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Constrained optimisation? Teacher salaries, school resources and student achievement

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\section*{ABSTRACT}

Should schools increase teachers’ salaries to improve pupil attainment? We study the potential implications of an individual school offering higher teacher salaries from within a fixed budget by exploiting a natural experiment that forces some schools within a local area to pay teachers according to higher salary scales, but does not offer any extra funding. We show schools follow this regulation and pay their teachers more. The characteristics of teachers are largely unaffected, but teachers at high pay schools are less likely to be absent. Teacher and assistant numbers are largely unchanged. Instead, schools balance their budgets by making sizeable reductions in other expenditures, particularly spending on equipment and services, amounting to around 4\% of non-instructional spending. There is no evidence of any overall effect on pupil attainment, however. It is likely that positive effect of the natural experiment through teachers is almost exactly countered by the negative effects of reductions in other expenditure.

\section{1. Introduction}

Schools across developed countries are gaining more autonomy over budget decisions and teacher salaries, meaning it is increasingly important to identify the effect of school spending choices on pupil attainment. In England, recent reforms have given state-funded schools more autonomy over the level and structure of teacher pay. In the US, charter schools have more freedom to set teacher pay outside regulations imposed on public schools, whilst the Race to the Top initiative encouraged states and school districts to decentralise more budgetary decisions to public school principals. Previous research has studied the effect of increasing the overall level of resources, with most recent work finding positive effects of higher resources (Jackson, Johnson, and Persico (2015), Gibbons, McNally, and Viarengo (2018), Hyman (2017), Lafortune, Rothstein, and Schanzenbach (2018), Jackson, Wigger, and Xiong (2018), Baker (2019). Other evidence suggests offering higher teacher salaries across large geographic areas may improve pupil attainment (Loeb and Page (2000), Gilpin (2012), Leigh (2012), Hendricks (2014), Britton and Propper (2016) and Tran (2017)). However, there is no existing evidence of the effects of an individual school offering higher salaries and the underlying mechanisms through which this may affect pupil attainment.

In this paper, we study a natural experiment that effectively forces some schools within a local area to pay teachers according to higher salary scales, holding school budgets constant. This allows us to produce convincing estimates of the effects of raising salaries at individual schools, and the underlying mechanisms driving the reduced form effects: teacher sorting and efficiency wage concerns, countered by reductions in other expenditure.

In contrast, existing estimates of the effects of teacher salaries (Loeb and Page (2000), Gilpin (2012), Leigh (2012), Hendricks (2014), Britton and Propper (2016) and Tran (2017)) typically consider the impact of raising teacher salaries with a commensurate increase in funding, which is not necessarily relevant for individual schools. Through studying the effects of differences in teacher and outside wages over wide geographical areas, the underlying mechanisms in these studies include teacher occupational choices (in addition to the sorting of teachers across areas/schools and efficiency wages) which is largely irrelevant for individual schools when considering whether to raise teacher pay.

The natural experiment we exploit is a sharp geographical discontinuity in teacher salary scales in England. During our period of study, teachers in England were paid according to centrally determined salary scales, holding school budgets constant. This allows us to produce convincing estimates of the effects of raising salaries at individual schools, and the underlying mechanisms driving the reduced form effects: teacher sorting and efficiency wage concerns, countered by reductions in other expenditure.
England. In the case of inner and outer London, higher teacher salaries come with higher levels of funding, and the boundaries of the pay zone coincide with other administrative geography that are likely to affect pupil attainment (boundaries of school districts and zoning for housing development). We instead focus on the boundary between fringe London and the rest of England. For a given level of experience, teacher salary scales are about £1,000, or about 5%, higher in fringe London as compared with the rest of England. This boundary often runs within school districts (or local authorities as they are called in England), meaning that education policy is relatively constant for schools in close proximity and either side of the boundary. Teachers are free to live either side of the boundary, the cost of living is likely to be constant within a small distance to the boundary and schools and communities are likely to be similar either of the boundary (which we confirm). Conditions and other benefits are also constant across the boundary given nationally governed pay and conditions. We therefore interpret the boundary as representing an exogenous increase in the salary that must be paid to a teacher of a given level of experience. We show that schools inside the fringe London boundary don’t receive proportionately higher funding to account for the regulated higher teacher salary scales. Schools must therefore pay the higher teacher salaries from within their fixed budget, which allows us to study the resource choices made by schools. Anomalies in funding differences across areas have already been studied in England to show that increases in funding (without increases in teacher salaries) can improve pupil attainment (Gibbons et al. (2018)).

We confirm that teacher pay follows the regulation and that schools in the “high pay” area spend a greater share of their budgets on teacher salaries as a result, with offsetting reductions in non-staff expenditures to balance the budget. There is little evidence that this leads to observable differences in the sorts of teachers at individual schools, although we have imperfect measures of teacher quality. We do find indirect evidence to support an efficiency wage mechanism, however, with teachers on the high pay side of the boundary less likely to be absent or sick. This is a valuable finding as there is little existing evidence of efficiency wage effects for teachers. Finally, there is little evidence of any net positive effect on pupil attainment from the combination of higher teacher salaries and reduced non-teacher spending. Due to the relative precision of our estimates, in our preferred specification we are able to rule out quantitatively small positive estimates of 0.046 and 0.036 standard deviations in English and maths at age 11, respectively.

This combination of results suggest that schools optimally adjust resources so that the combined effect of higher regulated teacher salary scales and consequent changes in other expenditure has few implications for student achievement. Given that the pay regulation has been in place since the 1970s, our estimates of a near zero policy effect represent a long-run equilibrium.

The near zero total policy effects could be because the positive effects of higher salaries and negative effects of reduced non-teacher expenditures are both small. However, it could also be that larger effects offset each other. We argue that the latter is a more plausible explanation. The recent literature on school resources shows significant effects of changes in school expenditures (Jackson (2018)), including negative effects of reductions in school resources overall (Jackson et al. (2018)). There is also a well-established literature showing that teacher sorting is sensitive to financial incentives (Cloftelther, Glennie, Ladd, and Vigdor (2008) and Steele, Murnane, and Willett (2010)). Cabrera and Webink (2019) argue that such incentives only improve pupil achievement if they lead to changes in teacher characteristics linked to pupil attainment, such as teacher experience. Whilst we don’t find any evidence of changes in teacher experience, we do find evidence of reduced teacher absence as a result of higher salaries, which is linked to higher student achievement (Herrmann & Rockoff (2012)).

Our results imply that the net benefits of a school offering higher teacher salaries from within a fixed budget are likely to be minimal. This is relevant to both regulated and autonomous schools in England, as both school types have similar freedoms on non-teacher expenditures, and, since 2013, almost complete autonomy over teacher pay and progression. Our results also imply that existing school resource decisions are relatively efficient as schools are able to adjust other resources in ways that lead to little overall change in pupil attainment.

These results are mainly relevant for schools with autonomy over teacher pay and the setting of non-instructional resources. However, our exploration of the size of the underlying mechanisms increases the relevance to all school systems, e.g. how teacher salaries can affect teacher absence and the likely negative effects of cuts to non-instructional spending. The main limitation is that the higher teacher salaries and cuts to non-instructional spending could affect wider outcomes we are not able to observe, such as other aspects of teacher characteristics or pupils’ mental health.

This paper proceeds as follows: Section 2 motivates our empirical approach by presenting a brief model of how student achievement relates to teacher wages and school resources. Section 3 summarises the key institutional details relating to schools and teachers in England. Section 4 describes our empirical strategy and data sources. Section 5 presents our empirical results. Section 6 concludes.

