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Ill Communication: Technology, distraction & student performance

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HIGHLIGHTS

- We investigate the impact of schools banning mobile phones on student test scores.
- We implement a difference in differences (DID) strategy.
- We combine a survey of school policies and England's National Pupil Database.
- There is an increase in student performance after schools bans mobile phones.
- These effects are driven by the previously lowest-achieving students.

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ABSTRACT

This paper investigates the impact of schools banning mobile phones on student test scores. By surveying schools in four English cities regarding their mobile phone policies and combining it with administrative data, we adopt a difference in differences (DID) strategy, exploiting variations in schools' autonomous decisions to ban these devices, conditioning on a range of student characteristics and prior achievement. We find that student performance in high stakes exams significantly increases post ban, by about 0.07 standard deviations on average. These increases in performance are driven by the lowest-achieving students. This suggests that the unstructured presence of phones has detrimental effects on certain students and restricting their use can be a low-cost policy to reduce educational inequalities.

1. Introduction

Technological advancements are commonly viewed as leading to increased productivity. Numerous studies document the benefits of technology on productivity in the workplace and on human capital accumulation.[1] There are, however, potential drawbacks to new technologies, as they may provide distractions and reduce productivity. Mobile phones can be a source of great disruption in workplaces and classrooms, as they provide individuals with access to texting, games, social media and the Internet. Given these features, mobile phones have the potential to reduce the attention students pay to classes and can therefore be detrimental to learning.

There are debates in many countries as to how schools should address the issue of mobile phones. Some advocate for a complete ban while others promote the use of mobile phones as a teaching tool in classrooms. This debate has most recently been seen with the Mayor of New York removing a ten year ban of phones on school premises in March 2015, stating that abolition has the potential to reduce inequality (Sandoval et al., 2015).[2] Despite the extensive use of mobile phones by students and the heated debate over how to treat them, the impact of mobile phones on secondary school student performance has not yet been academically studied.

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[1] E.g.: Kruger, 1993; Chakraborty and Kazarosian, 1999; Aral et al., 2007; Ding et al., 2009; and Malamud and Pop-Eleches, 2011.

[2] Other examples of the debate are: Telegraph 2012; Childs, 2013; Barkham and Moss, 2012; Drury, 2012; O'Toole, 2011; Johnson, 2012; and Carroll, 2013.

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0927-5371/

In this paper, we estimate the effect of schools banning mobile phones on student test scores. This differs from other technology in schools research in that it examines the removal of an unstructured piece of technology, rather than a technology introduction. The lack of consensus regarding the impact of mobile phones means that there is no UK government policy about their use in schools. This has resulted in schools having complete autonomy on their mobile phone policy, and so have differed in their approaches. We exploit these differences through a difference in differences (DID) estimation strategy. We compare the gains in test scores across and within schools before and after mobile phone bans are introduced, where previously there was no stated policy.[3]

In order to do this, we generated a unique dataset on the history of mobile phone and other school policies from a survey of high schools in four English cities (Birmingham, London, Leicester and Manchester), carried out in spring of 2013. This is combined with administrative data on the complete student population from the National Pupil Database (NPD). From this, we know the academic performance of all students since 2001, and so use differences in implementation dates of mobile phone bans to measure their impact on student performance. Moreover, the NPD tracks students over time, which allows us to account for prior test scores along with a set of pupil characteristics including gender, race, ever eligible for free school meals (FSM), and special educational needs (SEN) status. Although we do not know which individuals owned mobile phones, it is reported that over 90% of teenagers owned a mobile phone during this period in England; therefore, any ban is likely to affect the vast majority of students (Ofcom, 2006, 2011).[4] Even if a student does not own a phone themselves their presence in the classroom may cause distraction.

We find that following a ban on phone use, student test scores improve by 6.41% of a standard deviation. This effect is driven by the most disadvantaged and underachieving pupils. Students in the lowest quintile of prior achievement gain 14.23% of a standard deviation, while, students in the top quintile are neither positively nor negatively affected by a phone ban. The results suggest that low-achieving students have lower levels of self-control and are more likely to be distracted by the presence of mobile phones, while high achievers can focus in the classroom regardless of the mobile phone policy. This also implies that any negative externalities from phone use do not impact on the high achieving students. Schools could significantly reduce the education achievement gap by prohibiting mobile phone use in schools. We find the impact of banning phones for these students equivalent to an additional hour a week in school (Lavy, 2016), or to increasing the school year by five days (Hansen, 2011). We include several robustness checks such as event studies, placebo bans, tests for changes in student intake and a range of alternative outcome measures.

The rest of the paper is organized as follows: Section 2 discusses the related literature; Section 3 provides a description of the data, survey and descriptive statistics; Section 4 presents the empirical strategy; Section 5 is devoted to the main results and heterogeneity of the impacts; Section 6 provides a series of robustness checks; and Section 7 concludes with policy implications.

2. Related literature

Our paper is related to the literature on technology used on student outcomes. There is a growing literature on the impact of technology on student outcomes, which has yet to reach a consensus. Fairlie and Robinson (2013) conduct a large field experiment in the US that randomly provides free home computers to students. Although computer ownership and use increase substantially, they find no effects on any educational outcomes. Similar findings have occurred in recent randomized control trials (RCTs) in developing countries where computers have been introduced into the school environment (Barrera-Osorio and Linden, 2009; Cristia et al., 2012).

Some studies have found a positive impact from technology, such as Machin et al. (2007), who estimate the impact of information and communication technology (ICT) investment on student outcomes in England, using changes in funding rules as an exogenous shock to investment. They find that ICT investment has a positive effect on student test scores in English and science, but not for mathematics (where computers were rarely used). Barrow et al. (2009) examine the impact of structured computer aided instruction using a RCT design in three large urban school districts. They find that this maths software had large impacts on students algebra test scores (0.17 of a standard deviation).

Specifically relating to mobile phones, Bergman (2012), as part of an RCT, used mobile phones to inform parents of students' homework assignments through texting. The students of parents who were sent messages achieved higher test scores. Fryer (2013) provided free mobile phones to students in Oklahoma City Public Schools in a field experiment. Students received daily information on the link between human capital and future outcomes via text. There were no measureable changes in attendance, behavioral incidents, or test scores.[5]

The common theme in these education papers is that the mere introduction of technology has a negligible impact on student test scores, but when incorporated into the curriculum and being put to a well-defined use, technology has the potential to improve student outcomes. Oppositely to those papers, we are not looking at the introduction of technology, but the removal of un-structured presence on student outcomes.

The psychological literature finds that multitasking is detrimental to learning and task execution in experimental contexts. Many recent experimental papers present evidence that mobile phone use while executing another task decreases learning and task completion (e.g. Ophir et al., 2009; Smith et al., 2011; Levine et al., 2013; Kuznekoff and Titsworth, 2013; Dietz and Henrich, 2014). The distracting nature of mobile phones has been previously examined in other context such as incidence of road accidents. Bhargava and Pathania (2013) exploit a pricing discontinuity in call plans and show that there is a large jump in phone use after 9 p.m. This jump, however, is not followed by an increase in car accidents. Using vehicular fatality data from across the United States and standard difference in differences techniques, Abouk and Adams (2013) find that texting bans have only a temporary impact on car accident fatalities, suggesting that drivers react to the announcement of a legislation only to return to old habits shortly afterward.

Finally, our paper is closely related to the literature on student effort and distraction in the classroom. These distractions can occur from a variety of events. By example, Metcalfe et al. (2011) find, using the same UK dataset, that the timing of world cup soccer matches impacts students' exam performance. Beland and Kim (2016) find that student performance decreases following a school shooting.[6] Our paper differs in that these are rare events, whereas the presence of phones can be an everyday occurrence.

Our contribution to the literature is to estimate the effect of mobile phone bans on high stakes student test scores at the end of compulsory

[3] We argue that schools differ in years of implementation based on their reaction to phones becoming popular among students. This effect could potentially be an upper bound on the impact of banning mobile phones as the variation that we are exploiting is the introduction of bans among schools that expect to gain from this policy.

[4] We further discuss phone ownership rates in Section 3. The focus of this paper is the impact of a school level policy which may have impact on students who own a phone, but also on students who don't own a phone but could still be distracted through the actions of others.

[5] However, Fryer (2013) does find that students' reported beliefs about the relationship between education and outcomes were influenced by treatment, and treated students also report being more focused and working harder in school.

[6] See also Stinebrickner and Stinebrickner (2008); and De Fraja et al. (2010) for other examples of how events can affect student effort and distractions and lead to lower student performance.

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schooling, within schools that implemented them. This is of particular importance given the prevalence of mobile phone technology in schools today. Our data allows us to investigate which students are most strongly affected by mobile bans.

3. Student data, phone use and survey

3.1. Student characteristics and performance

The NPD is a rich education dataset of the complete public school population of England.[7] It contains information on student performance and schools attended, plus a range of student characteristics such as gender, age, ethnicity, FSM eligibility and SEN status. Each student is allocated an individual identifier, which allows for the student to be tracked over time and across schools. We generate a dataset that follows students from the end of primary school at age 11 through the end of compulsory school education at age 16.[8]

In England, students' progress through a series of five Key Stages. Our paper focuses on secondary school students and their exam performance at the end of compulsory education. As such they are high stakes exams and will have long run impacts on labour market outcomes. Students start secondary school at age 11 after completing Key Stage 2 in primary school. Key Stage 3 covers the first three years of secondary school and Key Stage 4 leads to subject-specific exams at age 16, called General Certificates of Secondary Education (GCSE). The panel nature of the data allows us to condition on student achievement before they entered high school. Moreover, it allows us to test whether the introduction of the ban changed the composition of the school intake in terms of test scores or other student characteristics.

