

**The Effects of Enrolling in Oversubscribed Prekindergarten Programs Through Third
Grade**

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Abstract

This study leverages naturally occurring lotteries for over-subscribed Boston Public Schools prekindergarten program sites between 2007 and 2011, for 3,182 children (M=4.5 years old) to estimate the impacts of winning a first choice lottery and enrolling in Boston prekindergarten versus losing a first choice lottery and not enrolling on children's enrollment and persistence in district schools, grade retention, special education placement, and third-grade test scores. There are large effects on enrollment and persistence but no effects on other examined outcomes for this subsample. Importantly, children who competed for oversubscribed seats were not representative of all appliers and almost all control-group children attended center-based preschool. Findings contribute to the larger evidence base and raise important considerations for future prekindergarten lottery-based studies.

The Effects of Enrolling in Oversubscribed Prekindergarten Programs Through Third Grade

Decades of research have shown that attending preschool improves children's cognitive and socio-emotional skills at kindergarten entry (Duncan & Magnuson, 2013). This evidence, along with dramatic increases in maternal employment, has helped to fuel currently high levels of public support and parental demand for public preschool. Via a combination of public dollars and parental spending, attending preschool is now the typical experience for U.S. four year olds (Chaudry, Morrissey, Weiland, & Yoshikawa, 2017). In all, 69% of four year olds attend some form of center-based preschool in the year before they enter kindergarten, though children from the top income quintile are much more likely to attend preschool than those in the bottom quintile (83% versus 50%, respectively; Whitehurst & Klein, 2015). Approximately 43% of four year olds access preschool through public funding, via state or local prekindergarten programs or Head Start (Barnett et al., 2017).

While the evidence is nearly incontrovertible that children who attend preschool enter kindergarten better ready to learn (Phillips et al., 2017; Yoshikawa et al., 2013), questions about how long the benefits of preschool persist are longstanding, dating back to the first major public investment in preschool in the U.S. – Head Start in the 1960s (Cicirelli, 1969). The overall pattern in the older literature is that the language, literacy, and mathematics test scores of preschool participants and non-participants tend to converge in the early elementary grades (i.e., by around third grade), sometimes partially and sometimes fully (Phillips et al., 2017; Yoshikawa et al., 2013). But in the studies examining long-run effects, preschool participants tend to outperform non-participants on a wide range of behavioral, health, and educational outcomes into adulthood. Evidence from modern-day, scaled-up programs so far largely mirrors this medium-term pattern, though a group of experts recently concluded that such evidence “is sparse, precluding broad conclusions” (Phillips et al., 2017). Furthermore, long-run evidence is not yet available for modern-day, large-scale programs.

In the present study, we address current needs in the literature by using lotteries for oversubscribed program sites as a window into the medium-term effects of the Boston Public

Schools (BPS) prekindergarten program. Specifically, using data from four cohorts of students, we examine whether children who won their first choice lottery and enrolled in Boston prekindergarten benefit more than children who lost their first choice lottery and ultimately did not enroll in BPS prekindergarten. Our outcomes are drawn from administrative records and include third grade state standardized reading and mathematics test scores, K-2 grade retention, and K-3 special education placement. We also examine whether prekindergarten leads children to enroll and persist in the BPS at higher rates, as one of the program's goals was to attract and retain families that might otherwise not have enrolled in BPS schools. Finally, to contextualize the findings, we descriptively examine children's post-prekindergarten schooling environments.

Importantly, given both calls in the field for more rigorous longitudinal studies of prekindergarten (Phillips et al., 2017) and increasing attention to external validity (Stuart, Bradshaw, & Leaf, 2015; Tipton, 2014), the effects of prekindergarten enrollment that we estimate apply to the subgroup of lottery compliers – i.e., children who won or lost their first choice lottery and either enrolled in the program (first choice lottery winners) or did not enroll in the program at all (first choice lottery losers). As we detail, our lotteries were highly concentrated in a small subset of BPS schools (75% of lottery applicants, for example, competed for about a quarter of eligible district schools) and the children who competed for oversubscribed seats were more advantaged than the average applicant. Virtually all of the control group members attended other center-based preschool programs, an unusual counterfactual in the public prekindergarten evaluation literature. To assess external validity, we followed the example of Abdulkadiroğlu and colleagues' (2011) seminal lottery-based study and used data on the full set of program applicants and enrollees to examine the generalizability of our results through descriptive and quasi-experimental analyses. These analyses are important given recent attention to how effects for compliers may not represent a generalizable test of the effects of a program on all members of a target population (Chyn, 2018).

When might prekindergarten benefits persist?

Multiple theoretical frames are relevant to examining whether and when attending prekindergarten might boost children's medium-term academic and school progress outcomes. First, the human capital accumulation theory from economics posits that a strong early foundation sets the stage for acquiring more advanced skills. Heckman (2000) referred to this perspective as “learning begets learning, skill begets skill.” Second, developmental cascades

theory, which has its origins in the field of developmental psychology, describes the processes by which antecedent conditions have different probabilities of leading to particular outcomes; functioning at a particular level or in a particular developmental domain is hypothesized to affect later competencies in multiple domains (Masten & Cicchetti, 2010). A third theoretical perspective for expecting persistence is based on transactional developmental theory (Sameroff, 2009) – that is, the reciprocal effects of child skills and environmental inputs on subsequent teacher behaviors, and effects of such behaviors in turn on students. Following this theory, the prekindergarten boost may persist because participants' later-grade teachers may respond to their students increased skill level by increasing the instructional opportunities that they offer students. There may be observer-expectancy effects in which teachers may either consciously or subconsciously behave in ways that facilitate students' progress in accordance with their own expectations of the students (Weinstein, 2004).

Most recently, Bailey and colleagues (2016) built on these theories and offered three hypotheses for the persistence (or not) of a preschool boost. First, their “sustaining environments” hypothesis posits that the quality (broadly defined) of children’s educational settings after preschool is critical in sustaining the preschool boost. As an example, repeating the same content in kindergarten as in preschool would not be a sustaining environment for the preschool boost. Having a high percentage of peers who are well prepared for kindergarten might spark their teacher to increase rigor and therefore sustain the boost. Second, their “foot-in-the-door” hypothesis posits that attending preschool may get children over an important hurdle in their K-plus experiences and thereby grant them access to a benefit or allow them to avoid a harm (e.g., unwarranted special education placement). They also hypothesized that another key to convergence of outcomes of attenders and non-attenders could be which skills are emphasized and measured in the prekindergarten through third-grade period. They argue for a boost to last, the focal skills must be malleable, fundamental for success, and unlikely to develop in the counterfactual. For example, the boost from a prekindergarten program that focuses on constrained skills (Snow & Matthews, 2016) – e.g., the discrete set of basic literacy and mathematics skills that almost all children master by third grade such as letter knowledge and simple counting – is likely to be less enduring than the boost from a program that focuses on students’ deeper unconstrained skills, meaning more broadband skills like world knowledge, vocabulary, conceptual thinking, and problem solving.

At this juncture, it is unclear which of these theories best describes patterns in the empirical evidence base. Empirically, in the medium term, the older evidence has shown that preschool has small-to-moderate effects in reducing grade retention and special education placement in the K-12 years (McCoy et al., 2017; Yoshikawa, Weiland, & Brooks-Gunn, 2016). In both older and more recent studies, language, literacy, and mathematics test scores between preschool participants and non-participants tend to partially or fully converge by the end of third grade, though some studies do show some evidence of medium-term persistence (e.g., Bassok, Gibbs, & Latham, 2018; Hill, Gormley, & Adelstein, 2015; Ladd, Muschkin, & Dodge, 2014; Lipsey, Farran, & Durkin, 2018; Phillips et al., 2017; Puma et al., 2012). Recent work on the trajectory of effects suggests most of the eventual medium-term convergence between preschool attenders and non-attenders occurs within one to two years after preschool (Hojman, 2015). Specifically, about half of the eventual convergence on cognitive outcomes occurs during kindergarten and then by about half again by the end of second grade (Li et al., 2016).

The relatively small number of studies that have followed preschool participants into adulthood have found long-term benefits such as increases in college enrollment, decreases in incarceration rates, and decreases in teen pregnancy, even when in the medium-term there is convergence in test scores (Deming, 2009; Yoshikawa et al., 2016). However, the jury is still out on whether today's preschool programs will yield long-term benefits to participants and society similar to programs from earlier decades, particularly in settings in which participants show medium-term fadeout. By necessity, all of the longer-term evidence is from participants who attended preschool decades ago and there are important differences in context between older studies versus those of today's preschools and preschoolers. Parents of all social classes today invest more time and money in their children's learning, on average, than in previous generations (Bassok, Finch, Lee, Reardon, & Waldfogel, 2016; Reardon, 2011). Also, more children attend non-parental care than in the past, changing the counterfactual against which a given preschool program is evaluated (Chaudry et al., 2017). Previous work suggests the counterfactual plays a substantial role in preschool evaluations. In a re-analysis of the Head Start Impact Study, Feller and colleagues (2016), for example, found persistence of positive effects on language through first grade only for children who in the absence of Head Start would have been at home with their parents and not for children who otherwise would have been enrolled in another preschool program.

