THREE ESSAYS IN TEACHER VALUE ADDED: TEACHER ASSIGNMENTS FROM THE SELF-CONTAINED CLASSROOM TO THE SUBJECT-SPECIFIC CLASSROOM

By

Xiao (Art) Peng

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Approved:

Dale R. Ballou

Matthew G. Springer

Jason A. Grissom

Michael J. Podgursky

For my mom and dad,

肖宝玲 and 彭于龙,

Who always love and support me.

And to my elementary, middle, and high school teachers,

With love and gratitude

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CHAPTER I

INTRODUCTION

This dissertation is an empirical analysis of the application of teacher value-added effectiveness to school improvement especially on student academic achievement in the core subjects of mathematics, English/language arts, science, and social studies in elementary schools. In particular, I am interested in (1) the relationship between teaching effectiveness and subject specialization; (2) the impact of subject specialization on student academic achievement; and (3) the potential gain in mathematics achievement that could be achieved through specialization within schools. This dissertation attempts to find out whether teachers who are relatively effective in raising student test scores in a subject have specialized fully or partially in teaching that subject and whether subject specialization can raise student academic achievement in elementary schools.

My dissertation comprises three essays presented in Chapters II through IV. The first essay investigates whether teachers specialize in the subject(s) where they are relatively more effective. The second essay studies whether subject specialization as practiced in Tennessee increased student test scores. The third essay explores the maximum potential gain in mathematics achievement that could be achieved through specialization. After the three essays, Chapter V concludes this dissertation and discusses future research needs relating teacher value-added effectiveness to student academic achievement, in general.

In Chapter II, the first essay raises an empirical question about the personnel decision—teacher assignments—in elementary schools. Teacher assignments made within schools in my dissertation determine who will teach and what grades and subjects those teachers will teach from one year to the next. Previous research shows that there is a diverse set of criteria used by educators and school administrators to make decisions on teacher assignments. The most common criteria include principals' subjective assessments, reports from parents, and student test scores. To my best knowledge, I am not aware of any literature that describes the application of teacher value-added effectiveness in making decisions about job assignments for teachers. In this essay, I test a hypothesis regarding whether teachers have specialized in teaching a subject if they are relatively more effective in teaching that subject. These findings are important to the debates about the potential of using value-added estimates for personnel decisions in schools with the aim to improve student learning.

In Chapter III, the second essay studies the impact of subject specialization on student test scores. It is common that in elementary schools, especially in the upper elementary grades 4 through 6, some students receive instructions in all core subjects from the same teacher (i.e., self-contained classrooms) and other students receive instructions in content-specific classrooms where teachers teach the same subject to different classes of students. I intend to investigate whether subject specialization in Tennessee's public elementary schools has increased average test performance. Regardless of the findings in the first essay, the research question in the second essay is still interesting. Specialization could be useful simply because it allows teachers to focus on one subject; therefore they become better at teaching that subject than they would if their efforts were spread over several subjects. If specialization has not raised student test scores, the reason may be that self-contained classrooms provide teachers with more flexibility to organize instructions for all subjects and better opportunity to integrate all subjects. To date, empirical evidence is inconclusive about the effects of organizational structures on student achievement. Prior studies are also limited by the ignorance of variation within a particular organization structure, relatively small sample size, relatively short time period of analysis, academic subjects available for study, and mean comparison of test scores between different organization structures. In this essay, I examine the impact of subject specialization, as practiced in Tennessee, on average test performance in schools.

Finally, the third essay discusses the maximum potential gains in mathematics achievement that could be achieved through specialization. It also asks a positive question. If teachers' past value-added estimates are used to make mathematics assignments for teachers, what would be the maximum potential gains in mathematics achievement that could be achieved through specialization? In this essay, I assume that teachers' past value-added estimates are used to make decisions on teacher assignments of mathematics specialization. I then estimate the maximum potential gains in mathematics achievement through such specialization. My findings can be particularly important to the schools seeking a way to raise student mathematics achievement through managing teacher assignments.

This dissertation uses data from the Tennessee Department of Education (TDOE). The quantitative analysis focuses on students in grades 4 through 6 in Tennessee's public elementary schools. Specifically, the first essay uses teacher effectiveness measures in a teacher-level model to predict teacher assignments in three school years 2009-2010 through 2011-2012; the second essay uses the degree of average specialization in a school-by-grade model to predict average test performance in a subject in nine school years 2003-04 through 2011-2012; and the third essay concentrates on the students and teachers in the 2010-2011 school year to estimate the maximum gains in mathematics achievement that could be achieved through specialization.

All essays are related to teacher value-added modeling and each essay uses teacher value-added estimates for different purposes. Given the longitudinal student and teacher course files, I am able to link students to teachers and courses in Tennessee. This dissertation implements the Wooldridge's dynamic ordinary least squares (DOLS) model to estimate teacher value added. Teacher value-added estimates are then merged to my analytical data with student, class, teacher, and school characteristics.

Overall, the contribution of this dissertation is threefold. First, I provide an empirical model that helps understand whether teachers specialize in the subjects where they perform relatively well. Second, I provide empirical evidence whether specialization in upper elementary grades has been an effective method to raise student test performance in Tennessee. Lastly, I estimate the maximum potential gains in mathematics achievement that could be achieved through specialization if educators and school administrators use teacher value added to make decisions on teacher assignments.

CHAPTER II

TEACHERS' HISTORY OF VALUE ADDED ON FUTURE JOB ASSIGNMENTS OF TEACHERS

Introduction

Decisions on teacher assignments are related to the measures that are used to inform teaching effectiveness. The most important criterion for making decisions about teacher assignments in elementary schools is an administrator's subjective evaluation of teachers. Often, administrators may have a great deal of information to inform their decisions about teacher assignments. According to Jacob and Lefgren (2008), this information comes from three main sources: principals' informal and formal observations, reports and requests from parents, and student test scores. Principals may differ with respect to the way they use this information to make decisions about teacher assignments.

Many such measures help educators and school administrators learn teachers and teaching effectiveness within schools. Literature indicates that there has been a great deal of interest in measuring teacher job performance in schools and a lot of discussion about using teacher effectiveness measures to make personnel decisions (e.g., employment, compensation, promotion, and assignments). One of the commonly known objective measures for teacher job performance is teacher value added.

As shown in the literature on teaching effectiveness, value-added modeling is one of the widely used strategies in building measures for teacher job performance in the United States. More recently, this strategy has quickly gained substantial numbers of users for evaluating teaching effectiveness. Value-added modeling could become even more increasingly dominant in the near future in teacher accountability systems.

Value-added studies in education have shown that teachers are important in improving student academic performance (Hanushek and Rivkin, 2010; Nye et al., 2004). Research has also given attention to the discussions of policies of using teacher value-added measures (Braun et al., 2010). Some recent education policies have tied teacher value-added measures to personnel decisions at school, such as merit-pay systems, tenure decisions, and teacher layoffs (Boyd, Lankford, Loeb, and Wyckoff, 2010; Goldhaber and Hansen, 2010a; Goldhaber and Theobald, 2011; Springer et al., 2010). However, it is entirely unknown whether teacher value-added estimates have been used to assign areas of specialty to teachers.

The research most relevant to my study has focused on the relationship between teacher value-added measures and various personnel decisions for teachers, such as tenure decisions, promotion to administrative positions, and reassignments to high/low-stakes positions (Chingos and West, 2011; Goldhaber and Hansen, 2010a). The findings of these studies demonstrate the existence of a relationship between teaching effectiveness and job transitions and suggest the possibility of using teacher value-added effectiveness in making tenure decisions for public school teachers.

My study concentrates on whether teacher value-added measures can provide information for making subject specialization. By subject specialization, I refer to the assignment of teachers to specialize fully or partially in particular subjects. I test the hypothesis that teachers have tended to specialize in a subject if they have been relatively more effective in teaching that subject.

This study further explores whether the impact of teacher value-added estimates on teacher specialization varies depending on teacher and school attributes. Those attributes include education level for teachers, years of teaching experience at all schools, years of teaching experience at the current school, teacher mobility, school enrollment, and school No Child Left Behind (NCLB) accountability. This study tests whether those moderator variables influence the relationship between teacher relative effectiveness in a subject and the degree of specialization in that subject.

Data for this study come from Tennessee's public elementary schools. This study only considers elementary school teachers because teachers are fully departmentalized in middle and high schools (i.e., in grades 7 through 12) where they provide instructions in one or two content areas to different classrooms on a school day in Tennessee. Specialization starts in early elementary grades in some Tennessee's public elementary schools and it becomes much more dominant by grade 6.

This study uses a school-fixed effect model to estimate the effects of teacher relative effectiveness in a subject on the degree of specialization in that subject. I find that high value-added increase specialization in mathematics and science separately in each upper elementary grade. This positive relationship between teaching effectiveness and teacher assignments is also found in English/language arts in grade 5 and in social studies in grade 4. Furthermore, my findings suggest that the impact of teacher job performance on assignments separately in each subject and each grade varies with teacher and school characteristics. While those results clearly suggest that teacher value-added estimates are associated with teacher assignments (i.e., the percent of students taught in a subject), the size of the effects is relatively small in grade 4 compared to the ones in grades 5 and 6. The effects of teaching effectiveness on assignments also vary across subjects. Teacher value added in mathematics in grade 6 has had the largest impact on mathematics assignments in Tennessee's public elementary schools. Teaching effectiveness in mathematics with one standard deviation above the mean increases 15.48 percent of students taught in mathematics (i.e., about four students in a classroom of 25 students).

There are several possible explanations for the small positive effects and not significant effects found in some grades and subjects in this study. First, while teacher value added is correlated with teaching effectiveness, teacher assignments are not mostly determined by teaching effectiveness. Second, when teachers are effective in teaching one subject, it is possible that some teachers are also effective in teaching other subjects; therefore, there is no subject specialization that assigns the areas of specialty to those teachers. Third, it is more challenging to make teachers to specialize in some schools. Often, teachers transfer across schools within districts. If a specialist teacher leaves from her/his current school, it is difficult to fill the vacancy. Instead, when a generalist teacher leaves from her/his current school, it is much easier to recruit a generalist teacher. Moreover, principals have tended to believe that self-contained classrooms are traditionally superior to departmentalized classrooms in helping student learning in elementary grades.

This chapter is organized in the following fashion. The next section reviews the literature on whether teacher value added are related to teaching effectiveness and the use of value added when making personnel decisions in schools. In Section 3, I introduce my research questions. Section 4 presents the data used to answer my research questions. Section 5 illustrates my method and analytical samples. Section 6 displays my findings. Section 7 provides some concluding remarks.

Literature Review

A large literature has focused on developing teacher effectiveness measures based on student test scores using value-added methods (Aaronson, et al., 2007; Hanushek and Rivkin, 2010; Nye et al., 2004). As an increasing number of states, districts, and schools that adopt value-added models for education purposes, the use of teacher value-added measures becomes more important. Prior research has suggested that teacher value-added data are used in many areas of education (Gallagher, 2009). Principals rely on these data to make decisions about professional development and employee hiring/placement for teachers (Tennessee State Board of Education, 2011; Tennessee Department of Education, 2007). Teachers use these data to evaluate instructional strategies (Hershberg, 2004). Policy makers use these data to make guidelines for principals to identify effective teachers and for teachers to improve instruction (Braun et al., 2010; Sanders and Horn, 1998). Furthermore, many researchers have seen teacher value-added estimates as important information not only to characterize teaching effectiveness but also to make personnel decisions at school (Chingos and West, 2011; Goldhaber and Hansen, 2010a).

1. Value-Added Estimates and Teaching Effectiveness

Student-teacher sorting is common at school.[1] Some researchers have argued that value-added modeling can produce biased estimates of teachers' causal effects (Koedel and Betts, 2009; Rothstein, 2010 and 2009). At the same time, research has shown that value-added estimates are positively correlated with teaching effectiveness (Goldhaber and Hansen, 2010a; Guarino et al., 2011; Kane and Staiger, 2008).

[1] Some teachers are assigned to more motivated students and to students with more engaged parents than other teachers.

Kane and Staiger (2008) explore whether teacher value-added estimates predict the differences in student achievement. They conduct a two-year experiment where students are randomly assigned to teachers. They use the pre-experimental estimates of teacher effects estimated under non-random assignment using various standard value-added methods to predict student achievement under random assignment. Their results suggest that value-added models generate the accurate and causal impact of a teacher on student test scores. They further suggest that using prior year achievement in the value-added model significantly reduce the sorting bias and the best prediction of teacher effects can be achieved through further controlling mean classroom characteristics.

Goldhaber and Hansen (2010a) also demonstrate that teacher value-added estimates predict teaching effectiveness later in teacher careers. Their study tests the stability of within-teacher job performance and uses the past teaching effectiveness to predict the teaching effectiveness in the future. Their results suggest that the prior-year estimated effectiveness in a subject is a good predictor of future estimated effectiveness in the same subject. They also find that if teachers have tended to be more effective in teaching mathematics they could be more effective in teaching students in reading later in their careers and vice versa.

The above studies have estimated teacher effectiveness using various value-added models. Researchers are then interested in which model can best predict teaching effectiveness for teachers. A simulation study done by Guarino at el. (2011) compares the estimated teacher effects across different commonly used value-added models. Their findings indicate that the dynamic ordinary least squares (DOLS) model provides relatively more accurate teacher value-added estimates than other value-added models. As a result, my study will use the DOLS model to estimate teacher value-added effects on student growth.[2]

2. Teacher Value Added Correlates with other Measures of Teacher Job Performance

Research has shown that there is little association or limited evidence between teacher observable characteristics (e.g., education degree, years of teaching experience, the quality of teachers' undergraduate institutions, and certification test scores) and teaching effectiveness (Clotfelter et al., 2006; Hanushek, 1986 & 1997, Harris and Sass, 2006; Rockoff, 2004; Wayne and Youngs, 2003). More importantly, those studies conclude that teacher characteristics are not correlated with teacher value added.

At the same time, some researchers compare principal evaluations and teacher value added. Jacob and Lefgren (2008) find that principals' subjective assessments are good at identifying more and less effective teachers at the top and bottom (i.e., 10 through 20 percent) of teacher value-added distribution, but their assessments are less likely to distinguish teachers in the middle of that distribution. Harris and Sass (2009) examine whether the past subjective ratings from principals predict teacher value added. They find that principals' ratings are positively correlated with teacher value added.

Harris and Sass also explore whether teacher personalities, subject matter knowledge, and teaching skill are associated with principals' ratings and teacher value added. Previous

[2] This study does not use teacher effects estimated in Tennessee Value-Added Assessment System (TVAAS). Teachers were not mandatory to participate in the TVAAS evaluation system until the 2008-09 school year and the estimates of teacher value added were available for TVAAS teacher participants. If TVAAS participation was associated with whether teaching effectiveness was used to make teacher assignments in schools, excluding non-TVAAS teacher participants will overestimate the relationship between value added and teacher assignments in this chapter. Appendix A presents the average percent students linked to TVAAS teachers over the total number of students with test scores by grade and subject over seven schools years 2004-05 through 2010-2011. In order to retain all teacher and student data in Tennessee in the school years used for this study, I use the student-teacher-course records to link students to their teachers in a subject.

studies have not considered this set of teacher characteristics. In Harris and Sass (2009), they find that those characteristics determine teacher productivity measured by both subjective ratings and teacher value added. Overall, if those measures and principals' ratings have been used to make teacher assignments, my study is to test a broader hypothesis whether teaching effectiveness determines subject specialization.

3. Using Teacher Value-Added Estimates in Making Personnel Decisions at School

There are number of potential areas where teacher value added can be used (i.e., promoting equity in effective teachers across schools, evaluating training programs for beginning teachers, determining the effectiveness of teacher instruction, and making employment decisions). However, much of the research on using teacher value-added data in education has not looked at making personnel decisions at school, with the exception of two studies, Goldhaber and Hansen (2010a) and Chingos and West (2011).

The first study explores the potential of using teacher value-added estimates for making tenure decisions using student and teacher data from North Carolina. It finds that the teacher effect estimates are reasonably stable within teachers over time and then suggests teacher value-added estimates can be used to determine teacher tenure.

