Going the distance?

The effects of commute distance on teacher body composition of schools

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Abstract

In this study, I estimate the causal effect of increased commute distance to schools on how well they can attract teachers. I identify the causal effect of an increase in commute distance using a natural experiment in which more than one-third of Danish teacher training colleges(TTCs) closed, where some schools experienced an increase in distance to the nearest TTC while other schools did not. I hypothesize that the increase in distance to the nearest TTC would have led to an increase in commute distance, particularly for newly graduated teachers, and that this would have adverse effects on schools' ability to attract teachers. I estimate the effects using a differences-in-differences design, accounting for the staggered rollout of TTC closures using newly developed estimators. While proximity to the nearest TTC is mentioned in the scholarly literature as a factor impacting schools' attractiveness to teachers, the results in this paper suggest that the effects are inconsequential. The results of this study suggest that 1) The hypothetical effects of commute distance are likely overestimated in the literature on teacher mobility and recruitment, and 2) The willingness of teachers to commute is likely underestimated. As such, the results of this study provide evidence that substantial increases in commute distance are required to produce changes in teacher composition

1 Introduction

Teachers are generally thought of as one of the most important contributors to childrens' learning during the time they spend in school(Rivkin et al., 2005). Teachers' role is indispensable, given that they provide the primary delivery of the curriculum that students are expected to master by the time they graduate. While teachers play a central role in students' learning, teacher mobility may play a role in exacerbating educational inequality. If teachers, especially skilled teachers, are more prone to be attracted by schools with academically high-performing students and vice-versa for schools with high-needs students, such a pattern of teacher mobility will exacerbate the achievement gap between high-performing and high-needs students.

In this paper, I will investigate, using high-quality danish administrative data, the impact of commute distance on how well schools can recruit teachers, i.e., how attractive schools are to teachers. The impact of commute distance on school attractiveness is important to study for several reasons: 1) We know relatively little of the impact of commute distance on school attractiveness compared to other school characteristics, e.g., student body composition. 2) Studying the impact of commute distance on school attractiveness can

help to reveal the root causes of geographical patterns of inequality in teacher shortages and, by extension, also geographical patterns of inequality in student achievement, e.g., the rural/urban-gap in student achievement(Young, 1998; Zhang et al., 2018). 3) It may be possible to change commute distance via policy initiatives, e.g., by planning the locations of new schools near residential areas attractive to teachers or by establishing programs for teacher education in rural areas. Thus, while changing commute distance via policy initiative may be costly, it is still a feasible policy lever. At the same time, other important factors, e.g., the home learning environment of students, may be much more challenging or infeasible to address via large-scale policy initiatives.
To investigate the change in schools' attractiveness, I will use a natural experiment that involved the closure of teacher training colleges(TTCs) in Denmark during the 1980s. The closure of TTCs would result in an increased distance to the nearest TTC for some schools. While this distance would be the same for other schools. The central hypothesis in this paper is that newly graduated teachers would still, in general, be living near the TTC from which they graduated and would seek employment at schools within acceptable commuting distance. Thus, schools that experienced an increase in distance to the nearest TTC would also experience an increase in commuting distance for newly graduated teachers and would then appear less attractive to newly graduated teachers. Using a quasi-experimental design, I thus aim to estimate the causal effect of decreasing the attractiveness of schools to teachers on teacher body composition, specifically by investigating the impact of an increase in commuting distance between schools and newly graduated teachers. As such, this paper contributes to the current literature by addressing three major gaps in the literature on teacher mobility, namely *the lack of studies estimating the causal effects of non-financial factors on teacher sorting*, *the lack of evidence on long-term impacts of changes in school attractiveness* and *The lack of studies outside a US context*

In this paper, I find, as expected, that increasing the distance to the nearest TTC increases the average commute distance for teachers employed at affected schools. Further, the increase in commute distance is larger for newly graduated teachers. However, despite an increase in commute distance, an increase in distance to the nearest TTC had no demonstrable impact on teacher body composition. Further, results show that newly graduated teachers commuted longer distances and were located further away from the nearest TTC in the period following the closure of TTCs. The increased willingness of newly graduated teachers to commute longer distances and to live further away from the institutions from which they graduated likely meant that the adverse effects of TTC closures were mitigated.

A large body of research shows that highly skilled teachers are unequally distributed across schools due to both teachers' and schools' traits, such as teacher credentials(Boyd et al., 2005a; Lankford et al., 2007; Podgursky et al., 2004), school level poverty(Allen et al., 2018; Smith and Ingersoll, 2007), school level achievement(Hanushek et al., 2015; Ingersoll and May, 2012), higher proportions of ethnic minority pupils(Allen et al., 2018; Carroll et al., 2000; Falch and Strøm, 2004; Feng, 2014; Hanushek et al., 2015; Shen, 1997), higher shares of inexperienced teachers, discipline problems, and inadequate support from the administration(Ingersoll, 2007a; Shen, 1997). Evidence also suggests that teacher turnover harms student achievement(Gibbons, 2018; Henry and Redding, 2020). Previous studies also indicate that highly skilled teachers are more responsive to changes in school characteristics that might change the attractiveness of schools, e.g., student body composition(Goldhaber, 2010; Jackson, 2009). Studies also find that disadvantaged schools "inherit" low-quality teachers from other disadvantaged schools, while high-quality teachers transfer to advantaged schools. In addition, newly graduated highly skilled teachers select into advantaged schools(Krieg et al., 2015). The consequence of such a situation is a "dance of lemons"(Goldhaber, 2012; Sass et al., 2012), where highly skilled teachers move from less attractive to attractive schools while less skilled teachers move between less attractive schools, leaving disadvantaged students with fewer highly skilled teachers.

The impact of commute distance on how well schools can attract teachers has not received the same attention as other factors. Current research does however, provide evidence that commute distance is negatively associated with attracting teachers. Some studies provide a source of indirect evidence. Barbieri et al. (2010), Boyd et al. (2005b) and Jaramillo (2012) find that teachers, in general, show strong preferences for locating in their home region, or similar regions. (Reininger, 2012) offers another source of indirect evidence and shows that teachers are much less mobile than other college graduates. More directly, (Boyd et al., 2005a) finds that increasing commute distance from 0 to 6 miles leads to a 19% increase in the probability of transferring to a different school. By contrast, increasing the proportion of students that fail a compulsory 4th grade English test from 40% to 60% leads to a 14% increase in the probability of transferring to another school. (Boyd et al., 2012) find that a teacher living within a distance of 1 mile from an average urban school would still prefer to work at an average urban school compared to an average suburban school located at least 21 miles away. This is despite there being a 60 and 52 percentage point difference between the average urban and suburban school in proportion of minority students and students living in poverty, respectively, as well as urban schools offering lower salaries. Johnston (2020) estimates that an additional 10 minutes of commute is equivalent to a reduction in yearly salary of 530$. By comparison, a ten-percentage point reduction in the proportion of students living in poverty is equivalent to a 320$ increase in salary and a ten-point increase in the average percentile of performance is equivalent to an increase in salary of 550$. As such, commute distance appears to be an important factor for teachers and one that is as important as other non-pecuniary factors that have been studied more extensively.

The relation between the proximity of schools to TTCs and commute distance has only been addressed in a few studies. (Boyd et al., 2005b) investigates the importance of distance to TTC directly, finding that new teachers are 36% more likely to find their first teaching position in the region in which they obtained their last educational credential, compared to other regions. Two studies offer evidence on the importance of the proximity of schools to TTCs. (Krieg et al., 2015) find that prospect teachers complete their student teaching near the college from which they obtained their degree, and that student teaching placement is highly predictive of where newly graduated teachers find their first teaching position. Using the same data(Goldhaber et al., 2020) find that an increase in distance to the nearest TTC results in a higher proportion of newly hired teachers with alternative credentials.(Goff and Bruecker, 2017) find similar results, finding that the number of applicants for vacant positions decreases as the distance to the nearest TTC increases.

As such, research provides evidence that commute distance is an important consideration for teachers when they choose to apply for a teaching position. Further, there is also evidence that newly graduated teachers are more prone to apply for teaching positions that are in proximity to the TTC from which they graduated, and that this phenomenon is a disadvantage to schools that are not located close to a TTC.

In terms of students' academic achievement, the scholarly literature suggests that teacher mobility exacerbates existing inequalities in students' academic achievement. However, most of the results are based on observational studies in which strong assumptions are needed to estimate a causal effect of teacher mobility on student achievement(Nguyen et al., 2020). While studies applying quasi-experimental designs are more prominent in the recent literature, most of these studies focus on how financial incentives impact teacher mobility(Nguyen et al., 2020). However, in this strand of the literature, financial incentives are generally shown to have minor impacts on teacher mobility, suggesting that other factors, e.g., working conditions, are more important to teachers than financial incentives. The literature on teacher mobility generally concerns short-term impacts of teacher mobility on student achievement or of teacher mobility on school characteristics, such as working conditions. This is likely due to the lack of long-run longitudinal data in which researchers can observe and link both teachers and students over long periods. However, results suggest that teachers can have long-run impacts on students(Chetty et al., 2014), making it worthwhile to study the long-run impact of changes to school attractiveness. Lastly, the literature on teacher mobility is limited mainly to the US context. Thus, while the current literature suggests the existence of teacher mobility patterns are unfavorable to high-needs students, the degree to which these results can be replicated outside the US context is still uncertain. It is not unlikely that teacher mobility patterns may appear quite different in other institutional contexts, given that, e.g., teacher certification, wages, and teacher labor markets are likely to be regulated very differently across such contexts.

1.1 Research questions

In this paper, I will answer the following two research questions.

- How does the impact of decreasing school attractiveness via an increase in distance to nearest TTC, impact schools' ability to attract teachers, and specifically newly graduated teachers?
- How does the impact of decreasing school attractiveness via an increase in distance to nearest TTC, impact schools' ability to attract highly skilled teachers and highly skilled newly graduated teachers?

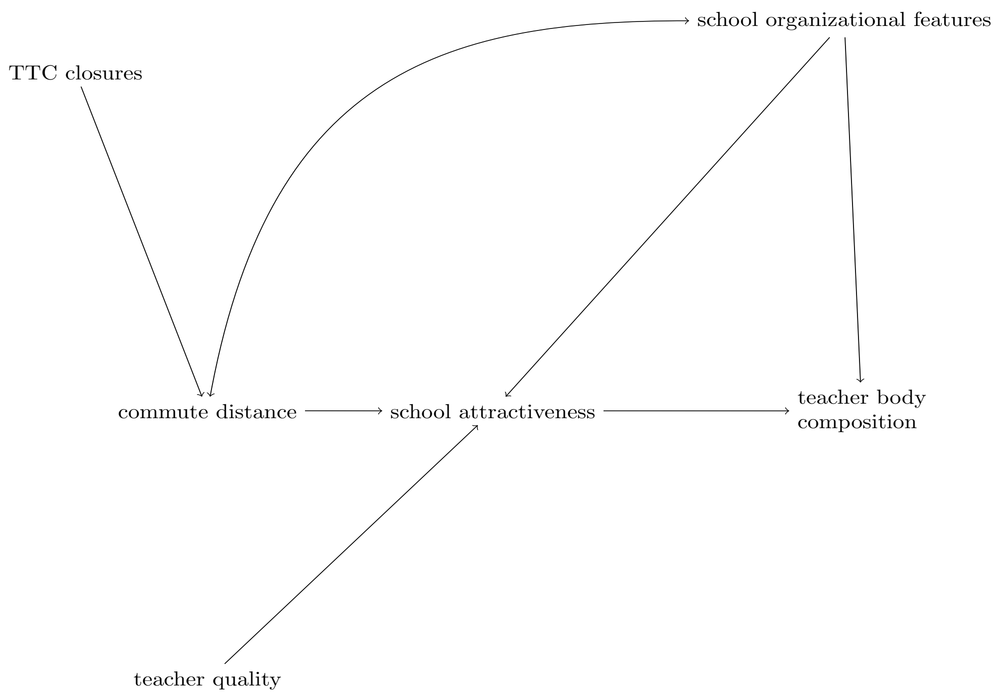
2 Theoretical framework

In this section, I outline the main mechanisms behind the effect of commute distance on teacher recruitment and student academic performance. As such, this section serves to give a theoretical perspective on *how* and *why* an increase in commute distance would negatively affect teacher recruitment and student academic performance.

The theoretical framework can be summarized in the directed acyclical graph(DAG) shown in figure 1.

In figure 1, the arrows represent causal paths between variables and thus depict how commute distance impacts school attractiveness, which will impact student achievement. Specifically, the diagram makes it clear that "commute distance" is assumed to be confounded by school characteristics and that the closure of TTCs represents a source of exogenous variation with which the causal effect of commute distance on school attractiveness can be identified.

Figure 1: Causal diagram of theoretical framework



In the following section, I will explain in more detail how each of the causal paths in figure 1 should be interpreted.

2.1 How does commute distance affect job attractiveness

Commute distance is generally tied to the attractiveness of a workplace, not just for teachers. Commuting is, in many cases, a time that most individuals would rather spend either at home or work(Rouwendal and Meijer, 2001) Thus, commute distance generally represents a cost to be minimized for workers. This impacts the attractiveness of workplaces to workers, as the cost of commuting must generally be offset by other factors, e.g., favorable working conditions.

As such, if a worker is offered similar job opportunities that entail different commute distances, the worker will generally opt for the job with the lowest commute distance. The willingness to commute may be increased if a job opportunity includes working conditions that make up for the cost of increased commute distance, e.g., higher salary, better professional environment, etc.

Studies suggest that teachers' preferences regarding commuting distance are not wholly different from the preferences of the general population(Horng, 2009; Johnston, 2020)

2.2 How do organizational features of schools impact school attractiveness and teacher staff, and how are they correlated with commute distance?

Besides commute distance, a range of characteristics unique to schools as a workplace likely impacts how attractive schools are to teachers.

Ingersoll (2007a) points to a range of organizational features of schools that act as “push- and pull factors” of schools towards teachers.

The organizational features cover characteristics such as employee compensation structure, administrative support, degree of conflict, and strife, and employee influence over the organization policies(Ingersoll, 2007a). Ingersoll’s central premise is that these factors impact, e.g., the cohesion among teachers and professional motivation and thus influence how likely teachers are to stay at or leave schools. Further, Ingersoll argues that schools faced with external challenges, such as difficulties in hiring teachers due to being located in a deprived neighborhood, are forced to decrease organizational standards. For instance, principals facing trouble attracting teachers specialized in teaching biology may assign teachers with no specialization in biology to teach biology classes

Following the previous section on the general impact of commute distances, the points made by Ingersoll underline how the characteristics of schools that impact how well schools can attract teachers, including commute distance can have a subsequent impact on the organizational features of schools that influence teacher retention and recruitment. As such, it is likely that distance to the nearest TTC is associated with the organizational features of schools in ways that may be difficult to disentangle in an empirical setting.

2.3 why would teacher characteristics, specifically teacher quality, play a role

While the preferences for schools with specific characteristics may be general across teachers, these preferences may also shift according to the characteristics of teachers.

While teachers search for jobs that will accommodate their preferences, principals are also searching for teachers who will fulfill the needs of their students. As such, teachers with high levels of skill may be more highly sought after by principals as teachers with high levels of skill are presumed to fulfill the needs of students better(Harris et al., 2010). Suppose teachers have some knowledge or expectation of principals’ preferences. In that case, they are likely to have some assumption regarding how much ease or difficulty they could navigate the job market. Suppose a teacher knows that she possesses many of the qualities that make her sought after among principals. In that case, she is likely to suspect that she could choose more freely among schools with working conditions that match her preferences(Feng and Sass, 2017; Jackson, 2009; Loeb et al., 2012). Conversely, teachers who assume they do not possess sufficient skills to easily navigate the job market, e.g., teachers with low levels of experience, may be more prone to accept job offers optimally aligned with their preferences.