Our main measure of student achievement is based on GCSE test scores from 2001 to 2011. Each GCSE is graded from A* to G, with an A* being worth 58 points and decreasing in increments of six down to 16 for a G grade. Students take GCSEs in different subjects; the mean number of GCSEs (or equivalents) taken in the sample is 9. We use an individual's sum of these GCSE points, standardized nationally each year, so that it has mean of 0 and standard deviation of 1. This is for ease of interpretation and to account for any grade inflation that may have occurred during this time period.[9]

We use several alternative measures of student performance to examine the robustness of the results. First, we use an alternate point score which reflects the differences in the difficulty of attaining certain grades. Then to account for students being able to take varying amounts of GCSEs, we use a capped measure based on their best eight test scores, whether the student achieved the widely recognized 'passing' high-school standard of five A*-Cs, including English and maths and finally restrict to scores based only on compulsory English and maths subjects. To examine the impact at younger ages we also estimate the impact on test scores at age 14 (Key Stage 3).

3.2. Mobile phone survey

There is no official policy or recommendation set out by the Department of Education in England regarding mobile phone usage in schools. Therefore, schools' mobile phone policies are decided at the school level by the headteacher and the school's governing body, which has resulted in a large variation in mobile phone policies. As information relating to school policies is not collected centrally, in the spring of 2013 we conducted a survey of high schools in four large cities in England (Birmingham, Leicester, London and Manchester) regarding their mobile phone policies. Before approaching schools, we obtained permission from the relevant Local Authorities.[10] Every secondary school from Local Authorities where permission was granted was then contacted. This consisted of two personalized emails, and a follow-up phone call seven days after the second email, had we not yet received a reply. We invited the headteacher or school administrator to complete an online survey, or reply to the questions via email or over the phone.[11]

The survey contained questions about the school's current policy toward mobile phones, when it was implemented, whether there was a previous mobile phone policy and, if so, when it was implemented. This was repeated until we could construct a complete mobile phone policy history at the school since 2000. These questions were supplemented with questions relating to punishments for violating the policy and the headteacher's views on how well the policy was complied with. We also asked if there were any other policy or leadership changes occurring over the same time period, to account for any other changes in educational policy at the school, this was supplemented with any major policy changes stated on the school's website.[12]

We received completed surveys from 91 schools, which represent 21% of the target high schools in the four cities in our sample. This response rate is comparable to other non-governmental survey in academic research such as Card et al. (2012); Hall and Krueger (2012); Heffetz (2011) or Brau and Fawcett (2006). Table 1 uses the NPD to illustrate the representativeness of the schools in our sample compared to schools in the cities and to England as a whole, over the entire period. Comparing standardized age 16 test scores, we see that schools in these cities score approximately the same as the national average, but that the schools in our sample over the whole period achieve significantly higher scores than other schools within these cities. In contrast, the cities have slightly lower age 11 achievement than the national average, and the sampled schools have an even lower intake quality, although not statically significant at the 10% level. Taken together, this implies that the schools in our sample over the 2001–2011 period have a higher gain in test scores than the average school. Despite this, the sample schools have a significantly more disadvantaged population than other schools in the cities and nationally, enrolling more minority and FSM-eligible pupils. There is no difference in the proportion of male students nationally, between the schools in surveyed cities or in the sample.

Table 2 presents statistics on when mobile phone policies were put into effect and how well they were complied with. We define a mobile phone ban to be in place if a school restrict their use on school premises. Only one school in our sample did not restrict the use of mobile phones between 2001 and 2011. No school in our sample reversed their phone policy during the survey period. Headteachers were asked to rate to what extent the policy was adhered to by students on a seven-point scale (with 1 meaning "not at all" to 7 meaning "completely"). A school was considered to have a high-compliance ban if the response was greater than four. The table shows that most bans were implemented between 2005 and 2010, and that bans are typically complied with. Since 2005 there has been a large increase in phone capabilities. We argue that schools differ in years of implementation based on their

[7] Students attending private schools are not present in the data, but only represent 7% of the student population.

[8] For more details on the NPD database see Murphy and Weinhardt, 2013.

[9] Grade inflation would not affect the final results, as the inclusion of year effects would account for them. However, standardizing by year does make the summary statistics easier to interpret.

[10] We did not obtain permission from five Local Authorities in London (Hackney, Lewisham, Newham, Redbridge and Tower Hamlets), which combined have 77 secondary schools. The City of London Authority does not contain any public schools and therefore was not approached. The remaining 27 London Local Authorities gave permission, with 337 secondary schools being approached.

[11] The survey questionnaire is presented in the Appendix. Survey website: http://mobilephoneatschool.weebly.com.

[12] This is open to recall bias, but we would expect that headteachers would be very familiar with school-level policies and leadership changes. To increase the information available on other policy changes, we complemented the survey information using additional information on policy and leadership changes from each of the schools' websites. We used schools annual statement to document changes in policies which were available on their websites. In total, we found that other changes occurred in 8 schools in our sample. Examples of changes are: uniform policy, new buildings, girls allowed in schools, school mergers and leadership changes. Six of the eight changes in policies occurred in the same year as the mobile phone ban.

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Table 1
Descriptive statistics on key variables responding vs non-responding schools in sampled cities.

Student characteristics	(1) All students in England	(2) Students in sampled cities	(3) Students in non-responding schools	(4) Students in responding schools	(5) Difference between columns (3) and (4)
Test scores: Age 16	0.000	0.003	−0.009	0.071	0.080*
	[1.000]	[1.022]	[1.035]	[0.937]	(0.041)
Test scores: Age 11	0.000	−0.043	−0.034	−0.094	−0.059
	[1.000]	[1.012]	[1.013]	[1.007]	(0.043)
Male	0.506	0.501	0.507	0.467	−0.040
	[0.500]	[0.500]	[0.500]	[0.499]	(0.032)
Minority	0.182	0.456	0.432	0.593	0.160***
	[0.386]	[0.498]	[0.495]	[0.491]	(0.040)
SEN	0.146	0.166	0.163	0.181	0.017
	[0.353]	[0.372]	[0.369]	[0.385]	(0.011)
FSM	0.162	0.248	0.238	0.308	0.070***
	[0.368]	[0.432]	[0.426]	[0.462]	(0.022)
Total Students	5,576,276	881,386	750,904	130,482	

Notes: Table 1 presents descriptive statistics for key variables for all schools, schools in city surveyed, schools in sample, with standard deviations shown in square parentheses. The difference between students in responding schools and students in non-responding schools shown in column 5, over the entire time period. Standard errors are shown in round parentheses. SEN means special educational needs students and FSM means Free School Meal students. Sources: National Pupil Database (NPD) and author-conducted mobile phone survey.

reaction to this new phenomenon. One should note that once a school introduces a ban, that older cohorts of students will be exposed to the ban for less time before their GCSE examinations compared to younger cohorts.

Table 3 provides descriptive statistics of the surveyed schools pre- and post-ban in comparison to other schools in their cities. The pre-policy averages allow us to compare the representativeness of the surveyed schools before the policies were introduced to other schools in the cities. We see that the responding schools appear very similar to other schools in their cities in terms of their age 16 test scores, SEN, and gender make up. The only significant difference is that they tend to recruit lower achieving students and have more minority and FSM students.

Table 2
Descriptive statistics on mobile phone policies.

Year	Mobile bans	High-compliance bans	Low-compliance bans
2000	0	0	0
2001	0	0	0
2002	3	2	1
2003	6	5	1
2004	9	7	2
2005	19	13	6
2006	29	20	9
2007	43	31	12
2008	58	38	20
2009	71	47	24
2010	85	54	31
2011	88	55	33
2012	90	56	34

Notes: Table 2 depicts the number of mobile phone bans in our sample each year. Headteachers were asked what their phone policy is and when it was introduced. A phone ban is classified as 1) A complete ban of mobile phones on school grounds; or 2) Students hand all phones in at the start of school. Headteachers were asked to rate the extent to which the policy is adhered to by students on a seven-point scale with 1 representing "Not at all" and 7 representing "Completely." A school was considered to have a high-compliance ban if the response was greater than four. *Sources*: Author-conducted mobile phone policy survey of schools in four cities in England: Birmingham, Leicester, London and Manchester.

Examining the post-ban characteristics provides the first evidence of any impact the policies may have along with any potential confounding changes in the compositions of the cohorts due to the change in phone policies. Comparing the changes over time, we see that student achievement at age 16 significantly increases post-policy compared to pre-policy, but that there is no corresponding significant improvement in the prior performance of these students in these schools. This implies that there is minimal sorting by parents according to mobile phone policies or any other changes that occurred in the school. Other permanent student characteristics change slightly pre- and post-ban, with an 8 percentage point increase in the proportion of minority students and a 5 percentage point increase in the proportion of SEN students. As these variables are not standardized each year, these differences may reflect general trends in the population. Once the changes over time and the differences across schools are taken into account, there are no significant differences in variables before and after bans are introduced.[13]

Reassuringly these permanent student characteristics are similar for the responding school that never introduced a mobile phone ban. On average students from this school do have higher grades on entry and exit compared to adopting schools. The raw value-added is very similar to the adopting schools pre-policy but lower than the schools post adoption. This, combined with the increase in age 16 test scores after ban, could be taken as an early indication of the benefits of restricting mobile phone use in schools.