The second study has analyzed the impact of teaching effectiveness on job transitions for teachers from high-stakes classroom positions (i.e., reading or math in grades 3 through 10 or science in grades 5, 8, or 11) to other jobs (i.e., administrative positions, low-stakes classroom positions, and non-teaching positions). These authors show that promotion and job reassignments are associated with teacher value-added estimates using student and teacher data in Florida. Besides these two studies, little research has focused on whether teacher value added has been used to make decisions about subject specialization.

Research Questions

Research has identified there is a mixed structure of the organization of schooling in elementary schools. Some teachers specialize fully or partially in some core subjects and other teachers teach self-contained classrooms. My study explores specialization by teachers over their career paths in teaching. Particularly, this study aims to determine how subject specialization varies with teaching effectiveness in elementary grades.

I use value added to measure teaching effectiveness. However, the hypothesis I test is broader than the hypothesis that teaching assignments respond to measured value added. It is possible that value added is correlated with other measures (e.g., principals' subjective ratings, teachers' subject knowledge, teaching skill, and intelligence) that also reflect teaching effectiveness (Harris and Sass, 2009; Jacob and Lefgren, 2008). Those measures probably have been used to determine teacher assignments. This study answers one research question below:

> Do teachers specialize in a subject if they are relatively more effective in teaching that subject in upper elementary grades 4 through 6?

This study measures subject specialization for teachers using the percent of students taught in a subject by individual teachers. In upper elementary grades, various combinations of four core academic subjects assigned to teachers result in a spectrum of teacher assignments in elementary schools. At the one end of the spectrum are teachers who teach four core subjects to the same class of students and at the other are teachers who teach one subject to different classes of students. Many teachers in between the two extremes teach two or three core subjects in one class and/or different classes of students. The higher the percent of students taught in a subject by a teacher, the more that teacher concentrates on teaching that subject. Depending on the percent of students taught in each subject, individual teachers are considered as being fully or partially specialized in teaching the concentrated subject(s) comparing with their counterparts who have taught the same class of students in all subjects.

To measure teaching effectiveness, this study estimates teacher value added in a subject over a fixed rolling window of years at each of six geographical locations defined by region and urbanicity. All districts in Tennessee are grouped based on three region indicators (i.e., west, middle, and east) and three urbanicity indicators (i.e., city, suburb and town, and rural). Two purposes of performing DOLS models at each location separately include: (1) each location provides a large enough sample to estimate teaching effectiveness since there are many small districts in Tennessee; and (2) schools and districts within the same geographical location are likely to share many commonalities with each other (e.g., local school policies and supports, diverse student bodies and socioeconomic status, and teacher recruitment and retention). The list of districts in each geographic location is provided in Appendix B.

My DOLS model for teachers in a subject over a fixed number of years is expressed as follows:

$$S_{it} = \beta_0 + \beta_1 S_{i,t-1} + \beta_2 \delta_k + \beta_3 X_{it} + \beta_4 P_t + \beta_5 \pi + v_{it}, \tag{1}$$

where S_{it} and $S_{i,t-1}$ are the standardized test scores for student *i* in a subject in years *t* and *t* – 1, respectively;[3] δ_k is the indicator of teacher *k* for student *i* within a fixed number of years; X_{it} is a set of time-invariant and time-variant characteristics of student *i* in year *t*; P_t is a set of time-invariant and time-variant characteristics of student peers in year *t*; π is a matrix of grade and year effects; and v_{it} is a random error. The error terms are not correlated over

[3] For details about the test scores used in this study, see the data section below.

time. While certain teachers have taught a subject in multiple grades, my DOLS model estimates teacher value-added effects across grades 4 through 8 taught by individual teachers.[4]

In addition to learn teaching effectiveness, this study further estimates teacher absolute advantage in teaching a subject. The absolute advantage measure informs teacher relative effectiveness within a group of teachers. This study is interested in whether some teachers are relatively more effective than other teachers in teaching a subject and whether the more effective teachers specialize fully and partially in that subject. I compare teaching effectiveness among teachers at the same school because this study only considers specialization within schools. Often, teacher assignments are locally made decisions. Teaching effectiveness for the teachers from one school does not matter to the assignment decisions for the teachers from another school.

Teacher absolute advantage in teaching a subject is equal to the differences between a teacher's effectiveness measure and the average of all teachers' effectiveness measure in that subject at a given school. The teacher's absolute advantage measure is expressed as follows:

$$X_{kt}^{s} = A_{kt}^{s} - A_{nt}^{s}, \qquad (2)$$

where A represents an effectiveness measure, *k* is a teacher, *s* is a subject, and *n* is a set of teachers who taught subject *s* in a school; A_{kt}^{s} is an effectiveness measure in subject *s* for teacher *k* in year *t*; A_{nt}^{s} is an average of effectiveness measures in subject *s* among all teachers *n* in year *t*.

[4] This study uses all students who have attended a teacher's classroom for at least 150 calendar days and who have valid test scores, and all teachers with more than five such students in grades 4 through 8 to estimate teacher value added. The calendar days do not include weekends, holidays, and enrollment gaps for individual students. For detailed about the student and peer-level variables used in DOLS, see the data section below.

The effectiveness measure (A_{kt}^{s}) in subject *s* for teacher *k* in year *t* refers to teachers' history of value added.[5] This measure is an average of teacher DOLS effects in a subject over multiple years. As Ballou (2005) states, it is possible that a substantial improvement in precision in a subject can occur if one averages multiple years of teacher effects estimates. This study then uses a three-year average of past teacher DOLS effects to compute teachers' history of value added.[6] The number of years of teacher value-added effects used to calculate a teacher's history of value added depends on the availability of data used to estimate teaching effectiveness.

Data

This study uses school, teacher, and student data from Tennessee's public elementary schools. These data include student test scores from the Tennessee Comprehensive Assessment Program (TCAP) in school years 2003-04 through 2011-2012; teacher and administrator personnel information from the Personnel Information Reporting System (PIRS) from the 2004-05 school year through 2011-2012; and the report card results on the NCLB accountability status for Tennessee's public elementary schools from the Tennessee State Library and Archives (TSLA) in school years 2008-09 through 2010-2011. I also receive course file records that contain information about teacher-student links in school years 2003-04 through 2011-2012.

1. Variables Available from Different Data Sources

The TCAP file contains the student background information and student test scores. The TCAP achievement tests are administered to all students in grades 3 through 8 each

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[5] The details on the estimation of A_{kt}^{s} is addressed in Section 4.3.

[6] Not all teachers have value added in a subject in three years prior to their current school year. Some teachers have two years and other teachers have one year of value-added data. The average of past teacher effects uses the data available to individual teachers in three school years prior to their current school year.

spring in Tennessee. The tests measure student achievement in four content areas, mathematics, English/language arts, science, and social studies. This study uses the scale scores derived from the norm-referenced component of the TCAP. I standardize the scale scores within grade and year in a subject to set all test scores to a common scale with a mean of zero and a standard deviation of one.

The TCAP data also contain information on demographic and program characteristics of each student, including sex, race/ethnicity, English language learner, free/reduced-price lunch eligibility, special education status, gifted status, and migrant status. This study further aggregates those student-level variables to build a set of the school-level variables (i.e., student peers). Both student and peer-level variables are used in the DOLS model to isolate the teacher value-added effects on student test performance.

The teacher and administrator personnel data include all certified employees in Tennessee's public K-8 schools, their education levels, and years of teaching experience in the teaching profession (i.e., at all schools). I create a set of variables using the longitudinal teacher data file: (1) years of teaching experience at the current schools; and (2) a set of mobility variables that indicate teacher stayers and movers.[7] The movers include transfer teachers who were new to the current schools and the returned teachers who had left from the current schools for some years. Teacher transfers and returners are mutually exclusive. The movers also include teachers who temporarily left the teaching profession. Those temporary leavers taught in a school in a current school year, but they have been not observed in my data in a year or two prior to the current school year.

[7] Since the teacher data are restricted to one and only one state and in nine school years, it is not known whether veteran teachers transferred from a school in another state and whether those teachers have taught in their current schools prior to the 2003-04 school year in Tennessee.

This study links teachers to their students using longitudinal student-course records prepared by the Tennessee Consortium on Research, Evaluation, and Development (TNCRED). Those files contain teacher, student, and course information. These data are collected annually for every course offered in Tennessee's public elementary schools and every certified teacher who was assigned to a class. The raw data are maintained by TDOE and, by far, are the most important piece of student-teacher records to link students to courses, to link courses to teachers, and eventually to link students to their teachers in Tennessee.

Finally, the school NCLB accountability data come from TSLA. Under the federal NCLB Act, all public schools should be held accountable for how much improvement their students at select grades in mathematics and English/language arts have made over each year. If the minimum requirements are not made, schools are placed in one of the sanction categories based on their accountability history. A school in "good standing" is not subject to NCLB sanctions. A "target" school receives no penalties, but this school has not made Adequate Yearly Progress (AYP) for at least one target goal for one school year. The NCLB sanctions include "school improvement", "corrective action/restructuring", and "state/LEA reconstitution" in which schools are under pressure to boost academic achievement.

2. Teacher Assignments in Tennessee's Public Elementary Schools

Teacher assignments in elementary schools play an important role in my study. It is necessary to discuss teacher assignments in upper elementary grades 4 through 6 in Tennessee's public elementary schools to show why my proposed question is answerable given the Tennessee's student and teacher data.

Teachers teach a number of subjects in elementary schools, four core academic subjects and other non-core academic subjects that include computer technology, health/safety, Art (major/minor), and physical education (PE). Often, the non-core academic subjects are fully specialized (i.e., one music teacher or one PE teacher) in some schools. If not, it is also possible that every teacher is responsible to teach non-academic subjects to their own classes in other schools.

This study excludes students in non-core academic subjects when estimating the degree of specialization for individual teachers. This is perhaps not surprising since there are no value-added estimates for teachers who taught non-academic subjects. In Tennessee, no standardized tests were administrated for non-core academic subjects and some of them have never been tested to learn teacher job performance in schools. Decisions on assigning teachers to teach core academic subjects over non-core academic subjects (or vice versa) are perhaps not determined by teaching effectiveness. Furthermore, the focus of this study is to explore changes of assignments within four core academic subjects over time given teaching effectiveness in those subjects.

The specialization measures then range from 0 to 100 percent. If a teacher completely specializes and teaches mathematics only, the degree of specialization measure is equal to 100 percent; if this teacher has half her/his students in mathematics and half in other subjects, this measure is equal to 50 percent; if this teacher taught in a self-contained classroom (i.e., with equal numbers of students in all four core subjects), this measure is equal to 25 percent; and if this teacher did not teach mathematics but taught other subjects, this measure is equal to zero.

To answer my research question, this study relies on three important facts about teacher assignments. First, there are a variety of different assignments that determines who will teach and what subject(s) those teachers will teach across teachers. Second, lots of those teachers have taken different assignments from one year to the next. Third, while teachers are taking different assignments over time, they tend to have taught fewer subjects and more students in those subjects during the course of their teaching career.

Table 1 presents the number of teachers who taught in three school years 2009-2010 through 2011-2012 by job assignments in grades 4 through 6 in Tennessee's public elementary schools.[8] Those teachers taught one and only one grade. Job assignments are described by a set of single-subject (4) and multiple subject (11) schemes. In the 2011-2012 school year for teachers in grade 4, 90 percent (2,509) taught all four core subjects, 1.6 percent (45) taught three subjects, 4.1 percent (115) taught two subjects, and 4.7 percent (132) taught only one subject. The number of teachers who teach four subjects decreased dramatically from grades 4 (90 percent) through 6 (18 percent). Conversely, roughly 63 percent of teachers in grade 6 taught one subject compared to the 4.7 percent of teachers in grade 4. The number of teachers who taught two/three subjects also increases in grades 5 and 6. In the 2011-2012 school year, there were 16 (or 19) percent of teachers in grade 5 (or 6) teaching two or three subjects.

[8] In this study, MTH represents mathematics; ELA represents English/language arts; SCI represents science; and SOC represents social studies.

Table 1
Number of elementary school teachers by grade and subject scheme in school years 2009-2010 through 2011-2012

School year	2009-2010			2010-2011			2011-2012		
Grade level	4	5	6	4	5	6	4	5	6
Single-subject schemes									
SOC	3	28	274	5	25	317	8	28	342
SCI	5	29	292	7	28	318	8	28	338
ELA	66	134	703	70	164	817	79	166	742
MTH	15	43	361	21	65	444	37	91	490
Multiple-subject schemes									
SCI-SOC	8	22	79	13	33	106	22	62	137
ELA-SOC	15	94	195	25	122	185	32	129	156
ELA-SCI	12	35	92	10	44	105	13	36	76
ELA-SCI-SOC	15	28	23	22	28	10	11	18	15
MTH-SOC	5	13	45	3	11	51	6	28	44
MTH-SCI	7	19	55	9	49	59	14	68	69
MTH-SCI-SOC	6	89	45	7	77	35	7	20	7
MTH-ELA	24	39	113	23	50	106	28	41	68
MTH-ELA-SOC	18	27	21	22	23	12	10	19	4
MTH-ELA-SCI	24	19	9	18	24	11	17	17	8
MTH-ELA-SCI-SOC	2,594	2,075	715	2,765	2,169	613	2,509	1,934	546
Percent of teachers who taught four subjects	92.08%	77.02%	23.66%	91.56%	74.48%	19.22%	89.58%	72.03%	17.95%
Total number of teachers	2,817	2,694	3,022	3,020	2,912	3,189	2,801	2,685	3,042

Notes: Sample includes all teachers who have lagged value-added estimates over a four-year span prior to their current school year, who have taught in grades 4 through 6 in three school years 2009-2010 through 2011-2012 at Tennessee's public elementary schools, and who have taught more than five students in at least one subject in their current school year. Sample excludes teachers who taught in multiple grades. Each of the six students attended their teacher's class in a subject for at least 150 calendar days. The calendar days do not include weekends, holidays, and enrollment gaps for individual students.

The number of teachers who taught in multiple grades in three school years is presented in Appendix C. This table presents various subject schemes assigned to individual teachers in a given grade. In the 2011-2012 school year, there were 5.7 percent of teachers (511) who taught in two or three grades. About 302 (41 percent) out of those 511 teachers taught the same subject schemes across grades. At the same time, there were 209 teachers who taught different subject schemes across grades. For example, a teacher taught social studies in grade 6 and English/language arts in grades 5 and 6.[9]

Secondly, a great number of teachers are assigned to different assignments from one year to the next. I first focus on whether teachers have taught the same subject(s) in the same grade in the same school in two adjacent years. Using teachers in grade 4 in the 2010-2011 and 2011-2012 school years, I find there are 8.3 percent of teachers (177) assigned to different assignments in two school years based on the subject schemes they taught.[10] Although 91 percent of those teachers are assigned to teach the same number of subjects in the same grade at the same school in two school years, it is possible that they may not be assigned to the same percent of students in each subject within a subject scheme taught from one year to the next.