2. Teacher wages, school resources and student achievement

This section presents a model of student achievement in relation to teacher salaries and school resource decisions. This motivates our focus on the effect of changing teacher wages at individual schools within a fixed budget and how this differs from the current literature on the effects of teacher wages. We also detail the mechanisms through which this resource allocation affects student achievement.

Consider the level of student achievement at an individual school within a large geographic area such as a state or city-region. Schools are indexed by s and there are many schools within the area. Taking a standard school production function approach (Hanushek (2006); Todd and Wolpin (2003)), as shown in Eq. (1), we assume average student achievement (Y) at school s is a function of the characteristics of pupils at the school (Xs), the pupil-teacher ratio at the school (Qs), the quantity of other resources per pupil (Qs) and the average quality of teachers at the school (Ts). We also assume that schools are provided with a fixed level of funding per pupil from government (Bs). Schools maximise Ys subject to a budget constraint, such that spending on teachers and spending on other goods is less than Bs (Eq. (2)).

Average teacher quality (Ts) is assumed to be a function of teacher wages at the school (Wp), the average wage at other schools in the area (Wp), the outside wage for teachers (Wp) and pupil characteristics (Xs) (equation 3).

\[
\text{max } Y_s = f(X_s, Q_s, Q_p, T_s) \text{ s.t. (1)}
\]

\[
B_s = Q_s W_s + Q_p W_p
\]

\[
T_s = g(W_s, W_p, X_s, Y_s)
\]

\[
X_p, p^0, B_s, W_p, W_p \text{ given (3)}
\]

We assume schools are able to set their own teacher wage rate, reflecting evidence that suggests they possess significant monopsonistic power over wages (Ransom & Sims (2010)) and the increasing autonomy over teacher salaries possessed by schools in England, the US and other countries. We assume that they are price takers for other inputs and that non-wage benefits (such as conditions of employment) are taken as fixed due to regulation.\footnote{In England, this will reflect national conditions of service. In the US, conditions of service are generally constant within school districts, which (Loeb &}
provided by government and taken as fixed by schools when making resource decisions.

This model incorporates a number of potential mechanisms by which changes in relative teacher wages can affect teacher quality and thereby student achievement. First, as per a standard Roy model (Roy (1951)), changes in relative teacher wages will affect the average quality of individuals who chose to become teachers through their occupational choices. Second, relative teacher wages could affect teacher effort levels through efficiency wage concerns (Shapiro & Stiglitz (1984)). Third, the level of teacher wages at individual schools will affect the sorting of teachers between schools. Schools choosing higher teacher salaries are likely to attract more applicants. As long as schools can observe potential teacher quality and high quality teacher prefer higher pay levels, this should allow higher pay schools to employ higher quality teachers.

To date, the literature has mainly focused on how teacher wages affect student achievement through the first two mechanisms (occupational choices and efficiency wages). Gilpin (2012), Leigh (2012), Loeb and Page (2000), Britton and Propper (2016) and Tran (2017) focus on differences in teacher wages across large geographical areas and are thus likely to exclude teacher sorting. Hendricks (2014) focuses exclusively on the occupational choices mechanism. de Ree, Muralidharan, Pradhan, and Rogers (2018) isolate the effect of higher teacher salaries on pupil attainment for existing teachers, and so through efficiency wages only. In contrast, the effect of an individual school changing teacher pay will reflect a combination of the second two mechanisms (efficiency wages and sorting across schools), as changes in teacher pay at one school are unlikely to affect occupational choices.

Our interest lies in the marginal policy effect of changes in teacher wages at individual schools on overall student achievement, holding the budget fixed, which has not been estimated in the literature to date. This overall effect will incorporate a combination of different mechanisms, potentially working in opposite directions. Pupil attainment could be boosted by increases in teacher quality ($T_i$) driven by a combination of efficiency wage and sorting effects. Clotfelter et al. (2008) and Steele et al. (2010) find that teacher sorting responds to financial incentives, for example, although some evidence suggests that the sorting of teachers to schools is more sensitive to school and pupil characteristics than wages (Hanushek, Kain, and Rivkin (2004); Bohnet, Falch, and Strom (2005)). There is no existing evidence on the direct implications of teacher sorting for student achievement. The overall effect will also include potential negative effects of reduced spending on other resources ($Q^3$), given that the budget must balance. The new literature on school resources suggests that such negative effects could be important (Jackson et al. (2015); Jackson (2018)). The existing work on teacher pay assumes, either explicitly or implicitly, that school budgets co-vary with changes in teacher pay (e.g. Loeb and Page (2000) state that pay higher salaries are also likely to provide higher levels of school funding). Also underlying our effect is any attempt by other schools or policymakers to respond to pay differences across schools, through pay or non-pay factors. We argue below that such effects are small in practice.

The main implication from this analysis is whether shifting school budgets towards higher teacher salaries can improve pupil attainment, i.e. whether the efficiency wage and sorting effects outweigh the negative resource effects. If there are large net positive or negative effects, this would imply schools are currently behaving inefficiently, as a simple shift in resources can improve pupil attainment. A near zero effect would imply schools are allocating current resources in an efficient manner. Furthermore, how other resources adjust to fund higher teacher salaries could in principle reveal new evidence on schools’ resource preferences.

Consideration of this model therefore highlights that changes in teacher wages can operate through three primary channels: occupational choices; efficiency wage concerns; sorting of teachers across schools, with the first unlikely to be relevant in our setting. The model also indicates that the offer of higher teacher wages by schools is likely to be an endogenous response to their situation. To identify the impact of higher teacher wages on student achievement one therefore cannot simply compare student achievement at schools offering different levels of teacher wages. Ideally, one would use a randomised experiment that forced some schools to offer higher teacher salaries, holding budgets fixed. In the next section, we describe a natural experiment in England that comes close to replicating such a scenario.

3. **Institutional background**

Our empirical strategy makes use of sharp geographical discontinuities in teacher pay levels in England. In this section, we describe how schooling and the teacher labour market operate in England, concluding with the implications for our empirical strategy.

3.1. **Schools and teachers in England**

The majority of pupils in England attend primary schools from ages 4–11 before attending secondary school after age 11 through to age 16. We focus on primary schools rather than secondary schools as they are more numerous, which increases the precision of our results. All pupils in state-funded schools in England must sit external assessments at the end of primary school in Maths and English, known as Key Stage 2 (KS2) tests. These are our main measures of student achievement.

There are two main types of school in England: maintained schools and Academies. The main differences are that Academies have more freedoms over school organisation, can deviate from the national curriculum and, before 2013, had more freedoms over teacher pay. Academies are very similar to US charter schools. However, it is only since September 2010 that primary schools could apply to become Academies. Over the period covered by our data (2006 to 2011), most state-funded primary schools were maintained schools and were the responsibility of the 151 Local Education Authorities (LEAs) across England.

LEAs are similar to US school districts. They are responsible for providing budgets to individual schools, coordinating admissions, assisting with the governance of the school and providing some central services for all schools in their area (e.g. support for children with special educational needs). Although LEAs are responsible for funding schools, this money is not raised through local taxation. It primarily comes from a grant from central government (called the Dedicated Schools Grant). This grant is supposed to reflect the differences in the needs and costs of providing schooling in different areas. Indeed, there is an “Area Cost Adjustment” to account for differences in costs, though prior work has suggested this has not always been perfectly aligned with actual differences in costs (Gibbons et al. (2018)). LEAs are then responsible for how to distribute this grant to different schools in their area. Each sets its own school funding formula, with the most important factors being pupil numbers and the socio-economic mix of pupils at the school (Sibieta (2015)).