These comparisons are made using the characteristics of the students that we use for the analysis. However, one may be concerned that the intake of the schools from younger cohorts, changes once the policy has been introduced. This may alter the nature of the schooling environment and hence impact on student test scores. While these potential affects could be interpreted as the total policy impact of a mobile phone ban in a partial equilibrium, with parents sorting between schools with and without bans, the goal of this paper is to estimate the impact of bans in schools that implemented them. To this end, we present series of event studies on the intake of these schools before and after the phone bans conditional on school and year effects in Appendix Fig. A.2. The characteristics (gender, FSM, SEN, minority status, age 11 test scores) of students enrolling in their first year of these schools before or after the ban are not significantly different from those enrolling in the year of the ban. There are slight trends in the type of student not captured by the year effects, but there is no change in these trends with the introduction of the ban. Moreover, the direction of these trends would work against finding an impact of banning policies as the student intakes are increasingly from underperforming groups (increasing rates of FSM, and SEN students and worsening prior test scores).

3.3. Mobile phone use

Any impact a school mobile phone ban would be tempered if teenagers did not use phones in the first instance. Survey research by the Office of Communications (Ofcom, 2011) finds that teenagers in the UK have similar mobile ownership rates as adults since mid-2000s. Ofcom (2011) reports that the proportion of individuals over the age of 13 owning a mobile phone steadily increased form 60% in 2000 up to 94% in 2011 (see Appendix Fig. A.1). Another survey of teenagers in 2005 found that 82% of 12–16 years old owned a mobile phone, being slightly higher than the overall rate of 80% (Ofcom, 2006). This masks the differential ownership rates among teens, there is a large increase in ownership and usage rates occurring between ages 14 and 16. Although there are differences by age, ownership rates do not vary considerably across income groups or gender among UK teenagers (Ofcom, 2011).

[13] We estimate the effect of these variables on an indicator variable if a policy has been introduced at that school, conditional on year and school effects. Each characteristic is tested separately and none were found to be significantly correlated. See Table A.2 for results; we find no evidence of sorting based on student characteristics.

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Table 3
Descriptive statistics on key variables pre- and post-policy.

Student characteristics	(1) Students in non-responding schools	(2) Pre phone ban	(3) Post phone ban	(4) Never ban phone	(5) Difference between columns (1) and (2)	(6) difference between columns (2) and (3)
Test scores: Age 16	−0.009	0.020	0.117	0.140	0.029	0.097**
	[1.035]	[0.957]	[0.916]	[0.926]	(0.047)	(0.039)
Test scores: Age 11	−0.034	−0.107	−0.085	0.019	−0.073*	0.022
	[1.013]	[1.009]	[1.006]	[0.954]	(0.044)	(0.041)
Male	0.507	0.466	0.467	0.534	−0.041	0.001
	[0.500]	[0.499]	[0.499]	[0.499]	(0.037)	(0.025)
Minority	0.432	0.549	0.630	0.693	0.116***	0.081***
	[0.495]	[0.498]	[0.483]	[0.461]	(0.045)	(0.025)
SEN	0.163	0.153	0.206	0.202	−0.011	0.053***
	[0.369]	[0.360]	[0.405]	[0.402]	(0.011)	(0.013)
FSM	0.238	0.300	0.317	0.223	0.062**	0.017
	[0.426]	[0.458]	[0.465]	[0.416]	(0.025)	(0.017)
Total students	750,904	62,214	66,266	2002		

Notes: Table 3 presents descriptive statistics for key variables pre- and post-policy and for all schools and schools in the city surveyed with standard deviations shown in square parentheses. The difference between students taking the examinations pre-band to post ban are shown in column 5.Standard errors are shown in round parentheses. SEN means special educational needs students and FSM means Free School Meal students. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Therefore, despite not having individual phone use data, we are confident that a school introducing a ban would potentially have a large impact on the access to phones. Moreover, it needs not be the case for an individual to use a phone to be distracted by them, their use by others in the classroom may cause disruptions.

4. Empirical strategy

We estimate the impact of a mobile phone ban on student achievement, exploiting differences in the timing of the introduction of policies across different schools. Eq. (1) presents our baseline specification:

$$Y_{ist} = \beta_0 + \beta_1 Ban_{st} + \mu_s + \gamma_t + \varepsilon_{ist} \quad (1)$$

where Y_{ist} is the test score of student i in high school s in year t. Our primary measure of student performance is test score at age 16.[14] Ban_{st} is the indicator variable of interest for whether school s prohibits mobile phones from its premises in time period t. Accordingly, the coefficient of interest β_1 captures the impact of the introduction of the mobile phone ban on student test scores, estimated using the within-school variation in test scores over time. Therefore, schools that have yet to adopt a phone ban act as our control group. We assume there are three components to the error term that are unobservable; μ is the difference in student performance due to school effects, γ represents common shocks to all students in a particular year, and ε is the idiosyncratic error and contains all of the variation in individual outcomes within a school year.

There may be a concern that only high-achieving schools introduce mobile phone bans, which could lead to overestimating the effects of a mobile phone ban. Similarly, if there was a positive trend in student test scores and phone bans were only introduced in the later periods, some of this growth would be incorrectly attributed to bans. We can account for these two possibilities by allowing for school and year mean achievement to vary through fixed effects. The inclusion of these fixed effects allows for the introduction of mobile phone bans to be non-random, i.e. more likely to occur in schools with low or high test scores, allowing for covariance between Ban_{st} and μ_s as well as γ_t.[15]

Specification (1) is restrictive, as it does not allow for differences in student outcomes within a school other than through ε_{ist}. The individual level panel aspect of the NPD allows us to condition on students' prior performance at the end of primary school (at age 11): Y_{ist-1}, accounting for student ability and all school and family investments up until the start of secondary school. This can be seen in specification (2). This changes the interpretation of the β_1 parameter from the increase in test scores due to the ban, to the increase in the gains in test scores due to the ban. In addition to prior achievement, we also condition on a vector of other observable student characteristics, X_i, representing: FSM eligibility, SEN status, gender and ethnicity. The inclusion of these individual controls ostensibly accounts for student sorting to schools on the basis of observable inputs. The extent to which β_1 changes with their inclusion provides us with a gauge for how many students sort to schools based on phone bans.

$$Y_{ist} = \beta_0 + \beta_1 Ban_{st} + \beta_2 Y_{ist-1} + \beta_3 X_{ist} + \mu_s + \gamma_t + \varepsilon_{ist} \quad (2)$$

A final potential threat arises if there are other positive changes to a school that are correlated with the introduction of a mobile phone ban. Up to this point, we have assumed that school effects are invariant over time; if schools introduced other policies that improved test scores at the same time as a phone ban, this again would lead to overestimating the effect of a ban. To address this, we use survey information to control for any leadership or policy changes that occurred during the period of analysis. $OtherPolicy_{st}$ is a dummy variable to control for other leadership or policy changes.[16] In our most demanding specification, we also account for mean peer prior achievement for each student $\overline{Y}_{-ist-1}$. We know which students are in the same school cohort as student i, and it is possible that students affect each other's growth in test scores through peer effects. The inclusion of prior peer achievement and information on other policy and leadership changes, as represented by Eq. (3), allows us to account for time-variant characteristics of the school.

$$Y_{ist} = \beta_0 + \beta_1 Ban_{st} + \beta_2 Y_{ist-1} + \beta_3 X_{ist} + \beta_4 OtherPolicy_{st} + \beta_5 \overline{Y}_{-ist-1} + \mu_s + \gamma_t + \varepsilon_{ist} \quad (3)$$

[14] We use test score at age 16 as our primary measures of student performance as mobile ownership is higher among older teens and test at age 16 are high stakes exams. We also estimate impacts on achievement level at age 14 in Table 9. Results using achievement level at age 14 are smaller and insignificant.

[15] Note it does not allow for the effect of the ban to vary across schools or student types. Standard errors are clustered at the school level to account for correlations within school overtime. We also tested using percentile-t cluster bootstrap as in Cameron et al. (2008) for the main specification. Results were similar.

[16] The variable $OtherPolicy_{st}$ takes a value of 1 for the years after a change at a school occurs. We combine information coming from our survey of headteachers and information from school's website. We do not observe multiple change of policies/leader in addition to the phone policy change, hence a binary variable can be used. Other policies occurred in 8 schools in our sample.

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Table 4
Effect of mobile bans on student performance.

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Mobile ban	0.0567	0.0619*	0.0654*	0.0669*	0.0641*
	(0.0364)	(0.0357)	(0.0361)	(0.0368)	(0.0373)
Prior test scores: Age 11		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Prior peer achievement					✓

Notes: Table 4 presents regression estimates for student performance. All specifications include school effects and year effects. The outcome variable is the standardized test score at age 16. The number of observations is 130,482. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means special educational needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Finally, we estimate the heterogeneity of the impact of mobile phone bans by student characteristics in a triple differences framework. β_{1c} is the additional difference in student outcomes by binary student characteristic c within schools that implemented a ban in period t. We use our most flexible specification (3) above for these estimates and obtain the additional effect of a ban on SEN students, FSM students, males, minorities and by achievement level at age 11.

$$Y_{ist} = \beta_0 + \beta_1 Ban_{st} + \beta_{1c} Ban_{st} * Characteristic_i + \beta_2 Y_{ist-1} + \beta_3 X_{ist} + \beta_4 OtherPolicy_{st} + \beta_5 \overline{Y}_{-ist-1} + \mu_s + \gamma_t + \varepsilon_{ist} \quad (4)$$

5. Results

5.1. Main results

Table 4 presents estimates of the impact of a mobile phone ban on individual student performance. There are five columns, which account for more potential confounders as one moves from left to right. Column 1 is the most basic specification that only accounts for the across-school and across-year mean differences in test scores. Here we find a positive relationship between the introduction of a mobile phone ban and student test scores of 5.67% of a standard deviation.

