reported a small but negative effect: a 10 percentage point increase in the teacher turnover rate is estimated to reduce student point scores by 0.3% to 1.1% of one standard deviation on average (Ronfeldt et al., 2013; Hanushek et al., 2016; Atteberry et al., 2017; Gibbons et al., 2021).

Conclusions drawn from previous studies may not necessarily apply to countries with more rigid and centralized teacher recruitment models. On the one hand, a more rigid system may bring higher predictability regarding teacher allocation rules, reducing the potential disruptions caused by the entry of new teachers. On the other hand, the lack of power by schools in choosing their professionals may increase the potential mismatches between teachers and schools, increasing the costs of teacher turnover.

Portugal is an example of a centralized teacher allocation system; it is one of nine European education systems that use a candidate list type of recruitment, managed by a top-level authority[2]. In such systems, a top-level authority ranks candidates according to several predetermined criteria, thus leaving schools with no autonomy. The Portuguese case is also interesting because of its high levels of teacher turnover: between 2008/09 and 2017/18, the average share of new teachers per school in a particular year (i.e. average teacher turnover) ranged from 17% to 36%, and was higher in disadvantaged schools (Nunes et al., 2022).

[1] This type of recruitment prevails in 75% of European countries (Eurydice et al., 2018).

[2] Other European countries with this system are Germany, Cyprus, Luxembourg, Malta, Albania, Belgium (French- and German-speaking communities), and Austria (Eurydice et al., 2018).

This study aims to identify the causal relationship between teacher turnover and student achievement. We use a fixed effects design and a rich set of student and school controls. Using data from four cohorts of students of the 2nd cycle of basic education[3] and their teachers, we measure the effects of teacher turnover (per school-subject groups and per school) on students' Portuguese and Mathematics standardized external exam scores. Defining teacher turnover as the share of teachers giving classes in a school in year t who were not there in year $t-1$ (i.e. the share of new-to-school teachers)[4], we estimate whether students in schools with higher rotation of teachers have, on average, higher or lower exam scores, keeping student and school factors constant. Further, we study potential lagged effects of turnover and disentangle the heterogeneity in the results across students and schools with different characteristics.

The main finding of this paper is that an increase of 1 standard deviation in the teacher turnover rate is associated with a decrease of 0.5% of a standard deviation in standardized exam scores. Essentially, this means that when teacher turnover increases by 10 percentage points, students are expected to score on average approximately 0.3% of a standard deviation less in standardized external exams. The results also show that the turnover effect we are capturing is based on an organizational disruption at the school level, and that it persists for at least one school year. Furthermore, we identify several heterogeneous effects across students and schools. The students bearing the negative costs of teacher turnover are students with low previous ability levels, those who receive school social support, and those with lower-educated mothers. Regarding teachers, we find that the negative effect of teacher turnover is associated with turnover among short-term contract teachers.

The remainder of the paper is structured as follows. Section 2 reviews the existing literature on teacher turnover and its effects on students. Section 3 provides an overview of the Portuguese educational system and the teacher allocation model. Section 4 describes the

[3]The 2nd cycle of basic education is composed of the 5th and 6th grades, as is further explained in Section 3.
[4]Turnover within the same school or within the same year will not be considered.

data used in the analysis and Section 5 explains the methodology and empirical strategy. The results obtained are reported in Section 6 and discussed in Section 7.

2 Literature Review

The literature on the economics of education shows that within schools, teacher input has the strongest effect on students' achievement. Studies using teacher value-added models provide evidence that teachers are important not only for students' academic performance (Rivkin et al., 2005; Aaronson et al., 2007; Kane and Staiger, 2008; Chetty et al., 2014a; Reis et al., 2021), but also for their adult outcomes (Rothstein, 2010; Chetty et al., 2014b). The development of these methods, and evidence of the effect teachers can have on a student's progress, has promoted the emergence of a new body of literature focusing on how teacher turnover affects student achievement.

Teacher entry rate can affect students via both direct and indirect routes. Students may be directly affected if they have two different teachers for the same subject in two consecutive years. This route concerns the effect of not having the same teacher across school grades. Several studies in the US have shown that teachers who leave are, on average, considerably less effective than those who stay, even in disadvantaged schools (Hanushek and Rivkin, 2010; Goldhaber et al., 2011; Boyd et al., 2011).

Conversely, the addition of new teachers will disrupt the organization of the school by changing existing interpersonal dynamics and possibly affecting staff cohesion (Guin, 2004). New teachers, who lack school-specific human capital, need to allocate time and effort to adjusting to the new school environment, and teachers who stay may need to spend extra time helping new teachers to integrate. It could be argued that this wider organizational disruption caused by turnover affects not only the students of new teachers, but also and indirectly the students of incumbent teachers (Ronfeldt et al., 2013).

The few studies that have investigated the causal effect of teacher turnover on students have analyzed both these direct and indirect routes: Ronfeldt et al. (2013); Hanushek et al. (2016); Atteberry et al. (2017); Gibbons et al. (2021). All such studies indicate a negative effect that is stronger in more disadvantaged schools. Ronfeldt et al. (2013) examine 4th and 5th grade New York students over eight years and regress exam scores on two measures of teacher turnover (entry and exit rate). They test two models using school-by-grade and school-by-year fixed effects, and find that (i) students from grades with higher turnover have lower scores in both English language arts courses and mathematics courses; and (ii) students of teachers of the same grade and in the same school perform worse in years of higher turnover. Overall, a 10 percentage point (p.p.) increase in turnover leads to a decrease in scores of 0.5%–1.0% of a standard deviation. This negative effect is experienced particularly by students in schools with a higher share of low-performing students and Black students. Further, the authors show that turnover has a disruptive effect beyond changing the distribution in teacher quality, indicating that even students who have the same teacher from one year to the next are affected by turnover.

Using a similar method, Hanushek et al. (2016) analyzes the effects of teacher turnover on the quality of instruction for students of the 4th to the 8th grades in Texas, over a period of five years. They point out that school-by-year and school-by-grade fixed effects alone may not be sufficient to isolate the causal effect of turnover if there are time-varying, grade-specific factors that affect both teacher turnover and student achievement. Thus, a grade reassignment control[5] and a set of specifications that aggregate turnover at a school-year level[6] were introduced. The first conclusion is that teachers who exit Texas public schools are less effective than teachers who stay in the school. Furthermore, and consistent with Ronfeldt et al. (2013), they find that higher turnover rates decrease students' math scores in

[5]The grade reassignment control mentioned in Hanushek et al. (2016) is defined as the share of teachers who were lecturing at a different grade in the same school in the previous year. They find a correlation of -0.17 between the share of teachers who moved from another grade and the share of new-to-school teachers, which suggests that there may be some sorting into grades.

[6]Two specifications of the model are tested: one measuring turnover as an average of transitions at the school-grade-year level, and another at the school-year level.

lower-achieving schools. The grade-specific knowledge and experience lost when teachers leave schools offset the potential gains from departing teachers being less effective than those who stay, on average. In higher-achieving schools, the negative effect of turnover is less evident.

Taking a slightly different approach, Atteberry et al. (2017) studies turnover both between and within schools. Using data from 1974 to 2010 on New York teachers and their students (3^{rd} to 8^{th} grades), the authors analyze differences in average teacher quality by transition type (i.e. changes within and between districts, and within schools). They conclude that, historically, students from low socioeconomic backgrounds may have a higher probability of being paired with a churning teacher, and that teachers' ethnicity is a predictor of the propensity to be reassigned to another grade/subject. Regarding the effect on students, they find a stronger negative effect of turnover for students who had a brand new teacher and a less strong effect on students assigned to teachers who are in the same school but new to their subject/grade.

Finally, using data over five years from 18 subject groups of students aged 16 years (11^{th} grade) and their teachers in England, Gibbons et al. (2021) measure the effect of turnover on the exam scores of each school-subject-year group, using student and school controls and a range of fixed effects (i.e. school-subject, school-by-year, and subject-by-year groups). With this design, the possible bias from the non-random allocation of teachers is smoothed, as the focus is on subject-specific teachers within one grade of high school. The main finding of this paper is that students who experience higher rates of teacher entry in their subjects have lower exam scores than other students. Specifically, an increase in the entry rate of 10 p.p. is expected to reduce attainment by approximately 0.4%–0.5% of one standard deviation. Additionally, the authors conclude that the primary mechanism by which turnover affects student performance is the absence of school-specific knowledge, such that new teachers are disruptive only in their first year in the new school.

To date, no studies have measured the causal effects of teacher turnover on student attainment in the Portuguese educational system. However, a recent correlation analysis by Nunes et al. (2022) shows that, on average, lower-achieving schools have a teacher turnover rate 3 p.p. above that of higher-achieving schools when the average exam scores from the 4th to the 12th grade are compared. Moreover, schools with a higher percentage of students receiving school social support or with low-educated mothers have, on average, teacher entry rates 5 p.p. higher. These results suggest that teacher turnover is more prevalent in disadvantaged schools and indicate the need for empirical studies of its effects.

It is important to note that all the previous studies on the causal effects of teacher turnover have been conducted in either the US or UK educational context, which differs in several ways from the Portuguese context. For example, the UK has an open recruitment system in which schools have the autonomy to hire staff (Eurydice et al., 2018); in the US, salaries are adjusted to the school context (Allen et al., 2018). In contrast, Portugal has a rigid teacher recruitment model, which allows schools no autonomy in the hiring process (this is further explained in Section 3), and the salary scheme is the same for the whole country. It is thus important to investigate the effect of teacher turnover in this type of more centralized recruitment system. This is especially relevant in the context of teacher shortages, as stability can increase the attractiveness of the teaching profession [7].

3 Portuguese Educational System

Compulsory education in Portugal is organized into four different cycles. The first cycle of basic education covers the 1st to 4th grades, the second cycle the 5th and 6th grades, and the third cycle the 7th to 9th grades. Accordingly, secondary education corresponds to the

[7] See Nunes et al. (2021) for an outline of future teacher recruitment needs and the characteristics of current teaching staff in Portugal compared with countries that use other teaching systems.