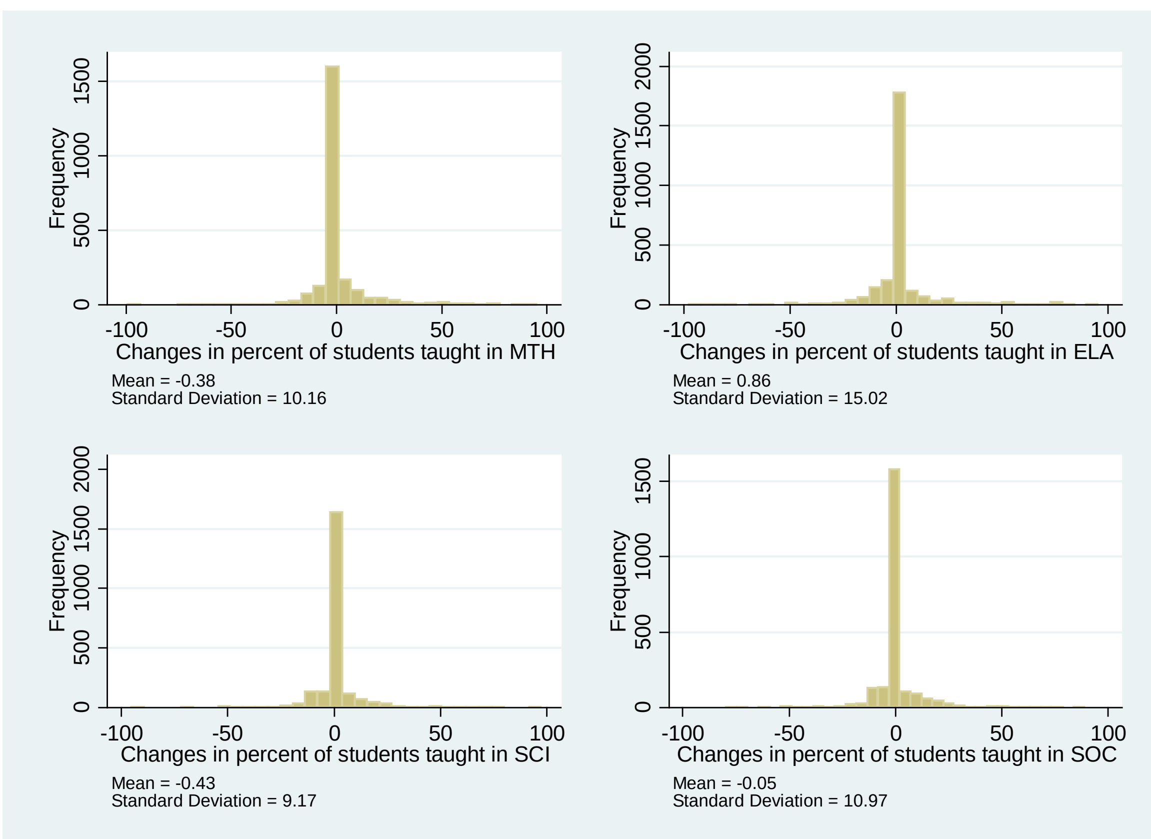
For those teachers, I then identify the changes on assignments as the difference of the percent of students taught at the same subject in the same grade for individual teachers

[9] There are several possible reasons not to use the grade-specific specialization assignment measures. It is no such thing that teachers should only teach one grade. Often, teachers have taught one grade in one year and a different grade in another year. For example, teachers follow their students in grades 4 through 6 over three years. It is reasonable to believe that teachers are effective in teaching a subject in one grade and can also be effective in other grades especially in elementary schools. Furthermore, instead of estimating a grade-specific value-added effect for teachers, the effectiveness measures used in this study have also taken into consideration the possible differences in performance across grades for teachers who have taught the same subject in different grades.

[10] For details on subjects taught by a teacher in two adjacent years in the same grade at the same school, see Appendix D. These tables present the number of teachers by teacher assignment (i.e., subject schemes). For example, there are 82 teachers who taught English/language arts in the 2010-2011 school year and 12 of those taught four academic subjects in the 2011-2012 school year.

in two adjacent years. Among the teachers who have taught the same subject in the same grade in two years (e.g., 91 percent of teachers in grade 4 in the 2010-2011 and 2011-2012 school years), I show how many of them have taught the same percent of students in two years and how many of them have taught a larger or smaller percent of students in year *t*+1 compared with the ones taught in year *t*. Figure 1 presents the distribution of changes in the percent of students taught at the same subject at the same school by individual teachers in two school years 2010-2011 and 2011-2012. On average, there are about 46 percent of teachers who taught a different percent of students in two adjacent years in a given subject. In short, many teachers are normally assigned to different jobs and the percent of students taught in a subject also may be changed from one year to the next.

Figure 1
Changes in the percent of students taught in grade 4 in two adjacent school years 2010-2011 and 2011-2012 by subject



Notes: Sample includes teachers who taught the same subjects in two school years 2010-2011 and 2011-2012 and who taught in grade 4 in Tennessee's public elementary schools. Students attended their teacher's class in a subject for at least 150 calendar days. The calendar days do not include weekends, holidays, and enrollment gaps for individual students.

Lastly, I consider whether teachers tend to specialize in some subjects as they progress in their career. One can measure whether teachers concentrate on fewer subjects using the Herfindahl index. In business, the Herfindahl index is a measure that describes competition or monopoly conditions within an industry among a set of firms (Bailey and Boyle, 1971). My Herfindahl index measures the sum of the proportion of student share in each of four subjects taught by a teacher in a school year. The formula is expressed as follows

$$H_{kt} = \sum_{s=1}^{S_{kt}} pct_s^2 \, , \quad (3)$$

where H_{kt} is the student share of teacher *k* in year *t*; S is the total number of subjects taught by teacher *k* in year *t*; and pct_s^2 is a square of the percent of students in subject *s*. For example, if a teacher has taught four core subjects and the same number of students in each subject, that teacher's Herfindahl index is .25; if a teacher has only taught one subject, that teacher's Herfindahl index is one. Figure 2 presents Herfindahl index for teachers who taught in grades 5 and 6 in Tennessee's public elementary schools.

To examine whether teachers specialize more over time, I estimate whether years of teaching experience are positively associated with teachers' Herfindahl indexes. If an upward trend of the Herfindahl index predominates among teachers, teachers specialize more over time. In regression analyses, teachers' Herfindahl indexes regress on dummy variables for years of teaching experience (i.e., how long she or he has been a teacher), education levels, grades, and school years. Teachers are assigned to each of the following experience categories, 0 to 5, 6 to 10, 11 to 15, 16 to 20, and 21 or more.[11] The omitted category for experience dummy variables is the teachers in the 0 to 5 category. The models then control for teacher fixed effects. This rules out confounding effects from teaching effectiveness that influences specialization and correlates with teaching experience over time. The models further control for interaction terms between dummy variables for years of teaching experience and grades.[12] I consider the potential variation of the impact of teaching experience on subject specialization across grades since teacher assignments in grade 6 are dramatically different from the ones in grades 4 and 5. The grade dummy variables indicate where teachers taught in a subject. I include grade dummy variables in my model because, as the grade level goes up in grades 4 through 6, it is known that teachers are more likely to specialize fully or partially in one subject or some subjects.

Using teachers' assignment data in nine school years 2003-2004 through 2011-2012, I show that teachers tend to specialize as they stay longer in teaching. Appendix E presents marginal effects of teaching experience on specialization. Model (2) controls for the interaction terms but not in Model (1). The lower panel also controls for teacher fixed effects. Both OLS and SCH-FE models report quantitatively similar findings and the results from the fixed-effect models are slightly smaller. The coefficient estimates on experience

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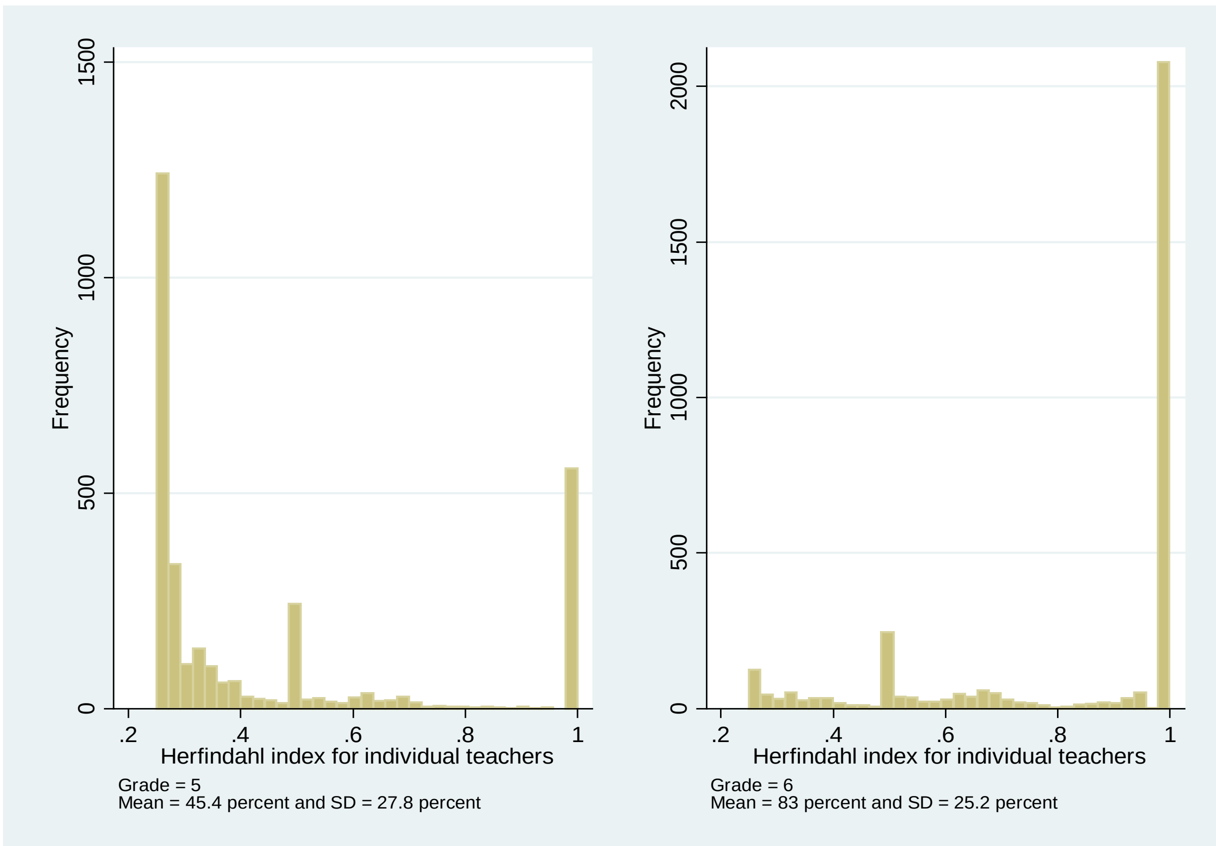
[11] I also run regressions using a continuous variable measuring the total number of years of teaching experience and a set of dummy variables for each year of teaching experience. All results suggest a positive relationship between teachers' Herfindahl indexes and teaching experience. There is no previous research that suggests additional teaching experience significantly changes the share of a teacher's students separately in each subject after a number of years of teaching experience. Based on the results using dummy variables for each year of teaching experience (the beginning teacher is the omitted category), teachers with 16 or more years of teaching experience have specialized more than the beginning teachers. I then use a set of five-year periods over 20 years to define dummy variables for years of teaching experience as well as a dummy variable for teachers who have taught 21 years or more.

[12] I provide F-test statistics to estimate the joint significance of those interaction effects. The test results show that the effects of teaching experience on specialization are not different across grades at $p < 0.05$.

dummy variables are positive and statistically significant at p < .05. Those results suggest that teachers tend to specialize in teaching some subjects as they stay longer in teaching in elementary schools.

Figure 2
Histogram of teachers' Herfindahl index by grade in the 2011-2012 school year



Notes: Sample includes teachers in grades 5 and 6 who have lagged value-added estimates over four years prior to the 2011-2012 school year. Students attended their teacher's class in a subject for at least 150 calendar days. The calendar days do not include weekends, holidays, and enrollment gaps for individual students.

3. History of Teaching Effectiveness and Absolute Advantages

The decision about the number of years used to estimate either teacher DOLS effects or teachers' history of value added relies on the longitudinal student and teacher data available for this study. The more school years used to estimate teacher DOLS effects, the fewer school years available for this chapter to estimate teachers' history of value added. The more school years used to estimate teachers' history of value added, the fewer school years available for this chapter to answer the research question. The current design presented below is to ensure there are three school years for my analysis.[13]

This study estimates teacher fixed effects in a subject over a four-year window using the DOLS model. Given a total of nine-year student achievement data, this study uses six rolling four-year spans to estimate fixed effects for teachers who taught in grades 4 through 8 separately in each of four subjects.[14] Teacher DOLS fixed effects are reported in school years 2006-07 through 2011-2012. I then compute a weighted average of teacher effects over three school years. These estimates refer to teachers' history of value added (A_{kt}^{s}). The weights are the proportion of students taught by a teacher in a school year in a subject. Those weighted teacher effects are then used to estimate teachers' absolute advantages (X_{kt}^{s}) relative to other teachers of the same subject at a given school in a school year. This study then uses the lagged absolute advantage measure to predict subject specialization for teachers in the current school years from 2009-2010 through 2011-2012.

Empirical Methodology

1. Analytical Model of Subject Specialization for Teachers

My estimation strategy intends to estimate whether a teacher has taught more students in a subject where that teacher is relatively more effective compared to other

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13 Two school years are considered to be too short to analyze my research question. If this study uses four years, the data panel has to reduce one year to estimate either teacher DOLS effects or teachers' history of value added. Both estimates are also required to be not too short. A three-year analysis for my research question gives enough school years used to estimate teacher effectiveness measures.

14 The test data in the first school year 2003-04 are served as the lagged test scores for students in grades 4 through 8 in the 2004-05 school year.

teachers who taught the same subject at the same school. This study uses an Ordinary Least Square model where teacher assignments in a subject in a grade in year *t* + 1 depend on teacher absolute advantages in teaching each subject in year *t*, a set of dummy variables for the number of years taught in each subject prior to the year *t* + 1, dummy variables for year effects, and school fixed effects.

The equation for the analysis of mathematics assignments in one grade is presented below:

$$\mathrm{TA}_{k,t+1}^{mth} = \beta_0 + \beta_1 X_{kt}^{mth} + \beta_2 X_{kt}^{ela} + \beta_3 X_{kt}^{sci} + \beta_4 X_{kt}^{soc} + \beta_5 W_{k\,(t,t-1,t-2,t-3)}^{\mathrm{S}} + \beta_6 \pi + \phi_m + e_{kt}^{mth}, \qquad (4)$$

where $\mathrm{TA}_{k,t+1}^{mth}$ is the percent of students taught in mathematics by teacher *k* in year *t* + 1; the explanatory variables include a set of absolute advantages in teaching mathematics X_{kt}^{mth}, English/language arts X_{kt}^{ela}, science X_{kt}^{sci}, and social studies X_{kt}^{soc} for teacher *k* in year *t*; a matrix W of dummy variables for the number of years taught separately in each subject $S \in (MTH, ELA, SCI, SOC)$ over a four year-window prior to the current school year *t* + 1; and a matrix π of year effects; fixed effects ϕ_m for school *m*; and a random error term e_{kt}^{mth}. I run the same regression separately in each grade since Table 1 has shown that teacher assignments in one grade are very different from the ones in another grade. The coefficient estimates indicate the grade-specific effects on teacher assignments in a subject and they are likely to be significantly different by grade. Furthermore, there are three more models for other non-mathematics subjects, respectively.

This mathematics model controls for absolute advantages in teaching non-mathematics subjects since it is not certain that teaching effectiveness in other subjects influences subject specialization in mathematics. Goldhaber and Hansen (2010a) find that an effective mathematics teacher have tended to be effective in teaching English/language arts.

Consider a case in which two teachers are equally effective in teaching mathematics; however, the first teacher is more effective in teaching English/language arts than the second teacher. Controlling the absolute advantage in English/language arts is to test whether being effective in English/language arts makes teachers less likely to increase the percent of students taught in mathematics.

This study further controls for dummy variables for the number of school years taught separately in each subject over a four-year window prior to the current school year, the matrix W. Some teachers have not taught a subject for four school years and/or taught a subject for fewer than four school years. The absolute advantages in the subjects those teachers have not taught for four school years are set to zero. The omitted category of the matrix W is the dummy variable for not teaching a subject in any school years over a four-year span. I test whether the number of school years taught in mathematics makes teachers more likely to increase their students in mathematics compared to the ones who have not taught mathematics over a four year span; and whether the number of school years taught in each of other subjects make teachers less likely to increase their students in mathematics compared to the ones who have not taught in each of other subjects over the same year span.

In addition, the matrix π of year effects captures any time-specific factors that may have influenced the percent of students taught in mathematics. Those factors may be common to all schools. One of those factors is changes on managerial efforts to manage teacher assignments under the pressure of school improvement. Others include teachers' own preferences for teaching particular subjects,[15] the difficulty to recruit teachers with

[15] In schools, some teachers have received pressure from school leaders to raise student test scores in the subject(s) they were not effective in teaching; and they probably have built their own preference

teaching effectiveness in mathematics, teacher retention and attrition, and changes on student enrollment. The dummy variable for year effects in the 2009-2010 school year is the omitted category.