This implies that, while teachers would, on average, likely prefer to minimize commute distance, skilled teachers may be less tolerant towards longer commute distances and would have a stronger response to an increase in commute distance than less skilled teachers. This difference in the impact of commute distance across teacher skill levels is represented in figure 1 by the edge between “teacher quality” and “school attractiveness”, which implies that the effect of “commute distance” on “school attractiveness” would vary by levels of “teacher quality” if one were to condition on “teacher quality”(Quintana, 2022)

2.4 Where do students, and especially student teachers, choose to live

In this paper, a central assumption is that students at TTCs prefer and choose to live close to the TTC where they study and still live close to this TTC when they graduate. In this regard, students at TTCs and future students are likely comparable to their peers in other college-level education programs, as areas with college-level education programs often also foster a local community and youth-culture formed by students who live in the area. As such, while commute distance is also a reason for students preferring to live close to the TTC where they study, commute distance likely plays a much smaller role compared to the wishes of students to transition into adulthood and to experience youth-, and college-culture(Terenzini et al., 1994). This phenomenon is less prevalent in some cultural contexts, e.g., Italian and Spanish youth who are more prone to live with their parents while studying. However, in Denmark, it is typical for students to move from their childhood home and closer to the institutions where they study(Van den Berg et al., 2021). Students' preferences to live close to the institutions at which they study likely persist from enrollment to graduation, as they transition from early adulthood to later adulthood. The preferences for living close to youth and college culture may wane during this transition. However, students may have gotten attached to the area in other ways, e.g., via romantic relationships, marriage, family formation, job opportunities, etc.(Bacolod et al., 2009; Busch and Weigert, 2010) Further, the attachment to a geographic area during a formative period of one's life may become a part of the identity of students, which likely persists beyond graduation, e.g., preferences for urban amenities developed throughout the years as a student(Buch et al., 2017) or the preference of living in an area populated with other college graduates(Berry and Glaeser, 2005). In a similar vein, one may also consider that the perceived membership of social class could have changed for college graduates if their college degree is often associated with a specific social class, e.g., college degrees that may lead to creative work that may be associated with the "creative class"(Florida, 2002). Specifically to newly graduated teachers, the location of the school at which they did their internship is also very likely to affect where newly graduated students choose to locate after graduating(Krieg et al., 2015) In other words, while the preference for youth- and college culture may not persist into later adulthood, newly graduated teachers may still be attached to the geographic area close to the TTC where they graduated in both direct and indirect ways. As such, moving to seek job opportunities in other geographic areas may seem disruptive and uncertain to newly graduated teachers, keeping them attached to the area where they lived when graduating.

2.4.1 Long-term impact of reduced attractiveness

While TTC closures are likely to impact newly graduated teachers to the largest extent, the long-term impacts of TTC closures may also include a reduced ability of schools to attract teachers in general. If schools that are impacted by TTC closures face difficulties in attracting newly graduated teachers, this may lead to a situation in which teachers employed at affected schools will have to cover the workload that should have been assigned to newly hired teachers(Ingersoll, 2007b). This may lead to discontent among the more experienced teacher staff and, consequently, worse working conditions and lower morale, leading to higher teacher turnover rates (Ingersoll, 2007a). Such consequences may deter other teachers from applying to affected schools, following the impact of organizational resources on teacher recruitment detailed earlier. As such, recruitment difficulties specific to newly graduated teachers may lead to a downward spiral that impacts the general recruitment of teachers.

3 Theoretical predictions

The previous section can be summarized in 3 hypotheses.

1. Schools with long commute distances will, on average, be less attractive to teachers.
2. Newly graduated teachers are more likely to be affected by TTC closures than older teachers
3. Skilled teachers will be more reluctant to apply for schools with long commute distances. As such, we may see that an increase in distance to the nearest TTC will adversely affect the teacher quality of affected schools, even if we do not see an effect on the overall recruitment. For instance, affected schools may choose to hire teachers of lower skill than they would normally have, in order to compensate for adverse effects on school attractiveness.
4. The closure of TTCs will impact the recruitment of newly graduated teachers. However, difficulties in recruiting newly graduated teachers may affect other elements of school attractiveness, which may, in turn, develop into general difficulties in recruiting teachers

4 Making the danish case

In this section, I will outline why the closure of TTCs in Denmark makes a good case for studying the effect of commute distance on teacher recruitment difficulties.

While Denmark is a small country, Danes are not among the populations in the OECD that commute the least. On average, Danes commute 39 minutes daily, while populations in much larger countries such as the US and Canada commute 25 and 26 minutes daily. Populations in other large European countries, such as Spain, France, and Italy, commute shorter distances than the danish population(Rodrigue, 2020). As such, the small geographical distances in Denmark do not imply that the average daily commute time of Danes is incomparably shorter than other OECD countries.

Further, the salary of public school teachers in Denmark is tightly regulated. The difference between danish public school teachers' annual salary at the entry-level and the highest levels is 8866 USD, making it the OECD country with the fifth lowest wage differential. In comparison, the average difference in the OECD is 28836 USD(OECD, 2019). This likely means that teachers in Denmark are more motivated by improvements in non-financial characteristics of schools, such as working environment and commute distance.

Lastly, the closure of TTCs in Denmark was a large-scale closure of TTCs. More than a third of TTCs closed, changing the landscape of teacher education in Denmark quite drastically. Such a large-scale change provides an opportunity to study the effects of commute distance at the extremes.

In sum, I argue that the small variance in teacher wages and the large scale of the TTC closure should result in noticeable effects of increased commute distance, given the current literature on the effect of commute distance on teacher recruitment. In other words, if commute distance really does impact teacher recruitment and, subsequently, also student performance, I expect that the current case provides optimal conditions to study such an effect.

5 Design of natural experiment

In the following section, I will describe a natural experiment that I aim to use to identify the causal effect of attracting fewer teachers on student achievement. This section will cover the background of the policy that gave rise to the natural experiment and its impact on the distance between affected schools and the closest TTC.

5.1 The closure of TTCs in Denmark in the period 1982-1989

Between 1982 and 1989, the Danish government decided to close 11 of the, at the time, 30 TTCs in Denmark. At the time, the government was concerned with a strong downward trend in fertility and a dire economic situation. The lower fertility would eventually lead to a smaller population of school-age children and, consequently, a lower demand for primary school teachers. As such, the government argued that the result would be widespread unemployment of primary school teachers without intervening. Thus, the government opted to close a range of TTCs. In general, the closure of TTCs happened in two "waves," with the first wave initiated in 1982 and the second initiated in 1988, with five TTCs closed during the first wave and the remaining six closed during the second wave. For the first wave, the reason specific TTCs were chosen for closing is not described in deep detail. Three TTCs were chosen primarily due to their location in the capital region, in which multiple other TTCs were left to accommodate prospective teachers. For the remaining two TTCs, no apparent reasoning for closure is given in official documents. For the second wave of closures, the criteria are described in more detail. According to the official documents, the number of students, opportunities for using the buildings for other purposes, operating expenses, and geographical position were considered when the government picked their candidate TTCs for closing. It is stated that the candidate TTCs were picked so that larger administrative regions in Denmark should have at least two TTCs, while smaller administrative regions should have at least one TTC.

5.2 How is treatment defined and assigned?

In this paper, I define schools as **treated** if they experienced **any** increase in distance to the nearest TTC following the closure of TTCs. Conversely, schools are **untreated** if they have never experienced any change in distance to the nearest TTC following the closure of TTCs.

As such, the treatment in this paper is defined as an increase in distance to the nearest TTC, which is assigned at the school level.

5.3 How does treatment status affect the commute distance of teachers?

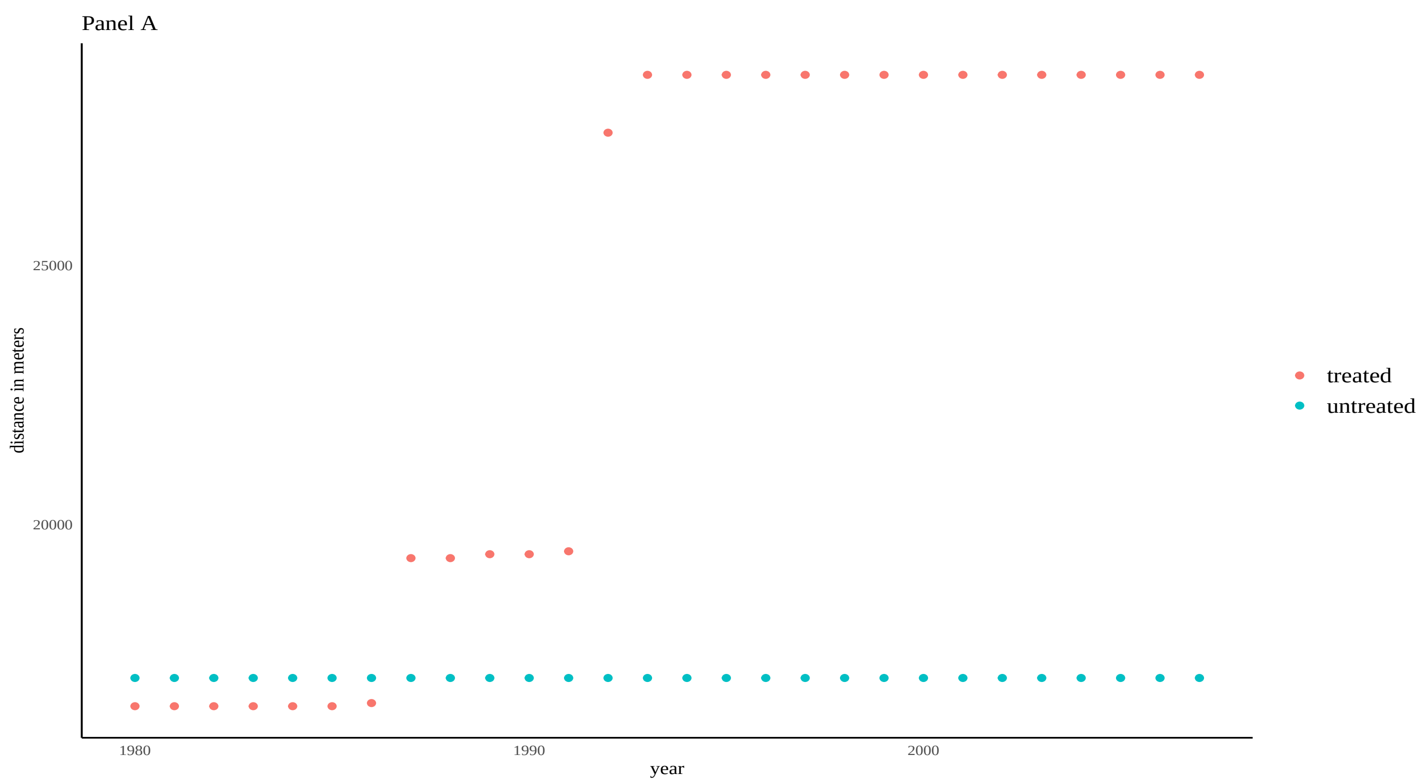
It is important to note that while treatment is assigned at the school level, treatment status is hypothesized to impact a variable at the teacher level, namely the commute distance of teachers and newly graduated teachers in particular. As detailed in the theoretical framework, teacher students are hypothesized to prefer living close to the college where they study and will also be likely to live close to the same college when they graduate. As hypothesized, newly graduated teachers will, on average, prefer to minimize commute distance to the school where they will eventually find employment. This means that newly graduated teachers who graduated **after** the closure of TTCs would, on average, have to commute longer distances to work at schools that experienced an increase in distance to the nearest TTC, i.e., the treated schools than teachers that graduated **prior** to the closure of TTCs.

5.4 How much did treated schools get longer to the nearest TTC, and how did it affect commute distance for teachers?

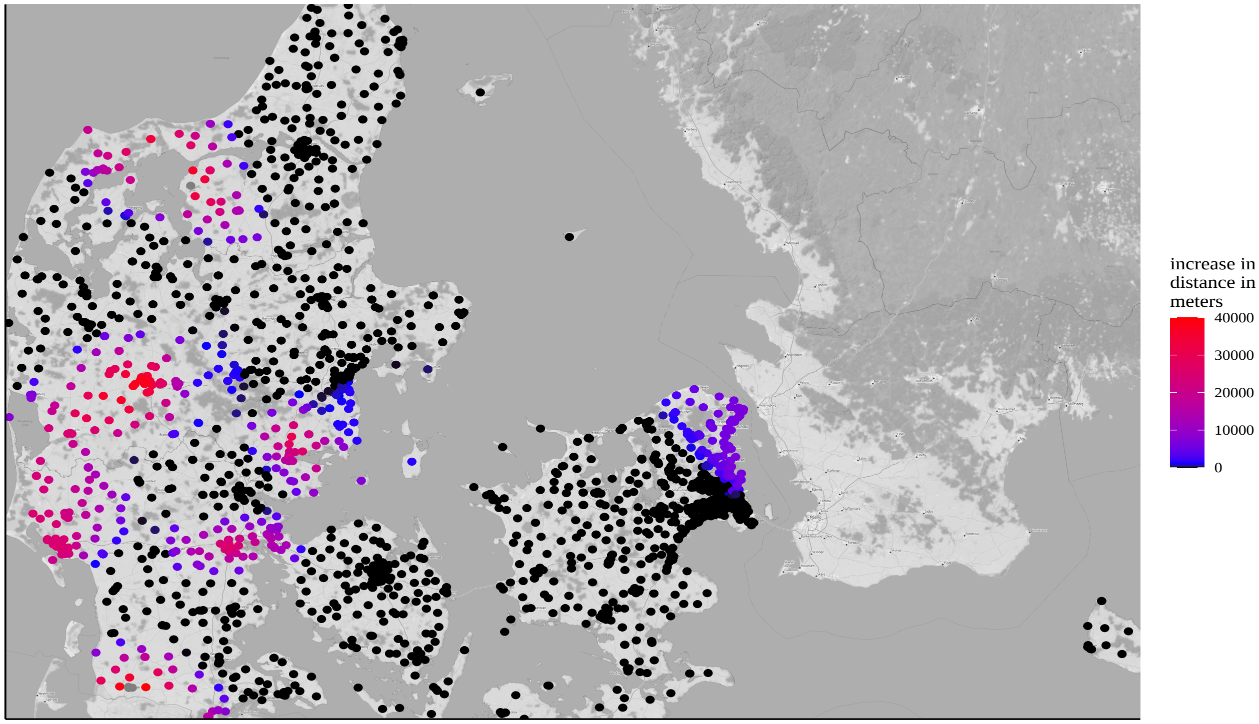
In this section, I will go through how the closure of TTCs impacted the distance to the nearest TTC for treated schools, i.e., *schools that experienced an increase in distance to the nearest TTC following the closure of TTCs*.

Figure 2 shows us two things. Panel A shows the average distance to the nearest TTC, measured in meters, for treated and untreated schools. We see that treated schools were, on average, located closer to the nearest TTC before the closure of TTCs and that distance to the nearest TTC increased quite dramatically during the period in which TTCs closed. Panel B shows the geographical distribution of how schools included in the data were affected by the closure of TTCs. We see that the increases in distance are not distributed in a geographically equal manner. As we see, schools in some regions of Denmark are largely unaffected. Specifically, schools in urban and affluent regions were less affected, although some schools in the north-eastern part of Denmark, traditionally one of the most affluent regions in Denmark, were affected to some degree.

Figure 2



Panel B



It thus seems evident that the distance to the nearest TTC increased on average for treated schools. However, the closure of TTCs affected some schools, and some "cohorts" of schools, to a much larger degree than others with some cohorts of schools only being affected to a minor degree.

6 Estimating the effects of distance to the nearest TTC

What makes a school attractive to teachers depends on many factors, as documented in earlier sections of this paper. As such, we may worry that distance to the nearest TTC is correlated with unobservable confounding variables. For instance, schools located further away from the nearest TTC may also be located in rural areas serving student populations from low-SES backgrounds due to, e.g., rural areas being unattractive to high-SES parents and political preferences to place TTCs in metropolitan areas.

I therefore focus on a natural experiment in which some schools experienced increased distance to the nearest TTC, while others did not. As I have argued in previous sections, the distance between a school and the nearest TTC is likely to impact the ability of the school to attract and retain teachers. Given that newly graduated teachers are likely to live close to the TTC from which they graduated, I expect that an increase in distance to the nearest TTC is *especially likely to increase the commute distance for young and newly graduated teachers*. Thus, schools closer to a TTC may be seen as more attractive, especially to young and newly graduated teachers. I further argue that the change in distance to the nearest TTC was unaffected by other factors that affect any of the outcomes that I study in this paper, i.e., that the relationship between change in distance to the nearest TTC, as a result of the natural experiment, and the school- and student-level outcomes is not confounded by either observable or unobservable factors.