10th to 12th grades[8]. At the end of the 4th, 6th, and 9th grades, students sit National Exams for Portuguese and Mathematics[9]. For most years, these were low-stakes exams (*Provas de Aferição*), so did not count towards students' final grade. However, in 2004/05 for the 9th grade, in 2011/12 for the 6th grade, and in 2012/13 for the 4th grade, these exams became mandatory and part of student evaluation. In 2015/16, the 4th and 6th grade National Exams were abolished. In the 12th grade, all students are required to take the Portuguese National Exam, whereas the Mathematics National Exam is only mandatory for Socio-Economic Sciences and Science and Technology students.

Teachers are categorized according to three main recruitment sections based on the grades that they teach: (i) 1st cycle teachers, (ii) 2nd cycle teachers, and (iii) 3rd cycle/secondary education teachers. There are several recruitment groups in each section, according to the subject the teacher specializes in[10]. For example, in the section we analyze, the 2nd cycle, there are eight recruitment groups[11]. It should be noted that although teachers are not restricted to their recruitment group, it is uncommon for a teacher to give classes in two groups at the same time.

Allocation of teachers to public schools is based on a centralized model. Internationally, there are three main teacher recruitment schemes: open recruitment, competitive examination, and candidate lists (Eurydice et al., 2018). Portugal has adopted the most rigid scheme, the candidate list based on their preferences, final college grade point average, and years of experience. Thus, teacher allocation is managed by the top-level education authority, allowing schools limited autonomy to choose their teachers. This means that a more experienced teacher with a higher graduation score will be given priority, and will have a greater chance

[8] Students in upper-secondary education can either follow a vocational track or four different scientific-humanistic courses: Languages and Humanities, Science and Technology, Socio-Economic Sciences, and Visual Arts.

[9] After being abolished in 1974, the National Exams for the 4th and 6th grades were reintroduced in 2000 as a way of ensuring school supervision and monitor student' learning at different stages.

[10] See Table A1 for the list of teacher recruitment groups by education level.

[11] The recruitment groups include the following fields: Sports, Music, Arts, Mathematics and Sciences, Portuguese, Portuguese and Social Studies/History, Portuguese and History, Portuguese and English.

of being allocated to their first school option. This model totally ignores the heterogeneity between schools and whether the candidate teacher has adequate skills for that school.

More specifically, this model incorporates both an internal and an external process. The internal process occurs every four years[12] and is applicable to long-term contract teachers, more specifically (i) Permanent teachers (*professores de Quadro de Agrupamento ou Escola não Agrupada*), who are associated with a specific school cluster, and (ii) District teachers (*professores do Quadro de Zona Pedagógica*), who belong to one of the 10 administrative zones of the Portuguese Educational System. This internal process consists of mandatory application for district teachers who apply to schools within their administrative zone. In contrast, the annual external process is applicable to (iii) short-term (less than one year) contract teachers (*professores Contratados*) who do not yet have a permanent link with the Ministry of Education. Those that are not allocated to a school may not have a full-time contract and will be considered part of the group of teachers able to answer emergency replacement staff needs throughout the year.[13]

4 Data and Descriptive Statistics

4.1 Sample

The data used for the analysis are based on anonymized administrative records of Portuguese students and teachers from the information system of the Ministry of Education (MISI), which is managed by the Direção-Geral de Estatísticas da Educação e Ciência (DGEEC) and linked to exam scores provided by the Júri Nacional de Exames (JNE). These rich databases are available from the years 2006/07 and provide information on student character-

[12]Formally, this process should occur every four years; however, there have been some exceptions. Since 2008/09, there have been internal processes in the following years: 2009/10, 2013/14, 2015/16, and 2017/18. Naturally, in these years, teacher turnover spikes are observed.

[13]These replacement teachers are normally allocated through a centralized system. However if the centralized system fails to fill a vacancy, schools may recruit autonomously.

istics (e.g. gender, age, nationality, social support, family background, place of residency), student scores in all subjects (i.e. teacher grading and national exam scores), and teacher information (e.g. gender, age, type of contract, experience, school assignment, subjects, classrooms taught).

We choose to focus our analysis on the 2nd cycle of studies (5th and 6th grades) to minimize the problem of teacher sorting. As mentioned by both Hanushek et al. (2016) and Gibbons et al. (2021), one of the obstacles to measuring the causal effect of turnover is the non-random allocation of incoming teachers to higher- or lower-performing student groups or to specific grades. As a teacher hired for the 2nd cycle can only teach two grades (the 5th and 6th), the probability of less effective teachers being allocated to lower-performing or "harder" grades is reduced, contrary to what may happen in the 3rd cycle/secondary education, where teachers can be allocated to many more grades (7th-12th grades)[14].

Our outcome variable of interest is the 6th grade exam scores for Mathematics and Portuguese (measured on a 0-100 scale). Only the years between 2011/12 and 2014/15, when high-stakes exams were in place, are considered. We disregard the years before 2011/12, as the low-stakes exam scores are graded on a 1-5 scale, and the years after 2014/15, because the 6th grade exams were eliminated in 2015/16. The exam scores are standardized by year and by subject to account for the possible effects of differences in difficulty between years.As a measure of each student's previous academic achievement, the model includes the scores for the 4th grade Mathematics and Portuguese exams (graded on a 1-5 scale).

There are various ways of measuring teacher turnover. The most commonly used method in the field, and the one used in this study, is the entry rate, defined as the share of teachers in

[14]If we focused the analysis on the 7th to 12th grades, we would capture a much wider and diverse group of teachers. For example, a 3rd cycle teacher can give classes from the 7th to the 12th grades, across several subjects. In this case, the probability of selective allocation of teachers to higher- or lower-performing grades would likely be higher.

a school in year t that were not there in year $t-1$[15] [16]. This measure is standardized by year and by subject, but other standardization strategies were tested. Our choice of standardization is mainly explained by the spikes in the turnover rate for years in which the internal process of teacher allocation occurred (in our sample for 2013/14), and by the fact that Mathematics teachers have, on average, higher turnover rates than Portuguese teachers (see Figure A1).

In our sample, there are 863 schools of which only 62 are not grouped together with other schools. The other 801 schools are organized into 696 school clusters, with an average of four schools per cluster[17]. School clusters have a common administration and management structure and can contain schools of different education levels, from kindergarten to high school.

As a teacher can give classes in several schools of the same cluster, in the same year, we define turnover as only those cases in which the teacher changed from one school cluster to another[18]. Turnover is measured as the share of 2$^{\text{nd}}$ cycle teachers of a particular subject giving classes in a school in year t who were not there in year $t-1$.

Finally, we combine information on teachers and students of public schools from mainland Portugal[19], culminating with data on 326,332 6$^{\text{th}}$ grade students, making a total of 650,543 exam-score observations over a period of 4 school years (2011/12 to 2014/15).

[15]Our database contains monthly entries, so for each teacher-school-year group, we consider the first time a new teacher is observed, regardless of the month. We do not require that all observations are from one particular month, but in Appendix Section E.2, we check whether the results would be different if we did.

[16]We opted not to measure turnover using the exit rate for two reasons. First, it is a noisier measure of turnover, as only some of the departures it captures will be replaced by new teachers (Hanushek et al., 2016). Second, because it is a noisier measure, the exit rate will always be larger than the entry rate in a context of decline in the number of teachers, as Ronfeldt et al. (2013) pointed out. Considering the demographic decline and consequent reduction in the number of Portuguese teachers during the last few years, it is more reasonable to measure teacher turnover using the entry rate.

[17]Approximately 96% of school clusters and non-clustered schools are present in all the years under analysis.

[18]Hereafter, when we mention *school(s)*, we are referring to school clusters (and non-grouped schools).

[19]Azores and Madeira have independent teacher-allocation processes, and are therefore not included in the sample.

4.2 Descriptive Statistics

Table A2 presents the summary statistics of the variables used in the study. The average teacher turnover rate of all 2ndcycle teachers varied between 18% and 31%, and was the highest in 2013/14, a year of internal process of teacher allocation (see Figures A1). Teacher turnover is always higher for Mathematics (19%–32%) than for Portuguese (18%–31%). Table A3 presents summary statistics of teacher turnover for the different subject-year groups.

Analyzing the correlations between teacher turnover and school characteristics, we find that lower-achieving schools tend to have higher teacher turnover rates, with a correlation between -0.18 and -0.12 (Figure A2). The correlations between teacher turnover and the percentage of students with school social support (-0.03 to -0.01) or the percentage of students with higher-educated mothers (0.01 to 0.06) are very weak[20].

Finally, to assess whether new-to-school teachers are being sorted into a specific grade (5th or 6th grade), we measured the turnover rate for each grade (5th and 6th) and subject (Portuguese and Mathematics). From Figure A5, we see that there is a slightly higher teacher turnover rate in the 5th than in the 6th grade in all four years, which may indicate that schools tend to allocate new teachers to grades in which there are no high-stakes exams. This could potentially lead to a lagged effect of teacher turnover, which we will explore further.

5 Empirical Strategy

The aim of this paper is to identify the average effect of teacher turnover on student academic performance. Detecting this causal link presents several empirical challenges owing to potential endogeneity problems, such as the non-random allocation of teachers to schools, classes, and grades. Although schools have very limited autonomy in the hiring and allocation process, their characteristics (i.e. socioeconomic background of students, social composition

[20]The signs of these correlations are different from the ones found in Nunes et al. (2022). A possible reason for this difference is the fact that we are considering a smaller sample, both in terms of the time period and the grades included.

of teachers, and school conditions) determine how attractive they are to applicant teachers. A consistent body of literature from the US (Boyd et al., 2013; Jackson, 2009; Hanushek et al., 2004) has shown that teachers typically prefer to teach in less disadvantaged schools (i.e. with lower percentages of poor, non-White, and low-achieving students). This means that less attractive schools may experience higher turnover, as teachers tend to stay in more attractive schools. Nunes et al. (2022) suggests this by showing that more disadvantaged schools, which are presumably less attractive, tend to have higher teacher turnover rates. If this is not fully taken into account in the model, there is a risk of omitting variable biases, because school characteristics may affect both teacher turnover and exam scores.