However, we may be concerned that student sorting by observable or unobservable characteristics may be driving this estimate; columns 2 and 3 include student characteristics in order to account for this. Conditioning on prior performance indicates that the growth in test scores is 0.062σ, and this remains relatively stable when other student characteristics are also controlled for (0.065σ).

The last two columns account for time-varying school characteristics. Including an indicator variable, which denotes whether there was a leadership change or other policy change has taken place at the school during the period in year t or later, increases the estimate slightly. Results of our preferred specification (5), which allows for mean peer effects, are marginally smaller, but continue to show an improvement in student performance after a school bans mobile phones. After a ban has been

Table 5
The effect of mobile phone bans on student performance by student characteristics.

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Mobile ban	0.0432	0.0457	0.0445	0.0621*	0.0405
	(0.0385)	(0.0393)	(0.0397)	(0.0374)	(0.0405)
Mobile ban * FSM	0.0658**				0.0382
	(0.0282)				(0.026)
Mobile ban * SEN		0.1100***			0.0591*
		(0.0327)			(0.0329)
Mobile ban * Male			0.0424		
			(0.0389)		
Mobile ban * Prior Test Scores				−0.0604***	−0.0488***
				(0.0133)	(0.0129)
Prior test scores: Age 11	✓	✓	✓	✓	✓
Student characteristics	✓	✓	✓	✓	✓
Other policy changes	✓	✓	✓	✓	✓
Prior peer achievement	✓	✓	✓	✓	✓

Notes: Table 5 presents regression estimates for student performance. The outcome variable is the standardized test score in a student's eight best subjects. All specifications include school effects and year effects. The number of observations is 130,482. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for using indicators for whether the student was male, a minority, SEN and FSM. SEN means special educational needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table 6
The effect of mobile phone bans on student performance by prior performance.

Age 16 test scores	(1)	(2)	(3)	(4)
Impact by age 11 test scores				
Mobile ban * 1st Quintile	0.1306***	0.1421***	0.1444***	0.1423***
	(0.0389)	(0.0396)	(0.0402)	(0.0404)
Mobile ban * 2nd Quintile	0.0868**	0.0984**	0.1007**	0.0986**
	(0.0385)	(0.0389)	(0.0398)	(0.0401)
Mobile ban * 3rd Quintile	0.0566	0.0659*	0.0677*	0.0654
	(0.0389)	(0.0395)	(0.0402)	(0.0409)
Mobile ban * 4th Quintile	0.0275	0.0245	0.026	0.0229
	(0.0399)	(0.0396)	(0.0403)	(0.0409)
Mobile ban * 5th Quintile	−0.0118	−0.0224	−0.0216	−0.0254
	(0.0412)	(0.0422)	(0.0428)	(0.0429)
Test scores: Age 11 categorical	✓	✓	✓	✓
Student characteristics		✓	✓	✓
Other policy changes			✓	✓
Prior peer achievement				✓

Notes: Table 6 presents regression estimates for student performance. The outcome variable is the standardized test score in a student GCSE exams. All specifications include school effects and year effects. The number of observations is 130,482. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. Key Stage 2 represents standardized test scores at age 11. In this table, student are divided into quintiles based on their achievement level at age 11, where group 1 is the lowest-achieving group and group 5 is the highest-achieving group. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

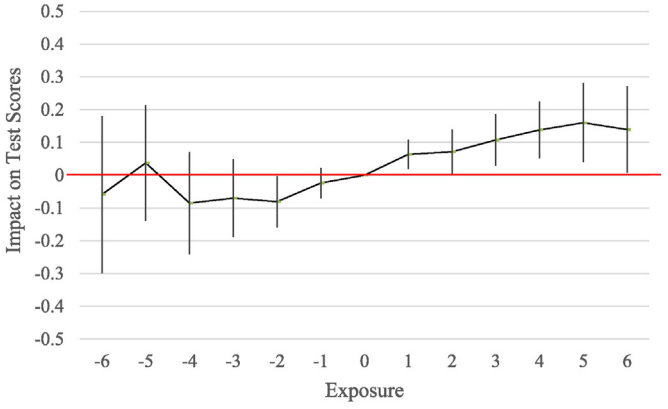

Fig. 1. Impact of phone ban by years of exposure. *Notes*: Estimated impact on age 16 standardized test scores of mobile phone ban by years of exposure, conditional on school and year effects, age 11 test scores and pupil characteristics. Reference year is the year prior to introduction. Error bars represent the 95% confidence intervals with robust standard errors clustered at the school level. *Sources*: National Pupil Data Base and author-conducted mobile phone policy survey of schools in four cities in England: Birmingham, Leicester, London and Manchester.

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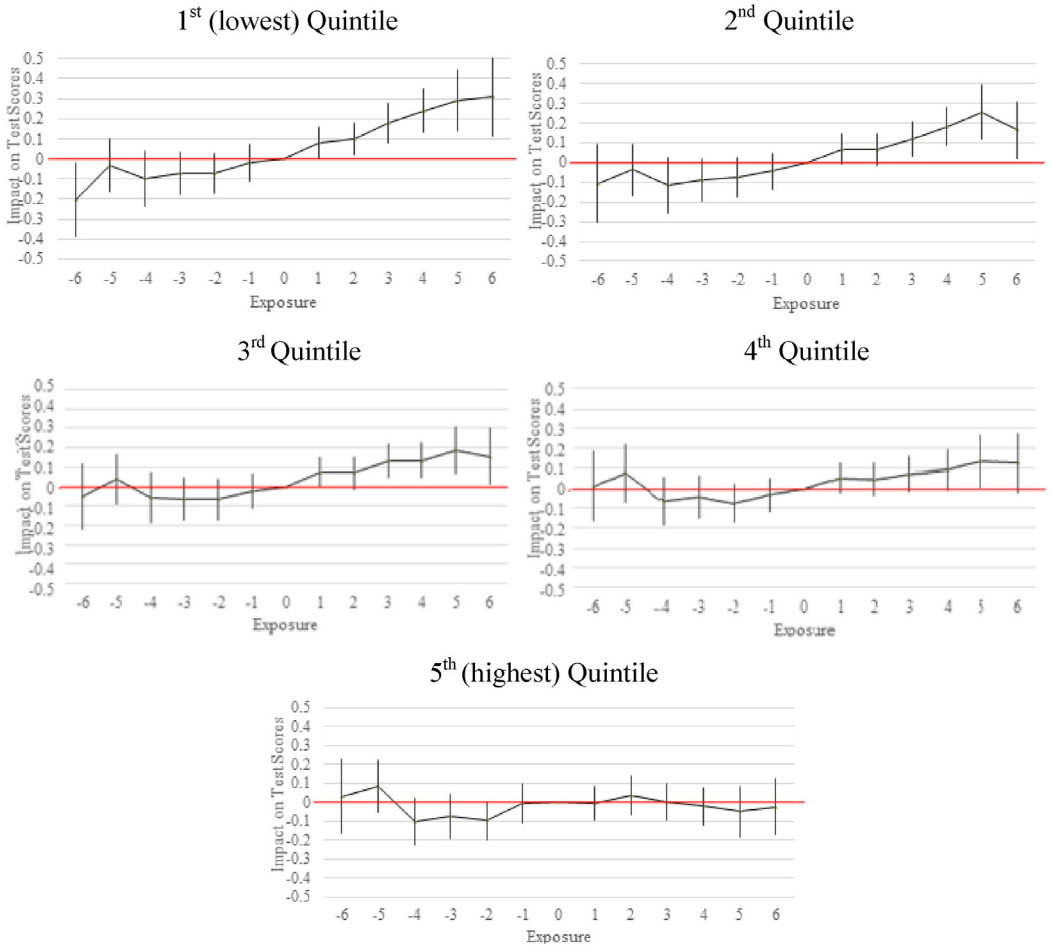

Fig. 2. Impact of phone ban by years of exposure and prior achievement quintile at age 11. *Notes*: Estimated impact on age 16 standardized test scores of mobile phone ban by years of exposure and by ability quintile at age 11, conditional on school and year effects, age 11 test scores and pupil characteristics. Reference year is the year prior to introduction. Error bars represent the 95% confidence intervals with robust standard errors clustered at the school level. *Sources*: National Pupil Data Base and author-conducted mobile phone policy survey of schools in four cities in England: Birmingham, Leicester, London and Manchester.

introduced, the average student attending that school has 6.41% of a standard deviation greater gains in test scores compared to a school that did not introduce a ban. These estimates are significant at the 10% level, with standard errors clustered at the secondary school level.