Individual schools are responsible for resource decisions, given the

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(footnote continued)

Page, 2000) difference out through school district fixed effects.

As discussed below, this mechanism is not relevant for our study, but we include it to compare our setting to the previous literature on the impact of teacher salaries on pupil attainment.

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1 Pupils in private or independent schools do not have to sit these tests, but account for only about 6% of each cohort of pupils.

2 LEAs are able to add to this grant if they wish, but very few do in practice (Sibieta (2015))
fixed budget from the LEA. In particular, it is individual schools who make hiring decisions for teachers and other staff and how much to spend on different types of resources, subject to regulations. For example, there are maximum class sizes for under 7s and there exists national pay and conditions for teachers, which are reflected in the School Teachers' Pay and Conditions Document (STPCD). All schools (maintained schools and Academies) have considerable freedom as to how they employ other members of staff (e.g. teaching assistants and administrative staff), who can be employed on temporary or fixed contracts. All schools also have freedom on spending on non-staff resources, such as books, services and energy.

3.2. Teacher pay

During the period we study, teachers in England were paid according to a national salary scale that had nine different points (M1-6, U1-3). In principle, schools had some discretion about how quickly their teachers move up the pay scale. In practice, position on the pay scale was almost entirely determined by years of experience. Schools could choose to use some additional payments to pay teachers above the salary scales if they wished, but these flexibilities were rarely used by schools.

Since September 2010, many primary schools have converted to Academy status and thus gained additional freedom over teacher pay, though few will have had any opportunity to use these freedoms before our final outcomes are measured in May 2011. From September 2013, all state-funded schools in England were given more autonomy over teacher pay, with pay scales replaced by minimum and maximum levels and all schools are required to have their own individual pay policies. Our research describes the likely implications of a school choosing to use these freedoms to offer higher salary levels, which is now a relevant choice for all schools in England.

In order to reflect the higher cost of living in or near London, the level of the pay scales varies across the London area. Specifically, there are four different pay zones: inner London (highest pay zone); outer London; the fringe area of London; and, the rest of England and Wales (lowest pay zone). These are shown in Appendix Fig. A.1, excluding the inner and outer London boundaries.

The boundary of the inner London and outer London pay boundary both coincide with the boundaries between LEAs. The outer London boundary also coincides with the boundary of the "green belt" (which severely reduces housing development on the low-pay side of the border). As a result, the inner and outer London boundary could be correlated with differences in schools policy and family background. By contrast, the fringe boundary (shown in Fig. 1) mostly runs within LEAs, along local authority district boundaries (e.g. within Kent or Buckinghamshire). Local authority districts are smaller local administrative units that are responsible for a number of non-education functions, e.g. waste collection. As a result, there is no reason to expect education policy or pupil characteristics to differ either side of the fringe boundary (which we confirm empirically).

The boundaries of the pay zones and the system of London allowances were introduced in 1974 following the recommendations of the Pay Board and Houghton Committee reports of the same year (Zabalza & Williams (1979)). The fringe zone was established in order to prevent a large step change in teacher salaries at the outer London boundary. The fringe boundary has not changed since it was first established and has largely remained as a fixed amount on top of the pay scales for the rest of England and Wales. Given that the fringe pay zone has existed for more than 30 years, our results represents the long-term equilibrium.

Our empirical strategy relies on the differences in pay scales across the fringe boundary. Fig. 2 shows the level of each point of the seven points in the pay scale either side of the fringe boundary over the period covered by our data (2006 to 2011). The differences across the boundary correspond to about £1,000 right across the pay scale throughout the period, or about 3–5% of teacher salary levels in the rest of England. These differences are within the range of increases in teacher salaries that individual schools could decide to award from within their fixed budgets, and so are policy relevant. It is unlikely that schools would be able to unilaterally offer substantially higher salaries.

3.3. Implications for school resource decisions and student achievement

We interpret the pay boundary as representing a difference in the minimum salary levels that must be paid to teachers with a given level of experience. We analyse the net implications of this rule for student achievement and detail the mechanisms driving this effect, including: actual teacher pay levels; school expenditure decisions; teacher sorting; and, teacher absences.

As argued in Section 2, the implications for school resource decisions and student achievement will depend on differences in school budgets at the boundary. Given that we find no difference in school budgets at the boundary, schools on the high pay side effectively face a higher price of employing teachers with no compensating change in their income. It therefore forms an ideal natural experiment to study the implications of increase in teacher pay from within fixed budgets.

The fact that there is no difference in funding per pupil at the fringe boundary is somewhat surprising. At the inner and outer London boundaries, schools do receive higher levels of funding (13–14%) to compensate for higher teacher salaries. It is not entirely clear why there is no evidence of any compensation for schools at the fringe boundary. It may be that because the differences in salaries are relatively small, local authorities felt they could be absorbed by schools. This is no longer the case, as new simpler local authority funding formulae were introduced in 2013, which explicitly recognise the fringe boundary. This, and the introduction of greater freedoms on teacher pay are the main reasons we do not extend our analysis beyond 2011.

Absent any restrictions on teacher numbers, the combination of higher teacher pay and unchanged budgets should lead to re-enforcing substitution and income effects that reduce teacher numbers (assuming teacher expenditure is a normal good). Regulation on teacher numbers (such as maximum class sizes for pupils aged 5–7) seems likely to limit any reduction in spending on teachers, however, and may even lead to an increase in spending if the restrictions are strong enough and the income and substitution effects are weak. Teachers are also a discrete good and schools might not be willing to reduce teachers numbers in response to a 5% increase in teacher salaries. However, there are ways that schools could reduce expenditure on teachers, e.g. limiting additional payments, hiring teachers with different experience or slowing teachers’ progress through the salary scales. Schools on the low-pay side of the boundary could further smooth the actual difference in teacher pay across the boundary by paying their teachers more. We test for such effects by examining the actual differences in teacher pay across the boundary, the level of additional payments and average position on the salary scale.

In principle, schools could consider adjusting wider conditions and non-pecuniary rewards to respond to the pay regulations. However, this is unlikely to be feasible in practice, given statutory national pay and conditions. Any changes to conditions of service could also be implemented by schools on both side of the boundary.

We therefore interpret the net impact on pupil attainment as the effect of higher teacher salaries and offsetting reductions in other expenditure, exploring these mechanisms in as much detail as possible given the available data.
4. Data and empirical methods

Our identification strategy relies on a sharp geographical discontinuity in teacher pay scales. In particular, we compare resource choices, teacher characteristics and student achievement at schools either side and within close proximity of the fringe London teacher pay zone boundary. We therefore require schools to be well balanced in areas in close proximity to the boundary. This section outlines our identification strategy, data sources and summary statistics that suggest our identification assumption is credible.

4.1. Empirical strategy

For ease of exposition, let us assume that the production function in equation 1 is additive and separable. Taking the difference in mean pupil attainment across schools in the high (H) and low-pay (L) regions gives:

\[ \gamma_H - \gamma_L = \beta_0(\bar{X}_H - \bar{X}_L) + \beta_1(\bar{Q}_H^T - \bar{Q}_L^T) + \beta_3(\bar{T}_H - \bar{T}_L) + (\bar{\epsilon}_H - \bar{\epsilon}_L) \]

where \( \bar{X}_H \) denotes observable pupil characteristics, \( \bar{Q}_H^T \) denotes the pupil:teacher ratio, \( \bar{Q}_H^O \) denotes the ratio of other inputs to pupil numbers, \( \bar{T} \) denotes average teacher quality, \( \epsilon \) denotes unobservable pupil characteristics and where \( \bar{x} \) denotes the mean of \( x \) across schools.