To overcome these limitations and isolate the effect of turnover, we regress students' 6th grade Portuguese and Mathematics exam scores on teacher turnover per school-subject, using a fixed effects design and a set of student and school controls. The main specification of the model is as follows:

$$S_{icst(g=6)} = \alpha + \beta T_{cst} + \gamma X_{it} + \theta I_{icst} + \delta S_{icst(g=4)} + \eta Z_{st} + \lambda_{ct} + \varepsilon_{icst}, \tag{1}$$

where $S_{icst(g=6)}$ is the standardized score in the 6th grade national exam of student i, for subject c, in school s, in year t. Teacher turnover is represented by T_{cst}, which stands for the share of new-to-school teachers from subject c, in school s, in year t. X_{it} is a vector of student controls: gender; age; nationality; school social support; access to a computer and internet at home; parents' education, nationality, and job status[21]. I_{icst} is a binary variable that takes the value of 1 if student i had a different teacher for subject c in the 5th and 6th grades[22]. As a measure of student prior achievement, and a proxy of student ability, we add $S_{icst(g=4)}$, the score in the 4th grade national exam. Z_{st} is a vector of time-varying school controls, including the share of female students, share of students with school social support, share

[21] Parents' education, nationality, and job status are binary variables for each parent. If the parent has higher education, Portuguese nationality, and is unemployed, all variables will be equal to 1.

[22] Under the condition that the student remained in the same school from one grade to the next.

of students with higher-educated mothers, share of female teachers, share of teachers with a permanent contract, teachers' average experience, number of teachers in the school, and number of students in the school. Finally, λ_{ct} are the subject-by-year fixed effects. Standard errors are clustered at the class level, as it is likely that the scores of students from the same class are not independent of each other.

Our coefficient of interest is β, which measures the change in students' 6$^{\text{th}}$ grade standardized exam scores resulting from a standard deviation increase in teacher turnover in the year the student sits the exam. After controlling for observed student factors and time-varying school characteristics, with the inclusion of student and school controls, and for unobserved time-varying factors specific to each subject (e.g. the difficulty of the exam), with the subject-by-year fixed effects, the turnover effect is identified from differences in teacher turnover between schools within each subject. After taking both subject and school factors into account, this is the most comprehensive specification, and thus our preferred one.

In addition, we estimate two more variations of the model. The first follows the approach taken by Gibbons et al. (2021), and includes only student, year fixed effects, and the individual turnover variable[23]. The student fixed effects control for student-specific observed and unobserved characteristics (e.g. ability, emotional skills, socioeconomic background). The year fixed effects control for yearly events that affected all schools (e.g. years of internal teacher allocation process, introduction of a new education policy, changes in the school calendar). Thus, turnover effect is identified from differences in teacher turnover within student and across subjects.

In the second alternative specification, school-by-year fixed effects are included, instead of subject-by-year fixed effects, and school controls are excluded. This allows us to control for school observed and unobserved time-varying factors (e.g. a change in the school director, the school culture, the school conditions). In this case, the turnover effect is identified from

[23]No other student or school controls are included in this specification.

differences in teacher turnover between subjects, within school-year groups.

6 Results

We start by analyzing the main results of our model when considering teacher turnover per subject (Section 6.1). Subsequently, we analyze school-level teacher turnover for all subjects (Section 6.2).

In Section 6.3, we investigate the long-term effects of teacher turnover on students' scores with lagged turnover measures. After examining the average effects, we analyze potential sources of heterogeneity (Section 6.4). Namely, we assess whether the effect is different for students with distinct characteristics, and if different types of schools are unequally affected. Finally, in Section 6.5, we present a summary of the main robustness checks.

6.1 Teacher Turnover per Subject

In column 1 of Table 1, we run an ordinary least squares (OLS) regression of exam scores against teacher turnover without controlling for potential confounders. In column 2, we add student and school controls, and in column 3, year fixed effects. The specification of column 4 includes student and year fixed effects. Column 5 presents the model with school-by-year fixed effects. Finally, the results of our preferred specification (eq. 1), with subject-by-year fixed effects, are presented in column 6.

The results suggest that higher teacher turnover rates are associated with lower exam scores; the coefficient is relatively stable across all specifications of the model that include covariates and fixed effects. Without controlling for either time-variant or time-invariant factors, the coefficient of column 1 indicates that an increase of one standard deviation in the teacher turnover rate, for a specific year and subject, is associated with a fall in the 6^{th} grade

Table 1: Effect of Teacher Turnover on 6th Grade Standardized Exam Scores

	(1)	(2)	(3)	(4)	(5)	(6)
Teacher Turnover	-0.0197^{***}	-0.0056^{**}	-0.0051^{**}	-0.0102^{***}	-0.0062^{*}	-0.0053^{**}
	(0.0031)	(0.0023)	(0.0022)	(0.0025)	(0.0032)	(0.0021)
Observations	643, 256	544, 807	544, 807	639, 006	544, 807	544, 807
R^2	0.000	0.440	0.453	0.835	0.478	0.463
Student Controls		✓	✓		✓	✓
School Controls		✓	✓			✓
Year FE			✓	✓		
School-by-Year FE					✓	
Subject-by-Year FE						✓
Student FE				✓		

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t that were not there in year $t-1$, standardized per subject-year groups. Results for the main specification (eq. 1) are presented in column 6. Student controls include gender; school social support; age; parents' education, nationality, and job situation; access to a computer and internet at home; 4th grade exam scores per subject; and whether the student had a different teacher in the 5th and 6th grades per subject. School controls include share of female students, share of students with school social support, share of students with higher-educated mothers, share of female teachers, share of teachers with a permanent contract, teachers' mean experience, number of teachers in the school, and number of students in the school. All coefficients should be interpreted in terms of standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

exam scores of 1.97% of a standard deviation, on average. With the inclusion of student and school controls in column 2, and year fixed effects in column 3, the magnitude of the estimate decreases considerably but remains statistically significant at a 5% level. For the specification in column 4, we see that an increase of one standard deviation in the turnover rate decreases exam scores by 1.02% of a standard deviation, on average. The sign of the effect is in line with previous results, but the magnitude is larger, considering that there are no controls at school or student level in this specification.

In column 5, for the specification with school-by-year fixed effects, the coefficient (-0.0062) is statistically significant at a 10% level, and more similar in magnitude to those of columns 2 and 3. Regarding our preferred specification (eq. 1) in column 6, we find that for a standard deviation increase in the teacher turnover rate, the 6th grade exam score is expected to decrease by 0.53% of a standard deviation, on average. Given that the standardization is calculated per year and subject, each subject-year group will have a different standard deviation value (see Table A3). This indicates that a 10 p.p. increase in the teacher turnover rate (47% to 66% of a standard deviation) decreases exam scores by 0.25% to 0.35% of a standard deviation. The magnitude of the effect is different in the specifications of columns 5 and 6, which indicates that not accounting for subject-specific factors may be relevant. Therefore, in the rest of the analysis, we will focus on our most comprehensive specification (column 6).

One of the student controls included is the individual turnover variable, which has a value of 1 if the student had a different teacher in the 5th and 6th grades for each subject. This control is statistically significant at a 1% level across all specifications, and varies between -0.03 and -0.05. However, the estimated coefficient of our variable of interest (teacher turnover) remains stable and significant. This means that part of the disruption caused by the entrance of new teachers in the school derives from the direct effect of changing the teachers of specific students, captured by individual turnover control. However, our variable of interest remains significant, indicating that the identified effect derives mainly from an organizational disruption at the school level.[24].

Overall, when teacher turnover increases by 10 p.p., exam scores are expected to decrease, on average, by 0.30% of a standard deviation. These results are in line with those of Ronfeldt et al. (2013); Hanushek et al. (2016); Gibbons et al. (2021), who find a small but not negligible effect.

[24]It should be noted that the individual turnover variable may be capturing other effects that are not possible to include in the model, such as teacher quality.

6.2 Teacher Turnover per School

In this section, we focus on a broader measure of teacher turnover by jointly considering 2nd cycle teachers from all subjects. Only the main specification will be estimated, as it is not possible to include school-by-year, or student and year fixed effects in a regression where the independent variable is measured at school-year level. In this way, we are analyzing whether students in schools with higher turnover rates of 2nd cycle teachers have higher or lower exam scores in Mathematics and Portuguese, holding time-varying factors specific to each subject constant. The results are presented in Table 2.

Table 2: Effect of 2nd Cycle Teacher Turnover on 6th Grade Standardized Exam Scores

	(1)
Teacher Turnover (2nd cycle)	-0.0022
	(0.0026)
Observations	$544,807$
R^2	0.463
Student Controls	✓
School Controls	✓
Year FE	
Subject-by-Year FE	✓

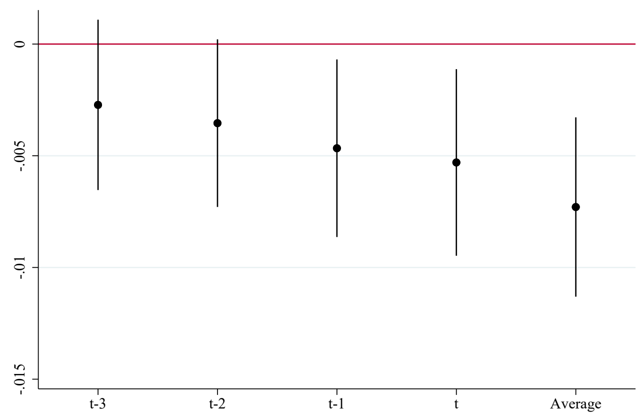
Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured by the share of 2nd cycle teachers in a school s in year t that were not there in year $t-1$, standardized by year. Results presented correspond to the estimation of the main specification (eq. 1). Student and school controls used are the same as those in Table 1. All coefficients should be interpreted in terms of standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

In contrast to what happens when measuring teacher turnover at school-subject-year level, the magnitude of the coefficient is substantially reduced and is no longer statistically significant. These results indicate that a broader measure of turnover fails to identify any effects on Portuguese and Mathematics exam scores. This suggests that scores on a particular subject are not affected by high turnover rates in other subjects. Organizational disruption owing to higher teacher turnover seems to occur within subjects. We explore this further in Section 6.5.

6.3 Lagged Effects

Up until this point, we have been evaluating the short-term effects of teacher turnover, as we are estimating the equations using contemporaneous variables. In this section, we explore dynamic effects by individually including three lags of teacher turnover. In Figure 1 we present the results of five different regressions: one for each year from $t-3$ to t and one for the average turnover rate of the last three years as the independent variable. The estimated coefficients are also shown in Table A4.