I will apply *difference-in-differences*(DID) to estimate the effect of an increase in distance to the nearest TTC $\theta_{TTCdistance}$. This involves comparing the outcome of treated schools in the period *before* they experienced treatment to the outcome of treated schools in the period *after* they had experienced treatment. This same comparison is done for untreated schools. Finally, the pre-treatment and post-treatment differences of treated and untreated schools are compared to compute $\theta_{TTCdistance}$. The estimation strategy can be expressed like so

$$\theta_{TTCdistance} = E(Y_{treated}^{pre-treatment} - Y_{treated}^{post-treatment}) - E(Y_{untreated}^{pre-treatment} - Y_{untreated}^{post-treatment})$$

It is important to note that DID, without additional strong assumptions, does not identify the average difference between receiving and not receiving a treatment, commonly referred to as the *average treatment effect* (ATE). Assuming that both treated and untreated schools would have experienced a similar change in an outcome, e.g., the share of certified teachers in the periods before and after the onset of treatment *had the treatment not occurred*(commonly referred to as the *"parallel trends assumption"*), we can use DID to infer what would have happened to the treated schools *if they had never received the treatment.* As such, DID identifies the *average treatment effect on the treated* (ATT):

$$ATT(TTCdistance) = \frac{1}{n_{treated}} \Sigma(Y_{treated}(TTCdistance_{increase}) - Y_{treated}(TTCdistance_{nochange}))$$

in which $Y_{treated}(TTCdistance_{nochange}))$ is the unobserved counterfactual outcome of treated schools if they had not experienced any increase in distance to the nearest TTC

6.0.1 DID with differential treatment timing

A growing literature within econometrics has recently brought attention to hitherto unknown pitfalls of estimating DID with time- and treatment-group fixed effects, commonly known as the Two Way Fixed Effects(TWFE), estimation strategy when groups receive treatment in different periods(Baker et al., 2021; Chaisemartin and dHaultfoeuille, 2022; Roth et al., 2023). For the Danish TTC closures, TTCs closed closed in the years 1986,1987,1989,1991,1992 and 1993. Due to this "staggered adoption" scheme, I will apply the estimator of Callaway and Sant'Anna(CSA)(Callaway and Sant'Anna, 2021).

The results of the CSA estimator is an ATT for each treatment cohort in each period, $ATT\ (\ g, t\ )$. I will therefore report the cohort-aggregated estimate, given by

$\theta_{sel}^{O} = \sum_{g \in \mathcal{G}} (\theta)_{sel}\ (\ g\ )\ P\ (\ G = g \mid G \leq \mathcal{T}\ )$

Callaway & Sant'Anna argue that this is the closest to the interpretation of the estimated parameter in the canonical "two periods, two groups" DID setup. In this paper, I will report the aggregated ATT, θ_{sel}^{O}, aggregated across the first 10 years following the closure of TTCS, i.e., the years 1987-2004, given that the last "treatment cohort" of schools were treated in 1993.

7 Methods

7.1 Data

In this paper, I will use Danish register data on all students, their parents and siblings, and teachers in the years 1980-2020. In this paper, the time period is restricted to 2007 since additional TTCs closed in the period 2008-2014. In addition, i also use data on all public schools. The sample of schools is restricted to public schools built before 1993, as the latest closure of TTCs occurred in 1993. The data on schools mainly concern the longitude and latitude of schools. The remaining school-level variables concern teacher- and student characteristics aggregated at the school level. Data on TTCs include the longitude and latitude of TTCs and the year in which each TTC closed.

In appendix E i outline the criteria by which public school teachers are defined in the administrative data, and how the link between schools and teachers is constructed.

7.1.1 When did TTCs close?

Several resources detail the year in which TTCs were planned to close. However, in several instances, students who enrolled the year before or in the year at which TTCs were planned to close were allowed to finish their education. For this reason, I defined the year of closure as the year in which the last class of students graduated from the TTCs. This information is available in the registries of Statistics Denmark.

7.1.2 Measuring distances

For the distances between schools and TTCs, I used the longitudes and latitudes of schools and TTCs to compute the distances[1].

7.1.3 Measuring commute distance

Measuring commute distance for teachers to schools was more involved as I do not have the exact coordinates of teachers' residence for each year. The best information I have, is information on the parish in which teachers resided for each year. Parishes are the smallest geographic administrative units in Denmark, with areas ranging from 7.47 km^2 for the smallest 10% of parishes to 46.67 km^2 for the largest 90% of parishes. The maximum distance across parishes range from 3.61 KM for the lowest 10% of distances to 10.67 KM for the top 90% of distances. In comparison, the area of Denmark in its entirety is approximately 45,000 km^2 with a maximum distance across of 451.56 KM.

Given that we cannot locate teachers precisely within parishes, teachers are assigned to the centroid of the parish in which they live. As such *the commute distance between teachers and the schools at which they are employed is measured by the distance between the centroid and the parish in which teachers live and the location of the school in which they are employed.*

[1] I used the R package "geosphere"(Hijmans et al., 2022) to compute the distances using the Vincenty Ellipsoid method(Vincenty, 1975)

In the following section, I will outline the outcomes on which I will investigate the impact of TTC closures. All outcomes are measured at the school level. All outcomes vary across years. As such, an outcome like the average high school GPA of teachers represents the average high school GPA of all teachers employed at a given school in a given year.

7.2 Teacher body composition

In this paper, I will investigate the impact of TTC closures on 6 different measures of teacher body composition:

1) Share of newly graduated teachers - This variable measures the share of teachers who graduated within the last five years employed at each school

2) Average high school GPA of newly graduated teachers at the school level - This variable measures the average high school GPA of teachers that have graduated within the last ten years. A decrease in the average high school GPA of teachers would indicate a decrease in teacher quality of newly graduated teachers.

3) Average seniority of teachers at the school level - This outcome measures the average number of years that teachers have been employed at the particular school at which they are currently employed. An increase in average seniority would indicate an increased difficulty in attracting newly graduated teachers.

4) Average years since graduation at the school level - This outcome measures the average number of years that have passed since graduation. An increase in average years since graduation would indicate increased difficulty in attracting newly graduated teachers

5) Student/teacher ratio - A measure of how many students are enrolled for each teacher at each school. As such, higher ratios indicate more students for each teacher, while lower ratios indicate more teachers for each student. An increase in student/teacher ratio would indicate fewer teachers for each student. An increased student/teacher ratio would indicate increased difficulty in attracting teachers.

6) Share of newly hired teachers with a teacher certification - This variable measures the share of teachers that were hired in the same year that had obtained a college degree as a primary school teacher. A decrease would indicate adverse effects on how well schools can attract qualified teachers

7.3 Covariates

In addition to the outcomes outlined above, I will utilize a range of covariates to assess whether treated and untreated schools differed on possible confounding variables prior to the closure of TTCs. The covariates outlined below, save for the number of students at each school, concern the student body composition of schools with regard to socio-economic status(SES) and ethnic origin. Student body composition has been shown to impact the attractiveness of schools(Jackson, 2009; Karbownik, 2020; Nguyen et al., 2020). Differences between treated and untreated schools on these covariates might indicate that the probability of being affected by the closure of TTCs was systematically related to other factors that might also impact school attractiveness and student performance, which would make the DID design of this paper less credible.

In this paper, I investigate six different covariates:

1 and 2) Average fathers' and mothers' disposable income, adjusted for inflation for each school

3 and 4) Average mothers' and fathers' total length of education, measured in months for each school.

5) The share of students who are, or whose parents are, born outside of Denmark at each school

6) baseline distance to TTC

8 Results

8.1 Descriptive statistics

In this section, I present descriptive statistics on the main outcomes, measured at the school level, pertaining both to the teacher body composition, student academic performance, and student academic attainment *prior to closure of TTCs*. Further, these descriptive statistics are contrasted between treated and untreated schools in order to assess whether the closure of TTCs was correlated with either teacher or student characteristics. This may also serve as an indication, whether the closure of TTCs was correlated with unobservable confounding variables.

In table 1, I present the means, the P-value for the difference in means, and a standardized difference between treated and untreated schools. The standardized mean difference(SMD) shown here is Cohens D(Cohen, 2013).

Panel A of 1 shows descriptive statistics for outcomes related to teacher composition. We see that the majority of baseline mean differences between treated and untreated schools are both statistically insignificant and very small.

Panel B shows the means and mean differences between treated and untreated schools for covariates. Here, we see more pronounced differences concerning the length of education for both mothers and fathers. SMDs are twice as large as for the average age of teachers in Panel A. Despite this, however, the effect sizes still imply a 91% and 90% overlap of distributions of treated and untreated schools for mothers' and fathers' length of education, respectively[2]. Similarly, the chance of randomly picking a treated school with a higher length of education than a randomly picked untreated school is 56% and 57% for mothers and fathers respectively[3]. Secondly, while there are statistically significant differences between treated and untreated schools concerning parents' length of education, this is not the case for the remaining covariates concerning student body composition, despite the high correlation between parents' education and parents' income. As such, this may indicate that the difference in parents' education is not evidence of a more general difference in student body composition between treated and untreated schools. In general, these results do not indicate large systematic differences between treated and untreated schools regarding observed characteristics.

[2]the overlap is computed by $1-(\Phi(\delta)-.5)$, where Φ is the cumulative distribution function of the standard normal distribution and δ is the Cohens D effect size estimate

[3]The "chance of superiority" is computed by $\Phi(\frac{\delta}{\sqrt{2}})$ Φ is the cumulative distribution function of the standard normal distribution and δ is the Cohens D effect size estimate

		mean treated	mean un-treated	p-value	SMD	N treated schools	N un-treated schools
Panel A	Average seniority	2.06	2.09	0.13	-0.02	409	999
	Student/teacher ratio	5.22	5.36	0.86	-0.01	234	613
	Share of newly hired teachers with teacher certification	0.76	0.77	0.83	-0.01	409	999
	Average high school GPA of newly graduated teachers	8.12	8.11	0.95	0.01	194	504
	Average years since graduation	6.03	5.92	0.18	0.06	403	989
	Share of newly graduated teachers	0.46	0.47	0.16	-0.05	403	989
	Average commute distance	7612.12	7359.65	0.77	0.02	407	990
	Average commute distance, newly graduated teachers	9167.13	9048.98	0.89	0.01	400	978
Panel B	Share not born in DK	0.01	0.01	0.20	-0.06	270	726
	Nr. of students	159.56	154.51	0.21	0.09	270	726
	Ed. length mom	134.47	131.64	0.00	0.23	270	726
	Ed. length dad	148.35	145.00	0.00	0.25	270	726
	Disp. inc. mom	103521.85	102248.51	0.07	0.09	270	726
	Disp. inc. dad	145995.54	141896.92	0.12	0.11	270	726
	Baseline distance to TTC	16490.74	17035.88	0.37	-0.04	534	1310

Table 1: Means, P-value for differences in means and Cohens D for treated and untreated schools in the period 1980-1985 across outcomes pertaining teacher body composition, student achievement and covariates

8.2 DID estimates of impact on commute distance

The estimates presented in this section act as a sort of “minimum requirement” for affected schools to have experienced any adverse consequences of closure of TTCs. If the closure of TTCs did not increase the average commute distance of teachers employed at affected schools, and specifically newly graduated teachers, then it seems unlikely that the closure of TTCs would have affected other characteristics of schools that are dependent on school attractiveness, e.g., the number and quality of employed teachers. In appendix F i present additional specifications in which i adjust for covariates. Adjusting for observed covariates does not alter the main conclusion that can be drawn from the results presented here, and they are therefore reported in the appendix.

As we can see in 2, the estimates support the hypothesis that the closure of TTCs increased both the average commute distance for all teachers and for newly graduated teachers, i.e. teachers with less than ten years of experience. As expected, these increases are small for all teachers compared to the overall distribution of commute distance prior to TTC closures. A school with a median level of average commute distance(5580.76 meters) would move to the upper 57% of the distribution had it been affected by TTC closure. In contrast, a school with a median level of commute distance for newly graduated teachers(6918.23 meters) would find itself in the upper 65% of the distribution of average commute distance of newly graduated teachers if it had been affected by TTC closure. Thus, the results indicate that the average commute distance for all teachers increased by seven percentile ranks, while this increase was 15 percentile ranks for newly graduated teachers.

As such, the effect for newly graduated teachers is, as expected, larger than for teachers in general. While some of this difference in effects is driven by the propensity of newly graduated teachers to commute longer distances, newly graduated teachers experienced more than twice as large an effect as teachers in general, when measured in percentile rank increase.

Reassuringly, the parallel trends assumption does not seem to be violated when one inspects the differences in distance to the nearest TTC between treated and untreated schools before the closure of TTCs, the so-called "pre-trends". Inspecting the pre-trends of the differences between treated and untreated units is often used as a robustness check on violations of the parallel trends assumption. Finding a trend of differences between treated and untreated units *before* the actual treatment took place is often taken as an indication of a violation of the parallel trends assumption(Roth et al., 2023). The results of this robustness check are reported in appendix A.1

var	estimate	n
commute distance	425.99(147.65;704.34)	1272
commute distance newly graduated teachers	1401.99(130.06;2673.93)	736

Table 2: Estimated ATT of TTC closures on the commute distance of all teachers and newly graduated teachers. Confidence intervals for the estimates are shown in parenthesis

8.3 DID estimates of impact on Teacher body composition

In this section, I will investigate how the closure of TTCs affected how well, schools could attract teachers, particularly newly graduated teachers. Here, I will estimate the effect of TTC closures on the following outcomes: Student/teacher ratio, average age of teachers at schools, average seniority at schools, the share of newly graduated teachers, the share of newly graduated teachers with a teacher qualification, the average high school GPA of teachers, the average high school GPA of newly graduated teachers, average years since graduation.

In table 3, I present the estimated effects on each of the outcomes pertaining to teacher composition. I also present a measure of effect size. This measure indicates the percentile rank of a school with a median level of an outcome in the distribution of the period before TTC closures(1980-1985) that experienced a change in the outcome corresponding to the estimated effect. For instance, for the outcome *Average years since graduation* the effect size of .52 indicates that schools with a median level of average age of teachers in the period before TTC closures would move to the upper 52% of the pretreatment distribution had they experienced a change in the average age of teachers corresponding to the change implied by the estimated ATT, which is 0.14 years of seniority[4].

As we can see in table 3, many of the estimated effects are small. Further, none of the estimates are statistically significant at 5% level, making it impossible to infer whether an effect is strictly positive or

[4] The effect size is computed by: 1. estimating the empirical cumulative distribution function, $ECDF_{pretreatment}(x)$, in the period prior to TTC closures of a given outcome 2. Estimating the median level of the outcome in the period prior to TTC closures. 3. Estimating the outcome of a treated school with a median level of the outcome in the pre-treatment distribution by adding the estimate of the effect of TTC closure on the outcome to the estimated median, $outcome_{median\,treated\,school} = median + estimate$ 4. plugging $outcome_{median\,treated\,school}$ into $ECDF_{pretreatment}(x)$, $ECDF_{pretreatment}(outcome_{median\,treated\,school})$, which will return the percentile rank in the pre-treatment distribution for a school with a level of the outcome corresponding to $outcome_{median\,treated\,school}$

negative. Notably, The estimate on the student/teacher ratio suggests a large positive effect of TTC closure. The estimate suggests that a school with a median level of student/teacher ratio would be among the 0.28% of schools with the most teachers per student. However, the width of the confidence interval suggests that the data is compatible with the school also being among the top 0.01% of the distribution, making it very hard to draw any conclusions based on this estimate. Apart from the estimate of the student/teacher ratio, all estimates suggest that treated schools would have moved less than 5 percentile ranks in the pre-treatment distribution of teacher body composition. Thus, these results suggest that TTC closures did not have any discernable effect, either positive or negative, on the teacher body composition of treated schools.

Similarly to the results pertaining to the effects of TTC closures on commute distance, additional results, reported in appendix A.2, do not suggest systematic violations of the parallel trends assumption.