By comparing schools in very close proximity to the boundary, we expect there to be very small differences in observable pupil characteristics (\( \bar{X}_H - \bar{X}_L \)) and unobservable characteristics (\( \bar{\epsilon}_H - \bar{\epsilon}_L \)). We test this assumption by examining the differences in a range of pupil characteristics at schools either side of the boundary, which suggests very few (if any) differences.

Our preferred specification estimates the difference in student achievement and resource choices using schools within 2 km of the boundary. We account for pupil and school characteristics using Fully-Interacted Linear Matching (FILM) (Blundell, Dearden, & Sianesi (2005)). FILM differs from standard OLS regression in that FILM linearly interacts the treatment effect with all pupil and school characteristics. This then provides an impact estimate for all schools in the sample given their characteristics, which we average across all schools in the high pay region to correspond to the average treatment effect on the treated (ATT). The main advantage of FILM compared to OLS is that it is more flexible in allowing the treatment effect to vary with school characteristics. In our case, the FILM estimates are also generally more precise than both OLS and propensity score matching.

We test the robustness of our results by comparing schools within various distances to the boundary (1, 2 or 3km) and using various methods to control for observable characteristics (raw differences, OLS

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Fig. 1. Fringe London pay boundary, notes and source: school teacher pay and conditions document; solid lack lines represent LEA boundaries.
and kernel matching). We also use local linear regression methods often used in regression discontinuity design (Lee & Lemieux (2010)) to confirm that student achievement is similar across the boundary no matter what distance we use. Data is pooled across years, but the point estimates are very similar when we estimate separately by year.

4.2. Data

We link together data from a number of administrative data sets over various years. In particular, we use data from the National Pupil Database from 2006 to 2011, which contains the test results and observable characteristics for every pupil in state-funded schools in England. Our main outcomes are the school-level average points scores in Key Stage 2 Maths and English, standardised at the national level. We disregard data for 2010 as a large number of schools boycotted Key Stage 2 national examinations in that year. Our sample consists of schools with non-missing Key Stage 2 results who remain in the sample for all years from 2006 to 2011 (excluding 2010) and who are close to the fringe boundary.

We derive various school level characteristics: number of pupils; proportion of pupil eligible for free school meals (FSM); proportion of pupil with English as an additional language (EAL); proportion of pupils with a statement of special educational needs (SEN), with and without statements; and, proportion of pupils from non-white ethnic backgrounds. Eligibility for free school meals is a rather coarse measure of deprivation, so we also use other measures of deprivation based on the area in which pupils live: average percentile rank on the Index of Multiple Deprivation and average percentile rank on the Income Deprivation Affecting Children Index (IDACI).

We use funding and expenditure levels defined in Section 251 outturn data, which reports funding and expenditure levels for each financial year (April to March) for all maintained schools in England. Information on staffing levels is taken from the Local Education Authority School Information Service (LEADIUS) and its later replacements. We also make use of Consistent Financial Reporting data (CFR), which shows spending per pupil on different types of inputs, grouped as follows: teachers; teaching assistants; all other staff; services (e.g. catering and energy); and, equipment (e.g. books, maintenance and other learning resources).

As Key Stage 2 tests are taken in the summer of each year, we link these results to school characteristics defined in January of the same year (taken from the Spring Census), staffing levels defined for the same academic year (LEADIUS) and to funding/expenditure levels in the financial year most recently ended (e.g. we link May 2011 test results to funding and expenditure per pupil for the 2010–11 financial year, which ended in March 2011).

For teacher pay levels, we make use of the School Workforce Census that contains the pay, experience, turnover, absence and broad characteristics for all employees in schools across England from 2010 onwards.

Our final sample consists of 238 primary schools (111 on the high-pay side of the boundary and 127 on the lower-pay side) which have a common sample of all outcomes.

4.3. Descriptive statistics

As discussed in Section 4.1, small or insignificant differences in observable characteristics across the boundary would make our identification assumptions more plausible. Table 1 (panel A) shows the average characteristics of schools within 2 km of the fringe London pay boundary and compares the characteristics of all schools just inside and outside each boundary.

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Fig. 2. Level of teacher salary scales across fringe and rest of England (2004/05 and 2010/11), Source: School Teachers Pay and Conditions Document.

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6 Externally assessed Science tests were stopped from 2009 onwards.

7 We make use of the School Workforce Census in 2011 only, given uncertainty regarding the quality of data in 2010.

8 This selection omits 18 primary schools - 9 on the high-pay side and 9 on the low-pay side - that have attainment results but not at least one other outcome.

9 The choice of distance does not change this finding. See Tables A.1 and A.2 for 1 km and 3 km, respectively. Figures are pooled across all years. Changes
5. Empirical analysis

This section presents our main empirical results for the differences in resources, teacher characteristics and student achievement at the fringe London pay boundary.

(footnote continued) over time in these characteristics for schools within 2 km of the boundary are presented in an online appendix (Fig. A.3)

Table 1
Balance of pupil characteristics and summary statistics across Fringe London Boundary (2 km).

| Within 2 km | Inside | Outside | Difference |
|------------|--------|---------|------------|
| A) Pupil Characteristics | | | |
| Prop. FSM | 0.076 (0.072) | 0.077 (0.084) | -0.001 |
| Prop. SEN (no statement) | 0.206 (0.101) | 0.207 (0.115) | -0.001 |
| Prop. SEN (statement) | 0.020 (0.023) | 0.016 (0.018) | 0.004*** |
| Prop. EAL | 0.070 (0.106) | 0.067 (0.101) | 0.003 |
| Prop. non-white | 0.162 (0.121) | 0.160 (0.133) | 0.002 |
| Number of Pupils | 259.82 | 256.17 | 3.65 |
| (119.8) | (110.2) |
| IMD Rank | 0.731 (0.172) | 0.704 (0.174) | 0.026** |
| IDACI Rank | 0.656 (0.173) | 0.649 (0.184) | 0.007 |
| Pseudo R-Squared | | | 0.054 |
| Likelihood Ratio Test (p-value) | | | < 0.01 |
| Total grant funding per pupil (log) | 8.201 (0.179) | 8.196 (0.190) | 0.005 |
| Total expenditure per pupil (log) | 8.195 (0.179) | 8.192 (0.195) | 0.003 |
| C) KS2 Outcomes | | | |
| English fine points score (std) | 0.123 (0.356) | 0.104 (0.357) | 0.019 |
| Maths fine points score (std) | 0.084 (0.348) | 0.098 (0.335) | -0.013 |
| Number of observations | 600 | 677 | |
| Number of Schools | 120 | 136 | |

Notes: *** denotes where difference between schools on inside and outside of boundary are significant at the 1%, ** at 5%, and * at 10% level. Standard deviations are in parentheses. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where each dependent variable is observed, within 1 km, 2 km or 3 km of the fringe London pay boundary. The coefficient reported represents the increase in income or expenditure per pupil associated with the high-pay side of the boundary. School controls include distance to the boundary, characteristics of the school: percentage of pupils eligible for free school meals, with English as an additional language, that are non-white, and have a special educational needs, the number of pupils in the school, dummy variables for region (North-East London, South-East London, South-West London), rank of index of multiple deprivation and rank of income deprivation affecting children index.

At the fringe area boundary, it is clear that schools are largely balanced in observable characteristics. Although a likelihood ratio test suggests that we should reject the null hypothesis that the differences are jointly zero, the actual differences are very small in absolute value. The low value of the pseudo R-squared (0.054) also suggests that these covariates explain very little of the variation in terms of whether schools are in high-pay area on the set of school characteristics reported in panel A.