Figure 1: Effect of Teacher Turnover on 6th Grade Standardized Exam Scores: Lagged Effects



Notes: This figure plots the coefficients and corresponding confidence intervals (at the 95% level) of OLS regressions at the student-subject level. The dependent variable is the standardized 6^{th} grade exam score of student i in subject c. Each point represents the coefficient of a different regression, resulting from the estimation of the main specification for three lags of teacher turnover ($t-3$, $t-2$, and $t-1$), for teacher turnover in year t, and for the average teacher turnover in the last three years. Student and school controls used are the same as those in Table 1. All coefficients should be interpreted in terms of standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. The same results are presented in Table A4.

Teacher turnover in year t has a stronger effect on exam scores than teacher turnover in years $t-3$ to $t-1$. We see that the closer we get to the current period (t), the larger the magnitude of the coefficient, which is consistently negative across all regressions. We also see that it is significant for $t-1$ and t at a 5% level, but not for $t-2$ and $t-3$. This suggests that there are some lagged effects of teacher turnover but that they are short-lived. An increase of one standard deviation in teacher turnover in the last year ($t-1$) leads to a decrease of 0.47% of a standard deviation in exam scores in the current year, just slightly smaller than that of year t (-0.53% of a standard deviation). When we average the teacher turnover of the last three periods, we find that the effect is strong: an increase of one standard deviation in the average teacher turnover of the last three periods leads to a decrease of 0.73% of a standard deviation in exam scores. This result provides additional evidence of the existence of teacher turnover lagged effects[25].

Overall, we present evidence that past teacher turnover is related to current student achievement, although this effect is concentrated mostly on the previous and current years. The short-lived lagged effects of teacher turnover identified could be interpreted in several ways. As teacher turnover in year $t-3$ does not have a significant effect on exam scores, the disruption caused is unlikely to be caused by enduring changes in teacher workforce characteristics. Thus, one possible explanation for the prevalence of the lagged effects mostly in period $t-1$ is the higher turnover rates observed for the 5th grade compared with the 6th grade (see Figure A5). Given that we measured student achievement in the 6th grade, a higher turnover in the 5th would indicate a higher turnover in year $t-1$ for the students we are observing at t.

6.4 Heterogeneity Analysis

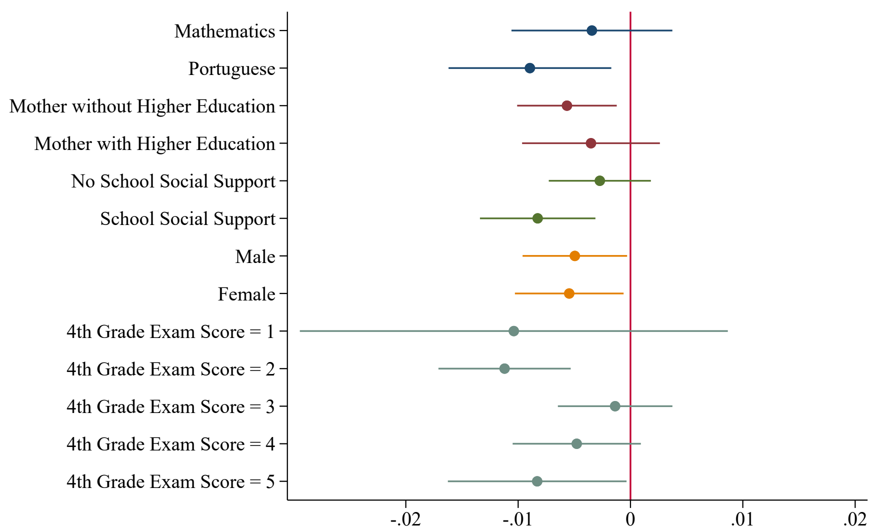
The average effects of teacher entry rates may hide substantial heterogeneity, as students and schools with different characteristics may be differently affected by turnover. In this section, we disentangle the marginal effects of teacher turnover across student characteristics (Section 6.4.1), the social composition of the school (Section 6.4.2), and the teacher workforce characteristics (Section 6.4.3) by including interaction terms in the main specification.

[25] In Table A5 we present the dynamic effects of teacher turnover, including all lags in the same regression.

6.4.1 Student Characteristics

To examine student heterogeneity, we include interaction terms between the main explanatory variable (standardized teacher turnover at a school-subject level) and the subject and several student characteristics, namely, mother's education, school social support, gender, and baseline exam score. Figure 2 plots the coefficients and confidence intervals for each dimension. The same coefficients are also shown in Table A6.

Figure 2: Heterogeneous Effects of Teacher Turnover on the Standardized 6$^{\text{th}}$ Grade Exam Scores: Student Characteristics



Notes: This figure plots the interaction coefficients and corresponding confidence intervals (at 95% level) of OLS regressions at the student-subject level. The dependent variable is the standardized 6$^{\text{th}}$ grade exam score of student i in subject c. Points with the same color present the coefficients of the same regression, resulting from the estimation of the main specification with an interaction term between teacher turnover and each student characteristic. The large confidence interval for the coefficient for having a score of 1 is, most likely, due to a very low share of students with that score, approximately 1% of the total. The student and school controls used are the same as those in Table 1. All coefficients should be interpreted in terms of standard deviation changes. Standard errors are clustered at class-level. The estimated coefficients are also presented in Table A6.

In all cases, the estimated effects of turnover are negative, although not always statistically significant. Comparing both subjects under analysis, we find a stronger negative effect for Portuguese than for Mathematics. Further, students whose mother does not have a higher education degree and students with school social support tend to experience heavier negative costs from higher teacher turnover. Additionally, we find that lower-achieving students, specifically those with non-passing scores in the 4^{th} grade exam (scores 1 and 2), are most adversely affected by teacher turnover in their results at the end of 6^{th} grade. Regarding gender, we do not observed relevant differences between the two coefficients.

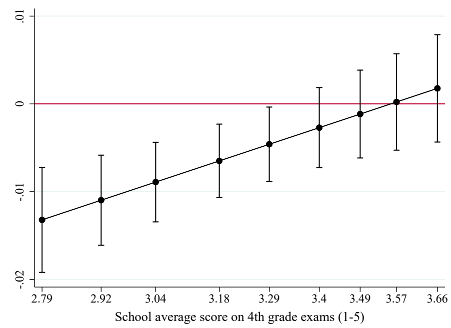
6.4.2 School Characteristics

In this section, we examine heterogeneity at the school level. We extend our specification in eq. 1 by including interaction terms between our main explanatory variable, the standardized teacher turnover rate, and school characteristics, namely, the average student achievement (measured by the mean scores of the 4^{th} grade exams, per school and year), the share of students with social support, and the share of students with higher-educated mothers. The marginal effects at each decile of the distribution of the referred variables are presented in Figure 3.

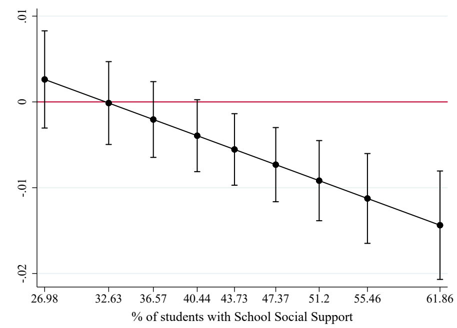
All the estimated interaction terms are statistically significant (Table A7). As Figure 3a shows, the effects of turnover in schools performing below the median (first five deciles) are negative and statistically significant. For a school in the 10^{th} percentile of the average achievement distribution (average score: 2.79), a one standard deviation increase in teacher turnover may decrease exam scores by 1.3% of a standard deviation. This outcome is in accordance with the findings of Ronfeldt et al. (2013) and Hanushek et al. (2016) that students from lower-performing schools are more affected by turnover.

As expected, the magnitude of the effect also differs between more and less socially disadvantaged schools. In Figure 3b, we see that schools with a share of students with school social support above the median experience a negative and statistically significant effect from teacher turnover, whereas for those below the median, no effect was detected. In particular, for a school from the 90^{th} percentile of the distribution (61.86% of students with school social support), an extra standard deviation in teacher turnover decreases exam scores by

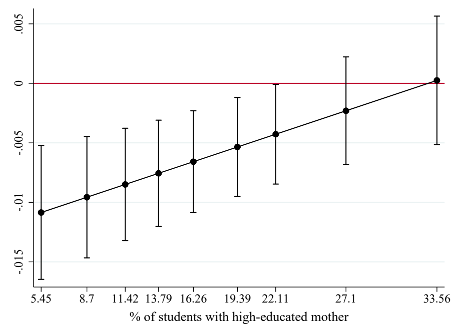
Figure 3: Heterogeneous Effects of Teacher Turnover on the Standardized 6th Grade Exam Scores: School Characteristics



(a) School Average Achievement



(b) Share of Students with School Social Support



(c) Share of Students with Higher-Educated Mothers

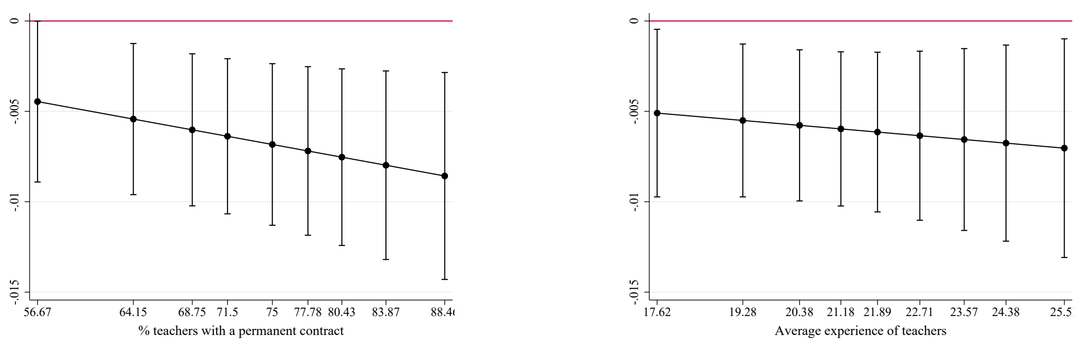
Notes: This figure presents the estimated marginal effects of teacher turnover on the standardized 6th grade exam scores, across the distribution of the following variables: school average achievement, the share of students with school social support, and the share of students with higher-educated mothers. Furthermore, within-year teacher turnover covariates are kept at their means. The results correspond to the estimation of the main specification (eq. 1). The horizontal axis corresponds to the 10 deciles of the distribution of the variables and the vertical axis corresponds to the standardized effect. The confidence level used was 95%.