In the model, school fixed effects capture any differences of teacher assignments that vary systematically by school as well as school fixed characteristics. I focus on the within-school teacher assignments. The school-specific characteristics include school average test performance, school size, school locale, school policy on teacher assignments, and administrative efforts for school improvement.[16] I also estimate similar regressions without school fixed effects and these estimates are quantitatively similar to the ones with school fixed effects while those estimates are slightly smaller.

2. Analytical Sample

The analytical sample includes teachers who taught core academic subjects in grades 4 through 6 in school years 2009-2010 through 2011-2012. Those teachers have taught a subject to at least six students who have been to their teachers' classrooms for at least 150 calendar days. I focus on teachers in upper elementary grades 4 through 6 since it is rare that elementary school teachers in grades 1 through 3 become content-specific teachers and there are no value-added data for teachers in these grades, either, in Tennessee. New teachers with zero year of teaching experience are excluded from this analysis since those teachers again do not have teacher effectiveness measures.

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in teaching some subjects over other subjects over time. It is possible that they use their own influence to affect their own assignments in schools.

[16] Some may argue that those factors are not completely fixed; however, they have been rarely changed over time in schools.

3. Teacher and School Moderator Variables

In addition to the baseline model presented above, this study is further interested in whether some teacher and school characteristics influence the relationship between teachers' history of relatively effectiveness in a subject and the degree of specialization in that subject. My mathematics model then controls for a vector Q of teacher and school characteristics and the interaction terms between X_{kt}^{mth} and Q. The teacher characteristics contain education levels (i.e., Bachelors, Masters, and Education Doctoral and above), years of teaching experience at all schools, a set of dummy variables for the number of school years taught at the current schools, and teacher mobility status. The school characteristics contain school size of tested students in a grade and a set of dummy variables for prior school NCLB accountability status levels. This set of analysis is also tested for subject specialization in other subjects.

The focus of this set of regressions is on the role of teacher and school characteristics to impact the percent of students assigned to individual teachers in a subject. Teachers with advanced degrees receive extra training in college which teachers with Bachelor's degree have not experienced. It is possible that the focus of such training is not on subject-specific information to enhance a teacher's productivity, but receiving an advanced degree at least signifies a higher human capital for teachers. Such difference in education levels leverages the possibility of assigning more students to the teachers with advanced degrees than the ones with Bachelor's degree.

The number of years of teaching experience is also associated with the probability of becoming specialist teachers in a subject. The more years a teacher has taught in her/his career, the more likely that teacher has acquired a specialty in one or some subject areas. It is possible that those teachers already have specialized in one of the four subjects for years. In addition, the longer a teacher has taught at the current school, the more information about that teacher's performance in teaching each of the four subjects can be revealed. This study then tests whether students are likely to be assigned to the teachers who have identified how effectively they have raised student test scores in a subject at the current schools.

This study also tests whether teacher mobility is associated with the percent of students assigned to individual teachers in a subject. One of the important differences between teacher stayers and movers is that teaching effectiveness for the former is usually available for use to determine teacher assignments, but teaching effectiveness for the latter is likely to be uncertain, although it is possible to ask how teacher movers have performed in schools where they have taught before. Furthermore, teachers move to a new school because they want to become specialist teachers and another possibility is that specialist teachers transfer to a new school because they want to become generalist teachers. In addition, some teachers do not change their teacher assignments in their new schools because they just want to be relocated to some other schools. Since assignments between teacher stayers and movers are less likely to be on an equal footing, I test a hypothesis regarding how schools operate assignments based on teacher mobility.

There are more teachers in schools with large student populations compared to small schools. It is possible that large schools have more specialist teachers and have more than one subjects specialized by those teachers. Another possibility is that there are more students with special needs of improvement in a subject in large schools. Usually, no such scale of specialization and needs occur in small schools mainly because of teacher mobility and school size. In a small school with four or five teachers, the likelihood of assigning most of students to one teacher in a subject may be low, but the cost of finding a replacement is definitely high if that teacher leaves from his/her current school. Instead, if a generalist teacher leaves from a small school, it is easy to recruit a teacher to teach all subjects or allow the rest teachers to take a share of the students who were taught by that teacher mover. This study intends to test whether school size increases the probability of assigning more students to some teachers in a subject.

Lastly, the schools placed in the target and/or sanction status levels in a previous year have more incentives to manage teacher assignments with the aim to improve student test scores. Receiving pressure from school NCLB accountability also leads to more teachers to specialize if specialization is the way to boost school performance in mathematics and English/language arts.

In summary, I use mathematics teachers to further illustrate the correlation between the degree of specialization and teacher/school characteristics. For two given mathematics teachers with the same relative effectiveness at the same school, this study explores whether either the teacher with the advanced degree, or the veteran teacher, or the teacher who has taught in the teaching profession (or at the current school) for a longer time is more likely to specialize in mathematics; and whether transfer/returned teacher is likely to be assigned fewer students in mathematics than teacher stayers. For such two mathematics teachers at two different schools, this study further considers whether the teacher at the school with large enrollment and/or under NCLB accountability pressure to boost school performance is likely to be assigned more students in mathematics.

Results

1. Teachers, Absolute Advantages, and Assignments in Tennessee

In school years 2009-2010 through 2011-2012, there are a total number of 30,654 teachers who taught in grades 4 through 6 and who have lagged absolute advantage measures in teaching some subjects or at least one subject. Among those teachers, a total number of 14,500 teachers have taught for at least four school years prior to their current school years and have not transferred to a different school over those years (i.e., teacher stayers). Most of those teacher stayers (95.9 percent) taught one grade (i.e., a single-grade scheme) in a school year, but a few teachers (4.1 percent and n = 594) were assigned to teach multiple grades. Some of the 4.1 percent teachers taught different subjects in different grades. Overall, a large proportion of teacher stayers in grades 4 and 5 taught in self-contained classrooms ranging from 71 to 92 percent across all school years while more than 86 percent of teacher stayers specialized in teaching one or two subjects in grade 6.

This study first offers a general and rough understanding about the potential influences of prior absolute advantages in teaching each subject separately on teacher assignments. I average absolute advantages in teaching a subject based on teachers' history of value added (A_{kt}^{s}) in that subject by assignment scheme in a grade in a current school year. By doing so, teachers are grouped within their assignment schemes and the average absolute advantages for those teachers are reported separately within each assignment scheme. I then examine whether teachers have continued teaching a subject they taught prior to a current school year based on their past average absolute advantages in teaching that subject and what other subjects they also taught in a current school year.

These average absolute advantages are reported separately in each of three analytical school years and further aggregated over all school years. Table 2 presents the average of past average absolute advantages in teaching a subject for all teachers over three school years by teachers' current assignment (i.e., assignment scheme) separately in each grade. The average absolute advantages based on A_{kt}^{s} in a subject in a given assignment scheme are averaged over three current school years, 2009-2010, 2010-2011, and 2011-2012.[17] This table also reports the total number of teachers over three school years in a given assignment scheme. The list of assignment schemes is sorted in an ascending order of the average of past average absolute advantages in teaching a subject. The mixed subject-by-grade scheme labeled as "Others" includes all teachers who taught in more than one grades.

This table provides descriptive statistics of absolute advantages in teaching a subject by assignment scheme over three analytical school years. Many teachers with higher past absolute advantages in teaching a subject not only have continued teaching that subject but also taught alternate subjects in all grades. In particular, this table reveals that the specialist teachers who taught one and only one subject in all grades in a current school year always had higher past average absolute advantages in teaching that subject than self-contained classroom teachers who taught all four core academic subjects except the science specialists in grade 5. In addition, all complete specialists in a grade have had prior absolute advantages in the subject they fully specialized higher than the average absolute advantages of all teachers in the same grade except the science specialist in grade 5.

[17] The first average is estimated within assignment schemes in a grade in a year; and the second average is estimated over three school years. Instead of reporting the average absolute advantages by assignment scheme in a current school year, I report the averages of average absolute advantages over three school years. The average absolute advantages by assignment scheme are quantitatively similar across school years.

Table 2
Descriptive statistics of average absolute advantages separately in each subject over three school years 2009-2010 through 2011-2012 based on teachers' history of value added by assignment scheme

Mathematics (M)			English/language arts (E)			Science (S)			Social studies (H)		
	Averages absolute advantages	Total # of teachers		Averages absolute advantages	Total # of teachers		Averages absolute advantages	Total # of teachers		Averages absolute advantages	Total # of teachers
Assignment schemes in grade 4											
H	-0.1308	8	H	-0.1018	8	H	-0.1098	9	S	-0.1644	6
SH	-0.1079	14	SH	-0.0659	20	MH	-0.0702	4	ES	-0.1124	13
ES	-0.0759	15	MH	-0.0409	6	ES	-0.0467	29	MSH	-0.0818	11
S	-0.0732	5	ES	-0.0370	29	ME	-0.0248	20	SH	-0.0482	34
MEH	-0.0434	31	ESH	-0.0107	36	EH	-0.0211	19	MEH	-0.0225	36
ESH	-0.0429	12	MES	0.0018	48	ESH	-0.0184	30	ME	-0.0142	19
MH	-0.0428	11	MESH	0.0035	6,502	MES	-0.0140	45	MES	-0.0113	20
MES	-0.0279	48	MSH	0.0065	8	SH	-0.0049	36	EH	0.0035	51
E	-0.0275	29	EH	0.0143	58	MESH	0.0008	6,406	MESH	0.0101	6,424
EH	-0.0164	27	MEH	0.0184	36	E	0.0013	35	ESH	0.0159	31
ME	-0.0053	58	E	0.0266	162	MS	0.0323	21	E	0.0213	37
MESH	-0.0030	6,432	S	0.0283	7	MEH	0.0341	15	H	0.0265	13
M	0.0315	50	ME	0.0284	58	S	0.0515	14	M	0.0341	20
MS	0.0464	25	MS	0.0524	15	MSH	0.0731	9	MS	0.0418	11
MSH	0.0810	9	M	0.0635	21	M	0.1010	18	MH	0.1062	11
Assignment schemes in grade 5											
ESH	-0.1038	20	MES	-0.0132	46	ME	-0.0900	30	ES	-0.0514	27
SH	-0.0488	41	ESH	-0.0105	53	MES	-0.0346	43	S	-0.0264	22
ES	-0.0125	28	SH	-0.0005	48	MEH	-0.0311	16	ME	-0.0145	37
E	-0.0092	70	H	0.0007	25	H	-0.0252	14	MS	-0.0131	65
MSH	-0.0052	144	ME	0.0059	95	EH	-0.0240	72	M	-0.0068	58
S	-0.0022	21	MESH	0.0070	5,161	S	-0.0221	75	SH	-0.0025	83
EH	0.0050	76	S	0.0096	21	MH	-0.0125	10	MSH	-0.0019	139
MES	0.0058	47	MEH	0.0108	50	ESH	-0.0054	47	ESH	0.0113	43
MH	0.0158	39	MSH	0.0128	40	E	-0.0049	77	MESH	0.0116	5,087
MESH	0.0211	5,085	EH	0.0174	289	SH	0.0073	79	MEH	0.0153	46
H	0.0253	16	M	0.0181	48	MESH	0.0079	5,069	MH	0.0218	34
ME	0.0311	101	E	0.0200	387	MSH	0.0222	140	E	0.0243	116
MS	0.0348	97	MH	0.0269	17	ES	0.0313	80	EH	0.0248	247
MEH	0.0427	48	ES	0.0344	84	M	0.0461	52	H	0.0328	69
M	0.0548	156	MS	0.0493	33	MS	0.0502	95	MES	0.0443	17
Assignment schemes in grade 6											
S	-0.0376	126	MS	-0.0400	34	EH	-0.1089	50	ES	-0.0363	42
MEH	-0.0316	25	MES	-0.0324	24	MEH	-0.1050	4	SH	-0.0248	215
ESH	-0.0189	9	S	-0.0293	182	ME	-0.0650	36	MSH	-0.0210	66
E	-0.0188	220	SH	-0.0276	74	H	-0.0307	97	MESH	-0.0185	1,048
H	-0.0171	102	H	-0.0110	199	MESH	-0.0157	1,008	MES	-0.0135	11
EH	-0.0156	51	ME	-0.0094	201	SH	-0.0117	230	ESH	-0.0006	30
SH	-0.0010	53	ES	-0.0051	199	E	-0.0110	227	E	0.0006	316
ME	0.0019	226	ESH	-0.0029	36	M	0.0022	198	M	0.0014	216
MS	0.0045	139	MESH	-0.0013	1,216	MES	0.0052	20	MH	0.0124	82
MESH	0.0047	1,027	EH	-0.0005	398	MH	0.0065	21	EH	0.0146	348
MSH	0.0168	70	M	0.0044	254	ES	0.0135	212	S	0.0166	148
ES	0.0233	33	E	0.0092	2,069	ESH	0.0178	25	H	0.0193	808
M	0.0257	1,181	MEH	0.0190	28	MS	0.0189	133	MEH	0.0241	25
MH	0.0260	100	MH	0.0497	34	MSH	0.0327	66	MS	0.0329	50
MES	0.0398	22	MSH	0.1090	19	S	0.0330	868	ME	0.0943	35
All schemes taught in a grade											
Grade 4	-0.0037	6,774		0.0041	7,014		0.0007	6,710		0.0093	6,737
	(0.1973)			(0.1521)			(0.1821)			(0.2069)	
Grade 5	0.0201	5,989		0.0086	6,397		0.0075	5,899		0.0112	6,090
	(0.1805)			(0.1456)			(0.1767)			(0.2007)	
Grade 6	0.0086	3,384		0.0016	4,967		0.0016	3,195		0.0007	3,440
	(0.1992)			(0.1815)			(0.2045)			(0.2032)	
All schemes taught in multiple grades											
Mixed grades	0.0051	559		0.0049	830		0.0038	528		-0.0022	536
	(0.1798)			(0.1642)			(0.1672)			(0.1974)	
All schemes taught in all grades											
All grades	0.0077	16,706		0.0050	19,208		0.0034	16,332		0.0082	16,803
	(0.1915)			(0.1587)			(0.1844)			(0.2036)	

Notes: Assignment schemes are notified using four upper letters and each letter represents a subject taught by individual teachers in a current school year, mathematics (M), English/language arts (E), science (S), and social studies (H). Sample includes teachers who have had prior absolute advantages separately in each subject and who taught in school years 2009-2010 through 2011-2012. Absolute advantages are averaged over three school years in a scheme in a grade and assignment schemes are sorted in an ascending order of average absolute advantages separately in each subject in a grade. In the bottom of this table, absolute advantages are further averaged over all schemes in a grade (and across all grades). The scheme for self-contained classrooms is highlighted as gray. Standard deviations are in parentheses.

A second finding in Table 2 is that some teachers with high past absolute advantages in teaching a subject they did not continue to teach that subject. I then ask how many teachers who have been "good enough" at teaching one subject over time did not teach that subject in their current school years. To define "good enough", I focus on the teachers with positive average absolute advantages in teaching a subject within assignment schemes that are also higher than the average absolute advantages across all assignment schemes. I use teachers who taught English/language arts in grade 5 as an example because their average absolute advantage is the highest among all other subjects separately in each grade. There are 12 schemes of teachers with positive average absolute advantages. Teachers in the first five assignment schemes have their average absolute advantages lower than the average over all assignment schemes (i.e., 0.0126); therefore, teachers in the other seven groups are labeled as "good enough" at teaching English/language arts. Teachers in four out of seven schemes, however, have not continued to teach English/language arts over three analytical school years. They all taught mathematics and 48 (35 percent) of them fully specialized in teaching mathematics. One possible explanation for this specific fact is that those teachers are good at teaching English/language arts and also good at teaching mathematics in schools where mathematics is one of the hard-to-staff subjects in schools.