Panel B shows that there are no significant differences in raw funding levels at the fringe boundary, which suggests schools must pay these higher teacher salaries within fixed budgets. Therefore, there is a relatively good balance in observable characteristics along the fringe boundary and no differences in school budgets.

To give a brief preview of our main findings on student achievement, panel C shows the small raw differences in average student achievement at schools either side of the boundary, measured by the average score of pupils in age 11 tests in Maths and English (standardised at the national level each year).

5.1. Resources

Table 2 shows the differences in means of total funding and expenditure per pupil between schools either side of the fringe pay boundary (and controlling for observable characteristics using FIML). This is shown for schools within 1, 2 and 3 km of the boundary. The first row shows there are small and generally statistically insignificant differences in total grant funding per pupil (always less than £56 per pupil). The second row then examines differences in total income per pupil, which incorporates any self-generated income (either through parent donations or renting out facilities). Such income is minimal for most schools, and differences in total income per pupil are again small and generally statistically insignificant. In principle, income need not exactly equate to expenditure each year as schools can run small surpluses and deficits. The third row, however, confirms that there are no large differences in total expenditure per pupil. The difference in total expenditure for schools within 3 km is statistically significant at the 10% level. However, this is small and actually suggests that schools on the high-pay side of the boundary spend less in total (£75 per pupil). Therefore, these results provide no evidence to suggest that schools on the high pay side of the boundary experience any increase in funding to compensate them for having to pay teachers according to higher salary scales.

Table 3 shows how schools on the high-pay side the boundary adjust resources in light of the higher salary scales and no difference in funding. We start by examining teacher remuneration (panel A). Note that data is only available for 2011 here. The first row shows the difference in base salary levels across the boundary (i.e. before any additional payments). For our preferred specification, the estimated difference in base salary levels (£550) is slightly below the difference in salary scales (around £1,000 for 2011). When we include all payments (including additional payments above base salary) in row 2, these differences more closely match the difference in salary scales (with estimates ranging from £645 to £1,130). In row 3, we examine whether there are any differences in the average salary scale point of teacher (a good proxy for teacher experience given the largely mechanical relationship between teacher salary scale and experience in operation.
This contrasts with Cruz (2018) who finds that school districts in Brazil not statistically significant, the point estimates for schools within 1 km during lessons or with administrative tasks (Sibieta (2015)). Although Teaching assistants are generally low-skilled staff who assist teaching is relatively lumpy, it might also be hard for schools to reduce teacher maximum class sizes for under 7 s). Given that expenditure on teachers is highly correlated with the budget, the estimates are not stable across distance cut-offs.

The lack of consistent evidence for a reduction in teacher numbers suggests that either the supply or income effects are weak, or that schools are unable to reduce teacher numbers due to regulation (e.g. maximum class sizes for under 7 s). Given that expenditure on teachers is relatively lumpy, it might also be hard for schools to reduce teacher expenditure by a small amount.

In the next row, we look at numbers of teaching assistants per pupil. Teaching assistants are generally low-skilled staff who assist teaching during lessons or with administrative tasks (Sibieta (2015)). Although not statistically significant, the point estimates for schools within 1 km

Table 3
Difference in input choices across Fringe/Rest of England Boundary 2006 to 2011: various distances to pay boundary.

| Outcome | (1) | (2) | (3) |
|---------|-----|-----|-----|
| Teacher Remuneration (2011 only) |       |       |     |
| Teacher Salary (£) | 632.55 | 550.82 | 537.22 |
| [991.63] | [601.9] | [461.68] |
| Teacher Total Pay (£) | 1129.67 | 687.19 | 645.42 |
| [1540.39] | [781.32] | [582.89] |
| Average salary Scale Point (1–9) | −0.11 | 0.10 | 0.03 |
| [0.24] | [0.28] | [0.21] |
| (B) Staff Ratios (years pooled) |       |       |     |
| Pupil:Teacher Ratio | 0.11 | −0.02 | 0.38 |
| [0.33] | [0.24] | [0.19]* |
| Pupil: Assistant Ratio | 22.56 | 14.20 | −12.79 |
| [16.63] | [12.23] | [13.23] |
| (C) Spending on different inputs (per pupil) (£) |       |       |     |
| Teachers | 29.00 | 34.33 | 11.58 |
| [32.02] | [22.94] | [18.57] |
| Teaching Assistants | 14.20 | −25.82 | −21.79 |
| [20.33] | [18.40] | [13.39] |
| Other staff | 3.36 | −20.78 | −16.63 |
| [15.32] | [10.80] | [8.80] |
| Services | −43.96 | −10.83 | −14.48 |
| [16.72]** | [11.74] | [10.59] |
| Equipment | −49.55 | −29.64 | −27.25 |
| (16.16)** | [10.34]** | [9.23]** |
| School and Year Controls |       |       |     |
| Observations (schools) | 542 (111) | 1152 (236) | 1651 (341) |
| 2011 Schools | 100 | 232 | 329 |

Notes: *** denotes significance at 1%, ** at 5%, and * at 10% level. Standard errors clustered at the local authority level. All columns report Fully Interacted Linear Matching estimates. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2009/2010 and 2011 and where each dependent variable is observed, within 1 km, 2 km or 3 km of the fringe London pay boundary. The coefficient reported represents the change in the resource margin associated with the high-pay side of the boundary. School controls include distance to the boundary, characteristics of the school: percentage of pupils eligible for free school meals, with English as an additional language, that are non-white, and have a special educational needs, the number of pupils in the school, dummy variables for region (North-East London, South-East London, South-West London), rank of index of multiple deprivation and rank of income deprivation affecting children index.

over this period). There is no evidence of any difference in average salary scale point across the boundary. This suggests more experienced teachers do not sort into schools on the high pay side of the boundary, either through the supply or demand side.

Panel B investigates whether schools adjust staffing levels at the pay zone boundary. This shows that there are small and statistically insignificant differences in pupil:teacher ratios for schools within 1 km and 2 km of the pay boundary, but a significantly higher pupil:teacher ratio for schools within 3 km of the pay boundary. This provides some evidence that schools choose to employ relatively fewer teachers on the high pay side of the boundary, but the estimates are not stable across distance cut-offs.

The lack of consistent evidence for a reduction in teacher numbers suggests that either the substitution or income effects are weak, or that schools are unable to reduce teacher numbers due to regulation (e.g. maximum class sizes for under 7 s). Given that expenditure on teachers is relatively lumpy, it might also be hard for schools to reduce teacher expenditure by a small amount.

In the next row, we look at numbers of teaching assistants per pupil. Teaching assistants are generally low-skilled staff who assist teaching during lessons or with administrative tasks (Sibieta (2015)). Although not statistically significant, the point estimates for schools within 1 km and 2 km of the pay boundary are consistent with schools choosing higher ratios of pupils to assistants on the high-pay side of the boundary, suggesting that schools might be responding by cutting assistant numbers. However, as for the pupil:teacher ratio, schools within 3 km of the boundary exhibit a different pattern.

Panel C then examines spending per pupil on teachers, teaching assistants, other staff, services and equipment. Here, there is suggestive evidence of slightly higher spending per pupil on teachers (reflecting higher salaries and little change in quantity) and typically a small reduction in spending on teaching assistants and other staff, per pupil. Spending on services per pupil is also lower on the high-pay side of the boundary (although not significantly so) which is noteworthy as this category of expenditure includes items that are typically difficult to shift (for example energy and catering expenditure). There are significant reductions in spending on equipment (learning resources, information communication technology and spending on the school premises) per pupil on the high-pay side of the boundary, around £30 for schools within 2 km of the boundary. These differences equate to reductions in other expenditure per pupil of about 3% and 6%, respectively.