Outcome	n	Estimate	Effect size
Average seniority	1249	-0.01(0.14;-0.17)	0.5(0.53;0.43)
Student/teacher ratio	715	-0.49(1.28;-2.26)	0.28(0.83;0.01)
Share of newly hired teachers with teacher certification	393	0.03(0.09;-0.03)	0.53(0.6;0.46)
Average high school GPA of newly graduated teachers	1642	0.03(0.12;-0.06)	0.54(0.59;0.49)
Average years since graduation	1157	0.14(0.4;-0.13)	0.52(0.58;0.47)
Share of newly graduated teachers	1157	-0.01(0.01;-0.03)	0.49(0.51;0.47)

Table 3: Estimated ATT of closure of TTCs on teacher composition outcomes. Lower and upper bounds of confidence intervals are in parenthesis

8.4 Heterogeneity of effects across treatment cohorts and treatment intensity

While some schools experienced an increase in distance of more than 20 km, several schools did not experience an increase in distance above 1 km. Similarly, some treatment cohorts only experience minor increases in distance to the nearest TTC. I therefore also investigated how effects varied across treatment cohorts and whether schools that experienced an increase in distance above a range of thresholds experienced larger effects. These results suggested that larger increases in distance resulted in larger and more negative consequences of TTC closure. However, for these results as well, the majority of estimated effects were associated with high degrees of uncertainty, and it was not possible to infer a direction for the majority of these effects. The results are similar for differences between cohorts. While the estimated effect varies across treatment cohorts, there is no clear pattern that suggests that the effect of TTC closures becomes more positive or negative for cohorts that experienced higher increases in distance. As such, while accounting for differences in increased distance would have seemed a natural explanation for much of the heterogeneity in response to TTC closures, the results do not suggest that accounting for heterogeneity between treatment cohorts or schools that experienced different increases in distance to the nearest TTC alters the main interpretation of the results.

Readers are referred to appendix B for the full reporting of these results.

8.5 Sensitivity checks

8.5.1 Different estimators

Given the abundance of alternative estimators that have been developed to estimate the effect of treatment in a staggered adoption setting, i compared the estimates of the CSA estimator with alternate estimators to make sure that reported results are not driven by the choice of estimator. Like the CSA estimator that I have used so far, all of these estimators can also accommodate the potential problems of estimating treatment effects within DID design with staggered treatment adoption using TWFE for estimation. I investigated the 2-stage difference-in-difference estimator(DID2S)(Butts and Gardner, 2023; Gardner, 2022), the DID imputation estimator(Borusyak et al., 2021; Butts, 2021), the multiple group-time estimator(DIDmulti)(De Chaisemartin and d'Haultfoeuille, 2020), the staggered DID(stagDID) estimator(Roth and Sant'Anna, 2023), the group-time interaction estimator(sunabDID)(Berge, 2023; Sun and Abraham, 2021) and the Extended TWFE(ETWFE) estimator(McDermott, 2023; Wooldridge, 2021). Lastly I also compare the results from these estimators to the regular TWFE specification.

In summary, the alternate estimators generally align with the CSA estimates. While some deviations were present, these were generally isolated to one or two estimators for a few outcomes. As such, the estimates presented in this paper do not systematically deviate from results that could have been obtained by alternate estimators, suggesting that the results are not sensitive to the choice of estimator.

Readers are referred to appendix C for a more in-depth investigation of how the choice of estimator impacts the results

9 Discussion

In this section, I would like to discuss two issues:

1) What are the possible reasons that we are not seeing any effects of TTC closures, despite the expected negative effect of TTC closure? and 2) How should the estimated effects be interpreted in terms of both previous literature on teacher sorting and policy implications

9.1 Why are we not seeing any effects of TTC closures?

Despite previous results on the impact of commute distance on teacher recruitment, the results of this paper do not indicate that increasing commute distance has any discernible impact on how well schools can attract teachers. One reason for this may be that teachers, especially newly graduated teachers, are more willing to adapt to a changes in commute distance than previously expected. Indeed, when computing the average distance between the nearest TTC and the current workplace of newly graduated teachers, this distance is about 25 KM in the period before TTC closures. This means that schools with a distance above 25 KM to the nearest TTC would be outside the range of which the average newly graduated teacher is willing to commute before the closure of TTCs. Following the closure of TTCs, one would have expected several schools to have transitioned outside this range if the commute distance of newly graduated teachers had remained unchanged. However, the distance between the workplace of newly graduated teachers and the distance to the nearest TTC did, in fact, increase substantially, peaking at the height of the period of TTC closures. In the years 1991-1994, newly graduated teachers were employed no less than 19% further away from a TTC compared to newly graduated teachers in the period 1980-1985. Had newly graduated teachers not increased their commute distance in the years 1991-1994, 21% of treated schools would have been outside the range of the commute distance of the average newly graduated teacher. However, due to increased commute distance among newly graduated teachers, no additional treated schools transitioned outside the range of the average newly graduated teacher. As such, one may argue that the increased willingness of newly graduated teachers to commute likely mitigated many of the adverse effects of TTC closures. Readers are referred to appendix D for a more in-depth investigation of changes in teachers' commute patterns.

9.2 Are effects of TTC closures large or small compared to the effects of changing other school characteristics?

While the effects reported in this paper are all very small, it is informative to relate them to the impact of other school characteristics. Here, we can compare the impact of TTC closure results reported in Nguyen (2018). While the results of Nguyen (2018) all concern the probability that a teacher leaves their current school, I will argue that it is still informative to compare the results in this paper to the results in Nguyen (2018)[5] . For instance, the absolute impact of improving the work environment is 3.43 times as impactful as the largest estimated effect of TTC closure on any outcome. Similarly, the absolute impact of introducing induction/ mentoring and improving administrative support is 3.17 and 2 times as impactful as the effect of TTC closures on the share of newly graduated teachers. This suggests that the effects of TTC closures can be mitigated several times over by, e.g., introducing induction or mentoring to new teachers. In other words, the results of this paper do not suggest that reducing the commute distance of teachers, especially newly graduated teachers, by placing TTCs closer to schools would be nearly as effective as other, arguably, much less costly alternatives.

10 Conclusion

In this paper, I have investigated how the closure of Teacher Training colleges(TTCs) affected how well schools could attract teachers. The effects of TTC closure on all outcomes were modest, even in the best and worst-case scenarios, as suggested by the upper and lower bounds of the confidence intervals. As such, the

[5]This comparison was done by converting the effect estimates reported in this paper to log-odds by using the T-values of the estimated effects(Lipsey and Wilson, 2001)

results in this paper do not suggest that TTC closures had any discernable impact on either teacher body composition or student academic achievement. These results are likely the result of two conditions:

2) **Effects are not as large as expected.** Despite the expectations outlined in this paper and the scholarly literature, the results in this paper do not provide evidence that the effects of TTC closure have any consequential impact on how schools can attract teachers. This is despite the fact that more than 1/3 of TTCs closed and that several schools experienced large increases in distance. In other words, the changes in the number of TTCs and distance to the nearest TTC are not small by any account. As such, if we really think that proximity to a TTC impacts the attractiveness of schools, particularly to newly graduated teachers, then the natural experiment investigated here should make an excellent case.

3) **TTC closures seemingly also affected the mobility of teachers.** As hypothesized, newly graduated teachers were willing to commute longer distances but lived closer to a TTC than more experienced teachers prior to the closures of TTCs. However, this pattern was not persistent and newly graduated teachers were willing to be employed at schools located further away from the nearest TTC following the closures of TTCs. As such, newly graduated teachers were seemingly less attracted to living close to a TTC and more willing to commute longer distances than expected. Such a change in mobility is likely to have offset some, if not much all, of the impact of the closure of TTCs

In summary, I would argue that two main points can be drawn from the results presented in this paper:

1) Increases in commute distance would have to be very substantial to have any discernable impact on schools' ability to attract teachers

2) The results presented in this paper do not suggest that altering commute distance is an effective means of mitigating teacher shortage or unequal geographic distribution of teachers

11 Bibliopgraphy

Allen, R., Burgess, S., Mayo, J., 2018. The teacher labour market, teacher turnover and disadvantaged schools: new evidence for England. Education Economics 26, 4–23. https://doi.org/10.1080/09645292.2017.1366425

Bacolod, M., Blum, B.S., Strange, W.C., 2009. Skills in the city. Journal of Urban Economics 65, 136–153.

Baker, A., Larcker, D.F., Wang, C.C.Y., 2021. How much should we trust staggered difference-in-differences estimates? SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3794018

Barbieri, G., Rossetti, C., Sestito, P., 2010. The Determinants of Teacher Mobility: Evidence from a Panel of Italian Teachers. Ssrn. https://doi.org/10.2139/ssrn.1699242

Berge, L., 2023. Fixest: Fast fixed-effects estimations.

Berry, C.R., Glaeser, E.L., 2005. The divergence of human capital levels across cities. Papers in regional science 84, 407–444.

Borusyak, K., Jaravel, X., Spiess, J., 2021. Revisiting event study designs: Robust and efficient estimation. arXiv preprint arXiv:2108.12419.

Boyd, D., Lankford, H., Loeb, S., Wyckoff, J., 2012. Analyzing the Determinants of the Matching of Public School Teachers to Jobs: Disentangling the Preferences of Teachers and Employers. Journal of Labor Economics 31, 83–117. https://doi.org/10.1086/666725

Boyd, D., Lankford, H., Loeb, S., Wyckoff, J., 2005b. The draw of home: How teachers' preferences for proximity disadvantage urban schools. Journal of Policy Analysis and Management 24, 113–132. https://doi.org/10.1002/pam.20072

Boyd, D., Lankford, H., Loeb, S., Wyckoff, J., 2005a. Explaining the Short Careers of High-Achieving Teachers in Schools with Low-Performing Students. American Economic Review 95, 166–171. https://doi.org/10.1257/000282805774669628

Buch, T., Hamann, S., Niebuhr, A., Rossen, A., 2017. How to woo the smart ones? Evaluating the determinants that particularly attract highly qualified people to cities. Journal of urban affairs 39, 764–782.

Busch, O., Weigert, B., 2010. Where have all the graduates gone? Internal cross-state migration of graduates in germany 1984–2004. The annals of regional science 44, 559–572.

Butts, K., 2021. Didimputation: Difference-in-differences estimator from borusyak, jaravel, and spiess (2021).

Butts, K., Gardner, J., 2023. did2s: Two-stage difference-in-differences following gardner (2021).

Callaway, B., Sant'Anna, P.H.C., 2021. Difference-in-differences with multiple time periods. Journal of Econometrics 225, 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Carroll, S., Reichardt, R., Guarino, C., Mejia, A., 2000. The distribution of teachers among California's school districts and schools. (No. RAND/MR-1298.0-JIF). RAND CORP SANTA MONICA CA.

Chaisemartin, C. de, dHaultfoeuille, X., 2022. Two-way fixed effects and differences-in-differences with heterogeneous treatment effects: A survey. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4034184

Chetty, R., Friedman, J.N., Rockoff, J.E., 2014. Measuring the impacts of teachers II: Teacher value-added and student outcomes in adulthood. American economic review 104, 2633–2679.

Cohen, J., 2013. Statistical power analysis for the behavioral sciences. Academic press.

De Chaisemartin, C., d'Haultfoeuille, X., 2020. Two-way fixed effects estimators with heterogeneous treatment effects. American Economic Review 110, 2964–2996.

Falch, T., Strøm, B., 2004. No . 1 / 2004 TEACHER TURNOVER AND NON- PECUNIARY FACTORS Torberg Falch Bjarne Strøm Department of Economics.

Feng, L., 2014. Teacher placement, mobility, and occupational choices after teaching. Education Economics 22, 24–47. https://doi.org/10.1080/09645292.2010.511841

Feng, L., Sass, T.R., 2017. Teacher quality and teacher mobility. Education Finance and Policy 12, 396–418. https://doi.org/10.1162/EDFP_a_00214

Florida, R., 2002. The rise of the creative class. Basic books New York.

Gardner, J., 2022. Two-stage differences in differences. arXiv preprint arXiv:2207.05943.

Gibbons, S., 2018. Teacher Turnover: Does it Matter for Pupil Achievement?

Goff, P.T., Bruecker, E.M., 2017. The role of place: Labor market dynamics in rural and non-rural school districts. Wisconsin Center for Education Research Working Paper.

Goldhaber, D., 2012. How Did It Get This Way? Disentangling the Sources of Teacher Quality Gaps Across Two States.

Goldhaber, D., 2010. Teacher Career Paths, Teacher Quality, and Persistence in the Classroom: Are Public

Schools Keeping Their Best? Journal of Policy Analysis and Management 29, 451–478. https://doi.org/10.1002/pam

Goldhaber, D., Krieg, J., Naito, N., Theobald, R., 2020. Student teaching and the geography of teacher shortages. Educational Researcher 50, 165–175. https://doi.org/10.3102/0013189x20962099

Hanushek, E.A., Kain, J.F., Rivkin, S.G., 2015. Why Public Schools Lose Teachers. Journal of Human Resources XXXIX, 326–354. https://doi.org/10.3368/jhr.xxxix.2.326

Harris, D.N., Rutledge, S.A., Ingle, W.K., Thompson, C.C., 2010. Mix and match: What principals really look for when hiring teachers. Education Finance and Policy 5, 228–246.

Henry, G.T., Redding, C., 2020. The Consequences of Leaving School Early: The Effects of Within-Year and End-of-Year Teacher Turnover. Education Finance and Policy 15, 332–356. https://doi.org/10.1162/edfp_a_00274

Hijmans, R.J., Karney, C., Williams, E., Vennes, C., 2022. Geosphere (version 1.5-18). R Foundation for Statistical Computing, Vienna, Austria.

Horng, E.L., 2009. Teacher tradeoffs: Disentangling teachers preferences for working conditions and student demographics. American Educational Research Journal 46, 690–717. https://doi.org/10.3102/0002831208329599

Ingersoll, R.M., 2007b. Why Some Schools Have More Underqualified Teachers Than Others. Brookings Papers on Education Policy 2004, 45–71. https://doi.org/10.1353/pep.2004.0005

Ingersoll, R.M., 2007a. Teacher Turnover and Teacher Shortages: An Organizational Analysis. American Educational Research Journal 38, 499–534. https://doi.org/10.3102/00028312038003499

Ingersoll, R.M., May, H., 2012. The Magnitude, Destinations, and Determinants of Mathematics and Science Teacher Turnover. Educational Evaluation and Policy Analysis 34, 435–464. https://doi.org/10.3102/0162373712454326

Jackson, C.K., 2009. Student demographics, teacher sorting, and teacher quality: Evidence from the end of school desegregation. Journal of Labor Economics 27, 213–256. https://doi.org/10.1086/599334

Jaramillo, M., 2012. The spatial geography of teacher labor markets: Evidence from a developing country. Economics of Education Review 31, 984–995. https://doi.org/10.1016/j.econedurev.2012.07.005

Johnston, A.C., 2020. Teacher preferences, working conditions, and compensation structure. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3573291

Karbownik, K., 2020. The effects of student composition on teacher turnover: Evidence from an admission reform. Economics of Education Review 75, 101960. https://doi.org/10.1016/j.econedurev.2020.101960

Krieg, J.M., Theobald, R., Goldhaber, D., 2015. A Foot in the Door: Exploring the Role of Student Teaching Assignments in Teachers' Initial Job Placements. Educational Evaluation and Policy Analysis 38, 364–388. https://doi.org/10.3102/0162373716630739

Lankford, H., Loeb, S., Wyckoff, J., 2007. Teacher Sorting and the Plight of Urban Schools: A Descriptive Analysis. Educational Evaluation and Policy Analysis 24, 37–62. https://doi.org/10.3102/01623737024001037

Lipsey, M.W., Wilson, D.B., 2001. Practical meta-analysis. SAGE publications, Inc.

Loeb, S., Kalogrides, D., Béteille, T., 2012. Effective schools: Teacher hiring, assignment, development, and retention. Education Finance and Policy 7, 269–304. https://doi.org/10.1162/EDFP_a_00068

McDermott, G., 2023. Etwfe: Extended two-way fixed effects.