2. Specialization and Teaching Effectiveness

Table 3 presents the marginal effect of teacher absolute advantages in a subject on the percent of students taught in that subject separately in each grade. A positive and statistically significant marginal effect indicates more students in a subject would be assigned to the teachers with an increases in absolute advantages in teaching the same subject.

Regressions in Table 3 control for school fixed effects. Those results are quantitatively similar but slightly larger to the ones without school fixed effects.[18]

Separately in each grade, I find that the relatively more effective teachers in mathematics and science specialize more in teaching those subjects, respectively. Instead, the positive and statistically significant effects are only found in grade 5 for teachers who teach English/language arts (6.60 percent at $p < 0.05$) and in grade 4 for teachers who teach social studies (1.23 percent at $p < 0.05$).

These findings suggest that teachers have been assigned to teach more students in the subjects where they are relatively effective, but the effects vary dramatically across grades within and across subjects. In grade 4, a mathematics teacher with one standard deviation increase in absolute advantage raises the percent of students taught in mathematics by 3.1 percent (i.e., less than one student if the average class size is 25) at $p < 0.01$; instead, this effect increases to 11.03 percent in grade 5 (i.e., more than two students) at $p < 0.001$ and 15.47 percent in grade 6 (i.e., more than three students) at $p < 0.001$. Similar results are also found for science teachers, but the effects are somewhat smaller in grade 5 (7.18 percent) and 6 (14.64 percent) compared to the ones for mathematics teachers.

[18] For results without school fixed effects, see Appendix F.

Table 3
Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in three school years

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**3.102****	-0.981	-1.628†	-0.493
	(1.141)	(1.386)	(0.981)	(0.864)
English/	-1.433	**2.981**	-1.046	-0.502
language arts	(1.295)	**(1.979)**	(1.080)	(1.033)
Science	0.622	-1.725	**2.973***	-1.870†
	(1.157)	(1.624)	**(1.173)**	(1.052)
Social studies	0.093	0.476	-1.684**	**1.115†**
	(0.703)	(0.859)	(0.629)	**(0.591)**
Observations	8,471	8,471	8,471	8,471
R-squared	0.336	0.416	0.331	0.316
Grade 5				
Mathematics	**11.023*****	-4.736*	-5.581***	-0.705
	(1.988)	(1.967)	(1.580)	(1.552)
English/	-4.574*	**6.869***	-1.217	-1.077
language arts	(1.955)	**(2.764)**	(2.126)	(2.097)
Science	-2.055	-5.026*	**7.176*****	-0.095
	(1.983)	(2.320)	**(1.984)**	(1.867)
Social studies	-0.642	2.633	-2.129†	**0.138**
	(1.203)	(1.675)	(1.103)	**(1.276)**
Observations	8,952	8,952	8,952	8,952
R-squared	0.387	0.437	0.391	0.317
Grade 6				
Mathematics	**15.479*****	-3.164	-7.687**	-4.629*
	(3.776)	(3.321)	(2.360)	(2.255)
English/language arts	1.181	**5.770**	-6.207**	-0.743
	(2.078)	**(3.620)**	(2.140)	(1.865)
Science	-7.321*	-8.348*	**14.499*****	1.170
	(2.889)	(3.355)	**(3.788)**	(2.332)
Social studies	1.124	-2.069	0.214	**0.731**
	(2.437)	(2.727)	(2.533)	**(3.128)**
Observations	9,955	9,955	9,955	9,955
R-squared	0.529	0.502	0.520	0.468

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for school fixed effects and dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

These models also control for absolute advantages in teaching alternate subjects. Table 3 shows that all of the statistically significant cross-subject effects are negative. The absolute advantage in teaching mathematics is negatively associated with the percent of students taught in all alternate subjects, ranging from 4.74 percent in English/language arts in grade 5 ($p < 0.05$) to 7.69 percent in science in grade 6 ($p < 0.01$). The absolute advantage in teaching English/language arts is negatively associated with the percent of student taught in mathematics in grade 5 (4.57 percent at $p < 0.05$) and science in grade 6 (6.21 percent at $p < 0.01$). The absolute advantage in teaching science is negatively associated with the percent of students taught in mathematics in grade 6 (7.32 percent at $p < 0.05$) and English/language arts in grades 5 and 6 (5.03 and 8.35 percent, respectively). In addition, the percent of students taught in science is also negatively influenced by absolute advantages in teaching social studies in grade 4 and 5 (1.68 and 2.13 percent, respectively). These results suggest that the stronger cross-subject effects, the fewer percent of students in the subject where teachers are relatively more effective in teaching. In particular, being effective in mathematics makes teachers less likely to increase the students in all other subjects in different grades.

This study further considers the potential effects of teacher and school characteristics on the percent of students taught in a subject. Table 4 displays the descriptive statistics on a set of teacher and school characteristics for teachers by grade and year. My analytical sample of teachers in grades 4 through 6 separately in each year contains a 43 to 46 percent of teachers with Bachelors, a 47 to 49 percent of teachers with Masters, and a 5 to 8 percent of teachers with education doctoral and above. On average, those teachers have had 11 to 12 years of teaching experience in all schools.

Table 4
Descriptive statistics on teacher and school characteristics by grade and school years in Tennessee's public elementary schools

	Grade 4			Grade 5			Grade 6		
	2009-2010	2010-2011	2011-2012	2009-2010	2010-2011	2011-2012	2009-2010	2010-2011	2011-2012
Education degree									
Bachelors	1,237	1,281	1,331	1,259	1,377	1,353	1,374	1,503	1,507
Masters	1,310	1,360	1,380	1,323	1,417	1,480	1,564	1,626	1,608
Education doctoral and above	147	177	207	212	226	251	223	243	269
Years of teaching experience in all schools									
	11.86	11.58	10.90	11.43	11.14	10.93	11.60	11.52	11.26
	(10.08)	(9.76)	(9.34)	(9.58)	(9.41)	(9.04)	(9.79)	(9.71)	(9.41)
Number of years taught in a current school since the 2003-04 school year									
Zero and one year	737	791	902	741	810	908	936	1,104	1,132
Two years	415	412	444	424	428	375	502	399	424
Three years	433	325	315	447	346	370	472	412	317
Four and more years	1,110	1,291	1,296	1,187	1,437	1,479	1,251	1,457	1,549
Mobility status									
Teacher stayers	2,403	2,423	2,549	2,453	2,566	2,725	2,877	2,983	3,140
Teacher movers	292	396	408	346	455	407	413	492	382
Teacher transfers	115	159	178	141	202	193	183	228	188
Returned teachers	5	9	14	8	7	13	9	7	8
Temporary leavers	172	228	216	197	246	201	221	257	186
Average school size of tested students									
	83	82	83	93	93	94	167	168	171
	(43)	(42)	(42)	(58)	(56)	(57)	(106)	(107)	(112)
Number of teachers in schools by NCLB accountability in school year t - 1									
Good standing	2,349	2,377	2,475	2,399	2,437	2,477	2,550	2,484	2,082
Target	256	269	233	255	328	309	278	545	730
Under sanctions	29	97	177	87	146	243	227	197	479

Notes: Standard deviations in parentheses. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

I further measure the number of school years teachers have taught at the same schools. Schools can be traced back to the 2003-04 school year. I count the number of years in which a teacher has taught at the same school from the earliest year observable to the year prior to a current school year. This estimate varies from zero to eight in my sample, but the actual number of years some teachers have taught at the same school is larger than my estimates due to the limited number of years available for me to observe those teachers and their schools before the 2003-04 school year.

Over three years 2009-2010 through 2011-2012, there have been 85 to 89 percent of teacher stayers and 11 to 15 percent of teacher movers. Teachers are grouped as stayers if they teach in a school where they taught last year. Those movers include teacher transfers, teachers who returned to the schools they have taught before, and temporary leavers. Teacher transfers refer to the ones who transferred to a new school they have not taught before in a current school year. Teachers may not always move to schools new to them. A few teacher movers (80 in three years) have returned to the schools they had taught before. Those teachers are labeled as returned teachers. Lastly, teachers temporarily left teaching profession for purposes of education, baby birth, and sickness. Those teachers after one or two years of leaving start their teaching career again. Some of them returned to the same schools at the time they left the teaching profession; and the others went to a new school. Those teachers are grouped as temporary leavers in this study. In my analytical sample, I observe those temporary leavers in year $t + 1$ (i.e., the current school year) in schools, but they did not teach in year t. I further keep tracking those teachers in recent years prior to the year t and I have observed those teachers teaching in Tennessee's public elementary schools.

The average number of tested students over three analytical school years in grades 4, 5, and 6 is about 83, 94, and 169, respectively. There are more teachers teaching in grade 6 than in grades 4 and 5. Majority of those teachers have taught in the schools in good standing based on NCLB accountability status. Over three school years 2008-09 through 2010-2011, Tennessee's public elementary schools have not been performing well. More schools have been placed under the target and sanction status levels. The number of teachers in good standing schools have dropped from 86 percent in the 2008-09 school year to 76 percent in the 2010-2011 school year. The omitted category for school NLCB dummy variables is the schools under NCLB sanctions.

To test changes on the percent of students taught by individual teachers, the equation (4) further controls for observable teacher and school characteristics and the interaction terms between the absolute advantage and all those additional control variables. In mathematics equation, the interactions are with the absolute advantage in teaching mathematics; likewise with the absolute advantage in teaching English/language arts in the English/language arts equation and so does in each of the equations in science and social studies.

Table 5a through 5c present coefficient estimates for teachers' absolute advantages and their interaction effects with a set of teacher and school characteristics. In each table, regression analyses use a sample of teachers who taught separately in each subject in a grade. Before interpreting the effects of teachers' absolute advantage on teacher assignments, I first preform a set of F-tests to determine the joint strength of the interaction terms. A majority of p-values from the F-test statistics are above the significance level 0.1 except the mathematics (p-value = 0.045) and English/language arts (p-value = 0.093) models in grade 5 and the social studies (p-value == 0.014) model in grade 6.

Table 5a
Marginal effects of absolute advantages on percent of students taught in a subject in grade 4 interacting with observed teacher and school characteristics in three school years

Outcomes	Percent of students taught in grade 4 in school year (*t*)			
	Mathematics	English/ language arts	Science	Social studies
	(1)	(2)	(3)	(4)
Marginal effects of Absolute advantages in school year t - 1	3.507**	2.792	2.622*	1.088
	(1.253)	(2.167)	(1.210)	(0.637)
Coefficient estimates				
Absolute advantages in school year *t* - 1	-0.438	5.075	1.442	-0.449
	(2.948)	(5.769)	(2.322)	(1.865)
Education degree (Omitted: Bachelors)				
Masters	1.355	-1.443	-0.539	-1.853
	(1.522)	(2.984)	(1.689)	(1.380)
Education doctoral and above	3.798	-0.822	1.721	-3.987
	(5.146)	(4.763)	(4.312)	(2.896)
Years of teaching experience in all schools				
	-0.018	-0.230	0.006	0.083
	(0.090)	(0.148)	(0.069)	(0.077)
Number of years taught in a current school since the 2003-04 school year (Omitted: Zero and one year)				
Two years	1.897	0.781	-0.970	0.017
	(1.638)	(2.585)	(1.633)	(1.506)
Three years	2.188	-3.293	2.333	0.527
	(1.927)	(4.054)	(1.985)	(1.787)
Four and more years	4.875*	-1.546	2.445	0.450
	(2.096)	(3.468)	(1.809)	(1.834)
Teacher mobility (Omitted: Teacher stayers)				
Teacher movers	1.807	-3.681	-2.784	-0.099
	(3.654)	(10.487)	(3.028)	(2.438)
School size of tested students in grade 4				
	-0.011	-0.035	0.001	0.013
	(0.014)	(0.040)	(0.013)	(0.011)
School NCLB accountability in school year *t* - 1 (Omitted: Under sanction)				
Good standing	-0.115	5.806	0.299	0.594
	(0.740)	(3.449)	(1.559)	(1.435)
Target	-0.479	3.392	-0.207	-1.488
	(0.609)	(4.731)	(1.747)	(2.241)
F-test				
H_0: Interactions terms are jointly equal to zero	*p*-value = 0.3363	*p*-value = 0.5418	*p*-value = 0.7242	*p*-value = 0.6081
Observations	8,222	8,222	8,222	8,222
R-squared	0.344	0.429	0.346	0.326

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for school fixed effects and dummy variables for school year and the number of years taught by subject. Additional teacher and school controls include dummy variables for education degree, school NCLB status in year *t* - 1, and mobility status; years of teaching experience at all schools and dummy variables for the number of years taught at the current school; school size of tested students in grade 4; and their interaction terms with absolute advantages in the subject under study. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Table 5b
Marginal effects of absolute advantages on percent of students taught in a subject in grade 5 interacting with observed teacher and school characteristics in three school years

Outcomes	Percent of students taught in grade 5 in school year (*t*)			
	Mathematics	English/ language arts	Science	Social studies
	(1)	(2)	(3)	(4)
Marginal effects of Absolute advantages in school year t - 1	11.316***	6.268*	6.855**	0.721
	(2.080)	(2.090)	(2.069)	(1.318)
Coefficient estimates				
Absolute advantages in school year *t* - 1	0.741	-6.616	8.291	-4.120
	(8.789)	(8.659)	(7.377)	(5.329)
Education degree (Omitted: Bachelors)				
Masters	1.105	8.137†	-3.539	-0.740
	(3.001)	(4.402)	(2.787)	(2.329)
Education doctoral and above	2.575	8.314	-5.929	-4.931
	(5.424)	(7.481)	(5.506)	(4.423)
Years of teaching experience in all schools				
	0.131	-0.236	-0.116	-0.103
	(0.147)	(0.244)	(0.151)	(0.138)
Number of years taught in a current school since the 2003-04 school year (Omitted: Zero and one year)				
Two years	10.338**	-4.787	-1.787	6.604*
	(3.563)	(5.079)	(3.476)	(3.298)
Three years	5.321	0.900	0.713	6.791*
	(3.937)	(5.741)	(3.732)	(3.364)
Four and more years	10.133**	-7.686	5.471	8.067*
	(3.406)	(5.393)	(3.451)	(3.238)
Teacher mobility (Omitted: Teacher stayers)				
Teacher movers	3.166	0.345	-10.737†	-1.308
	(5.610)	(10.208)	(6.234)	(4.583)
School size of tested students in grade 5				
	0.022	-0.022	-0.023	-0.045
	(0.026)	(0.037)	(0.049)	(0.029)
School NCLB accountability in school year *t* - 1 (Omitted: Under sanction)				
Good standing	-1.590	17.747*	4.027	5.917
	(8.396)	(7.002)	(4.235)	(4.513)
Target	2.834	22.024**	-3.839	3.807
	(9.259)	(7.188)	(4.651)	(4.852)
F-test				
H_0: Interactions terms are jointly equal to zero	*p*-value = 0.045	*p*-value = 0.0931	*p*-value = 0.2334	*p*-value = 0.2844
Observations	8,629	8,629	8,629	8,629
R-squared	0.397	0.454	0.405	0.331

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for school fixed effects and dummy variables for school year and the number of years taught by subject. Additional teacher and school controls include dummy variables for education degree, school NCLB status in year *t* - 1, and mobility status; years of teaching experience at all schools and dummy variables for the number of years taught at the current school; school size of tested students in grade 5; and their interaction terms with absolute advantages in the subject under study. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Table 5c
Marginal effects of absolute advantages on percent of students taught in a subject in grade 6 interacting with observed teacher and school characteristics in three school years