5.2. Heterogeneity

Table 5 studies the heterogeneity of a ban on students with different characteristics, under a triple differences framework, estimating the additional impact on SEN, FSM, male students and by prior test score. This is in addition to any baseline effects of the ban under specification (5). The results indicate that a mobile phone ban has a positive and significant impact on FSM-eligible students (Column 1) and SEN students (Column 2). The baseline effect of a mobile phone ban remains positive but not statistically significant at the 10% level in these specifications. The interaction of the ban with prior achievement is negative (Column 4), implying that it is predominantly low-ability students who gain from a ban. The coefficient of −0.060 means that students in the top percentile nationally would lose 0.060σ with the introduction of a ban compared to a student in the lowest percentile. However, there is a general positive effect of a ban of 0.062σ, and so overall high-achieving students are not harmed by a ban. The relative gains from a ban are tested formally in Table 6. Column 5 additionally includes interactions with FSM and SEN simultaneously; we find that the ability and SEN interaction terms are significant. This is in line with the heterogeneity results, with the most at-risk students gaining the most.

Table 6 examines the relationship of the impact of mobile phone bans by prior achievement in more detail. Students are grouped into five quintiles based on their achievement level at age 11 (before secondary school), where group 1 has the lowest level of achievement and group 5 has the highest. Here, the coefficients represent the total effect of a ban by ability quintile. Again we see that low-achieving students gain the most from a ban, and the impact gradually reduces throughout the prior ability distribution. Those in the two lowest quintiles gain 0.142σ and 0.099σ respectively after a ban has been introduced. Only the top quintiles do not significantly gain from the policy, but they are also not negatively affected.[17] This suggests that high prior achieving students are able to concentrate in class regardless of the mobile phone policy in place but low-achieving students are distracted by mobile phone use. This also implies that any negative externalities from phone use does not impact on the high achieving students. As high achievers are not impacted and low achievers are positively impacted, this suggest a reduction in educational inequality. This is in line with recent evidence that shows that lower ability students have lower self-control which can affect their outcomes (eg. Dohmen et al. (2010); Heckman et al. (2006) and Heckman and Kautz (2012)).

We further examine the impact of a phone ban, by the type of policy introduced. One may expect the impact of a mobile phone ban to vary according to head teacher reported compliance levels. We replace the single

[17] We reproduced Table 6 by gender: one table for males and one table for females. The results are very similar for both tables, with males and females in low-achieving groups at age 11 gaining the most from a mobile ban.

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Table 7
Effect of placebo mobile bans on student performance.

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Panel A: Mean Impact					
Placebo ban 1 year prior	0.0218	0.0156	0.0194	0.0209	0.0237
	(0.0387)	(0.0373)	(0.0381)	(0.0381)	(0.0387)
Panel B: Mean Impact					
Placebo ban 2 years prior	0.0288	0.0296	0.0240	0.0335	0.0326
	(0.0525)	(0.0503)	(0.0518)	(0.0501)	(0.0512)
Panel C: Impact by Age 11 Test Score Quintile					
Placebo ban * Q1		0.0556	0.0582	0.0680	0.0678
		(0.0485)	(0.0513)	(0.0497)	(0.0503)
Placebo ban * Q2		0.0338	0.0373	0.0459	0.0454
		(0.0505)	(0.0534)	(0.0521)	(0.0528)
Placebo ban * Q3		0.0237	0.0108	0.0193	0.0182
		(0.0518)	(0.0531)	(0.0519)	(0.0529)
Placebo ban * Q4		0.0000	−0.0130	−0.0038	−0.0044
		(0.0554)	(0.0562)	(0.0544)	(0.0556)
Placebo ban * Q5		0.0137	−0.0009	0.0115	0.0110
		(0.0585)	(0.0584)	(0.0571)	(0.0583)
Prior test scores: Age 11		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Prior peer achievement					✓

Notes: Table 7 presents regression estimates of placebo bans on student performance. A placebo ban is introducing the ban two years before it was actually introduced. All specifications include school and year effects, and use robust clustered standard errors at the school level. The outcome variable is the standardized test score at age 16. The number of observations is 130,482. Panel A presents the average impact, Panel B presents the impact by prior achievement measures. Panel B divides students into quintiles based on their achievement level at age 11, where group 1 is the lowest-achieving group and group 5 is the highest-achieving group. Panel A accounts linearly for prior test scores, Panel B uses categorical controls for prior test scores. All specifications additionally include indicators for actual phone bans. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** p < 0.01, ** p < 0.05, * p < 0.1. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table 8
Effect of mobile bans on student performance conditioning on age 14 test scores.

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Mobile ban	0.0655*	0.0535*	0.0599*	0.0598*	0.0586*
	(0.0376)	(0.0333)	(0.0333)	(0.0336)	(0.0341)
Prior test scores: Age 14		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Peer characteristics					✓

Notes: Table 8 presents regression estimates for student performance. The outcome variable is the standardized test score at age 16. All specifications include school effects and year effects. Estimated on the sample of students who had not been exposed to the ban when examined at age 14. The number of observations is 83,211. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** p < 0.01, ** p < 0.05, * p < 0.1 *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Ban_{st} variable with two variables: one for bans with high compliance, $HighCompliance_{st}$, and one for bans with low compliance, $LowCompliance_{st}$. Table A.1 shows the impact of the ban by level of compliance. As expected, we find larger effects in schools that report a high level of compliance with a ban compared to schools where compliance is weak, where there is no statistically significant impact.[18] The Panel B of Table A.1 shows the impact by ban rigidity. We replace the single Ban_{st} variable with two variables: one for strict bans, $StrictBan_{st}$, defined as phones were banned from the school premises or had to be handed in at the beginning of the day (survey responses A, B or F); and one for non-strict bans, $NonStrictBan_{st}$, defined as phones being required to be turned off or on silent (survey responses C, D, E). We find that less strict bans of mobile phones are more effective in raising student test scores than bans that prohibit phones to be on school premises. Exploring the impact of strict and less strict bans by prior student achievement, we find that both are effective in raising the test scores of the lowest performing students, but again that less strict bans are more effective.[19]

Table 9
Effect of mobile bans on student performance: alternative outcomes.

	(1)	(2)	(3)	(4)	(5)
Mobile ban on outcomes					
Panels					
A. Age 16 test scores (Table 4)	0.0567	0.0619*	0.0654*	0.0669*	0.0641*
	(0.0364)	(0.0357)	(0.0361)	(0.0368)	(0.0373)
B. Age 14 test scores	0.0077	0.0231	0.0268	0.026	0.0245
	(0.0187)	(0.0175)	(0.0176)	(0.0177)	(0.0173)
C. Total points from	0.0532	0.0588*	0.0618*	0.0627*	0.0600*
alternate point scores	(0.0335)	(0.0328)	(0.0333)	(0.0338)	(0.0341)
D. Total points from	0.0292	0.0347	0.0385	0.0395*	0.0380*
best 8 subjects	(0.0233)	(0.0228)	(0.0232)	(0.0236)	(0.0238)
E. Total Points from best 8	0.0376	0.0434*	0.0469*	0.0474*	0.0455*
subjects	(0.0238)	(0.0233)	(0.0238)	(0.0242)	(0.0243)
for the alternate points scores					
F. Achieved 5 GCSE	0.0190*	0.0214**	0.0221**	0.0208**	0.0201**
including English and Maths	(0.0098)	(0.0096)	(0.0094)	(0.0094)	(0.0094)
Prior test scores		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Prior peer achievement					✓

Notes: Table 9 presents regression estimates of mobile phone bans on student performance on test scores at age 16. Each panel represents an alternative outcome; A. Total points; B. Total points conditional on age 14 Test Scores; C. Total points from best 8 subjects; D. Total points from alternate point scores; E. Total Points from best 8 GCSE alternate points scores and F. Achieved 5 GCSE including English and Math). All specifications include school effects and year effects, with robust clustered standard errors at the school level. The number of observations are 130,482, excluding Panels B and C which have 112,212 and 83,211 respectively, due to age 14 testing stopped in 2008/9. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means special educational needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** p < 0.01, ** p < 0.05, * p < 0.1. Sources: National Pupil Database (NPD) and author-conducted mobile phone survey.

6. Robustness checks

6.1. Event studies & placebo tests

To discern whether the effects are driven by the mobile phone bans themselves and not unobserved shocks to the treated schools, we conduct several falsification tests. One crucial assumption to obtain unbiased estimates of β_1 is if $\mathrm{Cov}(\ Ban_{ist},\ \ \varepsilon_{ist}) = 0$. We provide evidence that this assumption is likely to hold. If schools that introduced a mobile phone ban were improving regardless, then these gains could be falsely attributed to the policy and we would have an upward biased result.

[18] The compliance measure is coming from our mobile phone survey. Headteachers were asked to rate to what extent the policy was adhered to by students on a seven-point scale (with 1 meaning "not at all" to 7 meaning "completely"). A school was considered to have a high-compliance ban if the response was four or greater. Results are similar if we consider high-compliance to have a response greater than three of five. We also created an alternative measure of compliance using punishment at the school after a phone is used. Results were similar and available upon request.

[19] Less strict bans increased the test scores of those in the lowest quintile of prior attainment by 0.305σ, compared with 0.109σ for stricter bans. It appears that policies that continue to allow phones but restrict their use are more effective than those that ban them completely. The reasoning behind this is unclear, however it could be the result of the cost in teacher time of enforcing such a strict rule.

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Table 10
Effect of mobile bans on student performance by subject.