Nguyen, T., 2018. The Theories and Determinants of Teacher Attrition and Retention. , .

Nguyen, T.D., Pham, L.D., Crouch, M., Springer, M.G., 2020. The correlates of teacher turnover: An updated and expanded Meta-analysis of the literature. Educational Research Review 31, 100355. https://doi.org/10.1016/j.edurev.2020.100355

OECD, 2019. Education at a glance 2019. https://doi.org/https://doi.org/https://doi.org/10.1787/f8d7880d-en

Podgursky, M., Monroe, R., Watson, D., 2004. The academic quality of public school teachers: An analysis of entry and exit behavior. Economics of Education Review 23, 507–518. https://doi.org/10.1016/j.econedurev.2004.01.005

Quintana, R., 2022. Embracing complexity in social science research. Quality and Quantity 57, 15–38. https://doi.org/10.1007/s11135-022-01349-1

Reininger, M., 2012. Hometown Disadvantage? It Depends on Where You're From. Educational Evaluation and Policy Analysis 34, 127–145. https://doi.org/10.3102/0162373711420864

Rivkin, S.G., Hanushek, E.A., Kain, J.F., 2005. Teachers, schools, and academic achievement. Econometrica 73, 417–458. https://doi.org/10.1111/j.1468-0262.2005.00584.x

Rodrigue, J.-P., 2020. The geography of transport systems. Routledge.

Roth, J., Sant'Anna, P.H., 2023. Efficient estimation for staggered rollout designs. Journal of Political Economy Microeconomics 1, 669–709.

Roth, J., Sant'Anna, P.H.C., Bilinski, A., Poe, J., 2023. What's trending in difference-in-differences? A synthesis of the recent econometrics literature. Journal of Econometrics 235, 2218–2244. https://doi.org/10.1016/j.jeconom.2023.03.008

Rouwendal, J., Meijer, E., 2001. Preferences for housing, jobs, and commuting: A mixed logit analysis. Journal of Regional Science 41, 475–505. https://doi.org/10.1111/0022-4146.00227

Sass, T.R., Hannaway, J., Xu, Z., Figlio, D.N., Feng, L., 2012. Value added of teachers in high-poverty schools and lower poverty schools. Journal of Urban Economics 72, 104–122. https://doi.org/10.1016/j.jue.2012.04.004

Shen, J., 1997. Teacher retention and attrition in public schools: Evidence from SASS91. Journal of Educational Research 91, 81–88. https://doi.org/10.1080/00220679709597525

Smith, T.M., Ingersoll, R.M., 2007. What Are the Effects of Induction and Mentoring on Beginning Teacher Turnover? Educational Evaluation and Policy Analysis 26, 681–714. https://doi.org/10.3102/01623737026003681

Sun, L., Abraham, S., 2021. Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. Journal of Econometrics 225, 175–199.

Terenzini, P.T., Rendon, L.I., Lee Upcraft, M., Millar, S.B., Allison, K.W., Gregg, P.L., Jalomo, R., 1994. The transition to college: Diverse students, diverse stories. Research in higher education 35, 57–73.

Van den Berg, L., Kalmijn, M., Leopold, T., 2021. Explaining cross-national differences in leaving home. Population, Space and Place 27, e2476.

Vincenty, T., 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. Survey review 23, 88–93.

Wooldridge, J.M., 2021. Two-way fixed effects, the two-way mundlak regression, and difference-in-differences estimators. Available at SSRN 3906345.

Young, D.J., 1998. Rural and urban differences in student achievement in science and mathematics: A multilevel analysis. School effectiveness and school improvement 9, 386–418.

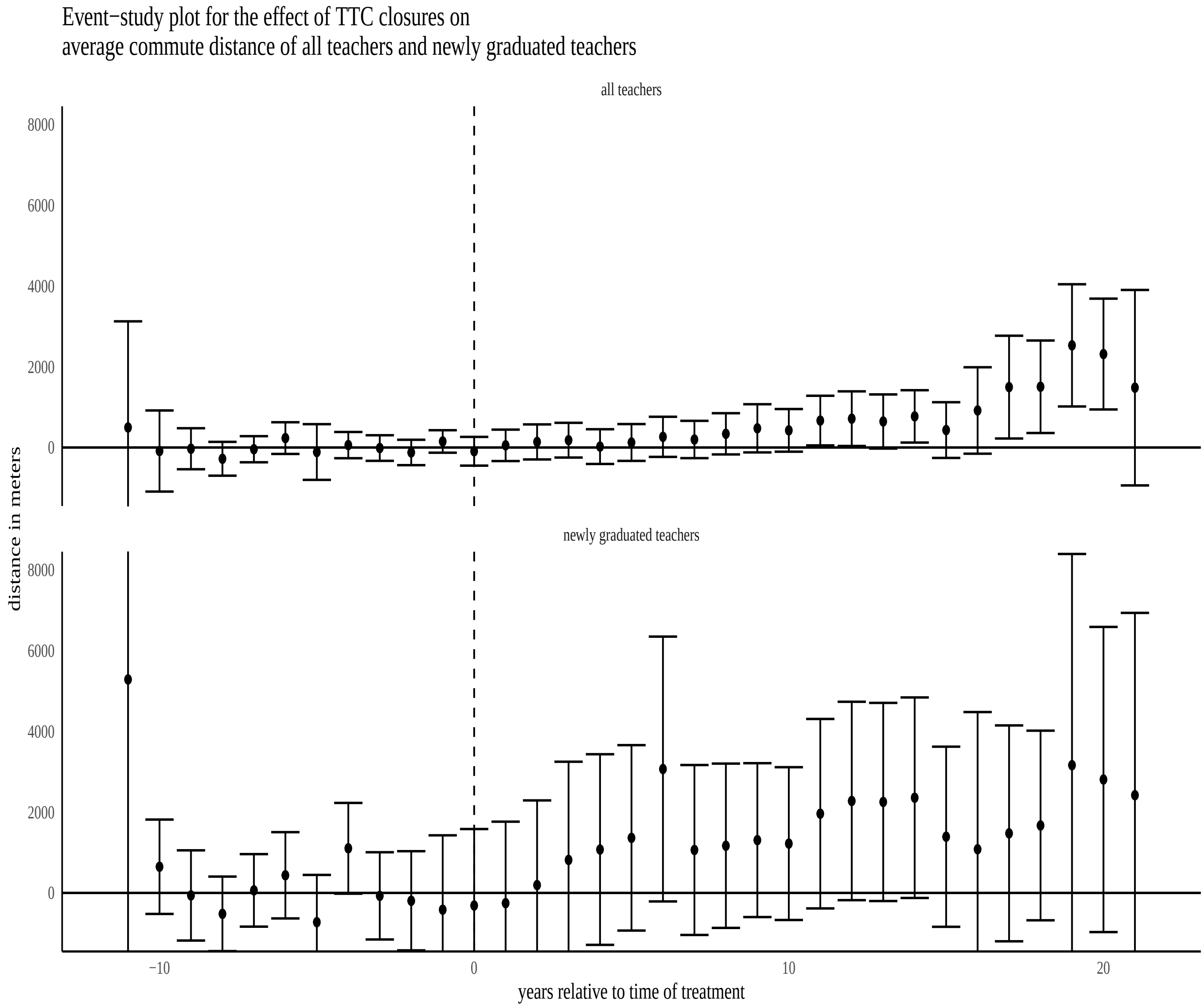
Zhang, J., Jin, S., Torero, M., Li, T., 2018. Teachers and urban-rural gaps in educational outcomes. American Journal of Agricultural Economics 100, 1207–1223.

A Event plots for inspecting pre-trends

A.1 Impact of TTC closure on commute distance event plots

In figure 3 we see that the effect grows in a nearly linear fashion. seemingly, it takes some time for the effects of the TTC closures to “kick in” and peak, as the graduates from the closed TTCs become a minority of teachers. However, it would also be expected that the effect would subside once newly graduated teachers from the remaining TTCs would start to change from the jobs they had as newly graduated teachers and perhaps relocate to other regions of the country. However 3 suggests that such a “repopulation” never took place. As can be seen the effects for newly graduated teachers occur much sooner, which is to be expected. One could have expected that the effect would have peaked around 10 years after the closure TTCs, as all teachers that had graduated within the last 10 years would have graduated from the TTCs that were not closed by that time. From the results presented here, it is hard to discern such a pattern, although there is not quite the same linear pattern as shown in the results all teachers. As expected, the estimates exhibit more uncertainty than the estimates for all teachers. Never the less, the estimates do show a rising pattern in the first 5 periods following the closing of TTCs. From thereon, the estimates never, in a stable manner, return to pre-treatment levels. In conjucntion with the aggregate estimate presented in the main results, i argue this is evidence in support of a lasting effect for newly graduated teachers.

Figure 3

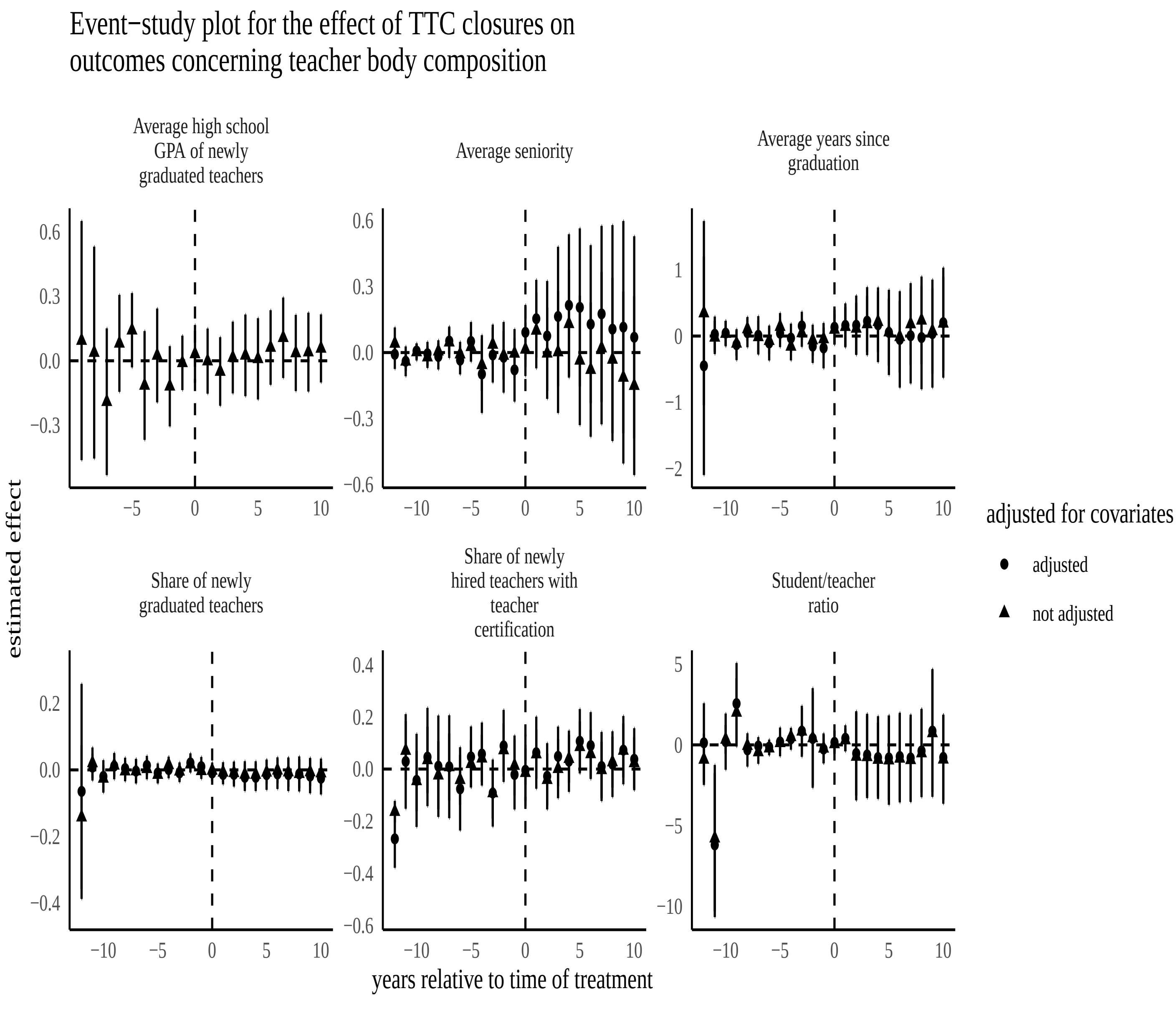


A.2 Teacher body composition event plots

The results in figure 4 shed additional light on how the closure of TTCs affect the treated schools across time. As such, we see that the effects on the student/teacher ratio settle at a quite consistent level following the closure of TTCs. The effects on other outcomes, such as the average high school GPA of teachers, the average years since graduation and, to a lesser extent, the effects on average seniority follow a pattern of relapse where the differences between treated and untreated schools seem to settle at pre-treatment levels after a period of time. The remaining outcomes show more erratic patterns, such as the share of newly graduated teachers and the share of newly graduated certified teachers.

While the the width of the confidence intervals, for the effects on all outcomes, suggest that the effects could have been both positive and negative. However, it is interesting to note, especially for the outcomes with unexpected results, that pattern of the effects across time remains the same. For instance, in the case of average GPA, the pattern shows that average GPA would have increased following the closure of TTCs. However, drawing such a kind of inference vased on the results presented in figure 4 may be unwarranted. The standard errors are associated with each estimate for each period separately. As such, the uncertainty concerns each effect size separately, and not the slope of the effect sizes that we see in figure 4

Figure 4



B Heterogenous effects

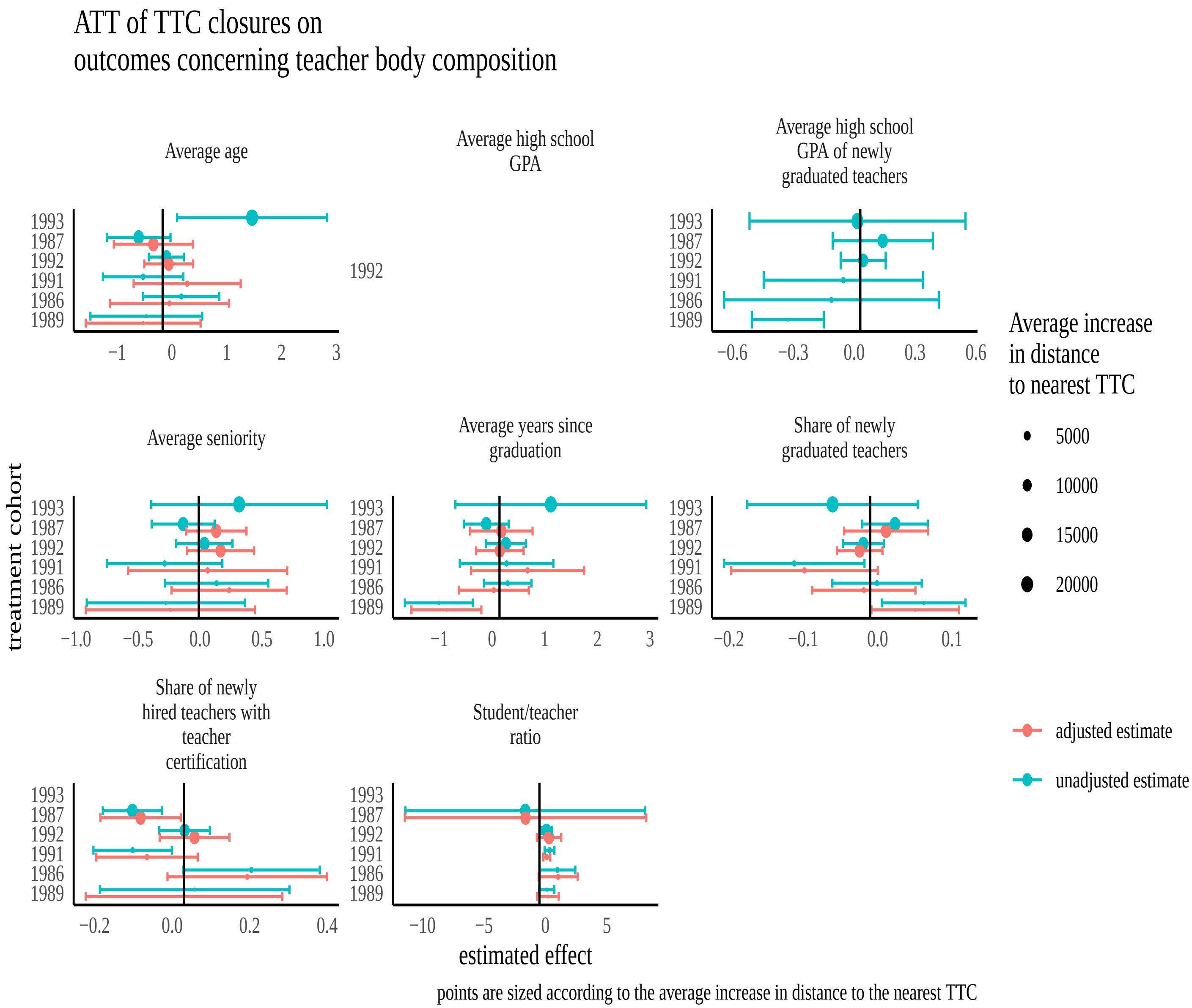
B.1 Across cohorts for teacher body composition

In 5 we see the average ATT for each treated cohort. In 5, the vertical line represents the overall average ATT presented in table X. The points are ordered from top to bottom according to the number of units present in the cohort, and thus the weight the cohort received when computing the overall average ATT. Additionally the points are sized according to the average increase in distance experienced by schools within each cohort. We see here, that the 1987, 1992 and 1993 cohorts clearly experienced a larger increase in distance than the remaining cohorts. While most of the cohort-specific estimates hover closely around the overall estimates, there are som exceptions. In particular, the 1993 cohort shows, in almost all cases, large effects of TTC closures that are in the expected direction. Thus, the estimates suggest that schools in the 1993 cohort, on average, experienced having older teachers, with higher seniority, who had graduated less recently and a lower share of both newly graduated teachers and newly graduated teachers with a teacher certification. However, it is only for two of the estimates, those for average age of teachers and the share of newly graduated teachers with a teacher certification, that we can infer a direction of the effect. For student/teacher ratio however, the estimate of the 1993 cohort is extremely negative, suggesting a very large positive effect. However the associated standard errors are also very large, and we cannot infer the direction for this effect.