Outcomes	Percent of students taught in grade 6 in school year (*t*)			
	Mathematics	English/ language arts	Science	Social studies
	(1)	(2)	(3)	(4)
Marginal effects of Absolute advantages in school year t - 1	17.674***	8.955*	12.627***	2.841
	(3.982)	(4.260)	(3.647)	(3.121)
Coefficient estimates				
Absolute advantages in school year *t* - 1	1.986	5.577	16.740*	14.689
	(11.059)	(10.264)	(8.251)	(9.968)
Education degree (Omitted: Bachelors)				
Masters	3.805	-1.645	-4.334	2.232
	(8.718)	(7.411)	(7.101)	(6.423)
Education doctoral and above	7.821	-6.602	8.690	15.412
	(16.021)	(10.374)	(14.176)	(13.804)
Years of teaching experience in all schools				
	-0.312	-0.024	-0.416	-0.416
	(0.463)	(0.361)	(0.412)	(0.386)
Number of years taught in a current school since the 2003-04 school year (Omitted: Zero and one year)				
Two years	3.064	1.088	-5.787	-6.909
	(8.270)	(6.382)	(7.077)	(8.060)
Three years	10.602	5.222	-2.983	30.418**
	(10.934)	(9.430)	(10.367)	(9.895)
Four and more years	16.541	15.106*	3.289	13.325
	(10.534)	(7.472)	(8.590)	(8.436)
Teacher mobility (Omitted: Teacher stayers)				
Teacher movers	2.277	9.318	-22.351†	24.264*
	(13.662)	(17.127)	(12.326)	(11.560)
School size of tested students in grade 6				
	0.035	0.008	0.032	-0.058†
	(0.028)	(0.035)	(0.032)	(0.032)
School NCLB accountability in school year *t* - 1 (Omitted: Under sanction)				
Good standing	0.526	-5.545	-1.232	-11.200
	(8.592)	(8.692)	(6.786)	(7.865)
Target	8.045	-5.137	-0.442	-15.906†
	(10.564)	(10.227)	(8.243)	(8.842)
F-test				
H_0: Interactions terms are jointly equal to zero	*p*-value = 0.6569	*p*-value = 0.8802	*p*-value = 0.4092	*p*-value = 0.0142
Observations	9,538	9,538	9,538	9,538
R-squared	0.546	0.520	0.535	0.485

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for school fixed effects and dummy variables for school year and the number of years taught by subject. Additional teacher and school controls include dummy variables for education degree, school NCLB status in year *t* - 1, and mobility status; years of teaching experience at all schools and dummy variables for the number of years taught at the current school; school size of tested students in grade 6; and their interaction terms with absolute advantages in the subject under study. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Although those test statistics show that the effects of teachers' absolute advantage on teacher assignments appear to be different between the models with and without interaction terms, there is no systematic patterns where coefficient estimates are significant across models separately in each subject and each grade. For all interaction terms but prior school NCLB accountability status, it is unlikely to believe that teacher and school characteristics affect the effects of teachers' absolute advantage on teacher assignments in different manners across subject and grades. In addition, the significant effects on prior school NCLB accountability interaction terms are different from what are normally expected. Test scores in social studies are not used to determine the annual school accountability status while I find a large but negative effect (-15.91 percent at $p < 0.1$) in the social studies model in grade 6. Moreover, the positive effects of school accountability found in the English/language arts model in grade 5 suggest a reversed relationship between receiving more pressure to improve school performance and the variation in teacher assignments. It is likely to be true that, when schools receive more pressures to raise student test scores in mathematics and English/language arts, rearranging assignments to take the advantage of relatively more effective teachers through specialization would be practiced in schools that were subject to NCLB sanctions (i.e., a negative effect on the dummy variables for schools in good standing and target under NCLB).

Overall, there are only 15 out of 120 interaction terms that are statistically significant across all models; and three out of 12 F-test statistics that indicate the coefficient estimates of interaction terms are not jointly equal to zero. These findings suggest that the select teacher and school characteristics do not strongly affect the effects of teachers' absolute advantage on teacher assignments in upper elementary grades 4 through 6 in Tennessee. The marginal effects reported in Tables 5a through 5c are roughly consistent with the ones in

Table 3, but slightly larger (smaller) in the regression analyses in mathematics (science).[19] The difference in the mathematics analyses is due to the weights used to estimate the overall marginal effects but not the changes in sample size and covariates.[20] Instead, the difference in the science analyses is mostly due to the changes in the sample and the inclusion of additional covariates.[21] The largest differences between models with and without controlling teacher and school characteristics happen in the equations in grade 6. For example, the effects of mathematics absolute advantage on mathematics assignment increase 12.4 percent from 15.48 percent in Table 3 to 17.67 percent in Table 5c. The two coefficient estimates are not statistically different from each other and this increase is only equivalent to an extra 0.5 student based a class of 25 students.

3. Additional Analyses Using Shrinkage Teacher Estimates

While teacher value added is subject to any kind of imprecision, literature has shown that researchers have adopted the empirical Bayesian estimator (also called "shrinkage estimators") to provide the best linear unbiased teacher estimates (Sander, 2000). This essay takes a step further where I use shrinkage teacher estimates to construct teacher absolute

[19] I discuss the results in mathematics and science analyses because the regression coefficients separately in each grade in those subjects are statistically significant. The regression coefficients are not always statistically significant in other subjects.

[20] To make this interpretation clear, suppose that the absolute advantage in teaching mathematics is interacted with a dummy variable and the impact on teacher assignments is higher when that dummy variable is equal to one. The overall marginal effects will increase when the analytical sample contains proportionally more records with ones in that dummy variable. Furthermore, I find that the regression coefficients are quite stable with and without controlling teacher and school characteristics.

[21] I find that the joint F-test statistics for all additional variables (including interaction terms) rejects the null hypothesis at $p < 0.01$. This indicates that at least one of additional covariates and their interactions with the absolute advantage in teaching science is not equal to zero. In fact, I find that teachers with Master degree are less likely to teach more percent of students in science than the ones with Bachelor degree (e.g., $p < 0.001$ in grade 4). It is likely that teachers with advanced degree have more influence to decide which subject they prefer to teach. The analyses in English/language arts show that the advanced degree is positively correlated with teacher assignments in English/language arts.

advantage and then re-estimate the impact of teacher relative effectiveness on subject specialization.[22]

Appendix G provides regression results using shrinkage estimates with and without school fixed effects. Tables G – 1 and G – 2 use the same three-year sample as shown in Table 3; instead, Table G – 3 and G – 4 use a sample of teachers in school years 2007-08 through 2011-2012. Since those analyses use shrinkage teacher estimates, it is not necessary to construct an average of teaching effectiveness over three years. This change allows me to use two more years of data for this study. These results are similar to the ones presented in Table 3, but they are significantly larger. For example, the impact of teacher absolute advantage in teaching mathematics on mathematics assignments increases by 10 percent for mathematics teachers in grade 6 in Table G – 1 compared to the one in Table 3. In addition, the six-year analyses suggest that teacher value added separately in each subject and in each grade is significantly and positively correlated with teacher assignments in each corresponding subject.

Conclusion

The purpose of this study is to examine the relationship between teacher value added and the share of a teacher's students in a subject in elementary schools. While researchers and statisticians have spent a great deal of effort to empirically develop measures for teaching effectiveness, few educators and policy-makers have paid attention to how those measures can be and why they should be used to improve teaching and learning in schools. This study fills this gap by considering whether teacher value-added estimates are useful for schools.

[22] For details on the model of shrinkage estimation for teaching effectiveness, see Chapter IV.

Overall, this study provides some empirical evidence that teacher value-added estimates are positively associated with specialization in four core academic subjects, mathematics, English/language arts, science, and social studies in all upper elementary grades or some grades. The findings suggest that teachers specialize in teaching those subjects where they are relatively more effective in grades 4 through 6 in Tennessee's public elementary schools.

These positive effects are small in grade 4, but large in grades 5 and 6 in mathematics and science. However, those effects are not statistically changed when considering the variation of teacher and school characteristics. The teaching effectiveness of mathematics teachers has the largest effects on subject specialization. The difference between the highest and the lowest impacts of teaching effectiveness is 12.38 percent (i.e., 15.48 – 3.1) between two grades 4 and 6. This suggests that, taking the 15.48 percent and a class of 25 students as an example, teachers who were one standard deviation above the average absolute advantage in teaching mathematics will teach roughly eight more students compared to the ones with one standard deviation below the average.[23]

Policy implications of this study are related to the potential of using teacher value-added data to make school personnel decisions. My findings indicate a positive relationship between teacher assignments and teaching effectiveness. Teachers do teach more students in the subject(s) where they are relatively more effective. The use of teacher value-added data in my analyses confirms this relationship regardless whether teacher value-added estimates have actually been used to make teacher assignments in Tennessee's public elementary schools. It is possible that the criteria used to make teacher assignments do not include teacher value-

[23] $25*(1+15.48\%) - 25*(1-15.48\%) = 7.74 \approx 8$

added data, but some of these criteria may be positively correlated with teaching effectiveness measured by teacher value-added estimates using my DOLS model.

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Appendix

Appendix A
Table A - 1
Number and percent of schools by grade, subject, and the average of TVAAS student participation rates over seven school years 2004-05 through 2010-2011

	Mathematics		English/ language arts		Science		Social studies	
	# schools	% schools	# schools	% schools	# schools	% schools	# schools	% schools
Grade 4								
90 - 100%	27	2.73%	27	2.73%	27	2.73%	29	2.93%
80 - 90%	125	12.63%	125	12.63%	122	12.32%	121	12.22%
70 - 80%	67	6.77%	71	7.17%	70	7.07%	70	7.07%
60 - 70%	85	8.59%	77	7.78%	80	8.08%	81	8.18%
50 - 60%	74	7.47%	77	7.78%	79	7.98%	76	7.68%
40 - 50%	104	10.51%	106	10.71%	100	10.10%	103	10.40%
30 - 40%	157	15.86%	158	15.96%	161	16.26%	156	15.76%
20 - 30%	310	31.31%	309	31.21%	309	31.21%	310	31.31%
10 - 20%	34	3.43%	33	3.33%	35	3.54%	37	3.74%
0 - 10%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total	983	100%	983	100%	983	100%	983	100%
Grade 5								
90 - 100%	49	5.31%	51	5.53%	49	5.31%	47	5.10%
80 - 90%	247	26.79%	248	26.90%	248	26.90%	246	26.68%
70 - 80%	107	11.61%	109	11.82%	107	11.61%	109	11.82%
60 - 70%	81	8.79%	81	8.79%	80	8.68%	78	8.46%
50 - 60%	75	8.13%	72	7.81%	72	7.81%	75	8.13%
40 - 50%	74	8.03%	71	7.70%	76	8.24%	75	8.13%
30 - 40%	82	8.89%	84	9.11%	85	9.22%	84	9.11%
20 - 30%	183	19.85%	182	19.74%	179	19.41%	184	19.96%
10 - 20%	19	2.06%	19	2.06%	21	2.28%	19	2.06%
0 - 10%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total	917	100%	917	100%	917	100%	917	100%
Grade 6								
90 - 100%	65	10.82%	67	11.15%	69	11.48%	66	10.98%
80 - 90%	364	60.57%	375	62.40%	353	58.74%	359	59.73%
70 - 80%	89	14.81%	80	13.31%	95	15.81%	91	15.14%
60 - 70%	27	4.49%	23	3.83%	28	4.66%	28	4.66%
50 - 60%	6	1.00%	8	1.33%	8	1.33%	9	1.50%
40 - 50%	11	1.83%	9	1.50%	9	1.50%	9	1.50%
30 - 40%	13	2.16%	13	2.16%	13	2.16%	13	2.16%
20 - 30%	16	2.66%	16	2.66%	16	2.66%	16	2.66%
10 - 20%	5	0.83%	5	0.83%	5	0.83%	5	0.83%
0 - 10%	1	0.17%	1	0.17%	1	0.17%	0	0.00%
Total	597	100%	597	100%	597	100%	596	100%

Notes: The reported number and percent of schools are placed into 10 quintiles of the average participation rates. The TVAAS student participation rate is equal to the ratio between the number of students linked to TVAAS teachers and the students with test scores at a given grade in a school. This study averages the participation rates over seven school years in a grade in a school (when available).

Appendix B
Table B - 1
District names by region and urbanicity category

	City	Suburb and Town		Rural		
	(1)	(1)	(2)	(1)	(2)	(3)
West Tennessee	Madison County	Dyersburg	McKenzie	Alamo	Fayette County	McNairy County
	Memphis	Hardeman County	Paris	Bells	Gibson Co Sp Dist	Milan
		Haywood County	Shelby County	Benton County	H Rock Bruceton	Obion County
		Humboldt	Trenton	Bradford	Hardin County	South Carroll
		Lauderdale County	Union City	Chester County	Henderson County	Tipton County
		Lexington		Crockett County	Henry County	Weakley County
				Decatur County	Huntingdon	West Carroll
				Dyer County	Lake County	
Middle Tennessee	Davidson County	Dickson County	Maury County	Bedford County	Humphreys County	Rutherford County
	Franklin SSD	Fayetteville	Putnam County	Cannon County	Jackson County	Sequatchie County
	Montgomery County	Franklin County	Sumner County	Cheatham County	Lawrence County	Smith County
	Murfreesboro	Lebanon	Tullahoma	Clay County	Lincoln County	Stewart County
		Lewis County	White County	Coffee County	Macon County	Trousdale County
		Manchester		DeKalb County	Marshall County	Van Buren County
				Fentress County	Moore County	Warren County
				Giles County	Overton County	Wayne County
				Grundy County	Perry County	Williamson County
				Hickman County	Pickett County	Wilson County
				Houston County	Robertson County	
East Tennessee	Bristol	Alcoa	Knox County	Anderson County	Greene County	Morgan County
	Cleveland	Athens	Maryville	Bledsoe County	Hancock County	Polk County
	Hamblen County	Carter County	Newport	Blount County	Jefferson County	Rhea County
	Johnson City	Clinton	Oak Ridge	Bradley County	Lenoir City	Richard City
	Kingsport	Dayton	Oneida	Campbell County	Loudon County	Scott County
		Elizabethton	Roane County	Claiborne County	Marion County	Sweetwater
		Etowah	Rogersville	Cocke County	McMinn County	Union County
		Greeneville	Sevier County	Cumberland County	Meigs County	Washington County
		Hamilton County	Sullivan County	Grainger County	Monroe County	
		Hawkins County	Unicoi County			
		Johnson County				

Notes: Special school districts are not included in this study.