1.4% of a standard deviation. Accordingly, in Figure 3c, we see that schools with lower concentrations of college-educated mothers, tend to be those in which the effect of teacher turnover is negative and stronger. For a school with only 5.45% of students whose mothers have a higher education degree (10th percentile), an increase of one standard deviation in turnover reduces exam scores by 1.1% of a standard deviation, whereas for a school on the 90th percentile of the distribution, the effect is not statistically different from zero. This indicates that teacher turnover tends to impose higher costs on students in more disadvantaged schools.

6.4.3 Teacher Workforce Characteristics

Schools may differ substantially in terms of the composition of the teacher workforce. For example, one would expect that a more experienced teacher workforce would have more tools and be better prepared to deal with the entrance of new teachers. Ultimately, this could be reflected in how students are affected by teacher mobility. With this in mind, we proceed to analyze whether the effect of teacher turnover differs between schools with a higher or lower percentage of teachers with permanent contracts, and between schools with a more or less experienced teacher workforce, by including interactions terms between those variables and the turnover variable. The results are shown in Figure 4 and the corresponding coefficients are presented in Table A7.

Figure 4: Heterogeneous Effects of Teacher Turnover on the Standardized 6th Grade Exam Scores: Teacher Workforce Characteristics



(a) Teachers with a Permanent Contract (b) Average Teacher Experience

Notes: This figure presents the estimated marginal effects of teacher turnover on the standardized 6th grade exam scores across the distribution of the following variables: share of teachers with a permanent contract and average teacher experience in years. Furthermore, within-year teacher turnover covariates are kept at their means. The results presented correspond to the estimation of the main specification (eq. 1). The horizontal axis corresponds to the 10 deciles of the distribution of the variables and the vertical axis corresponds to the standardized effect. The confidence level used was 95%.

The effect of turnover is negative across all the distributions. Contrary to what was expected, we find that schools with higher shares of permanent-contract teachers or schools with more experienced professionals show a stronger effect of teacher turnover. However, the difference between schools of the first and last deciles of both distributions is very small, approximately 0.2 to 0.3 p.p., and the estimated interaction term coefficients are not statistically significant, as shown in columns 4 and 5 of Table A7 of the Appendix. This suggests that there are no significant differences in the effect of turnover on student achievement between schools with more or less experienced teachers or between schools with more or less teachers with long-term contracts.

To further explore whether turnover among teachers with different types of contracts is important to determine the effect of turnover, we estimated the model with the turnover variable calculated for teachers with a short-term (ST) contract or for teachers with a long-term (LT) contract[26]. Table 3 presents the estimation results for both the complete time period under analysis and specifically for the year 2013/14. We choose to look at the results when considering only the year 2013/14, once the quadrennial internal process of teacher allocation had occurred in that year, which resulted in a notable spike of teacher turnover in our sample for both ST- and LT-contract teachers (see Figure A1).

Table 3 shows that the negative effect of turnover on exam scores is exclusive to short-term contract teachers, particularly for the one-year period, when there are not as many schools with zero turnover of LT-contract teachers[27]. The positive effect found for the turnover of long-term contract teachers, namely, the one in 2013/14 when these teachers were allowed to change schools, could be explained by the fact that the schools were replacing the teachers who wished to leave with new teachers who applied to the schools.

[26]See Section 3 for a detailed explanation of both contract types.

[27]The main specification of the model (as per the one in column 6 of Table 1) was re-estimated for only the year 2013/14, and a coefficient of -0.0020 with no statistical significance was found. This result is consistent with that of Table 3, as we find opposing signs for ST- and LT-contract teacher turnover.

Table 3: Effect of Teacher Turnover on 6th Grade Standardized Exam Scores: Type of Teacher Contract

	(2011/12 - 2014/15)		(2013/14)	
	ST contract	LT contract	ST contract	LT contract
Teacher Turnover	-0.0103^{***}	0.0018	-0.0170^{***}	0.0089^{**}
	(0.0021)	(0.0019)	(0.0044)	(0.0044)
Observations	544,807	544,807	131,973	131,973
R^2	0.463	0.463	0.442	0.442
Student Controls	✓	✓	✓	✓
School Controls	✓	✓	✓	✓
Subject-by-Year FE	✓	✓		
Subject FE			✓	✓

Notes: The table presents OLS regressions at the student-subject level. Regressions of columns 1 and 2 encompass the period 2011/12 to 2014/15 and regressions of columns 3 and 4 focus only on the year of the teacher turnover spike (2013/14). The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t that were not there in year $t-1$, standardized per subject-year groups. In columns 1 and 3, we consider the turnover rate of teachers with a short-term (ST) contract, and in columns 2 and 4 that of long-term (LT) contract teachers. Student and school controls used are the same as those in Table 1. All coefficients should be interpreted in terms of standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

6.5 Robustness Checks

Our estimates are robust to the inclusion of sets of different controls and fixed effects. However, in Section E of the Appendix we present four additional robustness checks to our main specifications. First, we estimate potential non-linear effects of teacher turnover on students' exam scores by adding a quadratic term to the model. The results are presented in Table A8. Both coefficients of our preferred specification (column 6) are statistically significant, which suggests that, although small, there may be some non-linearity. In Figure A6, we see that the effect is negative at each decile, but is stronger for schools with low levels of teacher turnover. For a student from a school in the 10th percentile, increasing teacher turnover by one standard deviation decreases exam scores by 1.6% of a standard deviation, but in a school in the 90th percentile, the marginal effect of turnover is no longer significant.

Second, we estimated our regressions using an alternative measure of teacher turnover. As of now, teacher turnover was calculated based on the first month the teacher appeared in our database, within school-year groups. We recalculated turnover such that the teacher entries considered were all based on a specific month (i.e. January and June) to investigate whether estimates would differ[28]. As the coefficients (Tables A10 and A11) are very similar to our main results (Table 1), we are confident that the effects of teacher turnover are independent of the way we measure it.

Third, we explore whether the results change if the teacher turnover variable is not standardized, and if the standardization is only by year or only by subject. In Table A12, we present the coefficients that result from the estimation of the main specification for each of these three cases. Our original estimation results are robust to the standardization approach used, as the coefficients of Table A12 are very similar to those of our main result. From column 1, we see that an increase of 10% in teacher turnover leads to a decrease of 0.3% of a standard deviation in exam scores[29]. From columns 2 and 3, an increase of one standard deviation in teacher turnover leads to a decrease of 0.52% of a standard deviation in exam scores. In other words, an increase of 10% in teacher turnover leads to a decrease of 0.25%-0.32% of a standard deviation in exam scores.

The fourth robustness check derives from the results of Table 2, when the turnover rate includes all 2nd cycle teachers. We saw that the effect was not statistically significant, suggesting that the disruptive effect from the entrance of new teachers occurs mainly within subject-specific teacher teams. To test this hypothesis, we perform a placebo test by regressing Mathematics exam scores on Portuguese teacher turnover, and vice-versa. As Table A13 shows, this placebo test showed no statistically significant effect. The results for the regression with teacher turnover for the whole 2nd cycle (Table 2) are therefore reinforced. The

[28]The limitation of this alternative measure of turnover is that if a teacher attended a school in a particular year, but has no entry in the database for these specific months, he/she will not be considered when calculating turnover. The advantage of this is that we are observing each teacher at the same moment in time.

[29]Teacher turnover is a percentage measured from 0 to 100.

effect of teacher turnover appears to be subject-specific, with exam scores in a particular subject being affected solely by turnover within that same subject.

7 Discussion and Conclusions

Findings from previous studies on the effects of teacher turnover on student achievement (all focused on the US and UK contexts) may not necessarily extend to more rigid and centralized teacher allocation systems like the Portuguese one. If a centralized system may bring a higher degree of predictability in teacher allocation rules, the lack of school autonomy in choosing the workforce or defining the profile of teachers may exacerbate the negative effects previously found. We thus contribute to the limited literature on this topic and provide evidence for Portugal. Our study draws a conclusion consistent with previous research: increasing teacher turnover is associated with a small decrease in students' achievement, on average.

Two findings result from the estimation of our main models: first, the effect of turnover is largely explained by the organizational disruption caused in schools[30]; second, by measuring turnover at subject-level and in the 6th grade, we conclude that this disruptive effect occurs mainly within subject-specific teacher teams, as Mathematics and Portuguese exam scores do not seem to be affected by the entrance of new teachers in other subjects. Furthermore, previous measures of teacher turnover, especially at $t-1$, seem to affect current student attainment. This behavior may be related to the higher entry rates in the 5th grade, suggesting that schools take some time to adjust.

Teacher turnover does not affect all students equally. Two main conclusions can be drawn from the heterogeneity analysis across student characteristics. First, we detect a stronger negative effect in Portuguese than in Mathematics. Second, students who benefit from school social support, students with a low-educated mother, and those with lower ability levels are

[30] Ronfeldt et al. (2013) also shows that turnover negatively affects students of teachers who stay in the school for two consecutive years, suggesting a disruptive effect of turnover beyond compositional changes in teacher quality.

negatively affected by teacher turnover[31]. In fact, previous research has shown that there is a strong association between teacher mobility and student characteristics (Boyd et al., 2013; Allen et al., 2018; Jackson, 2009). Analyzing heterogeneity at a more aggregated level, we find the low-achieving and socially disadvantaged schools to be the most affected by teacher turnover. This suggests that students from these schools not only experience higher turnover rates in their schools, on average (see Section 4.2), but that the negative consequences of higher turnover are also more pronounced for them. Regarding the characteristics of the teacher workforce, our comparison of the effects of turnover between short-term and long-term contract teachers showed that the negative effect was generated by the former.

Our findings have substantial policy implications for an educational system with a centralized teacher recruitment model. Albeit the small magnitude, high teacher turnover rates have detrimental effects on students. This highlights the importance of implementing targeted policies that promote continuity among school-subject-level teams over time, to ensure stability within the teacher workforce. It also suggests the importance of proper induction teacher policies to reduce the disruptive effects caused by the entrance of new teachers. Disadvantaged schools bear the largest brunt of turnover, with low-achieving and economically disadvantaged students experiencing the highest costs. It is therefore imperative to develop policies specifically tailored to these schools, perhaps through the establishment of incentive structures for teachers working in such contexts[32].

[31] Similarly, Gibbons et al. (2021) finds differences regarding students' ability, by showing that those with a medium baseline score were the most affected by turnover, but did not find any differences regarding gender.