Age 16 test scores in:	(1) English & Maths	(2) English Only	(3) Maths Only	(4) Other Subjects
Panel A				
Mobile Ban	0.0315*	0.0586***	0.0035	0.0519*
	(0.0159)	(0.0199)	(0.0187)	(0.029)
Panel B				
Impact by age 11 test scores				
Mobile ban * 1st Quintile	0.0273	0.0268	−0.0726***	0.1652***
	(0.0224)	(0.0287)	(0.0238)	(0.0451)
Mobile ban * 2nd Quintile	0.0635***	0.0884***	0.0322	0.0988***
	(0.0202)	(0.0234)	(0.023)	(0.0342)
Mobile ban * 3rd Quintile	0.0538***	0.0664***	0.0354	0.0372
	(0.0177)	(0.0206)	(0.022)	(0.0314)
Mobile ban * 4th Quintile	0.0388**	0.0590***	0.0165	−0.0176
	(0.017)	(0.0207)	(0.0196)	(0.0292)
Mobile ban * 5th Quintile	0.0124	0.0379	−0.0093	−0.0401
	(0.0232)	(0.0236)	(0.0272)	(0.034)
Test scores: Age 11 categorical	✓	✓	✓	✓
Student characteristics	✓	✓	✓	✓
Other policy changes	✓	✓	✓	✓
Prior peer achievement	✓	✓	✓	✓

Notes: Table 10 presents regression estimates for student performance. All specifications control for prior test scores at age 11, student characteristics, other policy changes and prior peer achievement. The number of observations is 124,567. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. Key Stage 2 represents standardized test scores at age 11. In this table, student are divided into quintiles based on their achievement level at age 11, where group 1 is the lowest-achieving group and group 5 is the highest-achieving group. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

We check for potential trends in student attainment that were present before the introduction of the ban, by replacing the treatment parameter of specification (1) with a sequence of leads and lags of implementation year at each school. Fig. 1 plots the impact of leads and lags of bans by exposure length. Estimates for negative exposure refer to the years prior to a ban, where we would expect the ban to have no impact, and so the omitted category is year zero, the year immediately before the ban was introduced. Fig. 1 shows that bans have significant effects only after they have been implemented. There is little evidence that schools were generally improving before introducing a phone ban, as all the years prior to the ban do not have impacts significantly different from zero and are not increasing. Post introduction, there is a general upward trend in the impact of the ban, which may reflect that students have experienced more time in a school with a phone ban in place.[20]

We previously saw that bans mainly benefited students of lower prior achievement, therefore we replicate Fig. 1 by prior achievement quintile in Fig. 2. Reassuringly we find no significant positive trend in student test scores for any achievement group prior to their introduction. The bans only have significant impact after they have been implemented and only on the low prior achieving students.

A further concern is that the type of students who take the examinations at the school after the ban changes after the ban has been introduced. Table A.2 tests, conditional on school and year fixed effects, whether observable characteristics of the students being tested change. We find no significant changes in the likelihood to be male, FSM, SEN, or have high prior achievement after then ban. Thereby reducing the concern that the effects are driven by compositional changes in students' immediate peer groups.

On a similar basis, the introduction of the phone ban may influence the type of student being tested at age 16 due to changing the probability of expulsion or school transfer due to the ban. To test this form of sample selection based on unobservables we test whether the introduction of the ban led to a change in the incidence of students leaving the school. Appendix Table A.3 presents estimates of the ban impacting on an indicator variable taking a value of one if the student had disenrolled from the school since their first year of secondary school after the ban had been introduced. We find no evidence of increased transfers away from the school with all estimates being marginally negative and insignificant.

A further possibility is that the enrolment of the school changes after the bans are introduced. Fig. A.2 presents a series of graphs plotting the high school intake before and after ban for different pupil characteristics. Even though these students will be five academic years below the students taking the exams, any positive change in their characteristics may reflect an easier workload on teachers in the school. However, event studies in Fig. A.2 show that the type of pupil is not sorting to schools due to the mobile phone ban being in place.

We next implement placebo tests, which is generated by turning on the ban dummy one or two years before it was actually initiated. This placebo intervention should have no significant impact on the gains in student test scores. If there is a positive significant relationship, then there are correlations between the trend and the intervention. Panel A of Table 7 presents a parallel set of results as Table 4, but with the effects of a placebo intervention occurring one or two years before they actually turned on. Placebo treatments do not produce significant gains in student test scores. We take this as further evidence that prior trends are not generating these results. Panel B of Table 7 repeats this procedure but estimates the impact of the placebo intervention by quintiles of achievement, a parallel set of results to Table 6. It again shows that there is no impact of the placebo intervention by prior achievement quintile at age 11.[21]

6.2. More recent prior ability measures

Thus far we have used age 11 test scores as a measure of prior achievement for student achievement at age 16. However, there is another statutory exam that takes place between these ages. We replicate Table 4 in Table 8 using achievement at age 14 as a measure of ability instead of the age 11 test scores. This has the advantage that it is a more recent measure of student ability, but has the disadvantage that these exams are conducted in secondary school and therefore could also be affected by the ban. To account for this, we only use the age 14 test scores of students attending schools that have not yet implanted a ban. As there is only two years between the age 14 and age 16 exams, this reduces the sample significantly, but also examines the short-run impact of phone bans. The estimates are very similar to our previous estimates. Conditional on age 14 test scores, mobile phone ban improves gains in test scores by 5.86% of a standard deviation. These results again in part address the issue of pre-trends, as we see that there are significant gains in test scores between age 14 and 16 for students who were attending schools that introduced a ban. This is a small window of time for other effects to occur. If a positive trends were in place in schools prior to this, the age 14 tests scores would be higher and gains in test scores would be accordingly lower. The heterogeneity of these results is replicated conditional on age 14 ability. Table A.6 presents similar results to

[20] Appendix Table A.4 presents results from an interrupted time series model which allows for a linear growth in test scores after the implementation of the ban. Results are similar to Table 4.

[21] One additional test is to exclude the 8 schools that had "Other Policy Changes" and see if results are robust. Results are presented in Table A.5 and are similar to Table 4.

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Table 6. The estimates by ability have slightly smaller positive effect for the least able students, but these effects are not significantly different from those in Table 6.

6.3. Alternative outcome measures

One may be additionally concerned that these results are dependent on the outcome measure that we are using. Therefore, Table 9 presents results using different outcome variables to establish the robustness of the estimates.

The first alternative outcome is the impact of phone bans on age 14 test scores mentioned above. We find the impact of the ban remains positive but is smaller and not significant. This may be reflective of the fact that mobile phone ownership is higher for older teens. Therefore, as the intensity of the treatment would be smaller among students aged 14, one would expect the impact of a mobile ban on student test scores at age 14 to be smaller (Panel B of Table 9).

The age 16 measure of achievement used so far in this paper is the standardized point score for all exams taken at the end of compulsory schooling. An alternate scoring system, which accounts for the different difficulties for attaining certain grades, is also used and associated coefficients can be found in Panel C of Table 9. The results and conclusion are once again similar. Appendix Tables A.7 and A.8 also replicate the heterogeneity table using the alternative age 16 test score measures, reaching the same conclusion.

As some students take more GCSEs than others, thereby allowing for higher total test scores, another measure that is sometimes used is the student's total score in their top eight subjects. Any general increase in exams taken over time will be accounted for by the within year standardization of test scores. In Panel D and E of Table 9, we provide results according to this measure with standard and alternative point scores and find similar results.[2221]

As noted previously, whether a student scores at least a C on at least five GCSEs, including English and maths, is also a recognized measure of achievement used by schools and parents. We derive a binary variable representing whether this standard is met for each student in our sample. This is used as the outcome of interest in the same specifications, and so assumes a linear probability model. In our most demanding specification, we find that a ban improves the probability of a student attaining a C or better on five GCSEs by 2.01 percentage points against a baseline of 38% students in our sample attaining this level (Panel F of Table 9). This outcome variable getting 5 GCSE A–C is the nearest equivalent of a student passing secondary school. Therefore, we find that banning mobile phone increase the probability of attaining the required level for secondary school completion. Table 10 presents results by subjects—maths and English, English only, maths only, and other subjects. It shows the impact of the ban is mostly on language based subject English and other subjects with no impact on mathematics. Here we see that the impact by lower prior achievement are driven by the gains in 'other subjects'. There are gains in English test scores in the middle of the test score distribution. Finally, we present results at the school level for attaining 5+ GCSEs (Appendix Table A.9), which again shows that schools improve after the introduction of a ban.

Overall, results are robust to alternative specifications and to a set of student characteristics, including different measures of prior achievement and peer effects. These numerous robustness checks provide confidence that mobile phone bans play a role in determining school and student performance.

7. Conclusion

This paper investigates the impact of restricting mobile phone use in schools on student productivity. We combine survey data on mobile phone policies in schools in four cities in England with administrative data on student achievement to create a history of student performance in schools. By exploiting differences in implementation dates, our results indicate that there is an improvement in student performance in schools that have introduced a mobile phone ban, which is driven by previously low achieving students.

The existing literature on the impact of technology in the classroom implies that the unstructured presence of technology has ambiguous impacts on student achievement. We add to this by illustrating that a highly multipurpose technology, such as mobile phones, can have a negative impact on productivity through distraction. Schools that restrict access to mobile phones subsequently experience an improvement in test scores. However, these findings do not discount the possibility that mobile phones could be a useful learning tool if their use is properly structured. Our findings suggest that the presence of mobile phones in schools should not be ignored.

Finally, we find that mobile phone bans have very different effects on different types of students. Banning mobile phones improves outcomes for the low-achieving students the most (14.23% of a standard deviation) and has no significant impact on high achievers. The results suggest that low-achieving students are more likely to be distracted by the presence of mobile phones, while high achievers can focus in the classroom regardless of whether phones are present. Given the heterogeneous results, banning mobile phones could be a low-cost way for schools to reduce educational inequality.