Appendix C
Table C - 1
Number of elementary school teachers who taught multiple grades by subject scheme in school years 2009-2010 through 2011-2012

Grade level			School year		
4	5	6	2009-2010	2010-2011	2011-2012
---	SOC	SOC	11	18	26
---	SOC	ELA	0	1	1
---	SOC	ELA-SOC	0	5	3
---	SOC	MTH-ELA-SCI-SOC	1	1	2
---	SCI	SOC	0	0	2
---	SCI	SCI	12	21	26
---	SCI	SCI-SOC	2	0	0
---	SCI	ELA-SCI	0	1	1
---	SCI	ELA-SCI-SOC	0	1	0
---	SCI	MTH	0	0	1
---	SCI	MTH-SCI	0	0	1
---	SCI	MTH-ELA-SCI-SOC	6	2	6
---	SCI-SOC	SOC	0	0	1
---	SCI-SOC	SCI	0	0	1
---	SCI-SOC	SCI-SOC	1	2	4
---	SCI-SOC	ELA	1	0	0
---	SCI-SOC	MTH-ELA-SCI-SOC	2	0	0
---	ELA	SOC	1	1	0
---	ELA	SCI-SOC	1	0	0
---	ELA	ELA	48	65	67
---	ELA	ELA-SOC	2	0	5
---	ELA	ELA-SCI	1	0	0
---	ELA	ELA-SCI-SOC	0	0	1
---	ELA	MTH-ELA	2	0	0
---	ELA	MTH-ELA-SCI-SOC	15	7	7
---	ELA-SOC	SOC	2	1	1
---	ELA-SOC	ELA	1	3	3
---	ELA-SOC	ELA-SOC	2	1	2
---	ELA-SOC	MTH-ELA-SCI-SOC	0	1	1
---	ELA-SCI	SCI	2	1	1
---	ELA-SCI	ELA	0	3	0
---	ELA-SCI	ELA-SCI	0	1	0
---	ELA-SCI-SOC	ELA-SCI-SOC	1	0	0
---	MTH	SCI	1	0	0
---	MTH	ELA	1	0	1
---	MTH	MTH	13	18	28
---	MTH	MTH-SOC	0	1	1
---	MTH	MTH-ELA	2	2	1
---	MTH	MTH-ELA-SCI-SOC	6	9	6
---	MTH-SOC	SOC	0	0	1
---	MTH-SOC	MTH	1	1	3
---	MTH-SOC	MTH-SOC	0	1	0
---	MTH-SCI	MTH	1	1	2
---	MTH-SCI	MTH-SCI	1	3	0
---	MTH-SCI	MTH-ELA-SCI-SOC	0	1	1
---	MTH-SCI-SOC	MTH-SCI-SOC	2	1	0
---	MTH-ELA	ELA	2	1	0
---	MTH-ELA	MTH	1	1	3
---	MTH-ELA	MTH-ELA	6	2	1
---	MTH-ELA	MTH-ELA-SCI-SOC	0	1	0
---	MTH-ELA-SOC	ELA	0	1	1
---	MTH-ELA-SCI	MTH-ELA-SCI	2	0	1
---	MTH-ELA-SCI	MTH-ELA-SCI-SOC	0	1	0
---	MTH-ELA-SCI-SOC	SOC	4	5	2
---	MTH-ELA-SCI-SOC	SCI	3	4	4

Grade level			School year		
4	5	6	2009-2010	2010-2011	2011-2012
---	MTH-ELA-SCI-SOC	SCI-SOC	1	4	3
---	MTH-ELA-SCI-SOC	ELA	8	13	13
---	MTH-ELA-SCI-SOC	ELA-SOC	1	2	0
---	MTH-ELA-SCI-SOC	ELA-SCI	0	1	0
---	MTH-ELA-SCI-SOC	ELA-SCI-SOC	1	0	0
---	MTH-ELA-SCI-SOC	MTH	6	2	3
---	MTH-ELA-SCI-SOC	MTH-SCI	0	0	1
---	MTH-ELA-SCI-SOC	MTH-ELA	1	0	1
---	MTH-ELA-SCI-SOC	MTH-ELA-SCI-SOC	10	16	4
SOC	---	SOC	0	0	1
SOC	SOC	---	0	4	2
SOC	SOC	SOC	1	1	0
SOC	SCI	SCI	0	0	1
SOC	SCI-SOC	SCI-SOC	0	0	1
SOC	ELA-SOC	---	1	1	5
SOC	MTH-ELA-SCI-SOC	---	1	1	2
SCI	---	SCI	0	0	1
SCI	SCI	---	3	7	3
SCI	SCI-SOC	---	0	1	0
SCI	ELA-SCI	---	2	0	2
SCI	ELA-SCI	SCI	1	1	0
SCI	MTH-ELA-SCI	---	0	0	1
SCI	MTH-ELA-SCI-SOC	---	2	5	7
SCI-SOC	---	SCI	1	0	0
SCI-SOC	SCI-SOC	---	3	2	2
SCI-SOC	ELA	---	1	0	0
SCI-SOC	ELA-SCI-SOC	---	1	1	0
SCI-SOC	MTH-ELA-SCI-SOC	---	1	0	4
ELA	---	SOC	0	0	1
ELA	---	SCI-SOC	0	0	1
ELA	---	ELA	0	1	4
ELA	SOC	---	1	0	0
ELA	ELA	---	57	64	78
ELA	ELA	ELA	11	6	4
ELA	ELA-SOC	---	0	1	0
ELA	ELA-SOC	ELA-SOC	0	0	1
ELA	MTH-ELA	---	0	0	1
ELA	MTH-ELA-SOC	---	1	0	0
ELA	MTH-ELA-SCI-SOC	---	9	7	12
ELA-SOC	SOC	---	4	2	2
ELA-SOC	ELA	---	1	0	0
ELA-SOC	ELA-SOC	---	1	4	0
ELA-SOC	MTH-ELA-SCI-SOC	---	1	2	6
ELA-SCI	SCI	---	3	3	4
ELA-SCI	ELA-SCI	---	2	4	1
ELA-SCI	MTH-ELA-SCI-SOC	---	0	0	1
ELA-SCI-SOC	ELA-SOC	---	0	0	1
ELA-SCI-SOC	ELA-SCI-SOC	---	0	1	1
MTH	---	SCI	1	0	0
MTH	---	MTH	0	0	2
MTH	MTH	---	11	16	10
MTH	MTH	MTH	1	1	1
MTH	MTH-SCI	---	1	0	0
MTH	MTH-ELA	---	2	3	4
MTH	MTH-ELA	ELA	1	0	0
MTH	MTH-ELA	MTH	1	0	0
MTH	MTH-ELA-SCI	---	0	1	0
MTH	MTH-ELA-SCI-SOC	---	1	4	8
MTH-SOC	MTH-SOC	---	1	0	1
MTH-SCI	MTH-SCI-SOC	---	0	1	0

Grade level			School year		
4	5	6	2009-2010	2010-2011	2011-2012
MTH-SCI	MTH-ELA-SCI	---	1	0	0
MTH-SCI	MTH-ELA-SCI-SOC	---	1	0	4
MTH-SCI-SOC	---	SCI	0	1	0
MTH-SCI-SOC	---	MTH-ELA-SOC	0	0	1
MTH-SCI-SOC	MTH-SCI-SOC	---	0	0	1
MTH-ELA	---	MTH-ELA	0	0	1
MTH-ELA	MTH	---	2	2	1
MTH-ELA	MTH	ELA	1	0	0
MTH-ELA	MTH-ELA	---	10	9	4
MTH-ELA	MTH-ELA	ELA	0	1	0
MTH-ELA	MTH-ELA	MTH-ELA	2	0	0
MTH-ELA	MTH-ELA-SCI-SOC	---	1	0	0
MTH-ELA-SOC	SOC	---	0	1	0
MTH-ELA-SOC	MTH-ELA-SOC	---	1	0	0
MTH-ELA-SOC	MTH-ELA-SCI-SOC	---	1	0	0
MTH-ELA-SCI	SCI	---	1	1	0
MTH-ELA-SCI	MTH-ELA-SCI	---	0	1	0
MTH-ELA-SCI-SOC	---	ELA	1	0	0
MTH-ELA-SCI-SOC	---	MTH-ELA-SCI-SOC	1	1	1
MTH-ELA-SCI-SOC	SOC	---	3	5	4
MTH-ELA-SCI-SOC	SCI	---	3	1	3
MTH-ELA-SCI-SOC	SCI	SCI	0	0	1
MTH-ELA-SCI-SOC	SCI-SOC	---	0	1	2
MTH-ELA-SCI-SOC	ELA	---	5	2	16
MTH-ELA-SCI-SOC	ELA-SOC	---	0	2	4
MTH-ELA-SCI-SOC	ELA-SCI	---	1	0	0
MTH-ELA-SCI-SOC	ELA-SCI-SOC	---	0	1	2
MTH-ELA-SCI-SOC	MTH	---	3	2	8
MTH-ELA-SCI-SOC	MTH-SOC	---	0	0	1
MTH-ELA-SCI-SOC	MTH-SCI	---	2	2	4
MTH-ELA-SCI-SOC	MTH-SCI-SOC	---	0	1	2
MTH-ELA-SCI-SOC	MTH-ELA	---	0	1	1
MTH-ELA-SCI-SOC	MTH-ELA	---	0	0	1
MTH-ELA-SCI-SOC	MTH-ELA-SCI	---	0	1	0
MTH-ELA-SCI-SOC	MTH-ELA-SCI-SOC	---	15	33	24
MTH-ELA-SCI-SOC	MTH-ELA-SCI-SOC	MTH-ELA-SCI-SOC	5	5	5
Total number of teachers			377	447	511

Notes: Sample includes teachers who taught at multiple grades, who have lagged value-added estimates over a four-year span prior to their current school year, who have taught at grades 4 through 6 in three school years 2009-2010 through 2011-2012 in Tennessee's public elementary schools, and who have taught more than six students in at least one subject in their current school year. Each of the six students attended their teacher's class in a subject for at least 150 calendar days. The calendar days do not include weekends, holidays, and enrollment gaps for individual students.

Appendix D
Table D - 1
Number of elementary school teachers who taught in grade 4 at the same school in the 2010-2011 and 2011-2012 school years by subject scheme

	School year 2010-2011														
Grade 4	SOC	SCI	SCI-SOC	ELA	ELA-SOC	ELA-SCI	ELA-SCI-SOC	MTH	MTH-SOC	MTH-SCI	MTH-SCI-SOC	MTH-ELA	MTH-ELA-SOC	MTH-ELA-SCI	MTH-ELA-SCI-SOC
School year 2011-2012															
SOC	4	0	0	0	0	0	1	0	0	0	2	0	0	0	2
SCI	0	5	2	2	0	1	0	0	0	0	0	0	0	0	3
SCI-SOC	1	3	7	0	0	0	4	0	0	0	1	0	0	0	4
ELA	0	1	0	67	4	2	0	0	0	0	0	1	0	0	14
ELA-SOC	0	0	0	0	11	0	2	0	0	0	0	1	3	0	11
ELA-SCI	0	1	0	0	0	5	1	0	0	0	0	0	0	0	7
ELA-SCI-SOC	0	0	0	0	2	0	2	0	0	0	0	0	0	1	2
MTH	1	0	0	0	0	0	0	16	0	0	1	6	0	0	8
MTH-SOC	1	0	0	0	1	0	0	1	2	0	0	0	0	0	1
MTH-SCI	0	0	0	0	0	0	0	1	0	4	0	1	0	1	2
MTH-SCI-SOC	0	0	1	0	1	0	1	0	0	0	2	0	0	0	2
MTH-ELA	0	0	0	1	0	0	0	3	0	0	0	10	0	1	9
MTH-ELA-SOC	0	0	1	0	0	0	0	0	0	0	0	0	5	0	2
MTH-ELA-SCI	0	0	0	0	0	0	0	0	0	0	0	0	0	6	7
MTH-ELA-SCI-SOC	1	0	1	12	3	4	3	3	0	1	0	4	5	7	1,813
Total number of teachers	8	10	12	82	22	12	14	24	2	5	6	23	13	16	1,887

Table D - 2

Number of elementary school teachers who taught in grade 5 at the same school in the 2010-2011 and 2011-2012 school years by subject scheme

	School year 2010-2011														
Grade 5	SOC	SCI	SCI-SOC	ELA	ELA-SOC	ELA-SCI	ELA-SCI-SOC	MTH	MTH-SOC	MTH-SCI	MTH-SCI-SOC	MTH-ELA	MTH-ELA-SOC	MTH-ELA-SCI	MTH-ELA-SCI-SOC
School year 2011-2012															
SOC	25	0	1	1	3	0	0	1	1	0	0	0	0	1	5
SCI	0	27	1	0	0	5	1	1	0	2	2	1	0	0	5
SCI-SOC	2	3	19	1	8	2	2	0	0	2	3	1	0	0	10
ELA	2	1	0	158	24	5	0	2	1	0	0	4	0	2	20
ELA-SOC	3	0	0	13	55	2	2	2	1	1	0	4	0	0	21
ELA-SCI	0	3	1	1	0	19	1	0	0	0	2	0	0	2	6
ELA-SCI-SOC	0	0	1	2	3	0	2	0	0	0	0	0	0	1	4
MTH	1	0	0	1	0	0	0	54	2	8	14	6	1	0	11
MTH-SOC	1	0	1	0	0	0	0	7	2	0	2	1	6	0	7
MTH-SCI	0	2	1	0	1	1	0	2	1	17	18	1	1	1	10
MTH-SCI-SOC	0	0	1	0	0	0	0	0	0	0	10	1	1	0	3
MTH-ELA	0	0	0	0	0	0	1	2	0	0	1	25	0	1	9
MTH-ELA-SOC	0	0	0	0	1	1	0	1	1	0	0	2	5	0	6
MTH-ELA-SCI	0	1	1	0	0	1	0	0	0	1	0	0	0	8	3
MTH-ELA-SCI-SOC	2	7	2	11	7	4	6	6	1	1	6	2	3	6	1,449
Total number of teachers	36	44	29	188	102	40	15	78	10	32	58	48	17	22	1,569

Table D - 3
Number of elementary school teachers who taught in grade 6 at the same school in the 2010-2011 and 2011-2012 school years by subject scheme

	School year 2010-2011														
Grade 6	SOC	SCI	SCI-SOC	ELA	ELA-SOC	ELA-SCI	ELA-SCI-SOC	MTH	MTH-SOC	MTH-SCI	MTH-SCI-SOC	MTH-ELA	MTH-ELA-SOC	MTH-ELA-SCI	MTH-ELA-SCI-SOC
School year 2011-2012															
SOC	203	1	7	9	31	0	0	5	4	0	0	0	0	0	20
SCI	1	203	11	5	1	21	1	6	1	1	0	0	0	0	36
SCI-SOC	6	11	51	2	6	1	1	1	0	3	4	0	0	0	8
ELA	6	1	3	506	24	7	0	3	0	0	0	5	1	0	59
ELA-SOC	13	0	1	31	56	0	3	1	1	0	0	2	2	0	12
ELA-SCI	0	7	2	7	2	39	0	0	0	0	0	0	0	1	7
ELA-SCI-SOC	0	0	1	0	3	2	0	0	0	0	0	0	0	0	2
MTH	2	1	2	6	2	1	0	266	14	17	6	24	2	2	40
MTH-SOC	1	0	0	1	2	0	0	4	12	0	2	2	1	0	5
MTH-SCI	1	3	0	1	0	2	0	6	1	27	11	2	0	0	3
MTH-SCI-SOC	0	0	0	0	1	0	0	0	0	0	2	0	0	0	2
MTH-ELA	0	0	0	4	0	0	0	9	0	1	0	27	0	1	10
MTH-ELA-SOC	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
MTH-ELA-SCI	0	1	0	1	0	0	0	0	0	0	0	1	0	1	2
MTH-ELA-SCI-SOC	19	18	4	56	16	7	0	23	3	0	1	9	0	1	270
Total number of teachers	252	246	82	629	144	80	5	324	36	49	26	74	6	6	477

Notes: Sample includes teachers who taught at two adjacent school years at the same school, who have lagged value-added estimates over a four-year span prior to their current school year, and who have taught more than five students in at least one subject in their current school year. Each of the six students attended their teacher's class in a subject for at least 150 calendar days. The calendar days do not include weekends, holidays, and enrollment gaps for individual students.

Appendix E
Table E - 1
Marginal effects of teaching experience on the share of a teacher's students in Tennessee's public elementary schools in nine school years 2003-04 through 2011-2012

Outcomes	Herfindahl index: Sum of square of the share of a teacher's students in each subject			
	Model (1)	Model (2)		
OLS Specification		Grade 4	Grade 5	Grade 6
Years of teaching experience (Omitted: Zero to 5)				
6 to 10	0.000	0.0039	-0.0010	-0.0022
	(0.004)	(0.0049)	(0.0061)	(0.0061)
11 to 15	0.005	0.0070	-0.0023	0.0115
	(0.005)	(0.0062)	(0.0082)	(0.0079)
16 to 20	0.021***	0.0228**	0.0347**	0.0060
	(0.006)	(0.0077)	(0.0108)	(0.0089)
≥ 21	0.019***	0.0163*	0.0196*	0.0207*
	(0.006)	(0.0066)	(0.0093)	(0.0083)
F-test statistics: *df* = 8; *p* -value: 0.0748				
Observations	96,597		96,597	
R-square	0.328		0.328	
	Model (1)	Model (2)		
TCH-FE Specification		Grade 4	Grade 5	Grade 6
Years of teaching experience (Omitted: Zero to 5)				
6 to 10	0.003	0.0023	0.0036	0.0022
	(0.003)	(0.0047)	(0.0045)	(0.0046)
11 to 15	0.008*	0.0070	0.0019	0.0159**
	(0.004)	(0.0061)	(0.0061)	(0.0059)
16 to 20	0.015**	0.0174*	0.0174*	0.0099
	(0.005)	(0.0071)	(0.0079)	(0.0068)
≥ 21	0.014***	0.0085	0.0105†	0.0225***
	(0.004)	(0.0064)	(0.0062)	(0.0058)
F-test statistics: *df* = 8; *p* -value: 0.1845				
Observations	96,597		96,597	
R-square	0.545		0.545	

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001; sample includes all teachers who have taught in grades 4 through 6 in nine school years 2003-04 through 2011-2012 in Tennessee's public elementary schools and who have taught more than five students in at least one subject in a school year. Models control for dummy variables for education levels, grades, and years. The models labeled as "TCH-FE" control for teacher fixed effects.