These more modern-day findings regarding the counterfactual are particularly relevant to the present study because, as we detail further in our findings section, an unusually high percentage of our control group compliers (88%) attended a center-based preschool program other than the Boston program and only 6% stayed home with a parent. As such, our study sits between two types of studies: 1) studies that compare a given preschool program against a more mixed counterfactual; and 2) studies in which all children attend the same preschool program but some attend an enhanced version. Examples of the former include the recent Tulsa quasi-experimental propensity score studies in which Tulsa prekindergarten is compared to a counterfactual in which 48% of children were in other center-based preschool programs (Hill, Gormley, & Adelstein, 2015) and the Tennessee VPK study in which 34% of comparison group were in other center-based preschool programs (Lipsey et al., 2018). Examples of the latter type of study include a recent preschool mathematics curricula trial that followed children into first grade, with the treatment group receiving an enhanced preschool experience and the control children business as usual preschool (Jenkins et al., 2018).

Increasingly, the evolving prekindergarten context adds nuance to understanding the effects of today's programs as well as raises new outcomes of interest. For example, one of our study's key medium-term outcomes – post-prekindergarten enrollment in the Boston Public Schools – has not been a focus in the literature to date, though it increasingly is a focus of localities that administer such programs. The only relevant evidence we are aware of is a recent study that found that Tulsa prekindergarten alumni were somewhat more likely to persist in the Tulsa Public Schools than were non-Tulsa prekindergarten and non-Tulsa Head Start attenders through eighth grade (Gormley, Phillips, & Anderson, 2018). There are, however, on-the-ground reports that schools in both New Orleans and DC – in which parent choice is a central feature of school assignment – have chosen to offer prekindergarten as a strategy to attract and retain families (D. Ewen, personal communication, June 19, 2017; Weixler, Lincove, & Gerry, 2017). In DC, school re-enrollment is also now a measure of school success/progress under the Every Student Succeeds Act (U.S. Department of Education, 2017). Seattle has framed its prekindergarten program not explicitly as a family retention strategy but as part of its affordability agenda (Slote & Kelly, 2015) – though presumably greater affordability would allow more young families to stay in the city. We expect that both the increasingly competitive educational markets and the rising cost of living in large cities will lead to increasing focus on

the effects of public prekindergarten on K+ enrollment decisions. And we expect more broadly that the changing prekindergarten landscape will lead to attention to other outcomes new to the literature.

The Boston Prekindergarten Program and the Boston K-3 Context

The Boston Public Prekindergarten program is a modern-day, relatively large-scale program that has been of interest in the recent literature because of its programmatic elements and its documented strong impacts on children's school readiness. The program began an expansion in 2005-2006, under the decree of then-Mayor Thomas Menino who argued that in addition to preparing children for school, the program could help attract families to the Boston Public Schools who might otherwise leave or choose other options. The program is based entirely in the public schools, pays teachers on the same scale as K-12 teachers, and subjects teachers to the same educational requirements of K-12 teachers (e.g., a masters degree within five years). Further, it is open to any child in the city, regardless of income. In our study years, about one-third of all four year olds in Boston enrolled in the program and about half of all children who enrolled in BPS kindergarten had attended BPS prekindergarten the year before (Shapiro, Martin, Weiland, & Unterman, 2019).

Since 2007, the program also has utilized a consistent curricula and coaching system. Specifically, the district implemented Opening the World of Learning, which targets children's early language and literacy skills and includes a social-skills component embedded in each unit, in which teachers discuss socio-emotional issues with children and integrate emotion-related vocabulary words (Schickedanz & Dickinson, 2005). It also implemented Building Blocks, an early mathematics curriculum which covers both numeracy and geometry and has a heavy focus on verbal mathematical reasoning (Clements & Sarama, 2007a). Both curricula have shown positive effects on children's outcomes in other studies (Ashe, Reed, Dickinson, Morse, & Wilson, 2009; Clements & Sarama, 2007b; Clements et al., 2011), though the evidence base for Building Blocks is stronger than that for OWL (Weiland & Yoshikawa, 2013).

In two of our four focal years (2007-2008 and 2008-2009), curricula implementation was supported via trainings and regular coaching, meaning weekly to bi-weekly on-site support from an experienced early childhood coach trained in both curricula. Thereafter, due to budget cuts, coaching was targeted to new teachers and to prekindergarten and kindergarten teachers in schools undergoing National Association for the Education of Young Children Accreditation, a

quality assurance process used in early childhood settings nationally. On the whole, Boston's structural and programmatic choices make it fairly unique among public programs nationally which tend not to require masters degrees, usually do not pay prekindergarten teachers on the same scale as K-12 teachers, do not require a proven, consistent curriculum, and do not employ coaching (Barnett et al., 2017).

The quality of the Boston program has been investigated in prior work using standard classroom observational tools. Boston classrooms score similarly to other systems nationally on structural quality and on emotional support (Weiland, Ulvestad, Sachs, & Yoshikawa, 2013). However, Boston has the highest average instructional quality of a large-scale program to date (Chaudry, Morrissey, Weiland, & Yoshikawa, 2017), scoring, for example, in the 2009-2010 school year 1.7 to 2.4 SDs higher on this dimension than current Head Start quality nationally (Weiland, 2016). It also showed strong effects on the language, literacy, mathematics, and executive function skills at kindergarten entry of children who attended the program in 2008-2009 in a large-scale regression discontinuity study that used the program's long-standing September 1 cutoff as its source of exogeneity (Weiland & Yoshikawa, 2013). Importantly, the care settings for control group children were relatively stronger than has typically been the case in past such studies because Massachusetts has some of the strongest child care standards nationally and approximately two-thirds of control-group children were enrolled in non-parental care during the treatment year, with about 57% in other center-based preschool programs (Weiland & Yoshikawa, 2013).

Post prekindergarten in our study's focal years, district K-3 teachers implemented the literacy curriculum Reading Street and the mathematics curriculum TERC Investigations. These curricula do not have a strong evidence base compared to the pre-k curricula used in the district (Agodini, Harris, Thomas, Murphy, & Gallagher, 2010; Gatti & Petrochenkov, 2010; Ladnier-Hicks, McNeese, & Johnson, 2010; What Works Clearinghouse, 2013), nor were they supported by coaching and training as systematically or as frequently as the pre-k program's supports. Reflective of these differing investment levels, classroom quality data collected by the Wellesley Centers for Women in spring 2012 on 84 K-3 classrooms in BPS and in spring 2010 on 83 prekindergarten classrooms and reanalyzed by our study team show that prekindergarten classroom instructional quality was markedly higher on average than K-3 instructional quality (see Table 1 in Appendix A). Notably, the district responded to this evidence and other related

evidence by subsequently (not in our study focal years) developing its own K-2 curriculum and associated professional development program (Boston Public Schools, 2017).

Current study

Using data from four cohorts of students who applied to the Boston Public Schools (BPS) prekindergarten program between the 2007-2008 and the 2010-2011 school year, we aimed to investigate the effects of enrolling in the Boston prekindergarten program versus students' other options. Ultimately, consistent with other lottery-based studies (explained in detail in the next section), we were able to leverage oversubscribed first choice lotteries to address our central research question: What is the effect of enrolling in a Boston prekindergarten program versus not at all on children's enrollment and persistence in BPS grades K-3; children's risk of being retained in grade in K-2 or of being classified as special-needs in K-3; and children's third-grade state standardized test scores in mathematics and reading?

Method

Dataset

We use data from Boston Public Schools (BPS) and the Massachusetts Department of Elementary and Secondary Education. We begin with data on students' choices and baseline demographics during the Boston Public Schools assignment process from the spring of the 2006-2007 through 2009-2010 school years (for enrollment in 2007-2008 through 2010-2011). We merge these data, using each student's unique identifier, with district and state administrative records covering the years students were age-eligible for prekindergarten (at age 4) through third grade.