[32] Clotfelter et al. (2008) studied the effects of a policy intervention in North Carolina, where the state awarded a bonus to teachers working in high-poverty and/or low-achieving schools, and found that the mean teacher turnover (measured by the teacher exit rate) was reduced by 17%.

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A Portuguese Educational System

Table A1: Teacher Recruitment Groups within Education Levels

Education Level	Recruitment Groups
1st Cycle of Basic Education	Basic Education - 1st cycle
2nd Cycle of Basic Education	Mathematics and Natural Sciences Moral and Religious Education Musical Education Physical Education Portuguese and English Portuguese and French Portuguese and Social Studies/History Visual Technological Education
3rd Cycle of Basic Education and Secondary Education	Agricultural Sciences Biology and Geology Computing Economics and Accounting Electrical Engineering English French Geography German History Mathematics Moral and Religious Education Music Philosophy Physical Education Physicochemical Portuguese Latin and Greek Spanish Technological Education Visual Arts

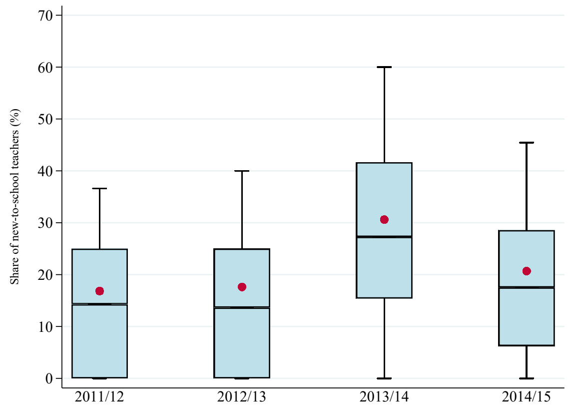
B Descriptive Statistics

Table A2: Summary Statistics

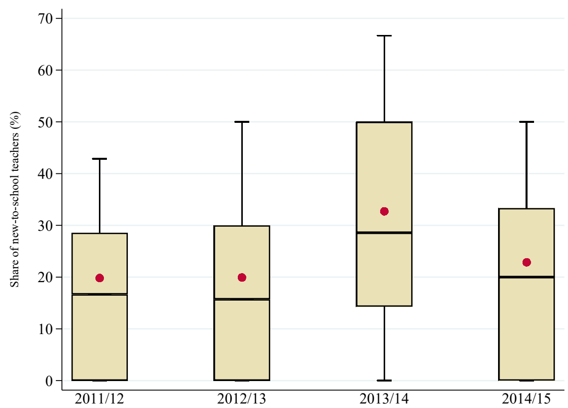
Variable	Mean	Std. Dev.	Min.	Max.	N
Measures at subject-school-year level					
Teacher turnover (%)	22.64	22.03	0	100	5,346
Teacher turnover of ST-contract (%)	14.72	17.23	0	100	5,346
Teacher turnover of LT-contract (%)	7.92	15.51	0	100	5,346
Measures at school-year level					
Teacher turnover of 2nd cycle (%)	22.61	17.11	0	100	2,671
Female teachers (%)	72.16	11.29	0	100	2,671
Teachers with permanent contract (%)	72.16	16.70	0	100	2,671
Average teachers' experience (years)	21.25	3.87	2.5	33.67	2,671
# Teachers per school	33.77	35.81	2	380	2,671
Female students (%)	49.11	6.98	0	100	2,733
Students with school social support (%)	47.10	15.45	0	100	2,733
Students with higher-educated mother (%)	15.86	11.24	0	70.86	2,733
# Students per school	238.13	260.50	10	2925	2,733
Measures at student level					
6th grade exam score (p/ subject)	53.62	20.35	0	100	650,543
4th grade exam score (p/ subject)	3.24	0.91	1	5	550,799
Female	0.49	0.50	0	1	650,543
Age	11.43	0.56	9.10	14.00	650,543
School social support (higher level)	0.23	0.42	0	1	650,543
School social support (lower level)	0.21	0.40	0	1	650,543
Portuguese nationality	0.98	0.15	0	1	650,543
Having a computer at home	0.70	0.46	0	1	650,543
Having access to internet at home	0.60	0.49	0	1	650,543
Mother with higher education	0.18	0.39	0	1	650,543
Father with higher education	0.12	0.33	0	1	650,543
Mother with Portuguese nationality	0.95	0.22	0	1	650,543
Father with Portuguese nationality	0.95	0.22	0	1	650,543
Mother is unemployed	0.13	0.34	0	1	650,543
Father is unemployed	0.08	0.27	0	1	650,543
Individual turnover	0.48	0.50	0	1	650,543

Notes: Variables measured at school-year level have different number of observations (2,671 or 2,733) given they are constructed from two different datasets - one for teachers and another for students.

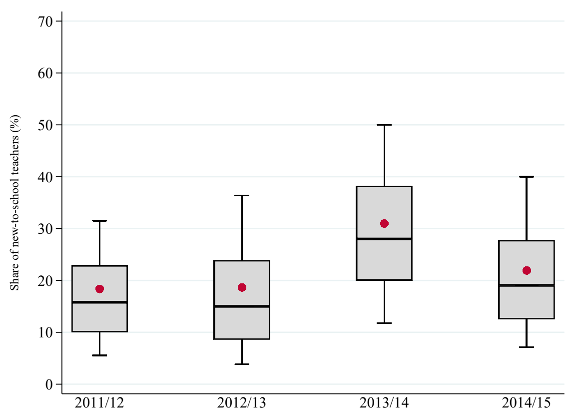
Figure A1: Annual Distribution of Teacher Turnover (2011/12 - 2014/15)



(a) Portuguese Teachers



(b) Mathematics Teachers



(c) 2^{nd} cycle Teachers

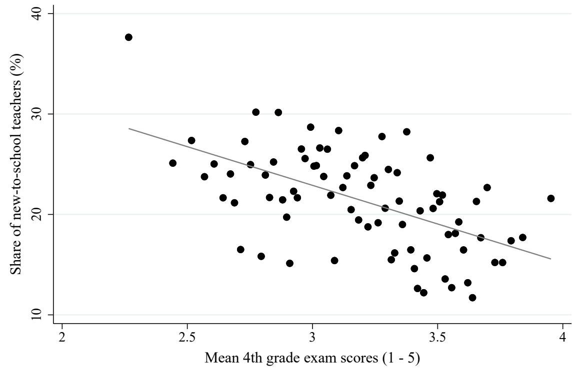
Notes: Teacher turnover is measured at a school level. The red dot represents the average rate in each year. The top line of each box represents the 90^{th} percentile of the distribution. The following lines represent the 75^{th}, the 50^{th}, the 25^{th} and the 10^{th}, respectively. In 2013/14 there was internal process of teacher allocation.

Table A3: Summary statistics of Teacher Turnover per Subject

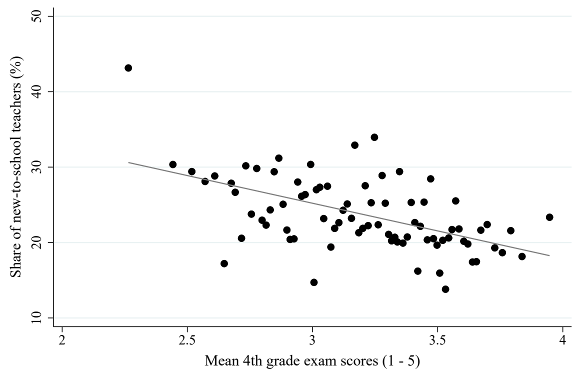
Year	Subject	Mean (p.p.)	Stand. Dev. (p.p.)	N
2011/12	Mathematics	19.95	16.97	87,730
	Portuguese	17.77	15.2	87,462
2012/13	Mathematics	19.01	17.43	80,524
	Portuguese	17.35	16.58	80,764
2013/14	Mathematics	31.34	21.1	78,158
	Portuguese	30.79	19.98	78,208
2014/15	Mathematics	21.62	17.55	75,169
	Portuguese	20.02	16.31	75,241

Notes: The table provides the mean and standard deviations of teacher turnover for each subject-year group.

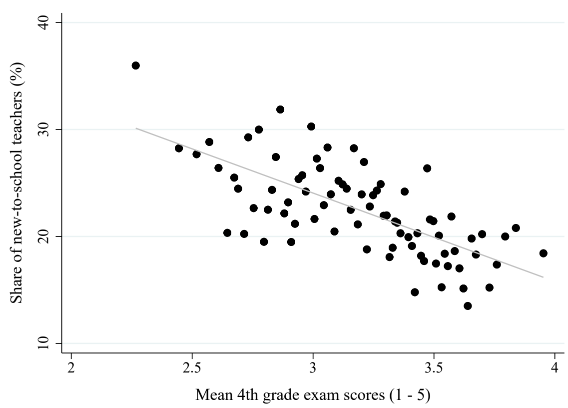
Figure A2: Correlation between Teacher Turnover and Average School Achievement



(a) Portuguese Teachers



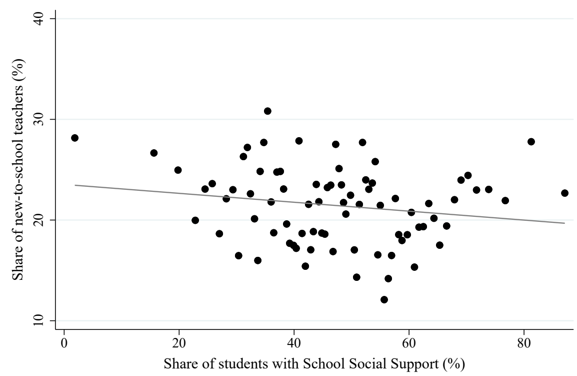
(b) Mathematics Teachers



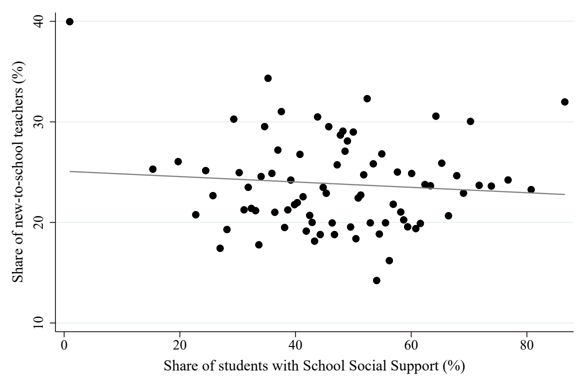
(c) 2nd Cycle Teachers

Notes: Correlations plot between teacher turnover and average achievement at school-year level. The horizontal axis corresponds to the mean 4th grade exam scores (1-5) and the vertical axis to the share of new-to-school teachers of Portuguese, Mathematics and entire 2nd cycle, respectively. The correlation for Portuguese is -0.133 (2672 observations), for Mathematics it is -0.116 (2669 observations) and for the 2nd cycle is -0.178 (2671 observations).