In general, there is no clear pattern to support that the estimates of cohorts that experienced a large average increase in distance to the nearest TTC lean in the same direction. However, cohorts that experienced a large increase in distance to the nearest TTC either have statistically significant estimates in the expected direction or have estimates that are very close to 0.

Appendix includes a plot which shows the full distribution of $ATT(g,t)$. The plot does not add much information to the results presented in figure 5, although it does show how the ATT of each cohort changes across time. As in figure 5, the 1993 clearly stands out, by having effects that steadily increase in the expected direction, except for student/teacher ratio.

Figure 5



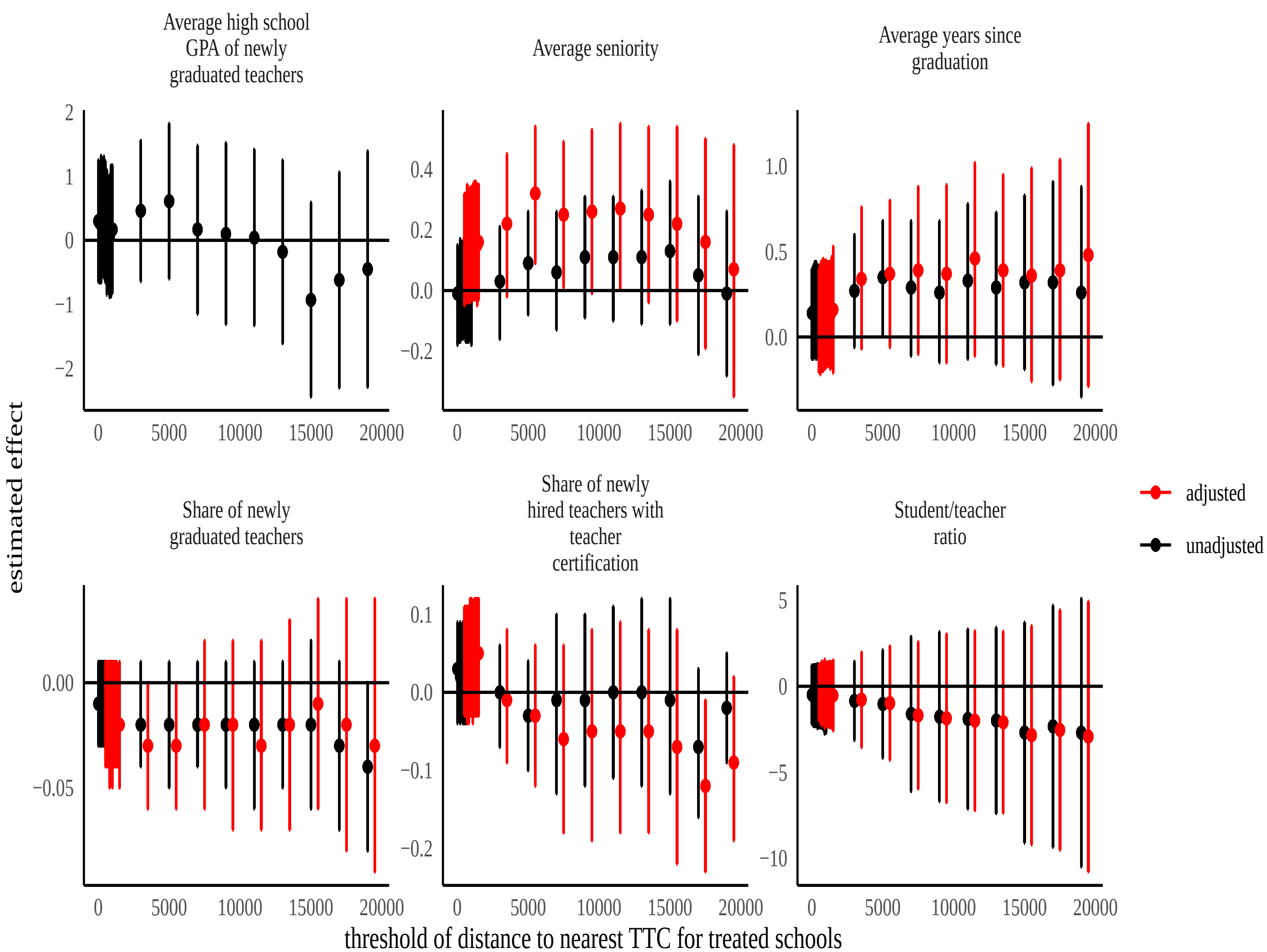
B.2 Varying the threshold for treatment for teacher body composition

In this section i will investigate the role of using different thresholds of increases in distance to the nearest TTC. In the results presented so far, schools that experienced any increase in distance to the nearest TTC were considered treated. However, several schools experienced increases in distance that were small, especially compared to the median level of average commute distance. For both all teachers and newly graduated teachers, the median level of average commute distance was above 5 KM. As such, it is likely that schools which experienced increases below this level experienced any discernible effect of TTC closure. Below i investigate the impact of moving the threshold of which schools are considered treated, with regards to increase in distance to the nearest TTC. In the results below, schools that are at or above a certain threshold of increase in distance to the nearest TTC are considered treated and compared to schools that did not experience an increase in distance to the nearest TTC and schools that had not yet experienced an increase in distance to the nearest TTC. Schools that experienced an increase in distance below a given threshold were excluded from the data.

in figure 6 we see that schools at higher thresholds in general experienced more adverse effects than schools at lower thresholds. However the estimates are associated with very large degrees of uncertainty, and the bounds of the confidence intervals suggest that the data is compatible with schools experiencing both positive and negative effects of TTC closures at nearly all thresholds. As such, we cannot identify, for any of the outcomes, a threshold beyond which schools conclusively experience negative or positive effects of TTC closure. Further, save for the estimates on student/teacher ratio, the estimated effects continue to be small even for schools that experienced substantial increases in distance to the nearest TTC. Excluding student/teacher_ratio, the average difference in percentile rank is 9 for schools that experienced an increase in distance above 15 KM. This means that schools at the median level of an outcome, in the pretreatment distrubtion, could expect to move an average of 3 percentile ranks had they experienced the same change in outcome as implied by the estimated effects.

Figure 6

Aggregated ATT across different thresholds of increases in distance to the nearest TTC for outcomes concerning teacher body composition



C Sensitivty to choice of estimator

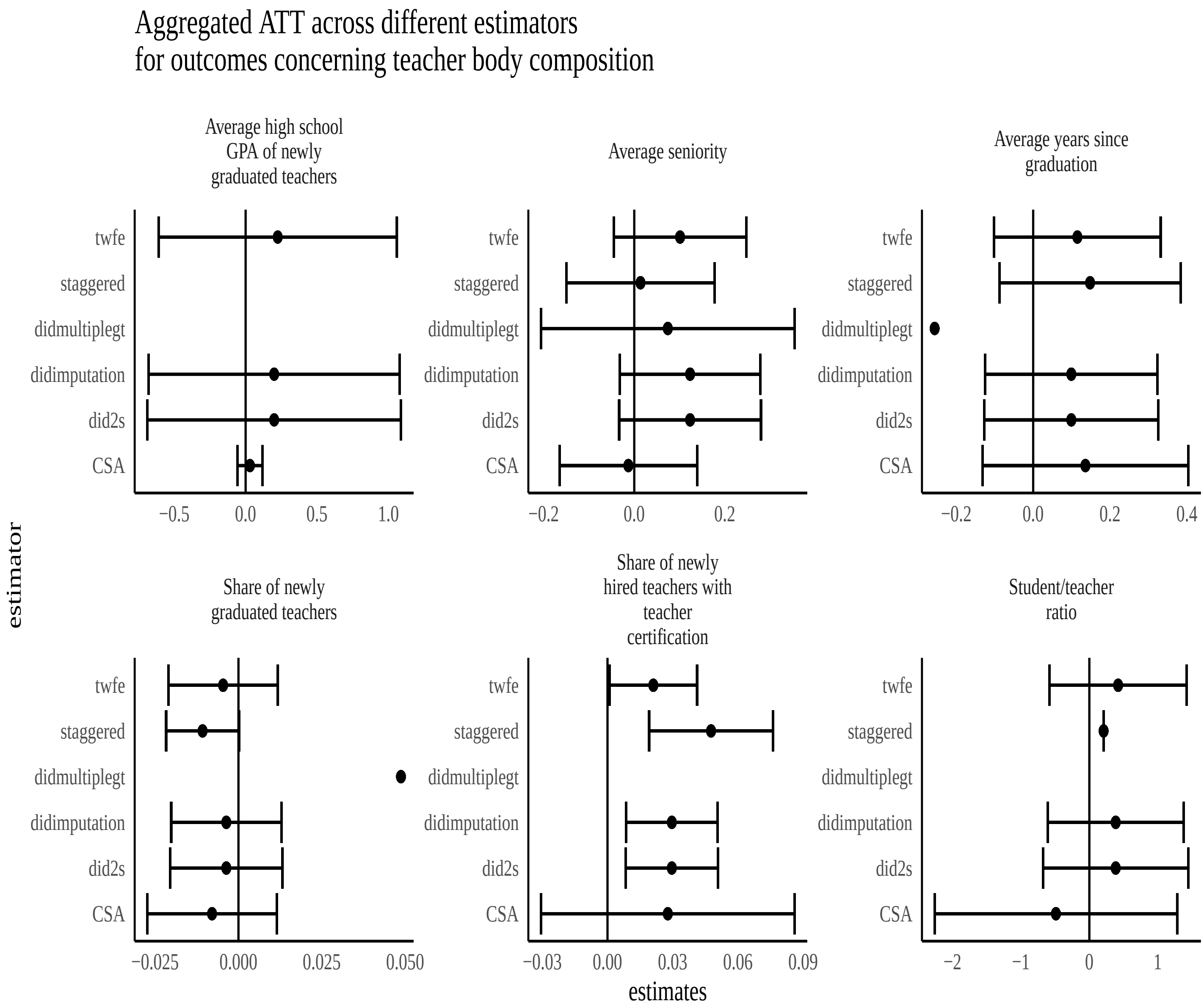
In summary the alternate estimators closely align with the CSA estimates for variables such as average high school GPA of teachers, average years since graduation, and the share of newly graduated teachers with teacher certification. However, for other outcomes, the estimates deviate to varying degrees from the CSA estimate, particularly for average high school GPA of teachers, average seniority of teachers, and teacher/pupil ratio, where the alternate estimates show opposite signs.

Despite these deviations, the majority of the alternate estimates fall within the confidence intervals of the CSA estimates, except for the estimated effect on the average age of teachers when using the stagDID estimator. In terms of cohort-specific ATTs, the CSA and sunabDID estimators exhibit close alignment in their estimates. In contrast, the ETWFE estimator substantially deviates from both CSA and sunabDID estimators for variables like average age of teachers, average seniority of teachers, and average years since graduation, often showing statistically significant adverse effects, with point estimates outside the bounds of CSA confidence intervals. Save for the estimates of the ETWFE estimator however, using alternate estimators does not alter the results in a manner that is sufficient to provide any conclusive evidence of the effects of increased distance to the nearest TTC

For the results pertaining to student academic performance and attainment, the estimates of the different estimators generally align well. On exception however is the stagDID estimator, which consistently estimates positive effects of TTC closures on student academic performance and attainment. While the point estimates, save for the estimate on average high school GPA, are within the bounds of the confidence intervals of the CSA estimator, nearly all estimates are statistically significant. In other words, the estimates of the stagDID estimator suggest that the closure of TTCs had positive, but small, effects on student academic performance and attainment. Given that Roth & Sant'Anna show that the stagDID estimator can yield estimates that are nearly twice as efficient as those of the CSA estimator, it isn't surprising that the stagDID estimator is more prone to yielding estimates that are statistically significant in this case. Whether or not the estimates of the stagDID estimator are more credible is less clear however.

For the cohort specific ATTs, the pattern is very reminiscient of the pattern for the outcomes pertaining to teacher composition. While the CSA and sunabDID estimates are very well aligned, the estimates of the ETWFE estimator are much more prone to show adverse effects on student academic performance and attainment. However, unlike the results for the outcomes pertaining to teacher composition, the confidence intervals are in most cases too wide to infer a direction of the estimated effects. As such, while the ETWFE estimator provides estimates that are generally in the expected direction and some cases suggestive of large effects, the estimates are very uncertain and the ETWFE estimator is in disagreement with the majority of the alternate estimators. Given that there is no apparent reason why the ETWFE estimator should provide more credible results in this case, i argue that the discrepancies between the CSA and the ETWFE do not constitute a serious concern regarding the estimates, for both teacher and student outcomes, of the CSA estimator.