Sample

Our sample comes from the population of students who applied to the Boston prekindergarten program for four year olds. As shown in Appendix A Figure 1, in all, 12,740 families applied to the program in our focal years. Nearly 10,000 of these families applied to the district's school choice lottery (described in greater detail in the next section) in the spring before their child was age-eligible for the program. This is what we call the "standard process"; it included four rounds and from these rounds we identified naturally occurring lotteries for students' first choice school involving 3,182 students, or 25% of all appliers and 32% of those who applied through the standard process. The distribution of the lottery sample across the four rounds of the standard process is as follows: 99% of the sample is drawn from round one, less

than 1% is drawn from round two, less than 1% is drawn from round three, and no students are drawn from round four. Another 2,769 (22% of applicants) applied via a later process after the four rounds had concluded. Their applications were considered on a rolling, as-space-is-available basis and they are not part of our lottery sample.

Our lottery sample was diverse in their background characteristics. As shown in Table 1, for example, 35% of first choice lottery winners and 40% of control group members were Hispanic; about a quarter overall were Black; another quarter were White; and the rest (~13%) were Asian or Other. About 58% of first choice lottery winners were eligible for free/reduced lunch (57% for control group children). A little over half spoke English at home, a quarter spoke Spanish, and around 20% spoke a non-English and non-Spanish home language.

Boston Prekindergarten school assignment process details

Under the BPS's school choice plan, in the winter and spring of each school year, families could apply to up to 10 schools they wanted their child to attend for prekindergarten the following fall (i.e., unlike most other systems, children were not automatically assigned to their neighborhood school). Families were assigned different priorities to different schools based on criteria set by the district, such as sibling and walk zone priority, sibling priority only, walk zone priority only, and no priority (listed in order from most to least priority). Importantly, when there was more demand than supply for a given school, the assignment algorithm used family choice lists, school priorities, and a random number to randomly assign some students (and not others) to the school.

In the present analysis, we used data from students' first application to prekindergarten to identify naturally occurring lotteries among students with the same preference to the same oversubscribed school/program (e.g., two students who listed school A's regular education program who both had walk-zone priority to it) that listed the program as their first choice. As discussed below, we constrained our sample to students' first choice lotteries as only these students clearly participated in the equivalent of an experiment. Appendix B includes more details on the district's school application and lottery process and how we identified the lotteries used in our analysis.

Appendix A Table 2 displays the number of applicants to the prekindergarten program in the focal years, the number of lottery sample members, and the percentage of lottery participants each year. As mentioned above, across the study years, 25% of applicants were in an

experimental lottery. The percentage of district schools represented across years in the lotteries ranged from 67-83% across years. However, some schools were highly over-represented and others were under-represented in the lottery sample – e.g., about half of the students competed for just 7 schools (10% of schools with prekindergarteners during this time period) and about 75% competed for just 18 schools (26% of schools with prekindergarteners during this time period).

Ultimately, although all lottery winners were offered the opportunity to enroll in the BPS prekindergarten program, 91% did so, according to BPS administrative records. Approximately 90% of lottery winners enrolled in their first choice school, 2% enrolled in a school not in their initial choice list, and 9% did not enroll in Boston prekindergarten. While all of the control group students lost the first lottery they competed in, roughly 62 percent of them enrolled in the program either by coming off of a waitlist, winning a subsequent lottery, being assigned to an under-subscribed school farther down their choice list, or participating and being assigned in a subsequent assignment round. Ultimately, roughly 13% of the control group enrolled in their first choice school, 29% enrolled in a school lower on their choice list, 23% enrolled in a school not on their initial choice list, and 35% did not enroll in Boston prekindergarten. Taken together, this suggests an estimated BPS prekindergarten enrollment rate difference of 29 percentage points (91% minus 62%), a difference that is low but not uncommon in research designs utilizing naturally occurring lotteries within choice processes (Abdulkadiroglu, Angrist, Narita & Pathak, 2015; Angrist, Cohodes, Dynarski, Pathak & Walters, 2016). In the data analysis section, we describe how we use these lotteries to estimate the effect of enrolling for the target of our analysis – those that won a seat in their first choice BPS prekindergarten and subsequently enrolled versus those lotteried out of the program who do not enroll (i.e., the compliers).

Outcomes

Enrollment and persistence in BPS. From district administrative records, we coded whether students enrolled in the Boston Public Schools in kindergarten through third grade. If a student enrolled in BPS at least one day in a given year, we set the enrollment variable for that year to 1 and to zero otherwise. From our yearly variables, we constructed a 0/1 coded “ever enrolled” variable for kindergarten to third grade and 0/1 “persistence” variable for continuous enrollment for kindergarten to third grade. As mentioned earlier, we included these outcomes because though unusual in the literature, they are increasingly relevant to public prekindergarten

programs and because attracting families to the Boston Public Schools who might otherwise leave or choose other options was an original goal for the program.

Grade retention and special needs placement. From administrative records, we constructed year-by-year measures of children's K-2 grade retention and K-3 special needs placement, defined as having an Individualized Education Plan (IEP). We also constructed measures of whether the child was ever retained from K-2 or ever had an IEP in K-3.

Notably, since 2008, the average districtwide retention rate in grades 1-3 in Boston has ranged from 2.9% to 7.5% at each grade level, meaning that the percentage of students ever retained by the end of third grade is around 10% (e.g., 2.9% and 7.5% averaged and multiplied by three; MA Department of Education, 2013). Nationally, the yearly annual retention rate was 1.5% in 2010 (Warren et al., 2014). Regarding special education placement, Massachusetts has the second highest rate of special education placement in the U.S. (Hehir, Grindal, & Eidelman, 2012). Approximately 19% of BPS elementary-school students in 2012 had been diagnosed with a disability (Grindal, personal communication, June 9, 2013).

Third grade standardized test scores. For third grade reading and mathematics analyses, we use students' statewide mathematics and reading standardized tests. Cohorts 1, 2, and 3 took the Massachusetts Comprehensive Assessment System (MCAS) in third grade, the test used for state accountability purposes in Massachusetts (see Appendix C for psychometric details). In 2015, the state of Massachusetts gave districts the choice between continuing to administer the MCAS or administering instead a new mathematics and ELA exam based on the Common Core standards, called the Partnership for Assessment of Readiness for College and Careers (PARCC) assessment (Massachusetts Department of Elementary and Secondary Education, 2015). In all, 54% of districts in the state switched to the PARCC while the rest continued to administer the MCAS. In the three largest school districts in the state – Boston, Worcester, and Springfield – individual schools chose which test to administer. In Boston, all but two schools with third grade students chose to administer the PARCC.

Amidst these changes, the state recommended that researchers standardize students' estimated theta (i.e., IRT) scores when conducting analyses that require pooling across the MCAS and PARCC exams (Massachusetts Department of Elementary and Secondary Education, 2016). We followed this advice and standardized each student's theta score on the mean and standard deviation of all third graders within the Boston Public Schools taking the given exam in

that year. Test score data in this paper accordingly can be interpreted as a given group's performance compared to the average BPS third grader. For both the MCAS and the PARCC, if students were retained, we used their score from their first third grade test administration.

Covariates

Using administrative records, we constructed a set of student-level covariates. We captured students' race/ethnicity using a set of dichotomous variables that identified whether a student was Asian, Black, Hispanic, White, or mixed/other. Similarly, we used a set of dichotomous variables to identify whether the students' home language was English only, Spanish, or another language. Using student birthdates, we calculated students' age as of September 1 in the year they were applying to prekindergarten. We also created dichotomous variables that identified whether the student was eligible for free-reduced priced lunch; whether the student was male; and whether the student's country of origin was the U.S.

School context variables

To capture each student's school experience in every follow-up year, we drew on publicly available data from the Massachusetts Department of Secondary Education (n.d.), which we merged on to each student's data row by follow-up year and enrolled school ID. If the student was enrolled in multiple schools in a given year, we used the value for the school in which the student was enrolled the longest. We included indicators of the school-level student sociodemographic characteristics – percentage of students from low-income families (see Appendix C regarding a definition change in this measure in our last study year); the school's percentage of English language learners; percentage of students with a non-English home language; percentage of students with disabilities; percentage of students who were African American, Asian, Hispanic, or White; and percentage of female students. For schools' academic context, we included the percentage of third-grade students who were proficient or higher on state English Language Arts and mathematics standardized tests (for cohorts 1-3, the MCAS and for cohort 4, either the MCAS or the PARCC, depending on which was used in the students' schools in third grade). Finally, we also included measures of schools' percentage of licensed teachers, student/teacher ratio, percentage of teachers rated as exemplary or proficient in the state's rating system, percentage of teachers retained or remained working in the same position compared to the previous school year, the percentage of students who remain in the school throughout the school year (stability rate), and average class size. Percentage of teachers rated as

exemplary or proficient in the state's rating system and average class size were available for cohorts 3 and 4 only. We averaged the characteristics of students' schools across the K-3 grades to create our key analytic variables.