Appendix A. Mobile phone survey questionnaire.

Question 1.1) What best describes the school's current mobile phone policy?

a) Complete ban of mobile phones on school grounds
b) Allowed on grounds, but must be turned off
c) Allowed on grounds, but must be turned to silent and off during classes
d) Allowed on grounds, but must be turned to silent at all times
e) Allowed on grounds, but must be considerate with use.
f) Other.
g) None.

Question 1.2) If Other, could you please briefly describe current policy.
Note: *Only Answer*: *Hand into reception, and collected at end of day.*
Question 1.3) When was the current policy first introduced?
Question 1.4) What are the punishments for misuse of phones on school grounds?
Question 1.5) Out of 7, to what extent would you say the policy is adhered to by students? [With 7 being "Completely" and 1 being "Not at all"]

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Question 2) Was there a different policy in place before this? - Yes/No.
If Yes, please answer the following.
If No, please skip to question 4.
In the space below, please answer questions 1.2 to 1.5 for this pervious policy (brief description of policy/introduction date/punishments/adherence).
Question 3) Was there a different policy in place before this?—Yes/No.
If Yes, please answer the following.
If No, please skip to Question 4.
In the space below, please answer questions 1.2 to 1.5 for this previous policy (brief description of policy/introduction date/punishments/adherence).
Question 4) Were there any other policy or leadership changes at the same time as the mobile policy change?
Question 5) Do you have any other comments?

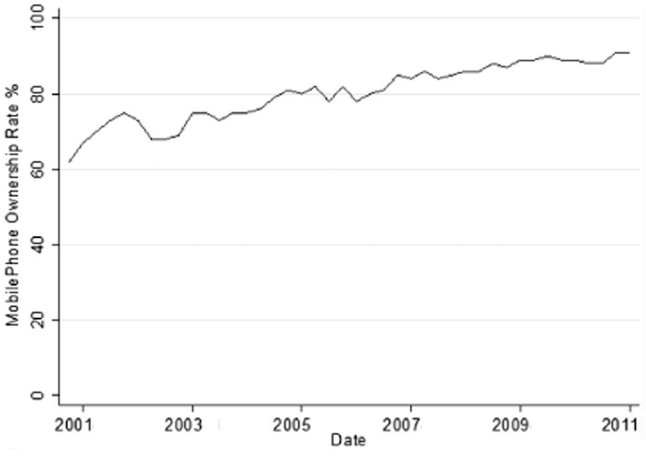

Fig. A.1. Mobile phone ownership rates in England. *Notes*: Phone ownership rates in England among individuals 13 years and older. *Sources*: Oftel/Ofcom, based on face-to-face survey data, 2011.

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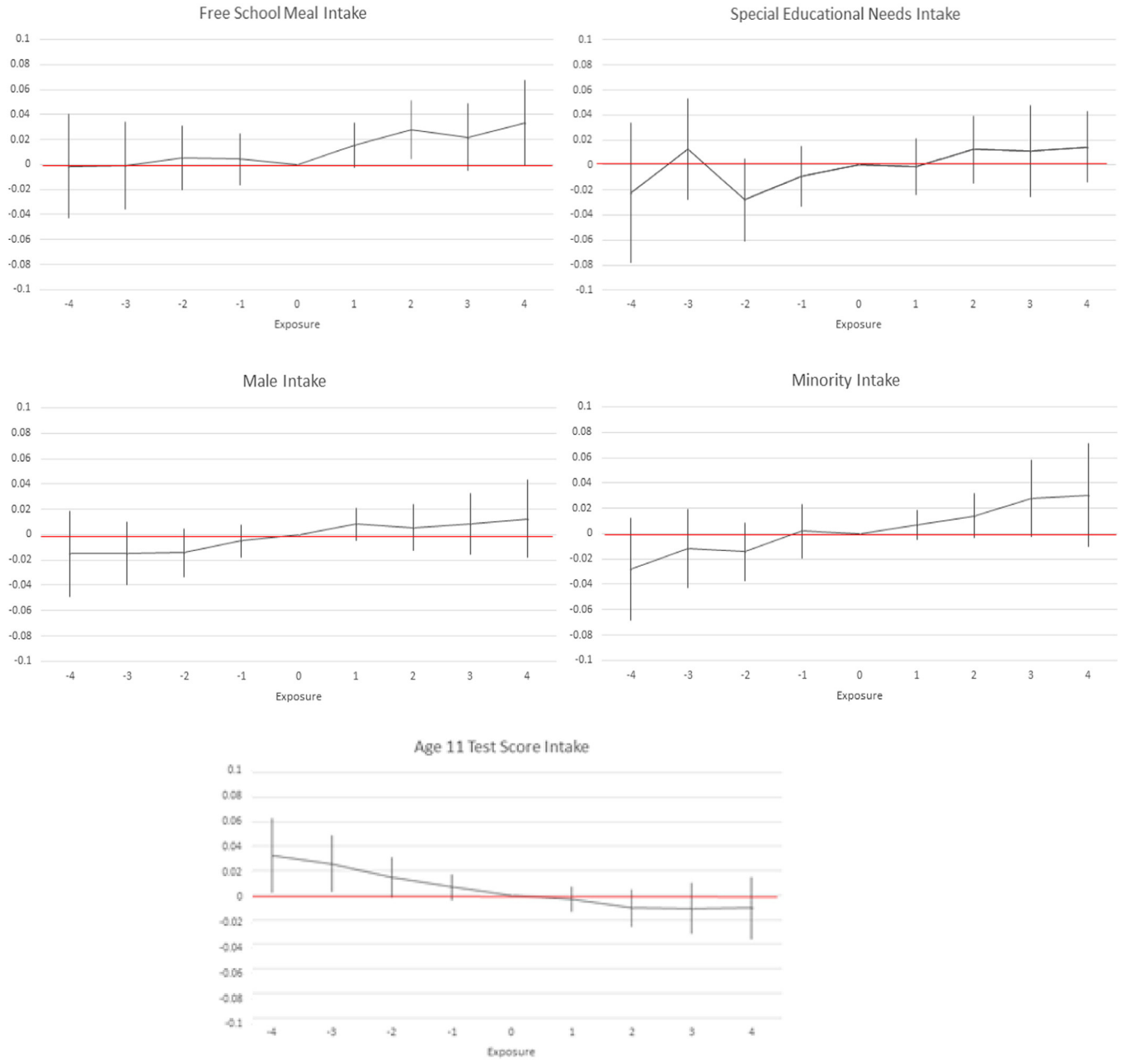

Fig. A.2. *Notes*: Estimated impact of mobile phone ban on school intake at age 11, by pupil characteristics conditional on year and school effects. Reference year is the year prior to introduction. Error bars represent the 95% confidence intervals with robust standard errors clustered at the school level. *Sources*: National Pupil Data Base and author-conducted mobile phone policy survey of schools in four cities in England: Birmingham, Leicester, London and Manchester.

Table A.1
The effect of mobile phone bans by ban compliance & rigidity.

	(1)	(2)	(3)	(4)	(5)
Panel A					
High Compliance ban	0.0619*	0.0668*	0.0699*	0.0717**	0.0692*
	(0.0402)	(0.0403)	(0.0405)	(0.0413)	(0.0413)
Low Compliance ban	0.0159	0.0233	0.0294	0.0298	0.0241
	(0.1109)	(0.1058)	(0.1051)	(0.1055)	(0.1079)
Panel B					
Non-Strict ban	0.1694*	0.1732*	0.1761*	0.1772*	0.1762*
	(0.0913)	(0.0911)	(0.0917)	(0.0920)	(0.0923)
Strict ban	0.0441	0.0491	0.0529	0.0545	0.0514
	(0.0395)	(0.0392)	(0.0399)	(0.0402)	(0.0403)
Non-Strict ban * 1st Quintile		0.2894***	0.3030***	0.3051***	0.3052***
		(0.0804)	(0.0789)	(0.0789)	(0.0787)

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Table A.1 (*continued*)

	(1)	(2)	(3)	(4)	(5)
Non-Strict ban * 2nd Quintile		0.2318**	0.2392***	0.2411***	0.2411***
		(0.0896)	(0.0901)	(0.0907)	(0.0905)
Non-Strict ban * 3rd Quintile		0.1936*	0.1966*	0.1981*	0.1966*
		(0.0992)	(0.0994)	(0.0998)	(0.1004)
Non-Strict ban * 4th Quintile		0.1220	0.1194	0.1205	0.1188
		(0.1054)	(0.1051)	(0.1054)	(0.1058)
Non-Strict ban * 5th Quintile		0.0161	0.0097	0.0092	0.0077
		(0.1009)	(0.1013)	(0.1013)	(0.1004)
Strict ban * 1st Quintile		0.0995**	0.1087**	0.1110**	0.1085**
		(0.0446)	(0.0459)	(0.0461)	(0.0458)
Strict ban * 2nd Quintile		0.0608	0.0736*	0.0759*	0.0734*
		(0.0418)	(0.0422)	(0.0427)	(0.0426)
Strict ban * 3rd Quintile		0.0383	0.0499	0.0517	0.0494
		(0.0394)	(0.0399)	(0.0404)	(0.0407)
Strict ban * 4th Quintile		0.0241	0.0219	0.0234	0.0201
		(0.0433)	(0.0435)	(0.0439)	(0.0443)
Strict ban * 5th Quintile		0.0025	0.0085	0.0074	0.0116
		(0.0420)	(0.0432)	(0.0437)	(0.0440)
Prior test scores: Age 11		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Prior peer achievement					✓

Notes: Table A.1 presents regression estimates for student standardized test score performance at age 16. All specifications include school and year effects and have robust standard errors clustered at the school level. Panel A separates bans into high-compliance (principal assessment score above 4 out of 7) and low-compliance mobile bans (4 and below). Panel B presents results by rigidity of the ban: strict (answer a, b or f) vs non strict ban (answer c & d). The number of observations are 130,482. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.2
Balancing test.