Figure 7



Aggregated ATT across different estimators
for outcomes concerning teacher body composition
Average high school GPA of newly graduated teachers
Average seniority
Average years since graduation
Share of newly graduated teachers
Share of newly hired teachers with teacher certification
Student/teacher ratio
twfe
staggered
didmultiplegt
didimputation
did2s
CSA
estimator
estimates
−0.5
0.0
0.5
1.0
−0.2
0.0
0.2
−0.2
0.0
0.2
0.4
−0.025
0.000
0.025
0.050
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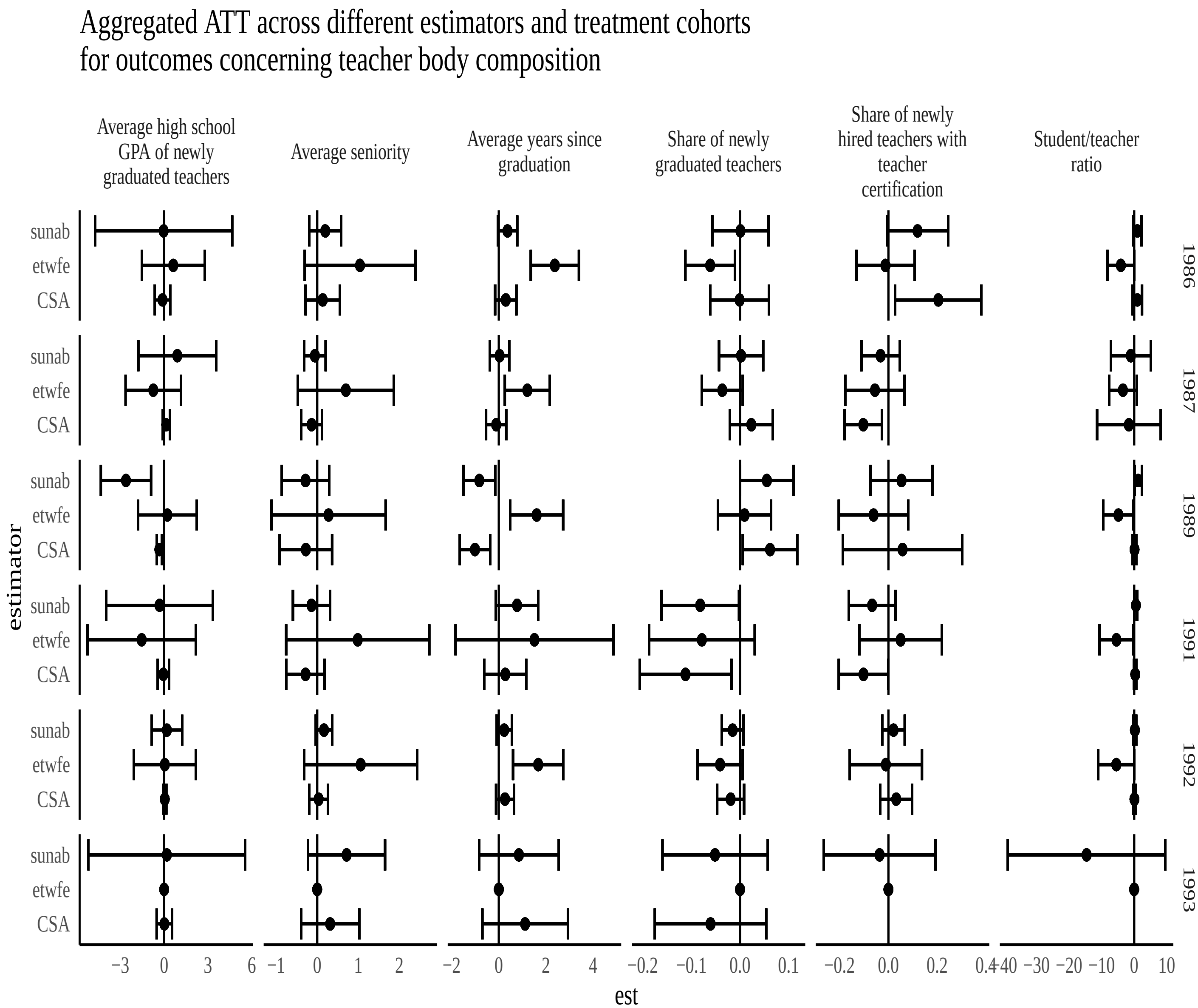
0.09
−2
−1
0
1



D Changes in teacher mobility patterns

In this section i will investigate if and how the mobility of teachers, and newly graduated teachers in particular, changed during the period 1980-2007. I will be inspecting two measures of mobility: 1) The commute distance of teachers to the school at which they are employed 2) How far teachers live from the nearest TTC

In previous sections i have outlined two main expectations regarding the mobility of teachers. Firstly, i expected newly graduated teachers to live closer to a TTC than more experienced teachers and secondly I expected more skilled teachers to be less willing to commute long distances.

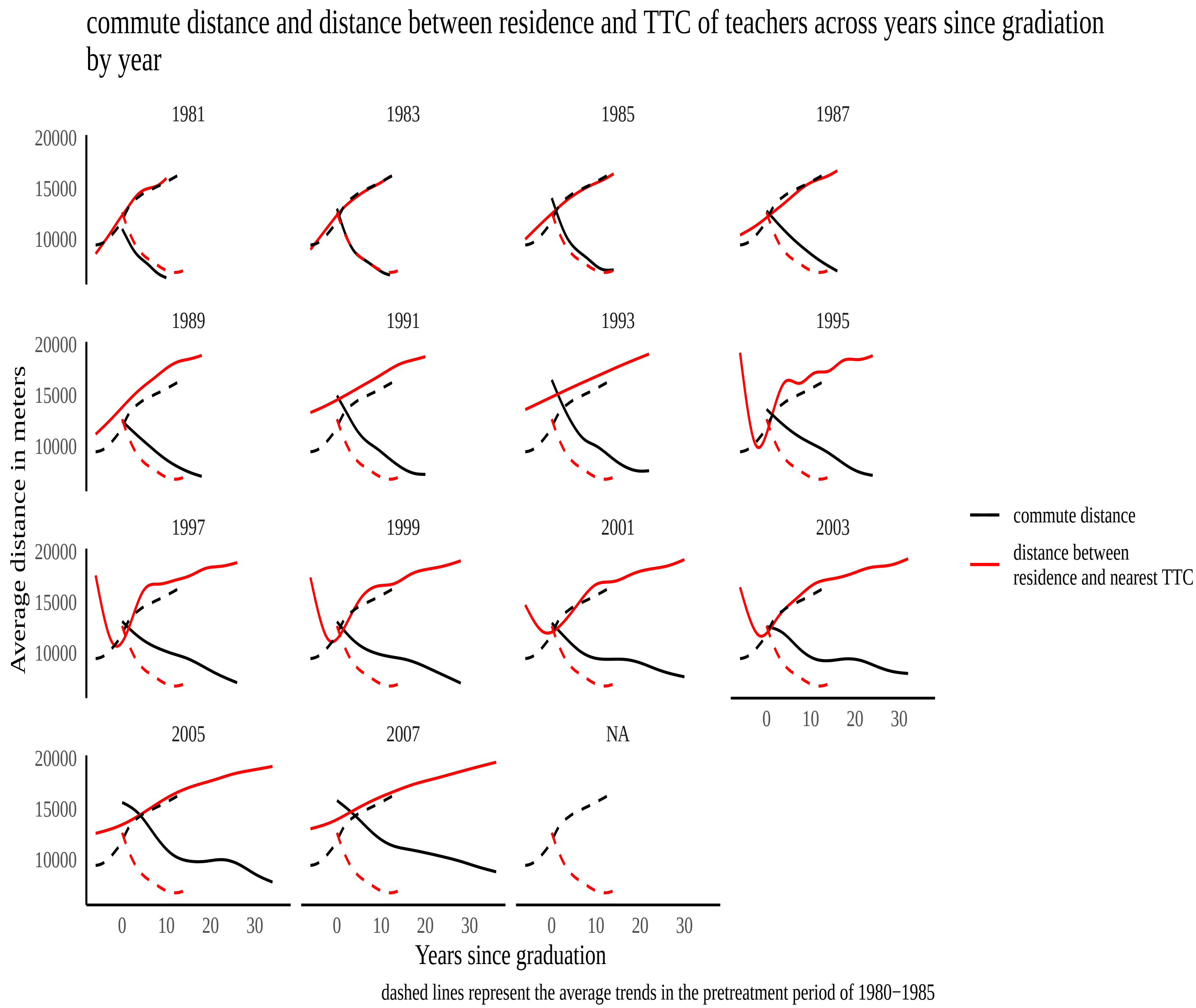
Implicitly, i did not expect substantial changes in teachers' mobility after the closure of TTCs. It is to be expected that a minority of newly graduated teachers would commute long distances after the closure of TTCs, given that some newly graduated teachers would likely be willing to commute to affected schools. However, i do not expect a large average increase of commute distance among newly graduated teachers.

In figure 8 we see a diverging pattern where the distance between teachers' location and the nearest TTC increases and the commute distance decreases as the experience of teachers increase. Thus, as expected newly graduated teachers do live closer to a TTC than more experienced teachers, although the live even closer to a TTC in the years prior to graduating. However, newly graduated teachers are also more willing to commute longer distances than more experienced teachers. This seems sensible, given that newly graduated teachers are less likely have "settled" by e.g. starting a family, being married or have acquired real estate, making them more mobile than experienced teachers. Secondly, newly graduated teachers will likely have to make some compromises when seeking employment, and commuting longer distances could likely be one of such compromises. More experienced teachers are more likely to have secured a permanent position, have thus obtained a more secure position in the labor market from which they don't have to make the same compromises.

Unexpectedly, we do see a shift in both a willingness to commute and a willingness to locate further away from the nearest TTC for newly graduated teachers. The shift peaks in 1993, the year in which some of the schools that experienced the largest increases in distance were affected by TTC closures, and following 1992 in which the majority of affected schools were affected by TTC closures. In the following years, newly graduated teachers locate within a distance of the nearest TTC that resembles the pre-treatment period. However, newly graduated teachers move further away from the nearest TTC at an earlier stage than before. As such, newly graduated teachers in 1997 will have roughly located as far away from a TTC as a teacher with 10 years of experience, in the period before TTC closures, already a few years after graduation. In 2005, the trend is nearly indistinguishable from the trend in the period before TTC closures. While the distance between teachers and the nearest TTC eventually decreases to pre-treatment levels, teachers' willingess to commute is consistently larger following the closure of TTCs. As such, while newly graduated teachers in 2005 live as far from a TTC as newly graduated teachers did before the closure of TTCs, they are willing to commute substantially longer distances than newly graduated teachers were before the closure of TTCs.

This implies that newly graduated teachers were willing to seek employment further away from a TTC following the closure of TTCs. We can construct a measure of how far away from a TTC newly graduated teachers were willing to seek employment, by adding teachers' distance to the nearest TTC and how far teachers' commute, ie. $job\,search\,radius = distance\,nearest\,TTC + commute\,distance$ In other words, we assume that if a teacher lives within a distance of 10 km to the nearest TTC and if that teacher commutes 10 KM, then that teacher is willing to seek employment in a 20 km radius from the nearest TTC.

Figure 8

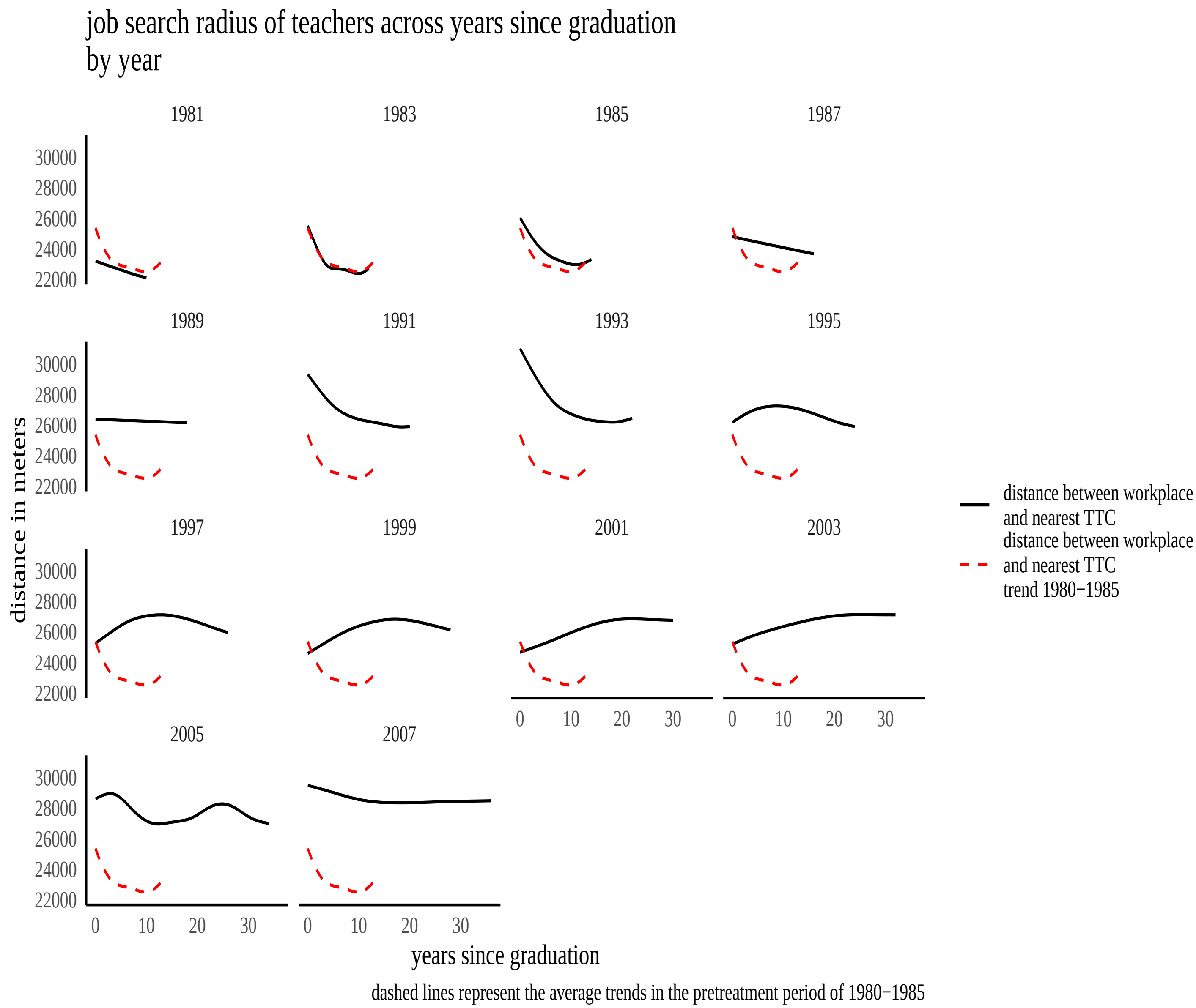


In figure 9 we see that the job search radius[6] increases during the period in which TTCs close, and peaks for newly graduated teachers in 1993. In the following years, we see that teachers who just graduated are willing to seek employment as far away from a TTC as in the period before TTC closures. However, newly graduated teachers expand their job search radius in the first few years after graduation, contrary to newly graduated teacher in the period before closure of TTCs.

As we have seen in figure 8 and in figure 9, the mobility of teachers underwent a visible change in the period during and after closure of TTCs. In general, the results show that newly graduated teachers were more willing to seek employment further away from a TTC in the period after closure of TTCs. It therefore makes sense to suspect these changes in mobility to have mitigated some of the possible adverse of TTC closures.