Prekindergarten year care settings

For our first two cohorts, when students applied to the Boston Public Schools, their parents answered a set of questions about their child's last child care experience. We used these data to identify the care setting of children not enrolled in BPS prekindergarten (e.g., the counterfactual) – Head Start, private preschool, family daycare, or parental/relative care. We also used state administrative records that captured whether a student attended preschool in a traditional public school or a charter school. We used district administrative records from the prekindergarten year to identify which sample children attended BPS prekindergarten.

The district changed its data collection form for this information for cohort 3 and cohort 4 such that setting type was not available to our study team. For this reason, we used control group care setting data for the first two cohorts only. More details on these data are available in Appendix C.

Data Analytic Plan

To estimate the impacts of enrolling in the Boston Public Schools prekindergarten program on study outcomes, we utilized naturally occurring lotteries in the Boston choice system. As is common when applying this experimental, lottery-based approach, our first step was to estimate the effect of being offered the opportunity to enroll in a Boston prekindergarten school [intent-to-treat (ITT)] using students' first choice applications (Abdulkadiroğlu et al., 2011; Bloom & Unterman, 2014; Dobbie & Fryer Jr, 2011). We constrained our sample to students' first choice lotteries because when a student is competing in any lottery other than her first lottery, her probability of being assigned to a lower choice may depend in part on her earlier choices (and not just her random number) and thus using these later lotteries could pose a threat to randomization (Bloom & Unterman, 2014). While students may not compete in a lottery in their first choice and may compete in a lottery at a later choice, we focus only on their first choice lotteries to ensure that we have identified a purely experimental sample.

Within our lottery-based research design, a set of students randomly “won” the opportunity to attend their first choice BPS prekindergarten program (the treatment group).

Another set of students randomly “lost” the opportunity to attend their first choice BPS prekindergarten program (the control group). Because the lottery randomly assigns students, students in the treatment and control groups were, in expectation, equivalent in all measurable and unmeasurable characteristics. The basic approach for the analysis is to estimate, for each lottery, differences in mean outcomes for winners and control group members, and to average the results across lotteries.

Specifically, we construct the following linear regression model:

$$Y_{ij} = \beta T_{ij} + \sum_{k=1}^K \pi_k I_{kij} + \sum_{p=1}^P \theta_p X_{pij} + \varepsilon_{ij} \quad (1),$$

where Y_{ij} is a relevant short- or medium-term outcome for student i in lottery j ; T_{ij} is a lottery winner indicator equal to 1 if student i wins lottery j and 0 otherwise; I_{ij} is a set of k lottery indicators equal to 1 for lottery j and 0 otherwise; X_{ij} is a set of p student-level covariates (race/ethnicity, gender, eligibility for free or reduced-price lunch, age, country of origin and home language status); and ε_{ij} is a random error for student i that is clustered by the prekindergarten school that students entered after their lottery. This latter information is available only for students that enroll in the Boston prekindergarten program. Thus, for this purpose, we assume that students who do not enroll in the program – the majority of whom are in the control group – are not clustered together in another setting. The $\hat{\beta}$ coefficient identifies the effect of winning a lottery on student outcomes and its associated t -statistic identifies statistical significance.

Our ITT estimates represent the effect of winning one’s first lottery and thus do not answer the question likely of most substantive interest to practitioners and policymakers – the effect of enrolling in Boston prekindergarten versus not doing so. Thus, we use students’ first lottery participation as an instrument for estimating the effects of BPS prekindergarten enrollment – often referred to in the literature as a complier average causal effect (CACE; Gennetian, Morris, Bos, & Bloom, 2005). In this context, the effect of enrollment represents the effect of enrolling in Boston prekindergarten for the subgroup of students – the compliers – who won their first choice lottery and enrolled in BPS prekindergarten compared with those that lost their first choice lottery and ultimately did not enroll in BPS prekindergarten. As mentioned previously, the overwhelming majority of lottery winners enrolled in their first choice school, making our enrollment effect more specifically represent the effect of enrolling in children’s first

choice program, versus not at all.

Because this approach is new to estimating the effects of prekindergarten (though it has been used in contexts with older children; Abdulkadiroğlu et al., 2011; Bloom & Unterman, 2014; Dobbie & Fryer Jr, 2011), it merits some additional explanation. In particular, what is a complier in this context? A complier is a student who randomly won or lost his/her first choice lottery and, for winners, enrolled in a Boston prekindergarten program (first choice or otherwise), and for lottery losers, did not enroll in Boston prekindergarten. Notably, some children who lost their first lottery won a slot to a school lower on their choice list and attended Boston prekindergarten in that school. Our estimates of the effect of enrollment ultimately do not apply to them (i.e., known as “always takers” in the literature), just as they do not apply to children who would not have enrolled in the program regardless of whether they won or lost their first lottery (i.e., “never takers”). Our instrument effectively carves out the exogenous variation in enrollment that is due children’s first choice lottery result and uses it to estimate the causal effect of enrollment for the subgroup of compliers. Notably, as mentioned previously, effects for compliers in some contexts have been shown not to generalize to the full population (Chyn, 2018). This aspect of our design is why we emphasize that our analysis is a window into the medium-term effects of the program, rather than an evaluation necessarily for all students. This is also why we also conduct multiple analyses of the generalizability of our results.

To calculate CACE, we conducted a two-stage least squares analysis (2SLS). The lotteries we drew on range in size with many of their samples being quite small. To avoid finite sample bias from “weak instruments” (Bound, Jaeger, & Baker, 1995), we estimated the CACE using a single-instrument model (also known as a Wald estimate). This approach has been used for past analyses of randomized experiments and lottery-based studies (Abdulkadiroğlu et al., 2011; Bloom & Unterman, 2014; Gennetian et al., 2005; Ludwig & Kling, 2007). The first stage was specified as:

$$E_{ij} = \beta T_{ij} + \sum_{k=1}^K \pi_k I_{kij} + \sum_{p=1}^P \theta_p X_{pij} + w_{ij} \quad (2)$$

where E_{ij} is a BPS prekindergarten enrollment indicator equal to 1 if student i ever enrolled in BPS prekindergarten and 0 otherwise, and all other terms are defined as in equation (1). Our first-stage F-statistic equals 11, which is just above the recommended threshold for instrument strength (Bloom, Zhu, & Unlu, 2010; Bound et al., 1995).

The second stage equation was specified as:

$$Y_{ij} = \delta \hat{E}_{ij} + \sum_{k=1}^K \pi_k I_{kij} + \sum_{p=1}^P \theta_p X_{pij} + e_{ij} \quad (3)$$

where \hat{E}_{ij} equals the fitted value of the enrollment outcome from the first-stage equation, e_{ij} is a random error that is clustered by the prekindergarten school that students entered after their lottery, and all other terms are defined as in equation (1). The estimated value of δ is a consistent estimate of the average effect of enrolling in BPS prekindergarten for target BPS prekindergarten enrollees. We fit our CACE models in SAS, using MDRC code described in detail in Bloom and Unterman (2014). Importantly, while the ITT approach meets the What Works Clearinghouse's highest standard of evidence, the CACE approach is considered quasi-experimental (What Works Clearinghouse, 2014).

Finally, there was a small amount of missing data on all covariates except age in our lottery sample, ranging from 0.4% to 4.2% (and likewise in our full sample, ranging from 0.4% to 4.0%; see the Table 1 note). We imputed missing covariates as our primary approach in our lottery approach, using multiple imputation with 40 datasets. Our lottery estimates are not sensitive to problems of missing covariate data (see the "robustness checks" section below). We describe missing data on outcomes in the next section.

Results

Balance on observables and attrition analysis. We compared the background characteristics of first choice lottery winners and control group members in the lottery sample (see Table 1 for this ITT analysis). There are 2 (out of 12) statistically significant differences between the two groups – lottery winners are 4.7 percentage points less likely to be Hispanic ($p = 0.005$) and 2.9 percentage points more likely to be Asian ($p = 0.005$). A joint F-test used to assess the statistical significance of the overall difference between the first choice lottery winners and control group members could not reject the null hypothesis that there was no difference between the two groups ($p = 0.200$). We controlled for these background characteristics (as is suggested by What Works Clearinghouse, 2014), both to improve precision and, for the characteristics for which there was evidence of imbalance, to reduce the threat of possible bias in our estimates. See Appendix A Table 3 for the estimated complier averages for these same background characteristics. On average, compliers were quite similar to the full ITT lottery sample.

In an analysis of the availability of our outcome data for our first choice lottery sample, we found that outcome data were missing at relatively low rates (3-16%) and that differences in outcome missingness by treatment status were relatively small (3-5 percentage points more likely to be missing for the control group, across outcomes). These levels of missingness meet the What Works Clearinghouse's standards for rigor (2014). Two of these differences, for retention and special education placement, were statistically significant ($p < .0001$). The resulting F-value from a joint F-test of differences in the background characteristics of children with non-missing outcome data by treatment status was not statistically significant. See Appendix D for full attrition details and results.