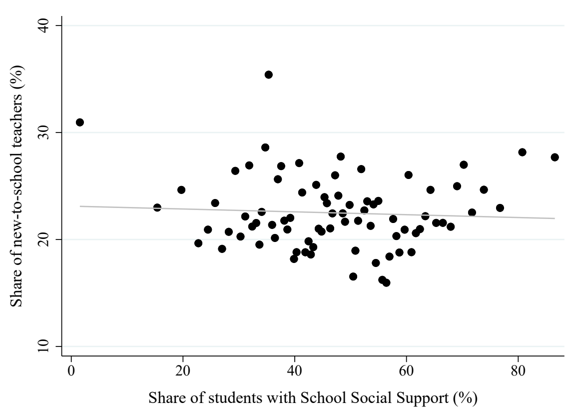
Figure A3: Correlation between Teacher Turnover and Share of Students with School Social Support



(a) Portuguese Teachers



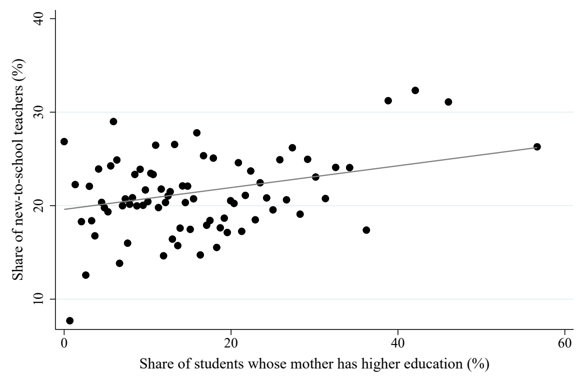
(b) Mathematics Teachers



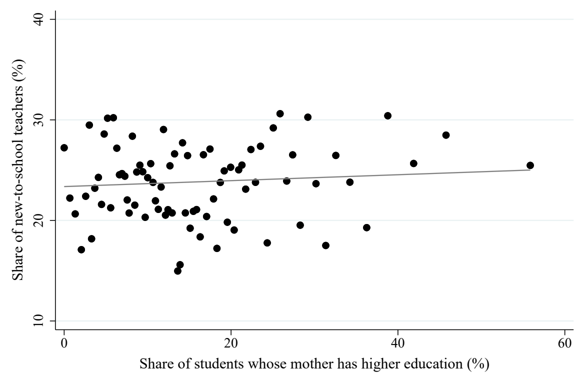
(c) 2^{nd} Cycle Teachers

Notes: Correlations plot between teacher turnover and average achievement at school-year level. The horizontal axis corresponds to the share of students with school social support and the vertical axis to the share of new-to-school teachers of Portuguese, Mathematics and entire 2^{nd} cycle, respectively. The correlation for Portuguese is -0.012 (2674 observations), for Mathematics it is -0.032 (2675 observations) and for the 2^{nd} cycle is -0.018 (2671 observations).

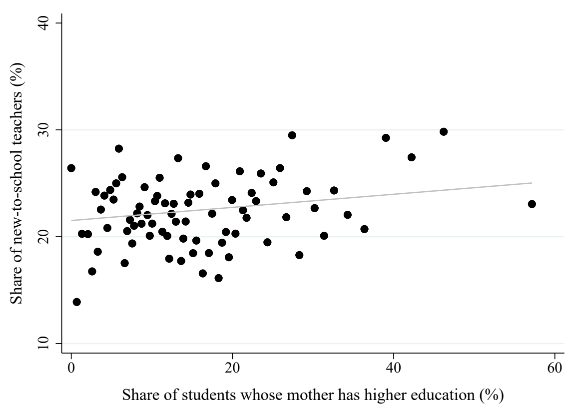
Figure A4: Correlation between Teacher Turnover and Share of Students with Higher-educated Mother



(a) Portuguese Teachers



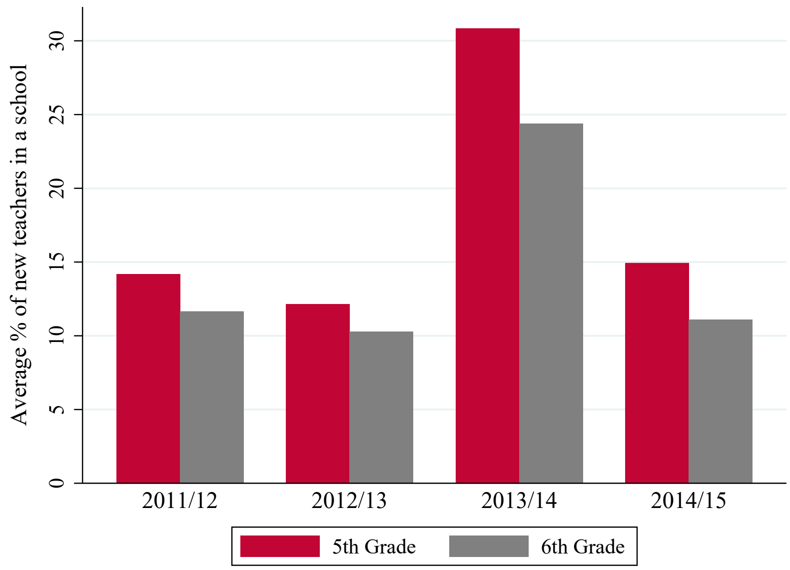
(b) Mathematics Teachers



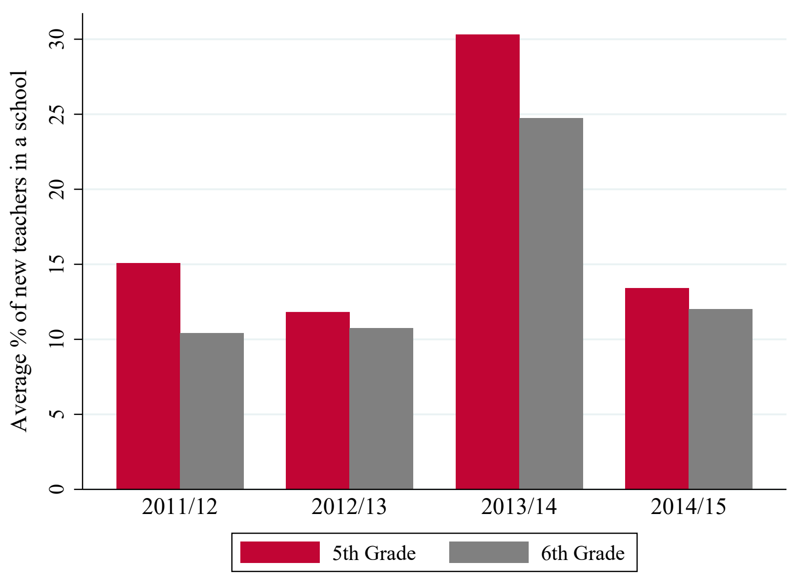
(c) 2^{nd} Cycle Teachers

Notes: Correlations plot between teacher turnover and average achievement at school-year level. The horizontal axis corresponds to the share of students with higher-educated mother and the vertical axis to the share of new-to-school teachers of Portuguese, Mathematics and entire 2^{nd} cycle, respectively. The correlation for Portuguese is 0.041 (2674 observations), for Mathematics it is 0.062 (2675 observations) and for the 2^{nd} cycle is 0.014 (2671 observations).

Figure A5: Share of new-to-school teachers in the 5th and 6th grades



(a) Portuguese Teachers



(b) Mathematics Teachers

Notes: The plots present the average share of new-to-school teachers for each grade (5th and 6th), per subject.

C Lagged Effects

Table A4: Impact of Teacher Turnover on 6th Grade Standardized Exam Scores: Lagged Effects

	$t-3$	$t-2$	$t-1$	t	Average
Teacher turnover	-0.0027	-0.0035^{*}	-0.0047^{**}	-0.0053^{**}	-0.0073^{***}
	(0.0019)	(0.0019)	(0.0020)	(0.0021)	(0.0021)
Observations	531,610	535,765	540,213	544,807	531,610
R^2	0.462	0.462	0.463	0.463	0.462
Student Controls	✓	✓	✓	✓	✓
School Controls	✓	✓	✓	✓	✓
Subject-by-year FE	✓	✓	✓	✓	✓

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Each column represents a different regression. In column 1, the independent variable is the teacher turnover rate of year $t-3$, in column 2 the rate of year $t-2$, in column 3 the rate of year $t-1$, in column 4 the rate of year t and in column 5 the average rate between years $t-3$ to $t-1$. Results presented correspond to the estimation of the main specification (eq. 1). Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table A5: Impact of Dynamic Teacher Turnover on 6th Grade Standardized Exam Scores

	(1)
Teacher turnover	-0.0071^{***}
	(0.0024)
Teacher turnover (t-1)	-0.0051^{**}
	(0.0022)
Teacher turnover (t-2)	-0.0047^{**}
	(0.0021)
Teacher turnover (t-3)	-0.0011
	(0.0020)
Observations	531,610
R^2	0.462
Student Controls	✓
School Controls	✓
Subject-by-year FE	✓

Notes: The table presents OLS regression at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Four measures of teacher turnover are included in this regression: teacher turnover at year t and 3 lags. Results presented correspond to the estimation of the main specification (eq. 1). Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

D Heterogeneity Analysis

Table A6: Heterogeneous Effects of Teacher Turnover on Standardized 6[th] Grade Exam Scores: Student Characteristics