Therefore, there is no evidence of any additional funding or total expenditure for schools on the high-pay side of the fringe boundary. Despite this, there is also no evidence of pay smoothing, with differences in actual teacher pay roughly in line with the salary scales. There is also no evidence of any differences in the composition of teachers in terms of their salary scale point (a good proxy for experience) or any changes in teacher numbers. Instead, there are small reductions in numbers of assistants per pupil and much larger reductions in other expenditure (particularly equipment) per pupil. Schools thus seem to respond to the higher salary scales and fixed budgets by paying the higher salaries and cutting non-instructional expenditure in order to do so. 10

Notes: *** denotes significance at 1%, ** at 5%, and * at 10% level. Standard errors clustered at the local authority level. All columns report Fully Interacted Linear Matching estimates. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where each dependent variable is observed, within 1 km, 2 km or 3 km of the fringe London pay boundary. The coefficient reported represents the change in the resource margin associated with the high-pay side of the boundary. School controls include distance to the boundary, characteristics of the school: percentage of pupils eligible for free school meals, with English as an additional language, that are non-white, and have a special educational needs, the number of pupils in the school, dummy variables for region (North-East London, South-East London, South-West London), rank of index of multiple deprivation and rank of income deprivation affecting children index.

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10 This contrasts with Cruz (2018) who finds that school districts in Brazil only increase teacher salaries when they receive extra funding. However, the
context of these findings is somewhat different. Cruz (2018) considers the effect of higher minimum salaries for teachers. We consider the effects of higher minimum salaries for teachers.\footnote{The administrative data contains some information on the highest level of qualification of teachers, but this information is incomplete, and a relatively poor proxy for teaching quality.}

Table 4 presents evidence for positive mechanisms which might offset the negative impact of lower non-teacher spending in schools on either side of the boundary as administrative data in England has no link between teachers and pupils.\footnote{11 The administrative data contains some information on the highest level of qualification of teachers, but this information is incomplete, and a relatively poor proxy for teaching quality.}

Table 5 presents evidence for positive mechanisms which might offset the negative impact of lower non-teacher spending in schools on either side of the boundary as administrative data in England has no link between teachers and pupils.\footnote{11 The administrative data contains some information on the highest level of qualification of teachers, but this information is incomplete, and a relatively poor proxy for teaching quality.}

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\begin{table}[h]
\centering
\begin{tabular}{lccc}
\hline
Outcome & (1) Within 1 km & (2) Within 2 km & (3) Within 3 km \\
\hline
KS2 Fine Points Score (std) & & & \\
English & 0.033 & 0.015 & 0.015 \\
& [0.031] & [0.021] & [0.018] \\
Maths & 0.018 & −0.007 & −0.006 \\
& [0.028] & [0.022] & [0.020] \\
School and Year Controls Observations (schools) & Yes & & \\
& 542 (111) & 1152 (236) & 1651 (341) \\
\hline
\end{tabular}
\caption{Difference in student achievement across Fringe/Rest of England Boundary 2006 to 2011: various distances to pay boundary.}
\end{table}

Notes: ** denotes significance at 1%, * at 5%, and * at 10% level. Standard errors clustered at the local authority level. All columns report Fully Interacted Linear Matching estimates. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where each dependent variable is observed, within 1 km, 2 km or 3 km of the fringe London pay boundary. The coefficient reported represents the change in the KS2 fine point score in each subject (standardised at the national level) associated with the high-pay side of the boundary. School controls include distance to the boundary, characteristics of the school: percentage of pupils eligible for free school meals, with English as an additional language, that are non-white, and have a special educational needs, the number of pupils in the school, dummy variables for region (North-East London, South-East London, South-West London), rank of index of multiple deprivation and rank of income deprivation affecting children index.

5.2. Mechanisms

Table 4 presents evidence for positive mechanisms which might offset the negative impact of lower non-teacher spending in schools on the high-pay side of the boundary. Unfortunately it is not possible to directly study teacher quality on either side of the boundary as administrative data in England has no link between teachers and pupils.\footnote{11 The administrative data contains some information on the highest level of qualification of teachers, but this information is incomplete, and a relatively poor proxy for teaching quality.}

To provide some evidence of teachers’ responses to the variation in pay levels, however, Table 4 shows two measures of teacher absence and two measures of teacher turnover. The proportion of teachers that are absent at the time of administrative data collection is around 6 percentage points, or 12%, lower on the high pay side of the boundary. The average level of absence is also lower in schools on the high-pay side of the boundary, although not significantly so. This may suggest that teachers on the high-pay side of the boundary respond to efficiency wages, or that teacher well-being is higher. The variation in teacher absence does not appear to translate into lower teacher turnover, however, with the proportion of new entrants to the school not significantly different across the boundary.

5.3. Student achievement

Table 5 shows the estimates for the differences in average pupil attainment in Maths and English. These are measured in terms of national standard deviations, so can be interpreted in effect size terms. This shows little evidence of any positive difference in student achievement at the fringe pay zone boundary. For English, the point estimate is 0.015 standard deviations for our preferred specification of

being within 2 km of the pay zone boundary and an alternative specification within 3 km of the boundary, and slightly higher (0.033) for 1 km.

The point estimates for Maths are generally very small across all specifications, with an estimate of −0.007 for our preferred specification. The estimates are also relatively precise. The 95% confidence intervals implied by our estimates mean that for our preferred specification we are able to rule out quantitatively small effects of 0.056 and 0.036 standard deviations in English and Maths, respectively.

Combined with our previous results, we find no empirical evidence that the offer of higher teacher salaries combined with reductions in other expenditure have any positive implications for student achievement. This suggests that schools optimally adjust other resources in response to the pay rules and lack of funding.

This could be because a positive effect of higher teacher salaries (perhaps through lower teacher absence or efficiency wage mechanisms more generally) is exactly canceled out by a negative effect of reductions in other resources. Recent evidence suggests that school resources have a significant impact on pupil attainment (Jackson (2018)).\footnote{Jackson (2018). We therefore hypothesise that schools efficiently balance the negative impact of reductions in other spending with the positive impact on teachers from marginally higher salaries.
As we have argued, however, it is the total effect that is the most relevant policy parameter for a school considering whether or not to offer higher salaries from within a fixed budget.}

5.4. Robustness checks

Tables A.3 and A.4 show our estimates of the effect of the pay differential at the fringe boundary for different measures of distance to the boundary, in raw and conditional terms (using a range of ways to control for observable characteristics) and across all years for Maths and English, respectively. This shows that the differences in student achievement are largely stable over time, and are qualitatively unchanged by how and whether we control for observable characteristics.

Figs. A.4 and A.5 estimate the raw difference in student achievement over a much longer time horizon for schools within 2 km of the boundary (1995 to 2011). Importantly, the pay zone boundary existed for all years covered by this data. As this makes use of older school-level data, we have to use a different measure of student achievement (the proportion of pupils achieving the expected level in English and Maths). Although the estimates are clearly more imprecise, the point estimates remain close to zero throughout the period. This suggests the long-term equilibrium we observe in the later 2000s has persisted since at least the early 1990s.