Care settings in the prekindergarten year. Table 2 displays results from fitting our ITT and CACE models with care setting information in the prekindergarten year for cohorts 1 and 2 as the outcomes, for children who had non-missing counterfactual data. The results shown are important for identifying what Boston prekindergarten is being compared to in our study. From our ITT results, 97% of lottery treatment group members enrolled in BPS prekindergarten and nearly all of treatment group members (99.6%) enrolled in some kind of center-based preschool. In the lottery control group, 72% enrolled in BPS prekindergarten and 97% enrolled in some kind of center-based preschool – substantially exceeding the national average of 69% (Whitehurst & Klein, 2015). Overall, 14% of control group members enrolled in private centers, 4% in Head Start, 4% in charters, 3% in other public programs, 1% in family daycares, and 2% were home with a family member.

By definition, for our BPS enrollment effect estimates, all of our treatment group compliers attended BPS and none of control group compliers did so. Among control group compliers, 88% were in other center-based preschool programs. All told, 48% of control group compliers attended private programs, 17% Head Start, 12% charters, 12% other public programs, 6% family daycares, and 6% were at home.

In recent preschool evaluations, about a third to half of the control group has attended other center-based preschools programs (e.g., 34% in Tennessee, 48% in Tulsa, about 50% in Head Start; Bloom & Weiland, 2015; Lipsey et al., 2018; Hill et al., 2015). These lottery-sample counterfactual findings accordingly are quite distinctive within the current evidence base.

Impacts. Examining lottery sample members' K-3 enrollment in the BPS, we found that first choice lottery winners enrolled in the Boston Public Schools at higher rates at each grade

compared to the control group. As shown in Table 3 Column 2, effects of winning a first choice lottery (ITT) ranged from about 7 to 10 percentage points ($p < .0001$). The effects for compliers who enrolled in BPS (CACE, see Column 6) at each grade level K-3 were large, ranging from 24 to 34 percentage points ($p < .0001$). There was also a large difference of 34 percentage points in consistent K-3 enrollment in the district between lottery winner compliers and control group compliers ($p < .0001$). Treatment and control group complier means shown in column 8 and 9 further illuminate these findings; 74% of lottery winner compliers enrolled in BPS continuously from K-3 versus just 39% of control group compliers. These findings demonstrate that pre-K enrollment markedly increased later enrollment in district public schools.

For other examined outcomes – children’s grade retention, special education placement, and standardized test scores – findings in Table 3 demonstrate that there were no effects of winning a first choice lottery (ITT; Column 2) nor of enrolling in Boston prekindergarten (CACE; Column 6). The effects of winning a first choice lottery (ITT) for these outcomes were uniformly small, close to zero in magnitude, and not statistically significant. Compliance rates across these outcomes were around 29 percentage points (see column 4; $p < .0001$). CACE estimates are larger than the ITT estimates; given the compliance rate of ~29 percentage points across outcomes, the magnitude of the CACE estimates reflects the low compliance rate difference. Also notable, CACE confidence intervals (Column 10) were relatively wide, ranging from substantially negative to substantially positive. For example, for “ever placed in special education,” the point estimate was 0.8% with a 95% confidence interval of –10% to 12%.

For these outcomes too, the treatment and control complier means are illuminating (see Columns 8-9). In kindergarten, for example, very few students were retained in grade – 1.6% of treatment compliers and 1.4% of control group compliers. These levels are substantially below the aforementioned district average of 2.9% to 7.5% in grades 1-3 at each grade level in BPS (MA Department of Education, 2013). For special education, mean levels for lottery compliers more closely approximate the district average of 19% of BPS elementary-school students diagnosed with a disability. Specifically, about 16% of treatment and control compliers were classified as special education students in third grade. For state standardized tests, both groups scored substantially higher than the average BPS third grader. In English Language Arts, lottery compliers scored 0.40 SD higher than the average BPS third grader, while control group members scored 0.38 SD higher than the average BPS third grader. In math, the means were

0.35 SD for lottery compliers and 0.53 for control compliers – a more sizable difference compared to other outcomes but statistically not significant.

Differences in students' K-3 school experiences. To provide context for these results, we examined whether differences in students K-3 contexts might have driven our findings, concentrating on the differences in contexts for compliers. Specifically, as described in the measures section above, we used publicly available school characteristics data and student enrollment records and calculated the average characteristics of the schools students were enrolled in from grades K-3. We then analyzed these student-specific measures as outcomes using our standard CACE model. As shown in Table 4, there were some statistically significant, though relatively small, differences in 9 out of 18 characteristics of treatment complier and control complier K-3 environments. For example, treatment compliers had fewer peers who were low-income students (66% vs. 72%, $p < .05$) and African-American (26% vs. 37%, $p < .001$) than did control compliers. Treatment compliers also had more peers who were Hispanic (40% vs. 33%, $p < .01$) and White (22% vs. 16%, $p < .05$). They also experienced slightly more licensed teachers (97% vs. 94%, $p < .01$) and were in schools with more stable student bodies (89% stable vs. 84%, $p < .001$). The percentage of children proficient on third grade tests in children's K-3 schools favored the treatment group compliers (e.g., 44% vs. 41% for ELA) but the difference was not statistically significant.

On the whole, while there were lottery-induced differences in students' K-3 school experiences favoring the treatment group, these were relatively small. Both groups of students attended elementary schools in which their peers were majority low-income and non-White and in which the majority of teachers were rated as exemplary or proficient by the state's teacher evaluation system.

Robustness checks. As a robustness check, we fit third-grade outcome models in the first choice lottery sample without multiple imputation of covariates or outcomes and with multiple imputation for both covariates and outcomes (versus our primary strategy of imputing covariates but not outcomes; see Appendix E Table 1). We also fit school context models that used characteristics of students' K and third grade schools only, in case averaging over different numbers of years for students with missing data in one or more of their K-3 years was distorting or misrepresenting the schooling context differentials (Appendix E Table 2). We re-fit third grade standardized test models dropping children who were ever retained, in case taking the test

at an older age or in a different year from the rest of the cohort somehow biased our estimates even though there were no impacts on retention (for parsimony, these results are available upon request). Also, most of our outcomes were dichotomous; we used linear probability models as our primary modeling strategy because our sample size is well over the threshold for doing so and as these models are more straightforward (Angrist & Pischke, 2009). We did, however, refit key models with dichotomous outcomes using logistic regression as a sensitivity check (results available upon request). We also refit impact models with prekindergarten enrollment defined as being enrolled in at least 150 days of the school year (rather than 1 day; see Appendix E Table 3). We chose 150 days because of the distribution of the enrollment variable in our sample; there is no agreed-upon threshold in the literature and recent preschool studies have used different thresholds (Lipsey et al., 2015; Phillips, Gormley, & Anderson, 2016). Across these checks, we found no evidence that our main results were sensitive to our data analytic decisions.

Finally, one assumption underlying our CACE analysis – that always-takers in both the treatment and control groups (i.e., children who would have enrolled in Boston prekindergarten regardless of their first choice treatment assignment status) experienced the same effect of enrollment – is difficult to evaluate. Treatment group always-takers in our study largely enrolled in their first choice school; among control group crossovers, approximately a third did so. If the level at which a student ranked a prekindergarten program is indicative of their match with the program or its quality, it is possible that the two-thirds of the control group crossovers that enrolled in lower choices experienced a lower-quality program. Empirically, when we compared the first-choice schools and BPS schools actually attended in prekindergarten for the two-thirds of control group crossovers who did not enroll in their first choice but enrolled in a lower choice, we found that their first choice and their school attended differed on 9 out of 13 school context characteristics, with first choice school appearing generally somewhat higher quality than the school in which they actually enrolled. However, we also found that school-level context variables were only weakly correlated with observed prekindergarten process quality (Weiland & Unterman, 2019). Further, among all control crossovers, about two-thirds were unassigned to the program after their first round; they were not assigned to a lower choice as part of the first round of the lottery system. These students crossed over later, which might indicate that their parents were particularly highly motivated and that therefore, they might have

benefitted more from their Boston prekindergarten classroom. Ultimately, the direction of any potential bias from violation of the always-taker CACE assumption is ambiguous.

Gauging external validity

Following other lottery-based studies (i.e., Abdulkadiroğlu et al., 2011), we explored the external validity of our results using descriptive and quasi-experimental analyses. This work was important in our context, given that (as previously mentioned) students in the lottery sample comprised 25% of all appliers in focal years. Also, some schools were highly over-represented and others were under-represented in the lottery sample – e.g., about half of the students competed for just 7 schools (10% of schools with prekindergarteners during this time period) and about 75% competed for just 18 schools (26% of schools with prekindergarteners during this time period).