VARIABLES	(1) Subject	(2) Mother Educ.	(3) SSS	(4) Gender	(5) Baseline Score
Turnover X Mathematics	-0.0034				
	(0.0037)				
Turnover X Portuguese	-0.0090^{**}				
	0.0037				
Turnover X No High. Educ.		-0.0057^{**}			
		(0.0023)			
Turnover X High. Educ.		-0.0035			
		(0.0031)			
Turnover X No-SSS			-0.0027		
			(0.0023)		
Turnover X SSS			-0.0083^{***}		
			(0.0026)		
Turnover X Male				-0.0050^{**}	
				(0.0024)	
Turnover X Female				-0.0055^{**}	
				(0.0025)	
Turnover X Score = 1					-0.0104
					(0.0097)
Turnover X Score = 2					-0.0112^{***}
					(0.0030)
Turnover X Score = 3					-0.0014
					(0.0026)
Turnover X Score = 4					-0.0048
					(0.0029)
Turnover X Score = 5					-0.0083^{**}
					(0.0041)
Observations	544,807	544,807	544,807	544,807	544,807
R^2	0.478	0.463	0.462	0.462	0.462
Student Controls	✓	✓	✓	✓	✓
School Controls		✓	✓	✓	✓
School-by-year FE	✓				
Subject-by-year FE		✓	✓	✓	✓

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6[th] grade exam score of student i in subject c. Teacher turnover is measured by the share of teachers of subject c, in school s, in year t that were not there in year $t-1$, standardized per subject-year groups. Each column presents the estimation results from a regression with the interaction between teacher turnover and a variable/student characteristic: the subject in column 1; mother's education level in column 2; school social support eligibility in column 3; gender in column 4; and 4[th] grade exam score in column 5. Student and school controls included are the same used in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Table A7: Heterogeneous Effects of Teacher Turnover on Standardized 6th grade Exam Scores: School Characteristics

VARIABLES	(1) Average Achiev.	(2) SSS (%)	(3) Higher Educ. Mother (%)	(4) Perm. Contract (%)	(5) Average Exper.
Teacher turnover	−0.0613***	0.0158***	−0.0130***	0.0029	−0.0008
	(0.0167)	(0.0058)	(0.0034)	(0.0061)	(0.0086)
Turnover X Aver. Achiev.	0.0172***				
	0.0051				
Turnover X SSS		−0.0005***			
		(0.0001)			
Turnover X Higher Educ.			0.0004***		
			(0.0001)		
Turnover X Perm. Contract				−0.0001	
				(0.0001)	
Turnover X Average Exper.					−0.0002
					(0.0004)
Observations	544,807	544,807	544,807	544,807	544,807
R^2	0.478	0.463	0.462	0.462	0.462
Student Controls	✓	✓	✓	✓	✓
School Controls	✓	✓	✓	✓	✓
Subject-by-year FE	✓	✓	✓	✓	✓

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured by the share of teachers of subject c, in school s, in year t that were not there in year $t-1$, standardized per subject-year groups. Each column presents the estimation results from a regression with the interaction between teacher turnover and a school-level variable: the average achievement in column 1; the share of students with school social support in column 2; the share of students with a higher-educated mother in column 3; the share of teachers with a permanent contract in column 4; and the average teachers' experience variable in column 5. Student and school controls included are the same used in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

E Robustness Checks

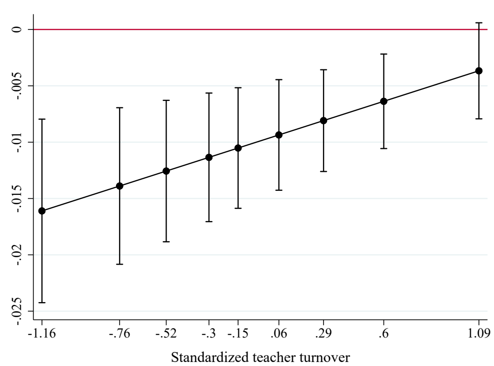
E.1 Non-Linear Effects

Table A8: Impact of Teacher Turnover per School-Subject on 6th grade Standardized Exam Scores: Quadratic Regressions

	(1)
Teacher turnover	-0.0101^{***}
	(0.0026)
(Teacher turnover)^2	0.0028^{***}
	(0.0009)
Observations	544,807
R^2	0.463
Student Controls	✓
School Controls	✓
Subject-by-year FE	✓

Notes: The table presents OLS quadratic regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t that were not there in year $t-1$, standardized per subject-year groups. Student and school controls included are the same used in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

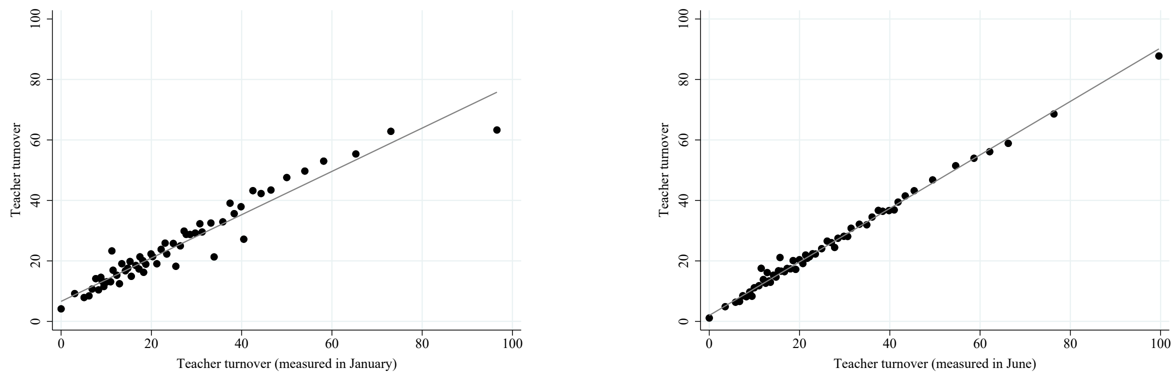
Figure A6: Non-linear Marginal Effects of Teacher Turnover on Standardized 6th grade Exam Scores



Notes: This figure presents the estimated marginal effects of teacher turnover on the standardized 6th grade exam scores from the regression estimated in Table A8. All other covariates are kept at their means. The horizontal axis corresponds to the 10 deciles of the standardized teacher turnover distribution and the vertical axis the standardized non-linear effect. The confidence level used is of 95%.

E.2 Alternative Measures of Teacher Turnover

Figure A7: Binscatter Plot Between Original Measure of Teacher Turnover and Alternative Measures



(a) Turnover measured in January

(b) Turnover measured in June

Notes: The plots presents the original measure of teacher turnover against the alternative measures, grouped in 100 equal-size bins.

Table A9: Correlations Table

	Teacher turnover	Teacher turnover (January)	Teacher turnover (June)
Teacher turnover	1.000		
Teacher turnover (January)	0.804	1.000	
Teacher turnover (June)	0.934	0.840	1.000

Notes: Correlation coefficients table. The following variables included: teacher turnover measured at the first month the teacher appears in a school-year group, teacher turnover measured in January, and teacher turnover measured in June. Variables are measured at student level. Number of observations = 636,834.

E.2.1 Teacher Turnover Measured in January

Table A10: Impact of Teacher Turnover per Subject on 6th grade Standardized Exam Scores: Measured in January

	(1)	(2)	(3)	(4)	(5)	(6)
Teacher turnover	-0.0179^{***}	-0.0044^{*}	-0.0048^{**}	-0.0122^{***}	-0.0059^{*}	-0.0049^{**}
	(0.0032)	(0.0024)	(0.0022)	(0.0027)	(0.0034)	(0.0021)
Observations	637,516	540,267	540,267	632,480	540,267	540,267
R^2	0.000	0.440	0.454	0.835	0.478	0.463
Student Controls		✓	✓		✓	✓
School Controls		✓	✓			✓
Year FE			✓	✓		
School-by-year FE					✓	
Subject-by-year FE						✓
Student FE				✓		

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t (in January) that were not there in year $t-1$, standardized per subject-year groups. Results for the main specification (eq. 1) are presented in column 6. Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

E.2.2 Teacher Turnover Measured in June

Table A11: Impact of Teacher Turnover per Subject on 6th grade Standardized Exam Scores: Measured in June

	(1)	(2)	(3)	(4)	(5)	(6)
Teacher turnover	-0.0218^{***}	-0.0058^{**}	-0.0066^{***}	-0.0118^{***}	-0.0063^{**}	-0.0068^{***}
	(0.0031)	(0.0023)	(0.0022)	(0.0025)	(0.0031)	(0.0021)
Observations	641,316	543,447	543,447	636,688	543,447	543,447
R^2	0.000	0.440	0.453	0.835	0.478	0.463
Student Controls		✓	✓		✓	✓
School Controls		✓	✓			✓
Year FE			✓	✓		
School-by-year FE					✓	
Subject-by-year FE						✓
Student FE				✓		

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t (in June) that were not there in year $t-1$, standardized per subject-year groups. Results for the main specification (eq. 1) are presented in column 6. Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

E.3 Standardization of Teacher Turnover

Table A12: Impact of Teacher Turnover per Subject on 6th grade Standardized Exam Scores: Standardization Strategies

	(1) No Standardization	(2) Standardization by Year	(3) Standardization by Subject
Teacher turnover	-0.0003^{**}	-0.0052^{**}	-0.0052^{**}
	(0.0001)	(0.0021)	(0.0022)
Observations	544,807	544,807	544,807
R^2	0.463	0.463	0.463
Student Controls	✓	✓	✓
School Controls	✓	✓	✓
Subject-by-year FE	✓	✓	✓

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c. Teacher turnover is measured as the share of teachers of subject c in a school s in year t that were not there in year $t-1$. In column 1 turnover is not standardized - it ranges from 0 to 100, in column 2 turnover is standardized per year, and in column 3 turnover is standardized per subject. Results presented correspond to the estimation of the main specification (eq. 1). Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

E.4 Placebo Test

Table A13: Impact of Teacher Turnover per Subject on 6th grade Standardized Exam Scores: Placebo Test

	(1)
Teacher turnover	-0.0017
	(0.0022)
Observations	$542,458$
R^2	0.462
Student Controls	✓
School Controls	✓
Subject-by-year FE	✓

Notes: The table presents OLS regressions at the student-subject level. The dependent variable is the standardized 6th grade exam score of student i in subject c_1. Teacher turnover is measured as the share of teachers of subject c_2 in a school s in year t that were not there in year $t-1$, standardized per subject-year groups. Results presented correspond to the estimation of the main specification (eq. 1). Student and school controls used are the same as the ones included in Table 1. All coefficients should be interpreted in standard deviation changes. Standard errors are clustered at class-level and presented in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

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