Figs. A.6 and A.7 replicate local linear regression methods recommended by Lee and Lemieux (2010) for regression discontinuity designs. This illustrates how outcomes vary with distance to the boundary. In particular, we show the local averages for schools in bins of size 200 m either side of the fringe boundary (black dots) up to 3 km from the boundary, as well as estimates of the relationship between distance to the boundary and each outcome based on a linear specification (dashed line) and a 7th order polynomial (solid line), each with a break at the discontinuity. We show this for English (Fig. A.6) and Maths (Fig. A.7), with data pooled across years. In both cases, there is no clear or consistent relationship between test scores and distance from the pay boundary (at least within 3 km either side of the pay boundaries). The relationship between distance to the boundary and attainment is best described by a flat line with noise, with the high order polynomial oscillating around the linear estimates. Indeed, in a linear regression we are unable to reject the null hypothesis that the slope coefficients on distance are zero either side of the boundary. There is also little evidence to suggest a positive jump at the pay boundary. This flexible approach confirms our main finding that there is no difference in student achievement at the pay zone boundary.
6. Conclusion

In response to increasing school autonomy and funding constraints, this paper provides the first evidence of the impact of increasing teacher salaries (and decreasing other spending) on pupil attainment. We use a natural experiment that forces some schools within a small local area to offer higher salaries with no compensating change in school budgets. Teacher pay follows the regulation, despite opportunities for schools to undo the difference in salary scales, suggesting that schools have some monopsonistic wage-setting powers. Schools do not, however, cut back on teacher numbers. Instead, schools use their budgetary autonomy to make large reductions in non-instructional spending to provide the higher teacher salaries, which reveals information about schools’ resource preferences.

We find no evidence of teacher sorting effects, measured by the average level of experience or higher teacher turnover. However, we do find evidence of potential efficiency wage effects through reduced teacher absence, equivalent to around a 12% reduction.

The total combined effect on student achievement of higher teacher salaries, reduced teacher absence and reduced non-instructional spending is estimated to be very close to zero. Schools seem to adjust resources optimally in response to the pay regulation and no extra funding, effectively moving around the Pareto frontier. Given recent evidence showing a positive effect of school resources on student achievement and human capital (Jackson et al. (2015); Jackson (2018)) and negative effects of teacher absence Herrmann and Rockoff (2012), we interpret our results as representing offsetting negative resource and positive effects from reductions in teacher absence.

This suggests that offering small increases in teacher salaries from within a fixed budget are unlikely to be a good use of new freedoms on teacher pay for schools in England or the US. This finding is relevant both to autonomous and regulated schools in England, particularly given that all schools have similar freedoms on non-instructional spending and have had flexibility in teacher pay awards since 2013. The results are generalisable to educational systems with similar flexibilities and comparable levels of teacher pay relative to outside wages.

Comparing our results with previous work on teacher pay (Loeb and Page (2000); Gilpin (2012); Leigh (2012); Hendricks (2014); Britton and Propper (2016)) suggests that teacher quality is more sensitive to pay levels when individuals make their occupational choices, rather than when they decide where to teach. In future work, it will be important to understand the reasons driving why the sorting of teachers across schools might not be sensitive to pay levels. This could be because teacher decisions are more sensitive to pupil characteristics or non-pecuniary rewards (Hanushek et al. (2004); Bonesronning et al. (2005)) or because potential teacher quality is not observable among a pool of applicants (Delfgaauw and Dur (2007); Bö, Finan, and Rossi (2013)). Investigating this explanation would require a more detailed understanding about how schools make hiring decisions by collecting data on the characteristics of the pool of applicants for individual teacher positions.

Furthermore, although we observe no difference in student achievement at the pay boundary, it might be that changes in non-instructional spending have implications for other non-achievement outcomes, for example pupil behaviour or health, which would require further data collection and research.

Declaration of Competing Interest

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work. This work was funded by grants from the Economic and Social Research Council between Spring 2012 and late 2014 (grant references ES/J006076/1, RES-544-28-0001 and ES/M010147/1). The paper on which this article is based was shared with the funder for reporting purposes. However, ultimate editorial control was retained by the authors. During and over the three years prior to the start of the work, we have also received other research grants, which were not directly related to the work on which the article is based, from the following potentially interested parties:

- Department for Education (and its predecessor departments)
- Department for Work and Pensions
- Children’s Commissioner's Office for England.
- Child Poverty Unit
- Social Mobility and Child Poverty Commission
- Nuffield Foundation
- Joseph Rowntree Foundation
- CBT Education Trust
- Esmee Fairbairn Foundation
- Sutton Trust
- Education Endowment Foundation
- Teach First
- Social Mobility Foundation

This work was undertaken by the authors as employees of the Institute for Fiscal Studies. In addition, Luke Sibieta is employed by the Education Policy Institute and Sibieta Economics of Education Ltd. He is also currently affiliated to UCL Institute of Education as a part-time PhD student. Ellen Greaves is also affiliated to the University of Bristol as a full-time PhD student.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from luke_s@ifs.org.uk

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## Appendix A

### Table A.1
Balance of pupil characteristics and summary statistics across Fringe Boundary (1 km).

| Within 1 km | Inside | Outside | Difference |
|-------------|--------|---------|------------|
| (A) Pupil Characteristics |        |         |            |
| Prop. FSM | 0.07 (0.07) | 0.08 (0.08) | −0.01 |
| Prop. SEN (no statement) | 0.21 (0.10) | 0.21 (0.12) | 0 |
| Prop. SEN (statement) | 0.02 (0.02) | 0.01 (0.02) | 0.01*** |
| Prop. EAL | 0.06 (0.09) | 0.06 (0.10) | 0 |
| Prop. non-white | 0.15 (0.11) | 0.15 (0.13) | 0 |
| Number of Pupils | 246.3 (124.5) | 231.6 (100.4) | 14.77 |
| IMD Rank | 0.75 (0.15) | 0.72 (0.17) | 0.03* |
| IDACI Rank | 0.68 (0.16) | 0.66 (0.18) | 0.02 |
| Pseudo R-Squared | 0.08 |
| Likelihood Ratio Test (p-value) | <0.01 |
| (B) Funding and Expenditure |        |         |            |
| Total grant funding per pupil (log) | 8.218 (0.177) | 8.204 (0.194) | 0.014 |
| Total expenditure per pupil (log) | 8.209 (0.176) | 8.198 (0.194) | 0.012 |
| (C) KS2 Outcomes |        |         |            |
| English fine points score (std) | 0.139 (0.332) | 0.097 (0.374) | 0.042 |
| Maths fine points score (std) | 0.108 (0.319) | 0.098 (0.331) | 0.011 |
| Number of observations | 280 | 319 |  |
| Number of Schools | 56 | 64 |  |

Notes: *** denotes where difference between schools on inside and outside of boundary are significant at the 1%, ** at 5%, and * at 10% level. Standard deviations are in parentheses. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where the school is within 1 km of the fringe London pay boundary. The likelihood ratio tests the null hypothesis that the differences in school characteristics are jointly zero. The Pseudo R-squared is taken from a probit regression of an indicator of whether schools are in the high-pay area on the set of school characteristics reported in panel A.