To explore external validity, we first compared the background characteristics of first choice lottery sample members to those of children in the full applicant sample. As shown in Appendix F Table 1, while the two samples appeared to be similar in age, country of origin, and gender, the lottery sample was more economically advantaged and more likely to be White than all BPS prekindergarten applicants. About 51% of the lottery sample qualified for free-/reduced-price lunch while 65% of all BPS appliers did. Regarding students' race/ethnicity, White students comprised 28% of the lottery sample versus 17% of all BPS prekindergarten appliers; Hispanic students comprised 39% of the lottery sample versus 44% of all BPS prekindergarten appliers. About 21% of the lottery sample was Black versus 28% of the full applicant sample. Fifty-seven percent of the lottery sample spoke English at home versus 50% of the full sample.

Next, we compared the comparison group care settings of our lottery sample to the full applicant sample. Among children whose families applied to the BPS prekindergarten but did not enroll (i.e., full sample non-enrollees), 76% attended a non-BPS center-based preschool (vs. 97% of lottery control group members and 88% of lottery control group compliers) and types were markedly different than those in the lottery control group (see Table 2 and Appendix F Table 6). For example, 37% of full sample non-enrollees attended private centers, 26% attended Head Start, and 13% attended other public programs. For lottery control compliers, 48% attended private centers, 17% attended Head Start, and 24% attended other public programs. In all, 18% of full sample non-enrollees were at home versus 6% of lottery control group compliers.

Using K-3 school context data, we also examined the representativeness of schools in our

lottery-based analysis. We defined over-represented schools as schools for which 50% (N=6 schools) or 75% (N=17 schools) of first choice lottery sample members competed. As shown in Appendix A Table 4, over-represented schools (75% threshold) in our lottery-based study had a considerably lower average percentage of free-reduced lunch students compared to other district schools (64% vs. 77%, respectively; $p < .001$), proportionately more White students (24% vs. 13%, respectively; $p < .01$), more exemplary teachers rated as exemplary by administrators under the state's teacher evaluation system (23% vs. 14%, $p < .05$; MA DESE, 2017), and more third graders scoring advanced/proficient on state standardized tests (47% vs. 33% for ELA, $p < .001$; 54% vs. 41% for math, $p < .01$, respectively). Our lottery estimates therefore are heavily weighted towards applicants to schools with more advantaged, higher performing students than in the district overall, though the over-represented schools too enrolled majority low-income and non-White students.

Finally, we used a propensity-score approach to estimate the relationship between BPS prekindergarten enrollment and our key outcomes and thus to examine the representativeness of our lottery-based estimates. Specifically, we predicted the probability that a student would be treated conditional on their background characteristics, their cohort year, and the public school each student lived closest to as a proxy for neighborhood characteristics. We then inverted these propensities to obtain an inverse probability weight (IPW) that we could use in our subsequent regression analysis to counteract selection into the program (Imbens & Wooldridge, 2009; Murnane & Willett, 2010). The covariates available for this work are the key covariates in our impacts work (i.e., race/ethnicity, gender, free/reduced lunch, age, country of origin, and home language; see Table 1). The exception is that in our additional analysis we add a fixed effect for the closest public elementary school to the student, a proxy for neighborhood which we use because lottery blocks by definition are not available for the full sample. These covariates are considerably less rich than those in some other recent prekindergarten evaluations which have been able to include covariates such as parent education, home literacy measures, internet availability in the home, and number of working parents (Hill et al., 2015; Lipsey, Farran, & Hofer, 2015; Phillips et al., 2016). Therefore, to gauge whether they captured selection into the program and following Abdulkadiroğlu and colleagues (2011), we began by replicating our lottery-based findings first.

Specifically, we replicated the lottery-based ITT findings by estimating the association

between being in the first choice lottery sample treatment group with grade retention, special education, and test scores in third grade using the sample of all students who applied to Boston prekindergarten during the four application rounds (N~ 9,700). With this replication sample, we found results that were very similar to our lottery ITT estimates, with the exceptions of a marginally significant and larger result on special education placement in Kindergarten (0.36 percentage points ITT compared with -1.68 percentage points for the replication sample) and a marginally significant result of similar magnitude on third grade math scores (-0.05 ITT and -0.06 replication). We then used our IPW approach to estimate the association between BPS prekindergarten enrollment and later outcomes on the full sample of prekindergarten applicants and enrollees (N~11,790), effectively including in the replication sample an additional group of students who enrolled in prekindergarten but did not apply through the standard process (see Appendix F for more information on available data in the full sample and other details on our IPW approach). With the full sample, we find larger and statistically significant associations between prekindergarten enrollment and grade retention outcomes (enrollees were 4 percentage points less likely to be retained in grades K-3, $p < 0.001$), special education placement (enrollees were 7 percentage points less likely to be placed in special education in grade K-3, $p < 0.001$), and MCAS scores (enrollees scored 0.04 standard deviations higher than the average BPS third grader on both Math and English Language Arts, $p < 0.05$). We view these findings as best interpreted as associations for gauging external validity and not as causal estimates; the internal validity of our IPW findings is bolstered somewhat by the lottery-based validation but ultimately, it is difficult to assess the internal validity of these findings.

Taken together, our analyses gauging external validity point to a first choice lottery sample that was more advantaged than the full applicant sample and raise caution in generalizing our lottery sample findings to all applicants and enrollees.

Discussion

While the evidence is clear that children who attend preschool have stronger school readiness skills at kindergarten entry than children who do not attend preschool (Duncan & Magnuson, 2013; Phillips et al., 2017), the longer-run evidence base on large-scale prekindergarten programs is just emerging. In the current study, we used a rigorous lottery-based approach as a window into the effects of one such program, the Boston Public Schools prekindergarten program, on key child outcomes through the end of third grade. We also

examined counterfactual care settings and K-3 settings for first choice lottery-sample children to contextualize our results and we explored the generalizability of our key results beyond the lottery sample.

For special education placement, retention, and standardized test scores, in the first choice lottery sample, we found no differences in outcomes through third grade between first choice lottery winners who enrolled in BPS prekindergarten and control group members who did not. We did find evidence that Boston prekindergarten succeeded in drawing families into the BPS and in retaining them, which was one of the program's original goals. Effects for compliers on enrollment and persistence in the BPS were large – about 91% of lottery winners who enrolled in Boston prekindergarten also enrolled in BPS kindergarten, versus just 67% of control group members who did not enroll in Boston prekindergarten. Overall, 74% of lottery winner compliers were enrolled in BPS from K-3 versus only 39% of control compliers. In increasingly competitive urban educational markets, offering prekindergarten in the public schools appears to be one avenue for attracting and retaining families that might otherwise enroll elsewhere. Notably results like these – medium-term convergence of outcomes for prekindergarten attenders and non-attenders in the early elementary grades in our lottery sample – is a common (though not universal) finding overall in the literature (Phillips et al., 2017). The why behind this pattern is a puzzle and one that likely has no consistent answer across study contexts, given the wide range in program quality, counterfactuals, child demographics, and elementary school quality nationally. In our context, our results could be seen as surprising, given the high quality of the Boston program and its promising short-term effects on children's school readiness (Weiland & Yoshikawa, 2013). Several factors are highly important in placing our results within the broader context.

First, as we emphasize throughout the paper, our analysis is not an evaluation of the effects of the full sample of Boston prekindergarten programs, for the full sample of children who attended. Rather, lotteries were highly concentrated in a subset of schools; 75% of lottery applicants, for example, competed for about a quarter of eligible district schools. There were also important differences between children in our first choice lottery-based sample and the full sample generally appearing more advantaged. On the one hand, more popular schools might be higher quality and thus more effective and thus we might have expected more persistence of impacts among this sample. However, our generalizability work showed that students enrolled in

prekindergarten in these schools appeared more advantaged and thus might have been less likely to benefit from the program than their less advantaged peers in less popular schools. In that case, less persistence of impacts might be expected among the lottery compliers. Supporting this hypothesis, in our propensity score work, we found associations suggestive of small benefits for the full population of Boston prekindergarten enrollees on all examined outcomes. Descriptively, lottery sample control group members were also quite high performing, scoring 0.46-0.49 SD higher than the average Boston Public Schools third grader on standardized math and literacy tests, versus 0.15-0.17 SD for the full sample. The full population of enrollees were also less likely to attend other preschool programs than lottery sample members and more likely to persist in BPS.