Variables	Age 11 student performance	Male	Minority	SEN	FSM
Mobile ban	−0.0094	−0.0042	−0.0005	0.0096	0.0053
	(0.0124)	(0.0043)	(0.0072)	(0.0101)	(0.0061)

Notes: Table A.2 presents regression estimates for different outcome variables to investigate whether schools that impose a ban are different and if students are sorting into schools based on student characteristics. All specifications include school effects and year effects. SEN means the proportion of students that are Special Educational Needs students and FSM means the proportion of students that are Free School Meal students. Male and Minority are the proportion of students that are male or from a minority group, respectively. We use robust clustered standard errors at the school level with school and year fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.3
Effect of mobile bans on transfer from school.

Transfer from school	(1)	(2)	(3)	(4)	(5)
Mobile ban	−0.0114	−0.0113	−0.0114	−0.012	−0.0117
	(0.0099)	(0.0099)	(0.0098)	(0.0099)	(0.0102)
Prior test scores: Age 14		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Peer characteristics					✓

Notes: Table A.3 presents regression estimates for students' transfers away from the school after the ban. The outcome variable is an indicator variable for if the student is enrolled in different school at age 16 than 11. All specifications include school effects and year effects. Estimated on the sample of students who were attending the responding schools at age 11. The number of observations is 132,041. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. Peer characteristics are calculated at age 1. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.4
Effect of mobile bans on student performance with interrupted time series model.

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Panel A					
Mobile ban	0.0660*	0.0695*	0.0652*	0.0657*	0.0651*
	(0.0374)	(0.0359)	(0.0367)	(0.0372)	(0.0381)
Panel B					
Mobile Ban	0.0513	0.0555	0.0499	0.0503	0.0472
	(0.0374)	(0.0366)	(0.0375)	(0.0379)	(0.0386)

(continued on next page)

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Table A.4 (*continued*)

Age 16 test scores	(1)	(2)	(3)	(4)	(5)
Exposure	0.0375**	0.0357**	0.0387**	0.0387**	0.0397**
	(0.0171)	(0.0175)	(0.0179)	(0.0179)	(0.0177)
Prior test scores: Age 11		✓	✓	✓	✓
Student characteristics			✓	✓	✓
Other policy changes				✓	✓
Prior peer achievement					✓

Notes: Table A.4 presents regression estimates for student performance. Specifications also include school specific time trends. The outcome variable is the standardized test score at age 16. The number of observations is 130,482. We use robust clustered standard errors at the school level. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means special educational needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** p < 0.01, ** p < 0.05, * p < 0.1. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.5
Effect of mobile bans on student performance excluding schools with "other policy changes".

Age 16 test scores	(1)	(2)	(3)	(4)
Mobile ban	0.0785**	0.0893**	0.0913**	0.0865**
	(0.0353)	(0.0351)	(0.0348)	(0.0356)
Prior test scores: Age 11		✓	✓	✓
Student characteristics			✓	✓
Prior peer achievement				✓

Notes: Table A.5 presents regression estimates for student performance. All specifications include school effects and year effects. The outcome variable is the standardized test score at age 16. The number of observations is 99,229. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means special educational needs students and FSM means Free School Meal students. The Table focus on schools without any "Other Policy changes". The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. In this table, we exclude schools that that other policy changes at the same time as the policy. *** p < 0.01, ** p < 0.05, * p < 0.1. *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.6
Effect of mobile bans on student performance by prior achievement group age 14.

Age 16 test scores	(1)	(2)	(3)	(4)
Impact by age 14 test scores				
Mobile ban * 1st Quintile	0.1015***	0.1100***	0.1118***	0.1046***
	(0.0353)	(0.0351)	(0.0355)	(0.0368)
Mobile ban * 2nd Quintile	0.0935**	0.1074***	0.1095***	0.1032***
	(0.036)	(0.0358)	(0.0367)	(0.0378)
Mobile ban * 3rd Quintile	0.0551	0.0615	0.0638	0.0564
	(0.038)	(0.0382)	(0.0393)	(0.0394)
Mobile ban * 4th Quintile	0.0213	0.0223	0.0246	0.0178
	(0.039)	(0.0387)	(0.04)	(0.0406)
Mobile ban * 5th Quintile	−0.0072	−0.0014	0.0016	−0.0027
	(0.044)	(0.0449)	(0.0463)	(0.0463)
Test scores: Age 14 categorical	✓	✓	✓	✓
Student characteristics		✓	✓	✓
Other policy changes			✓	✓
Peer characteristics				✓

Notes: Table A.6 presents regression estimates for student performance. The outcome variable is the standardized test score. All specifications include school effects and year effects. We use robust clustered standard errors at the school level with school and year fixed effects. The number of observations is 83,211. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. In this table, students are grouped into five categories based on their achievement level at age 14, where group 1 is the lowest-achieving group and group 5 is the highest-achieving group. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** p < 0.01, ** p < 0.05, * p < 0.1 *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.7
Effect of mobile bans on student performance by student characteristics.

Age 16 alternate test scores	(1)	(2)	(3)	(4)	(5)
Mobile ban	0.0405	0.0464	0.0442	0.0582*	0.0407
	(0.0351)	(0.0358)	(0.0366)	(0.0341)	(0.0367)
Mobile ban * FSM	0.0614**				0.038
	(0.0254)				(0.0233)
Mobile ban * SEN		0.0815***			0.0343
		(0.0303)			(0.0297)
Mobile ban * Male			0.0342		
			(0.036)		
Mobile ban * Prior test scores: Age 11				−0.0531***	−0.0448***

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Table A.7 (*continued*)

Age 16 alternate test scores	(1)	(2)	(3)	(4)	(5)
				(0.0129)	(0.0124)
Prior test scores: Age 11	✓	✓	✓	✓	✓
Student characteristics	✓	✓	✓	✓	✓
Other policy changes	✓	✓	✓	✓	✓
Peer characteristics	✓	✓	✓	✓	✓

Notes: Table A.7 presents regression estimates for student performance. The outcome variable is the alternate test scores at age 16 which accounts for different difficulty for attaining certain grades. All specifications include school effects and year effects. The number of observations is 130,482. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ *Sources*: National Pupil Database (NPD) and author-conducted mobile phone survey.

Table A.8
Effect of mobile bans on student performance by prior achievement quintile: age 11.

Age 16 alternative test scores	(1)	(2)	(3)	(4)
Impact by age 11 test scores				
Mobile ban * 1st quintile	0.1080***	0.1189***	0.1203***	0.1183***
	(0.036)	(0.0371)	(0.0374)	(0.0375)
Mobile ban * 2nd quintile	0.0910**	0.1018***	0.1032***	0.1013***
	(0.0353)	(0.0358)	(0.0364)	(0.0366)
Mobile ban * 3rd quintile	0.0593	0.0680*	0.0691*	0.0669*
	(0.0365)	(0.0370)	(0.0376)	(0.0381)
Mobile ban * 4th quintile	0.0267	0.0237	0.0247	0.0217
	(0.0370)	(0.0368)	(0.0372)	(0.0377)
Mobile ban * 5th quintile	−0.0111	−0.0212	−0.0207	−0.0243
	(0.0381)	(0.0393)	(0.0397)	(0.0399)
Test scores: Age 11 categorical	✓	✓	✓	✓
Student characteristics		✓	✓	✓
Other policy changes			✓	✓
Peer characteristics				✓

Notes: Table A.8 presents regression estimates for student performance. The outcome variable is the alternate test scores at age 16 which accounts for different difficulty for attaining certain grades. All specifications include school effects and year effects. The number of observations is 130,482. We use robust clustered standard errors at the school level with school and year fixed effects. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. In this table, students are grouped in five categories based on their achievement level at age 11, where group 1 is the lowest-achieving group and group 5 is the highest-achieving group. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Sources*: National Pupil database (NPD) and author-conducted mobile phone survey.

Table A.9
Effect of mobile bans on school performance.

School performance: % of students Achieving 5 Cs, including English & math	(1)	(2)	(3)	(4)
Mobile ban	0.0188*	0.0208**	0.0204**	0.0207**
	(0.0106)	(0.0104)	(0.0096)	(0.0098)
Prior test scores: Age 11		✓	✓	✓
Mean student characteristics			✓	✓
Other policy changes				✓

Notes: Table A.9 presents regression estimates for proportion of student who pass five GCSEs including English and Maths examinations. The number of observations is 816. All specifications include school effects and year effects. We use robust clustered standard error at the school level. Student characteristics are controlled for whether a student is male, a minority, SEN or FSM. SEN means Special Educational Needs students and FSM means Free School Meal students. The "Other policy changes" variable controls for whether there was a leadership or policy changes occurring at the time of the introduction of a mobile phone ban. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ *Sources*: National Pupil database (NPD) and author-conducted mobile phone survey.

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