### Table A.2
Balance of pupil characteristics and summary statistics across Fringe Boundary (3 km).

| Within 3 km | Inside | Outside | Difference |
|-------------|--------|---------|------------|
| (A) Pupil Characteristics |        |         |            |
| Prop. FSM | 0.083 (0.084) | 0.087 (0.095) | −0.003 |
| Prop. SEN (no statement) | 0.209 (0.106) | 0.208 (0.114) | 0.001 |
| Prop. SEN (statement) | 0.020 (0.022) | 0.017 (0.020) | 0.003*** |
| Prop. EAL | 0.067 (0.097) | 0.072 (0.106) | −0.005 |
| Prop. non-white | 0.169 (0.134) | 0.167 (0.146) | 0.002 |
| Number of Pupils | 266.73 | 246.19 | 20.534*** |
| IMD Rank | 0.717 (0.185) | 0.692 (0.186) | 0.025** |
| IDACI Rank | 0.639 (0.186) | 0.637 (0.193) | 0.002 |
| Pseudo R-Squared | 0.051 |
| Likelihood Ratio Test (p-value) | <0.01 |
| (B) Funding and Expenditure |        |         |            |
| Total grant funding per pupil (log) | 8.204 (0.180) | 8.214 (0.189) | -0.01 |
| Total expenditure per pupil (log) | 8.198 (0.180) | 8.207 (0.191) | -0.01 |
| (C) KS2 Outcomes |        |         |            |
| English fine points score (std) | 0.105 (0.434) | 0.102 (0.361) | 0.003 |
| Maths fine points score (std) | 0.070 (0.449) | 0.093 (0.349) | -0.023 |
| Number of observations | 865 | 966 |  |
| Number of Schools | 173 | 195 |  |

Notes: *** denotes where difference between schools on inside and outside of boundary are significant at the 1%, ** at 5%, and * at 10% level. Standard deviations are in parentheses. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where the school is within 3 km of the fringe London pay boundary. The likelihood ratio tests the null hypothesis that the differences in school characteristics are jointly zero. The Pseudo R-squared is taken from a probit regression of an indicator of whether schools are in the high-pay area on the set of school characteristics reported in panel A.
Table A.3
Estimated difference in student achievement in English across the Fringe London, various years, distances and methods for controlling for observables.

| Kernel          | Within 1 km                                      | Within 2 km                                      | Within 3 km                                      |
|-----------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
|                 | Raw gap | OLS     | FILM | Matching | Raw gap | OLS     | FILM | Matching | Raw gap | OLS     | FILM | Matching |
| Within 1 km     |         |         |      |          |         |         |      |          |         |         |      |          |
| 2006            | 0.038   | 0.040   | 0.038 | 0.052    | 0.027   | 0.027   | 0.036 | 0.007    | 0.039   | 0.037   | 0.045 | 0.022    |
|                 | [0.077] | [0.048] | [0.032] | [0.078]  | [0.077] | [0.023] | [0.021] | [0.052]  | [0.076] | [0.026] | [0.015] | [0.043]  |
| 2007            | 0.133   | 0.134   | 0.124 | 0.054    | 0.037   | 0.033   | 0.029 | 0.034    | 0.017   | 0.017   | 0.013 | 0.012    |
|                 | [0.101] | [0.088] | [0.053] | [0.100]  | [0.067] | [0.028] | [0.016] | [0.058]  | [0.077] | [0.023] | [0.015] | [0.043]  |
| 2008            | 0.009   | −0.038  | −0.045 | −0.089   | 0.003   | 0.005   | 0.003 | 0.006    | −0.017  | −0.035  | −0.033 | −0.083   |
|                 | [0.079] | [0.040] | [0.037] | [0.077]  | [0.086] | [0.025] | [0.025] | [0.051]  | [0.098] | [0.026] | [0.011] | [0.041]  |
| 2009            | 0.075   | 0.036   | 0.038 | 0.011    | 0.051   | 0.020   | 0.007 | −0.003   | 0.022   | −0.001  | −0.011 | −0.036   |
|                 | [0.113] | [0.051] | [0.040] | [0.076]  | [0.083] | [0.032] | [0.016] | [0.050]  | [0.118] | [0.065] | [0.031] | [−0.070] |
| 2011            | −0.019  | 0.000   | −0.034 | −0.041   |          |          |      |          |          |          |      |          |
|                 | [0.118] | [0.065] | [0.032] | [0.076]  |          |          |      |          |          |          |      |          |

Notes: *** denotes significance at 1%, ** at 5%, and * at 10% level. Standard errors in brackets clustered at the local authority level. FILM refers to Fully Interacted Linear Matching. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where each dependent variable is observed, within 2 km of the fringe London pay boundary. The coefficient reported represents the difference in KS2 fine point score in English (standardised at the national level) associated with the high-pay side of the boundary.

Table A.4
Estimated difference in student achievement in Maths across the Fringe London boundary, various years, distances and methods for controlling for observables.

| Kernel     | Within 1 km of the Fringe Boundary | Within 2 km of the Fringe Boundary | Within 3 km of the Fringe Boundary |
|------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Raw gap    | OLS                               | FILM                              | Matching                          |

(continued on next page)
Table A.4 (continued)

| Year | Raw gap | OLS       | FILM       | Matching     |
|------|---------|-----------|------------|--------------|
| 2006 | 0.011   | 0.007     | 0.014      | −0.012       |
|      | [0.074] | [0.018]   | [0.018]    | [0.042]      |
| 2007 | 0.013   | 0.020     | 0.017      | 0.006        |
|      | [0.079] | [0.020]   | [0.014]    | [0.046]      |
| 2008 | 0.004   | 0.009     | −0.007     | −0.002       |
|      | [0.098] | [0.028]   | [0.024]    | [0.049]      |
| 2009 | −0.033  | −0.031    | −0.045     | −0.045       |
|      | [0.092] | [0.021]   | [0.012]**  | [0.038]      |
| 2011 | −0.017  | 0.000     | −0.016     | −0.028       |
|      | [0.104] | [0.034]   | [0.021]    | [0.040]      |

Notes: *** denotes significance at 1%, ** at 5%, and * at 10% level. Standard errors in brackets clustered at the local authority level. FILM refers to Fully Interacted Linear Matching. The unit of analysis is the school. The sample includes all primary schools that are present in the National Pupil Database in all of the academic years 2005/2006, 2006/2007, 2007/2008, 2008/2009, 2010/2011 and where each dependent variable is observed, within 2 km of the fringe London pay boundary. The coefficient reported represents the difference in KS2 fine point score in Maths (standardised at the national level) associated with the high—pay side of the boundary.

Fig. A.1. All teacher pay regions, Source: School Teachers Pay and Conditions Document.
Fig. A.2. Inner and Outer London pay regions, Source: School Teachers Pay and Conditions Document.

Fig. A.3. Changes in covariates over time for schools inside and outer pay boundaries, Notes Sample includes primary schools within 2 km of each boundary. 'Treatment' refers to schools on the high−pay side of the boundary. Source: National Pupil Database and LEASIS.
Fig. A.4. Difference in proportion achieving level 4 or above in KS2 English at Fringe boundary for schools within 2 km (with 95% CIs). Notes Solid lines represents raw difference in proportion of pupils achieving level 4 in English at schools within 2 km and either side of the fringe London pay boundary. Dashed lines show 95% confidence intervals.

Fig. A.5. Difference in proportion achieving level 4 or above in KS2 Maths at Fringe boundary for schools within 2 km (with 95% CIs). Notes Solid lines represents raw difference in proportion of pupils achieving level 4 in Maths at schools within 2 km and either side of the fringe London pay boundary. Dashed lines show 95% confidence intervals.
Fig. A.6. Relationship between distance to the Fringe boundary and English test scores. Notes Dashed line represents linear specification estimated either side of boundary, solid line is based on a 7th order polynomial and dots are local averages by 200m from the pay zone boundary. KS2 English test scores are standardised at the national level.

Fig. A.7. Relationship between distance to the Fringe boundary and Maths test scores. Notes Dashed line represents linear specification estimated either side of boundary, solid line is based on a 7th order polynomial and dots are local averages by 200m from the pay zone boundary. KS2 Maths test scores are standardised at the national level.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.econedurev.2019.101924

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