Second, previous research has shown that the counterfactual matters greatly in preschool studies (Feller et al., 2016). In our lottery sample, a large majority of the lottery control group attended a center-based preschool program (97% ITT, 88% CACE; see Table 2). More typically, about a third to half of the control group has attended other center-based preschools programs in large-scale causal evaluations of publicly funded ECE (e.g., 34% in Tennessee, 48% in Tulsa, about 50% in Head Start; Bloom & Weiland, 2015; Hill et al., 2015; Lipsey et al., 2015). Ours is not a test of preschool versus no preschool; rather, our results indicate that compliers who attended a free public prekindergarten program versus largely a mix of other preschool programs did about equally well at the end of third grade. This may be because ultimately, the treatment-control contrast (Bloom & Weiland, 2015) may not have been large enough to generate lasting impacts for our lottery sample. Unfortunately, we lacked information on the quality of control group care settings that would have allowed us to identify the full treatment-control contrast. Notably, in the regression-discontinuity evaluation of the Boston program described earlier in this paper that found strong impacts on children's school readiness skills, parents of control group children reported that in the year their children were too young to enter the Boston prekindergarten program (e.g., their age 3 year), 57% experienced another type of center-based care and 33% were in parental care (Weiland & Yoshikawa, 2013) – considerably higher than the national average of 42% of three year olds enrolled in preschool programs (Whitehurst & Klein, 2015) but far fewer than in our lottery-based study.

A third reason for nuanced interpretation is that we lack information on children's kindergarten entry skills and thus were unable to identify whether lottery complier children had

experienced an initial boost from Boston prekindergarten compared to control compliers. In other words, interpreting our results as either surprising or expected in terms of persistence is complicated by not knowing whether compliers' experienced benefits from the program in the first place. Underscoring this point, few of the children who participated in the previous regression-discontinuity (RD) evaluation study of Boston prekindergarten that showed strong impacts on kindergarten readiness (Weiland & Yoshikawa, 2013) were included in our lottery sample. Specifically, the RD sample represented approximately 85% of district schools and 70% of eligible children in those schools in 2008-2009. Only 125 children were in both the previous study's RD treatment group and the current study's lottery winner group – constituting about 47% of the lottery treatment group for the 2008-2009 school year and only 13% of the RD treatment group overall.

The K-3 schooling experiences of children in our sample are also important to highlight to place our results in the context of the “sustaining environments hypothesis” – the idea that sustaining the boost from preschool depends on the quality of K+ schooling environments (Bailey et al., 2017). So far, the evidence on this hypothesis is mixed (Bassok, Gibbs, & Latham, 2015; Bierman et al., 2014; Clements et al., 2013; Jenkins et al., 2018; Johnson, 2013; Swain, Springer, & Hofer, 2015; Zhai et al., 2012). We found that the quality of K-3 programming in Boston was lower on average than that of the district's prekindergarten program (see Appendix A Table 1). Notably, Massachusetts and Boston do show higher performance relative to other states and similar districts nationally, respectively (NCES, 2013; Reardon, 2017). But relative to other districts in the state, Boston in our focal years had relatively weak third grade performance, scoring around the bottom 11% of districts on the state third grade standardized math test and the bottom 5% of districts for third grade reading (Massachusetts Department of Elementary and Secondary Education, 2014). Also, for our study's cohort years, prekindergarten to third grade alignment reforms (see Boston Public Schools, 2017) had not yet taken place in the district. Prekindergarten attenders during our study years may have repeated some of the same content in kindergarten, offering an opportunity for control compliers to catch up; content repetition has been associated with less growth in kindergarteners' math skills in a nationally representative study (Engel, Classens, & Finch, 2013). However, ultimately, simply knowing that K-3 quality was lower than prekindergarten quality and that Boston scored lower than most other districts does not answer the question of whether there is a threshold of quality needed to sustain effects.

More nuanced measurement would have been required to answer questions about threshold effects.

In addition to contributing to the field's understanding of medium-term convergence patterns, our study's lottery-based design also has methodological implications for the field. As recently reviewed by a group of experts (Phillips et al., 2017), the rigor of longitudinal studies of today's large-scale preschool programs thus far has been mixed. This is due in part to the difficulties of randomly assigning children to a given preschool program in localities that already have universal preschool (i.e., Oklahoma, West Virginia), as well as to difficulties not unique to preschool in gaining buy-in/agreement from local stakeholders. However, with the recent expansion of public preschool programs in contexts that, like Boston, use lottery-based assignment algorithms to assign children to preschool (e.g., Washington DC, Denver, San Francisco, New York, and New Orleans), the field is seemingly poised for additional rigorous studies of the impact of public preschool.

Our lottery sample findings drive home the importance of understanding the characteristics of students in a city-based school lottery versus all students receiving the program and the lottery-induced treatment contrast, especially within naturally occurring randomized trials. This may be particularly important in contexts with prekindergarten programs that, like Boston's, are open to families of all income levels. Families with higher social capital are likely to be better at navigating choice and lottery systems than other families and may be over-represented in prekindergarten lottery studies similar to ours. In addition, as explained above, our study's lottery-induced treatment contrast amounted to comparing sample members first choice Boston prekindergarten programs to other mostly private and other public preschool options. This is generally not the policy question of interest to policymakers seeking to expand access to preschool. Given that most four year olds now attend some form of center-based care, future lottery studies may likely to encounter this situation as well. Depending on the context, future lottery studies may be better poised to compare different preschool programs to each other than to answer the preschool versus none question.

There are several limitations that should be highlighted. The measures in our study were limited to those available via administrative records. Measures of other important school readiness and success skills such as children's socio-emotional and executive function skills were not available. Our knowledge of the program's effects is accordingly more limited than we

would like. Also, as explained in the robustness check section, one assumption underlying our CACE analysis – that always-takers in both the treatment and control groups (i.e., children who would have enrolled in Boston prekindergarten regardless of their treatment assignment status) experienced the same effect of enrollment – is difficult to evaluate.

In closing, unpacking the preschool convergence phenomenon is one of the most pressing issues facing the field of early education research (Phillips et al., 2017). Rigorous research on today's programs is beginning to catch up to the rapid pace of preschool expansion nationally, through efforts like the present paper; efforts in North Carolina (Dodge, Bai, Ladd, & Muschkin, 2016), Tulsa (Hill et al., 2015; Phillips et al., 2017), and Tennessee (Lipsey et al., 2018); and the five place-based teams tracking children from preschool to third grade in the Institute of Education Science Early Learning Network (2016). In addition, the field is potentially poised for additional rigorous lottery-based studies that permit longitudinal analysis like in our paper – though it remains to be seen what policy questions these studies will be able to answer. Our lottery-based findings, combined with our analysis of the relevant counterfactual and our quasi-experimental work on the full sample, contribute to the new generation of public preschool studies that will hopefully help point the way to ensuring a stronger, lasting boost for all children.

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Table 1

Balance on observables in the first choice lottery sample

	Lottery winners	Control group	Estimated difference	P-value
Race/ethnicity (%)				
Hispanic	35.22	39.90	-4.68***	0.003
Black	25.00	23.35	1.65	0.271
White	26.73	24.34	2.39	0.144
Asian	10.13	7.28	2.85***	0.005
Other	2.92	4.14	-1.22	0.146
Male (%)	50.27	46.95	3.32	0.126
Eligible for free/reduced lunch (%)	57.66	56.68	0.98	0.604
Age	4.51	4.53	-1.97	0.117
Country of origin USA (%)	94.89	94.53	0.36	0.701
Home language (%)				
English	52.18	55.06	-2.88	0.133
Spanish	25.18	25.19	-0.01	0.994
Other	22.64	19.75	2.89	0.074
N children	1,101	2,081		

Note. There was a small amount of missing data on all baseline characteristics except age: 12 children (0.4%) were missing race/ethnicity and male information, 34 (1.1%) were missing male and free/reduced lunch information, 113 (4.2%) were missing country of origin information, and 5 (0.2%) were missing home language information. Means in the table were computed using non-missing data. Values for first choice lottery winners are the simple means for each requisite group. Values for the difference between lottery winners and control group members are obtained from a regression of a given baseline characteristic on a series of indicator variables that identify each lottery plus an indicator variable that equals 1 for lottery winners and 0 for lottery losers. The coefficient on lottery indicator equals the difference in the mean baseline characteristic between lottery winners and control group members,

respectively. The value for control group members equals the corresponding value for lottery winners minus the estimated difference between lottery winners and control group members. A two-tailed t-test was applied to the estimated differences. An F-test was used to assess the statistical significance of the overall difference between lottery winners and control group members reflected by the full set of baseline characteristics in the table. The resulting F value is not statistically significant ($p = 0.2004$). Statistical significance levels are indicated as: ***=.1 percent