[6]job search radius is comprised of commute distance+distance between residence and nearest TTC

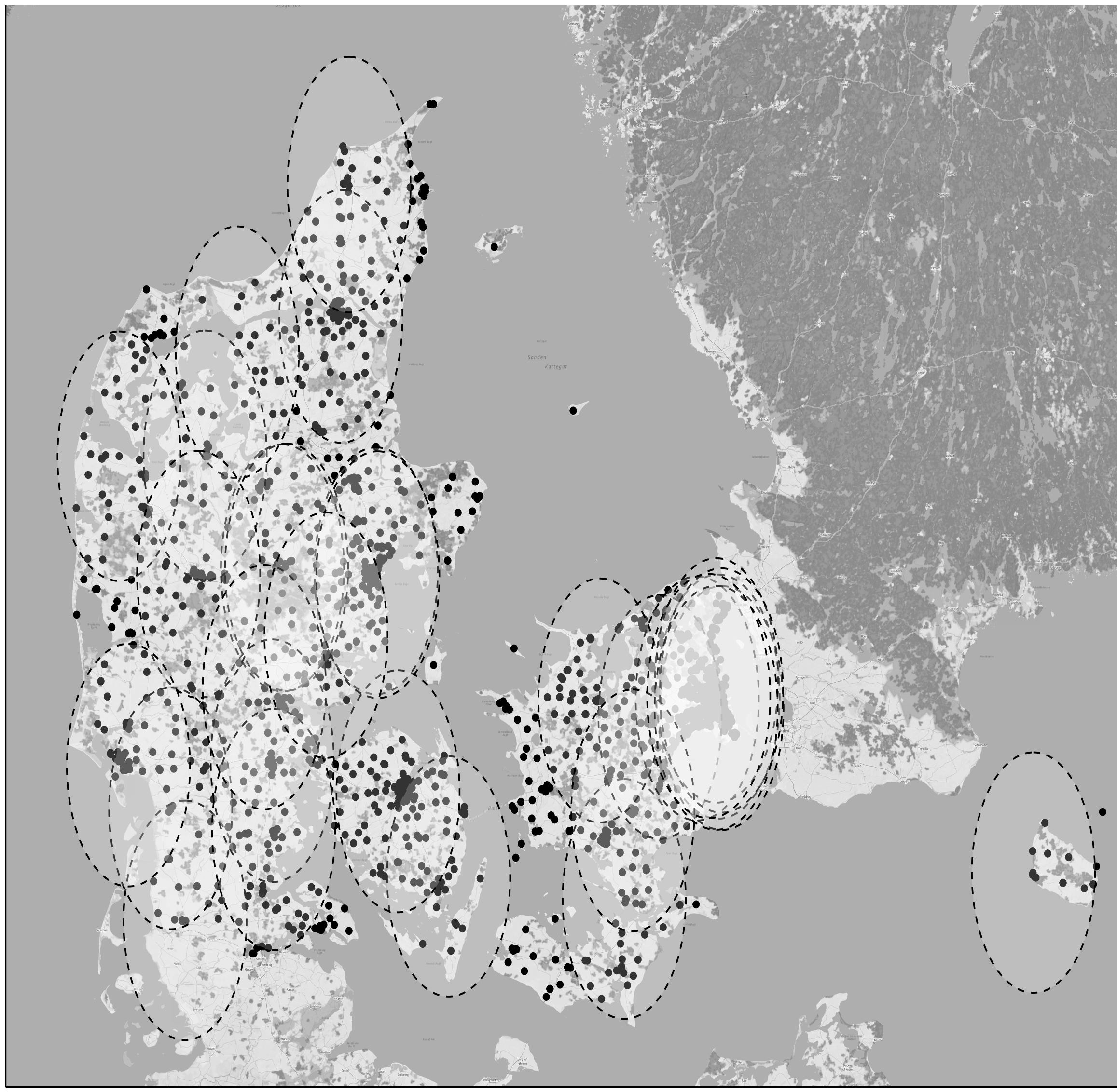
Figure 9



To show the impact of this change we can show how many, and which, schools would have been covered by the median job search radius of teachers with 5, or fewer, years of experience before and after the closure of TTCs. We can further divide the coverage of the median job search radius after the closure of TTC by showing the coverage that would have occurred if teacher mobility had not changed and the coverage that actually occurred in the period following the closure of TTCs

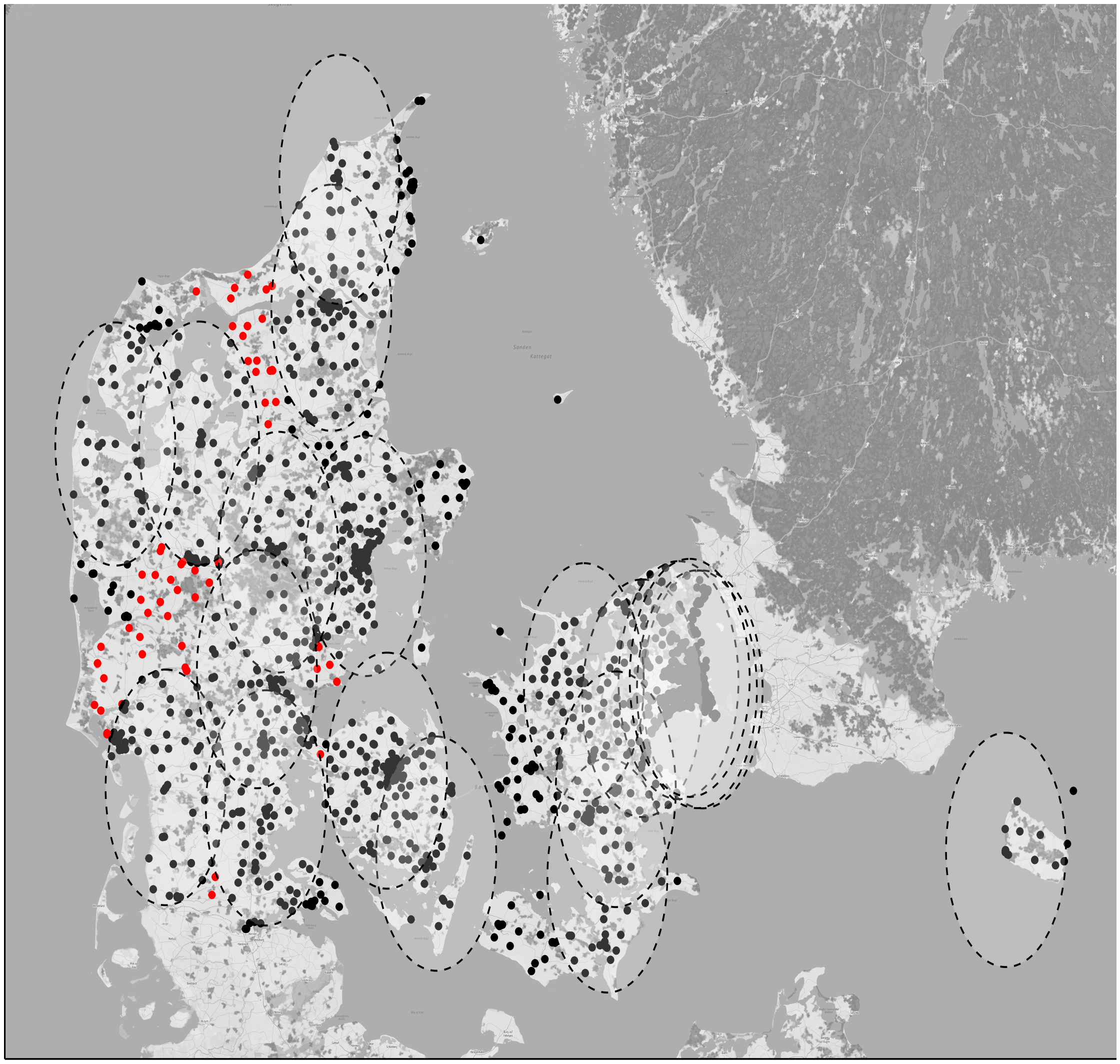
In figure **??**, Panel B, we see that if the mobility of newly graduated teachers had not changed after the closure of TTCs, a substantial amount of schools would no longer have been within the reach of the median job search radius of newly graduated teachers. However of we use the job search radius that actually occurred following the closure of TTCs, shown in Panel C, we see that the amount of schools that are no longer within reach of the median job search radius is heavily reduced. Further, a number of schools that were not previously within the median job search radius are now covered by the median job search radius

schools encompassed by the average job search radius in 1980−1985, relative to the nearest TTC,
in the period 1980−1985(before closure of TTCs



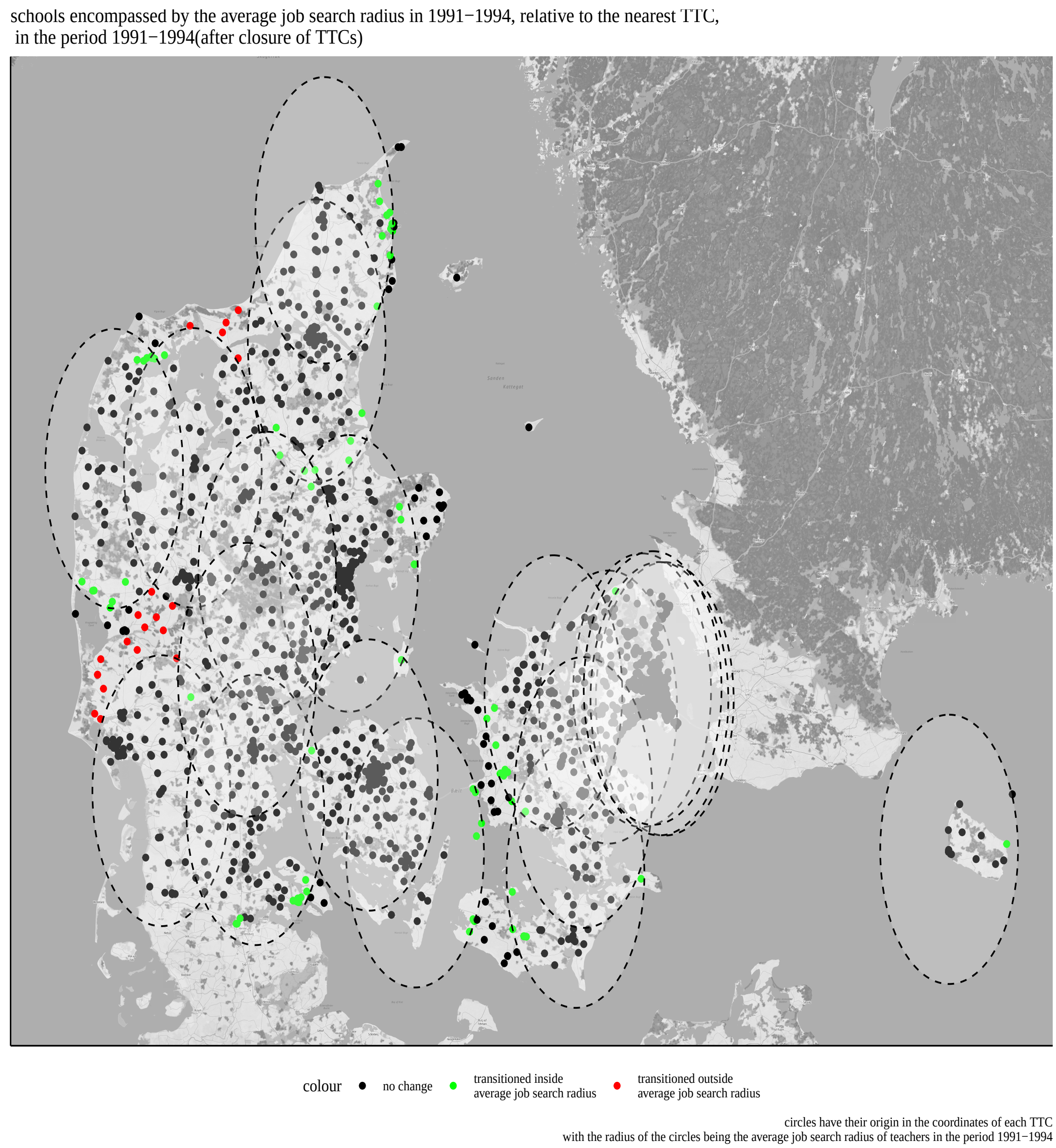
circles have their origin in the coordinates of each
with the radius of the circles being the average job search radius of teachers in the period 1980−

schools encompassed by the average job search radius in 1980−1985, relative to the nearest TTC,
in the period 1991−1994(after closure of TTCs)



colour ● no change ● transitioned outside average job search radius

circles have their origin in the coordinates of each TTC
with the radius of the circles being the average job search radius of teachers in the period 1991−1994



E Identifying teachers and linking teachers to schools

E.1 Who is a teacher?

In this paper teachers have been defined based on registered information of the danish population available in the registers of Statistics Denmark. Specifically all individuals in the population who complied with the following criteria were designated as primary school teachers and were included in the data used in this paper:

Teachers were identified using the following codes for highest attained education(HFAUDD) in the UDDA register of STatistics Denmark

- 5440 Primary school teacher, graduate degree
- 5441 Graduate from “Den Frie Lærerskole”
- 812 Specialization in physical education
- 9132 Elementary school teacher

Teachers were identified using the following codes for occupation(DISCO08) in the RAS and IDAN registers of Statistics Denmark

- 234110 Teaching at primary school level, Children and adults
- 234120 Teaching at primary school level, 1st grade-10th grade
- 235210 Teaching with special assistance, Children and adults
- 235220 Teaching with special assistance, 1st grade-10th grade
- 234130 Teaching at primary school level, kindergarten grade
- 233100 Teaching at primary school level, excl. kindergarten grade
- 233110 Teaching in primary schools, excl. kindergarten grade

Teachers were identified using the following codes for occupation groups(NYSTGR) in the AKM register of Statistics Denmark

- 4313 Public official, teacher

Documentation for the variables and registers used to identify primary school teachers in this paper can be found at https://www.dst.dk/en/TilSalg/Forskningsservice/Dokumentation

While this procedure allows me to identify teachers in the entire period, it is not without some degree of uncertainty and risk of missclassification. While Statistics Denmark can provide data in which one can unambigiously identify public primary school teachers, this particular data does not cover years earlier than 2013.

E.2 Linking teachers and schools

While the registries of Statistics Denmark contain high quality links between individuals and their workplaces, there is no direct link between individual workplace IDs and IDs of public primary schools. It is possible to create such a link by linking a range of different registries.

To do this i relied on the ID variable “P-NR” which identifies workplaces. This ID variable is also assigned to danish educational institutions, and can be accessed via the register of danish educational institutions, INST, https://data.stil.dk/instreghistorik/. In the educational institutions register, institutions are assigned a unique institutional ID, “INSTNR”, as well as the ID variable “P-NR” identifying them as a workplace. Using the LONN register from Statistics Denmark, containing information on current workplace and salary, it is possible to link individuals, via the ID variable PNR, to institutions via the workplace ID variable "P-NR". As such, linking the INST and LONN register, via "P-NR", it is possible to link the institutional IDs, contained in "INSTNR", to IDs of indivdiual teachers, contained in the variable "PNR". One challenge of this approach however is the coverage of the variable "P-NR", given that "P-NR" does not have any coverage before 2008, making it only possible to link teachers and schools from 2008 onward. To extend the link to earlier years i also include the workplace ID variable "ARBNR", which is also contained in the LONN register. The ID variable ARBNR covers from 1997, making it possible to extend the teacher/school. Additionally the ID variable "ARBNR", as well as the individual ID variable "PNR", are also available in the register IDAN, which concerns employments. Importantly, the IDAN register contains an additional workplace ID variable, "LBNR" which covers from 1980 and onward. Thus by linking the INST-LONN dataset to the IDAN register, via the ID variables "ARBNR" and "PNR", it is possible to link teachers and schools from 1980 and onward using the "INSTNR" -> "P-NR" -> "ARBNR" -> "LBNR" workplace ID link and the ID variable "PNR" concerning individual teachers.

In addition i also used data which contained all public primary school teachers in the years 2013-2020, in which school identifiers and individual identifiers were linked. I then linked this particular dataset to data containing individuals linked with workplace identifiers. This resulted in a dataset in which individual teachers were linked to both school and workplace identifiers in the years 2013-2020. Following this procedure i constructed a link between school and workplace identifiers by finding the most prevalent workplace identifier within each school. For instance, if the workplace ID 0002341 was shared by the most teachers in school 1, then the workplace ID 0002341 would be assigned to school 1.

F Results including estimates adjusted for covariates

Outcome	n	Estimate	n for model with covariates	Estimate when adjusted for covariates	Effect size for unadjusted estimate	Effect size for adjusted estimate
Average seniority	1249	-0.01(0.14;-0.17)	713	0.14(0.33;-0.06)	0.5(0.53;0.43)	0.53(0.54;0.47)
Student/teacher ratio	715	-0.49(1.28;-2.26)	713	-0.36(1.44;-2.17)	0.28(0.83;0.01)	0.34(0.86;0.01)
Share of newly hired teachers with teacher certification	393	0.03(0.09;-0.03)	282	0.04(0.11;-0.03)	0.53(0.6;0.46)	0.55(0.61;0.46)
Average high school GPA of newly graduated teachers	1642	0.03(0.12;-0.06)	NA	NA	0.54(0.59;0.49)	NA(NA;NA)
Average years since graduation	1157	0.14(0.4;-0.13)	681	0.1(0.41;-0.21)	0.52(0.58;0.47)	0.52(0.58;0.45)
Share of newly graduated teachers	1157	-0.01(0.01;-0.03)	681	-0.02(0.01;-0.04)	0.49(0.51;0.47)	0.48(0.51;0.45)

Table 4: (#tab:restab with covars)Estimated ATT of closure of TTCs on teacher composition outcomes. Lower and upper bounds of confidence intervals are in parenthesis