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Table 2

Children's care settings (cohorts 1 and 2) in the prekindergarten year

	<u>ITT</u>				<u>CACE</u>			
	Lottery winners	Control group	Estimated difference	P-value	Lottery winner compliers	Control group compliers	Estimated difference	P-value
Any center-based preschool	99.55	96.72	2.83***	<.0001	100.00	88.40	11.60	<.0001
Preschool types								
BPS	96.64	72.26	24.39***	<.0001	100.00	0.00	100.00***	<.0001
Non-BPS center-based preschool	2.91	24.47	-21.56***	<.0001	0.00	88.40	-88.40***	<.0001
Private	2.01	13.62	-11.60***	<.0001	0.00	47.57	-47.57***	<.0001
Head Start	0.00	4.18	-4.18***	0.0084	0.00	17.14	-17.14***	0.0084
Public	0.00	2.81	-2.81***	<.0001	0.00	11.54	-11.54***	<.0001
Charter	0.89	3.86	-2.96	0.0667	0.00	12.15	-12.15	0.0667
Other settings								
Family daycare	0.00	1.39	-1.39	0.3717	0.00	5.71	-5.71	0.3717
At home	0.45	1.88	-1.44	0.5117	0.00	5.88	-5.88	0.5117
Total	100.00	100.00	--	--	100.00	100.00	--	--

Note. Care setting types were reported by parents at the time of application to Boston kindergarten (e.g., the winter, spring, or summer preceding kindergarten fall), were pulled from Boston prekindergarten enrollment records, or were pulled from age 4 state administrative records on traditional public school or charter school enrollment. Values were obtained from fitting our primary ITT and CACE equations with each care setting as the requisite outcome. Data were missing for 11.5% of students. Bolded numbers sum to 100. Statistical significance levels are indicated as: ***=.1 percent ** = 1 percent; * = 5 percent

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Table 3

First choice lottery sample ITT impacts, compliance rates difference, and CACE

	Intent to treat (ITT)		First stage (compliance)	First stage SE	CACE	CACE (SE)	Lottery winner compliers mean	Control group compliers mean	Confidence interval
Enrolled in BPS (%)									
Prekindergarten	29.47***	1.06	--	--	--	--	100	0	--
Kindergarten	7.02***	1.73	0.29***	0.01	23.81***	5.97	91.06	67.25	12.51 - 35.89
1st grade	10.14***	1.90	0.29***	0.01	34.41***	6.53	85.60	51.19	22.16 - 48.77
2nd grade	8.49***	2.00	0.29***	0.01	28.80***	6.88	79.05	50.24	15.78 - 42.76
3rd grade	7.54***	2.04	0.29***	0.01	25.57***	7.02	75.77	50.2	12.22 - 39.75
Enrolled K-3	10.05***	2.07	0.29***	0.01	34.10***	7.13	73.58	39.49	20.68 - 48.62
Ever enrolled	8.24***	1.48	0.29***	0.01	27.97***	5.09	100	72.03	18.45 - 38.39
Retained in grade (%)									
Retained in Kindergarten	0.04	0.59	0.29***	0.01	0.14	2.05	1.55	1.41	-3.87 - 4.16
Retained in 1st grade	1.24	0.80	0.29***	0.01	4.28	2.77	4.19	-0.09	-1.14 - 9.71
Retained in 2nd grade	-0.03	0.62	0.29***	0.01	-0.09	2.15	1.93	2.01	-4.30 - 4.12
Ever retained	1.22	1.10	0.30***	0.01	4.20	3.79	7.50	3.31	-3.23 - 11.63
Special Education Classification (%)									
SPED in Kindergarten	-0.36	1.26	0.29***	0.01	-1.23	4.36	7.47	8.71	-9.78 - 7.30
SPED in 1st grade	0.21	1.41	0.29***	0.01	0.73	4.87	10.55	9.81	-8.82 - 10.28

SPED in 2nd grade	1.5	1.53	0.29***	0.01	5.18	5.27	13.56	8.39	-5.15 - 15.51
SPED in 3rd grade	0.01	1.66	0.29***	0.01	0.02	5.74	15.94	15.91	-11.22 - 11.27
Ever SPED	0.25	1.67	0.30***	0.01	0.84	5.77	17.27	16.42	-10.46 - 12.15
MCAS & PARCC									
English Language Arts	0.01	0.04	0.29***	0.01	0.02	0.13	0.40	0.38	-0.24 - 0.28
Math	-0.05	0.04	0.29***	0.01	-0.18	0.14	0.35	0.53	-0.45 - 0.10

Note. There was no missing data on enrollment variables. Other outcomes were missing data as follows: grade retention 11-15% across variables; special education 9-14% across variables; and test scores, 12%. Note that we also calculated ITT and CACE effect sizes for MCAS and PARCC (the continuous outcomes) by dividing the estimated effect by the standard deviation of the control group and found they were nearly identical in magnitude to the ITT and CACE estimates shown in the table. Statistical significance levels are indicated as: ***=.1 percent ** = 1 percent; * = 5 percent

Table 4

CACE estimates of K-3 school context differences between lottery winner compliers and control group compliers

	Lottery winner compliers	Control group compliers	Estimated difference	P-value
Student background characteristics				
% Low-income	65.62	72.21	-6.59*	0.019
% ELL	28.35	26.41	1.94	0.305
% non-English home language	39.58	35.77	3.81	0.065
% Disabilities	17.45	17.81	-0.36	0.631
% African-American	26.34	36.98	-10.64***	<0.001
% Asian	8.07	10.39	-2.33*	0.034
% Hispanic	40.43	32.54	7.89**	0.001
% White	22.17	16.04	6.12*	0.030
% Female	48.23	48.47	-0.24	0.511
Student performance – % proficient in 3rd grade				
ELA	44.28	40.61	3.67	0.117
Math	51.29	47.69	3.60	0.144
Teacher and school characteristics				
% Licensed Ts	97.29	93.79	3.50**	0.003
Student-T ratio	13.76	13.23	0.53**	0.011
% Exemplary Ts	14.63	11.41	3.22	0.109
% Proficient Ts	78.85	79.74	-0.89	0.680
% T retention	81.36	78.42	2.94**	0.009
Stability	89.12	83.90	5.21***	<0.001
Avg class size	19.06	18.44	0.61	0.258

Note. Using publicly available data from the Massachusetts Department of Elementary and Secondary Education, we averaged available school-level data across the schools in which a student was enrolled for

the longest period of time each year in kindergarten, first, second, and third grade. If data were missing for a student in a given year (e.g., 1st grade), we used non-missing data to compute the student's K-3 context averages (e.g., K, 2nd, 3rd). Across variables, data were missing for 8-11% of students overall and 5% of treatment students were missing data compared with 13% of their control group counterparts. Percentage of teachers scoring proficient or exemplary on state ratings and average class size was available for cohorts 3 and 4 only. ELA=English Language Arts; Ts=teachers. Statistical significance levels are indicated as: ***=.1 percent ** = 1 percent; * = 5 percent.

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Table 5

Lottery ITT results and IPW results for the lottery replication sample and the full prekindergarten applicant sample

	Lottery sample (ITT)	Replication sample	Full sample
Retained in grade (%)			
Retained in Kindergarten	0.04 (0.59)	-0.59 (0.37)	-2.46*** (0.38)
Retained in 1st grade	1.24 (0.80)	0.58 (0.57)	-1.36** (0.45)
Retained in 2nd grade	-0.03 (0.62)	-0.35 (0.45)	-0.31 (0.37)
Ever retained	1.22 (1.10)	-0.26 (0.77)	-3.87*** (0.64)
Special education classification (%)			
SPED in Kindergarten	-0.36 (1.26)	-1.68* (0.83)	-5.28*** (0.70)
SPED in 1st grade	0.21 (1.41)	-0.61 (0.96)	-5.92*** (0.76)
SPED in 2nd grade	1.50 (1.53)	0.48 (1.06)	-5.31*** (0.81)
SPED in 3rd grade	0.01 (1.66)	0.47 (1.11)	-5.78*** (0.85)
Ever SPED	0.25 (1.67)	-0.01 (1.12)	-6.51*** (0.85)
Third grade test scores			
English Language Arts	0.01 (0.04)	-0.01 (0.03)	0.04* (0.02)
Math	-0.05	-0.06*	0.04*

(0.04)

(0.03)

(0.02)

Note. For the lottery sample (ITT), outcomes were missing data as follows: grade retention 13-17% across variables; special education 10-17% across variables; and test scores, 22%. For the replication sample, outcomes were missing data as follows: grade retention 6-10% across variables; special education 3-10% across variables; and test scores, 15%. For full sample, outcomes were missing data as follows: grade retention 9-14% across variables; special education 6-14% across variables; and test scores, 20%. Statistical significance levels are indicated as: ***=.1 percent ** = 1 percent; * = 5 percent.

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