Appendix F
Table F - 1
Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in three school years without school fixed effects

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**2.543****	-0.126	-1.504†	-0.913
	(0.947)	(1.050)	(0.801)	(0.707)
English/	-0.722	**1.993**	-0.811	-0.460
language arts	(1.047)	**(1.631)**	(0.886)	(0.883)
Science	0.350	-1.377	**2.325***	-1.297†
	(0.873)	(1.256)	**(0.908)**	(0.825)
Social studies	-0.125	0.055	-1.249*	**1.319****
	(0.547)	(0.636)	(0.497)	**(0.500)**
Observations	8,471	8,471	8,471	8,471
R-squared	0.275	0.324	0.266	0.242
Grade 5				
Mathematics	**8.788*****	-5.656***	-3.738**	0.606
	(1.507)	(1.505)	(1.183)	(1.188)
English/	-3.911*	**6.884****	-1.332	-1.640
language arts	(1.660)	**(2.368)**	(1.737)	(1.762)
Science	-1.267	-4.124*	**5.976*****	-0.585
	(1.554)	(1.934)	**(1.585)**	(1.535)
Social studies	-1.081	2.435†	-2.062*	**0.707**
	(0.913)	(1.324)	(0.835)	**(1.051)**
Observations	8,952	8,952	8,952	8,952
R-squared	0.338	0.367	0.349	0.259
Grade 6				
Mathematics	**14.370*****	-3.103	-7.319***	-3.948*
	(3.377)	(2.873)	(2.129)	(1.963)
English/	0.997	**5.826**	-5.817**	-1.007
language arts	(1.892)	**(3.406)**	(1.947)	(1.714)
Science	-7.269**	-8.344**	**14.096*****	1.517
	(2.529)	(2.971)	**(3.335)**	(2.015)
Social studies	1.393	-2.226	0.370	**0.463**
	(2.203)	(2.458)	(2.229)	**(2.802)**
Observations	9,955	9,955	9,955	9,955
R-squared	0.503	0.462	0.496	0.437

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Appendix G

Table G - 1

Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in three school years 2009-2010 through 2011-2012

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**4.659****	-1.191	-2.688	-0.780
	(1.544)	(1.839)	(1.412)	(1.243)
English/ language arts	-3.627	**5.854†**	-0.772	-1.455
	(2.190)	**(3.022)**	(1.971)	(1.956)
Science	1.153	-3.981	**4.583***	-1.755
	(1.624)	(2.299)	**(1.804)**	(1.600)
Social studies	-0.016	0.716	-2.495**	**1.795***
	(1.004)	(1.218)	(0.897)	**(0.883)**
Observations	8,471	8,471	8,471	8,471
R-squared	0.3362	0.4166	0.3314	0.3161
Grade 5				
Mathematics	**18.305*****	-7.376**	-7.623**	-3.306
	(2.913)	(2.749)	(2.364)	(2.162)
English/ language arts	-10.984***	**14.764****	-4.529	0.749
	(3.202)	**(4.974)**	(3.564)	(3.316)
Science	-3.863	-9.212**	**13.571*****	-0.496
	(2.896)	(3.355)	**(3.125)**	(2.496)
Social studies	0.131	1.396	-3.905*	**2.378**
	(1.848)	(2.194)	(1.579)	**(1.909)**
Observations	8,952	8,952	8,952	8,952
R-squared	0.3878	0.4375	0.3922	0.3169
Grade 6				
Mathematics	**25.924*****	-4.551	-11.055**	-10.318**
	(5.530)	(4.246)	(3.489)	(3.241)
English/language arts	-0.503	**13.328***	-10.942**	-1.883
	(3.546)	**(6.196)**	(3.840)	(3.681)
Science	-8.737*	-16.004***	**24.718*****	0.023
	(3.950)	(4.353)	**(5.139)**	(3.586)
Social studies	2.658	-3.567	-3.160	**4.069**
	(3.722)	(4.137)	(3.304)	**(5.068)**
Observations	9,955	9,955	9,955	9,955
R-squared	0.5301	0.5024	0.5210	0.4685

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Shrinkage estimates for teachers are used to estimate absolute advantages in teaching separatel each subject. Models control for school fixed effects and dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Table G - 2

Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in three school years 2009-2010 through 2011-2012 without school fixed effects

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**3.603****	0.441	-2.506*	-1.538
	(1.277)	(1.441)	(1.150)	(1.031)
English/ language arts	-2.441	**3.939**	-0.621	-0.877
	(1.770)	**(2.511)**	(1.625)	(1.632)
Science	1.097	-3.345	**3.612***	-1.364
	(1.223)	(1.750)	**(1.404)**	(1.252)
Social studies	-0.287	0.019	-1.923**	**2.191****
	(0.812)	(0.909)	(0.726)	**(0.755)**
Observations	8,471	8,471	8,471	8,471
R-squared	0.275	0.324	0.266	0.242
Grade 5				
Mathematics	**14.489*****	-7.550***	-5.407**	-1.533
	(2.216)	(2.087)	(1.777)	(1.647)
English/ language arts	-10.278***	**14.288*****	-3.734	-0.275
	(2.657)	**(4.236)**	(2.921)	(2.750)
Science	-1.944	-7.679**	**11.058*****	-1.435
	(2.262)	(2.794)	**(2.488)**	(2.020)
Social studies	-0.758	1.202	-3.398**	**2.954†**
	(1.377)	(1.717)	(1.182)	**(1.547)**
Observations	8,952	8,952	8,952	8,952
R-squared	0.340	0.368	0.350	0.260
Grade 6				
Mathematics	**23.991*****	-5.360	-9.696**	-8.935**
	(4.946)	(3.813)	(3.110)	(2.880)
English/ language arts	-0.576	**13.520***	-10.340**	-2.605
	(3.246)	**(5.796)**	(3.526)	(3.381)
Science	-9.237**	-15.621***	**23.916*****	0.943
	(3.475)	(4.004)	**(4.576)**	(3.102)
Social studies	2.898	-2.804	-2.927	**2.833**
	(3.378)	(3.730)	(2.894)	**(4.570)**
Observations	9,955	9,955	9,955	9,955
R-squared	0.504	0.463	0.497	0.437

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Shrinkage estimates for teachers are used to estimate absolute advantages in teaching separatel each subject. Models control for dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Table G - 3

Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in five school years 2007-08 through 2011-2012

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**3.107****	-0.554	-1.499	-1.054
	(0.996)	(1.131)	(0.780)	(0.722)
English/	-2.233	**4.068†**	-0.331	-1.505
language arts	(1.449)	**(2.202)**	(1.306)	(1.312)
Science	0.526	-1.729	**2.778****	-1.574
	(1.052)	(1.393)	**(1.040)**	(0.932)
Social studies	-0.072	-0.340	-1.734*	**2.145****
	(0.746)	(0.936)	(0.680)	**(0.698)**
Observations	13,963	13,963	13,963	13,963
R-squared	0.3462	0.4041	0.3281	0.3271
Grade 5				
Mathematics	**11.751*****	-4.875**	-4.388**	-2.488
	(1.702)	(1.832)	(1.443)	(1.448)
English/	-7.407***	**11.388****	-2.023	-1.958
language arts	(2.114)	**(3.685)**	(2.321)	(2.065)
Science	-2.369	-6.916**	**9.634*****	-0.350
	(1.692)	(2.315)	**(2.245)**	(1.642)
Social studies	-1.147	0.976	-4.110**	**4.281****
	(1.338)	(1.714)	(1.294)	**(1.654)**
Observations	14,701	14,701	14,701	14,701
R-squared	0.3876	0.4244	0.3742	0.3158
Grade 6				
Mathematics	**21.069*****	-4.375	-8.652***	-8.041**
	(4.137)	(3.225)	(2.536)	(2.575)
English/language arts	-2.557	**12.503***	-7.715*	-2.232
	(3.065)	**(4.898)**	(3.114)	(3.011)
Science	-7.541**	-6.954*	**16.441*****	-1.946
	(2.667)	(3.222)	**(3.795)**	(2.451)
Social studies	0.238	-2.301	-5.351*	**7.414†**
	(2.567)	(3.046)	(2.656)	**(4.018)**
Observations	16,325	16,325	16,325	16,325
R-squared	0.5222	0.4891	0.5112	0.4579

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Shrinkage estimates for teachers are used to estimate absolute advantages in teaching separatel each subject. Models control for school fixed effects and dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

Table G - 4

Marginal effects of teachers' absolute advantages on teacher assignments separately in each grade in five school years 2007-08 through 2011-2012 without school fixed effects

Outcomes	Percent of students taught in the school year (*t*)			
Marginal effects of absolute advantages in school year *t* - 1	Mathematics (1)	English/ language arts (2)	Science (3)	Social studies (4)
Grade 4				
Mathematics	**2.751****	0.538	-1.630*	-1.659**
	(0.842)	(0.948)	(0.662)	(0.618)
English/	-1.618	**2.975**	-0.213	-1.144
language arts	(1.238)	**(1.933)**	(1.117)	(1.140)
Science	0.402	-1.670	**2.321****	-1.053
	(0.852)	(1.154)	**(0.870)**	(0.773)
Social studies	-0.321	-0.841	-1.174	**2.337*****
	(0.646)	(0.800)	(0.600)	**(0.626)**
Observations	13,963	13,963	13,963	13,963
R-squared	0.300	0.335	0.278	0.270
Grade 5				
Mathematics	**10.008*****	-5.145***	-3.277**	-1.586
	(1.389)	(1.474)	(1.136)	(1.152)
English/	-6.557***	**10.842*****	-2.247	-2.038
language arts	(1.922)	**(3.281)**	(2.072)	(1.837)
Science	-1.974	-5.965**	**8.809*****	-0.870
	(1.449)	(2.080)	**(1.934)**	(1.419)
Social studies	-1.249	0.791	-4.007***	**4.465****
	(1.097)	(1.472)	(1.072)	**(1.429)**
Observations	14,701	14,701	14,701	14,701
R-squared	0.350	0.374	0.345	0.272
Grade 6				
Mathematics	**19.691*****	-4.983	-7.303**	-7.405**
	(3.821)	(2.944)	(2.386)	(2.384)
English/	-2.614	**12.185****	-6.951*	-2.620
language arts	(2.881)	**(4.715)**	(2.939)	(2.882)
Science	-8.137**	-7.410*	**16.146*****	-0.599
	(2.505)	(3.081)	**(3.475)**	(2.213)
Social studies	0.538	-2.011	-4.561	**6.035**
	(2.408)	(2.955)	(2.404)	**(3.727)**
Observations	16,325	16,325	16,325	16,325
R-squared	0.503	0.456	0.493	0.433

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Shrinkage estimates for teachers are used to estimate absolute advantages in teaching separatel each subject. Models control for dummy variables for the number of years taught separately in each subject and school year. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

CHAPTER III

EFFECTS OF SUBJECT SPECIALZIATION ON STUDENT ACHIEVEMENT

Introduction

Elementary school teacher certification is for generalists prepared to teach in self-contained classrooms, where students receive instructions in all subjects from the same teacher. Although such certifications allow elementary school teachers to teach a wide range of subjects, those generalist teachers are not equally effective in teaching all subjects (Anderson, 1962). The research literature on teaching effectiveness has also shown that teacher job performance may often differ substantially across subjects.

Researchers have found that some elementary school teachers teach in self-contained classrooms while other elementary school teachers teach different classes of students, and have done so since the 1920s. The latter group comprises content-specific teachers who specialize fully or partially in teaching one subject or some subjects in elementary schools. The observed specialization in elementary schools, to some extent, may result in some structural changes in the organization of schooling where teachers teach in their area of specialization and move from one classroom to another for instruction (i.e., a typical departmentalized organization which is widely operated in middle and high schools).

Many studies have documented mixed school organization structures (i.e., both self-contained classrooms and departmentalized organizations) in upper elementary grades 4 through 6. Specialization becomes increasingly widespread as the grade level goes up. The degree of specialization for teachers in elementary schools varies not only with grade levels but also across school districts.

To date, empirical evidence is inconclusive about the effects of organization structures on student achievement (Contreras, 2009; Garrigan, 1992; Des Moines Public Schools, 1989). There have been no definitive studies of the advantages of specialization classroom structure over the self-contained classroom structure in elementary schools.

Recently, education reform has turned to the question whether departmentalized elementary schools will increase student achievement (Jacob and Rockoff, 2011). Given the purpose of specialization to improve student test scores in elementary schools, there is a need for some empirical evidence of managing teacher assignments in order to see if subject specialization is associated with an increase in student test performance. In this study, I analyze the impact of specialization on student academic performance in elementary schools. This study compares students in schools where teachers are highly specialized to students in schools where teachers are mildly specialized.

The impact of specialization on student test performance may be related to how specialization has been practiced within schools. One important concern on who should specialize is the effectiveness of specialist teachers in teaching their specialized subject(s). The effects of specialization may largely depend on whether the high-performing or low-performing teachers specialize. One possibility of subject specialization that aims to raise student test scores is to allow relatively more effective teachers in a subject to specialize in teaching that subject. This study then concentrates on whether student test performance is associated with how specialization has been practiced within schools.

To describe subject specialization based on teaching effectiveness within schools, this study estimates teacher value added. There is a long history of research that focuses on measuring teacher job performance. Researchers have developed value-added models to measure teaching effectiveness based on student achievement. Some states have implemented a state-wide value-added system that aims to evaluate teacher job performance and to hold teachers accountable for student learning. This study uses teacher value-added estimates to identify teaching effectiveness and then constructs a specialization measure weighted by teachers' value added to indicate whether the high-performing teachers have specialized and taught more students in that subject in a school.

This study uses a longitudinal teacher-student database from the state of Tennessee in upper elementary grades 4 through 6 in school years 2003-04 through 2011-2012.[1] I implement the Wooldridge's dynamic ordinary least squares (DOLS) model to estimate teacher value added. The teacher effectiveness data are available in school years 2006-07 through 2011-2012.[2]

This study finds that specialization has not raised average test scores in mathematics, English/language arts, and social studies in upper elementary grades 4 through 6 in Tennessee. Instead, specialization by teachers in science in grade 6 has had a positive effect on average science scores. This study then explores a variety of potential factors that affect the relationship between specialization and average test performance. In particular, my findings suggest that specialization based on teacher value added is positive and statistically significant in predicting average scores in mathematics, English/language arts, science, and social studies in upper elementary grades 4 through 6 in Tennessee. This specialization measure based on teacher value added is constructed as the sum of the weighted specialization for individual teachers multiplied by teachers' value added in the same subject

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[1] In Tennessee, not all middle schools begin in grade 6, where some schools departmentalize subjects with several teachers but other schools continue running self-contained classrooms until grade 7. Since schools in grade 6 are not fully departmentalized in Tennessee, I include grade 6 in my study. Furthermore, instead of separating grades by elementary and middle schools, I use the phrase "upper elementary grades 4 through 6" in this Chapter.

[2] For details on the value-added model used to estimate teacher effects, see Section 3 in Chapter II (pages 14 through 15).

separately in each grade within schools. I refer this measure as subject specialization weighted by value added. The impact of subject specialization weighted by value added on average test scores is substantially large at $p < 0.001$. One standard deviation increase in specialization weighted by value added raises average test scores by more than one standard deviation across grades 4 through 6 ranging from 1.04 through 1.40.

This study is organized in the following fashion. In Section 2, I review literature on patterns of organization structures in elementary schools and the impact of both departmentalization in elementary schools and self-contained classroom on student test performance. Section 3 introduces my research questions. Section 4 illustrates my method, variables, and analytical samples. Section 5 presents the data used to answer my research questions. Section 6 presents my findings and section 7 concludes this chapter.

Literature Review

Research indicates that departmentalization has increased in upper elementary grades 4 through 6, and many elementary schools have adopted alternative classroom structure models to facilitate student learning (i.e., variations of departmentalization).[3] The effects of elementary school organization on student achievement have been examined in many empirical studies from 1920s to 1980s. The key research questions are centered on the relative advantages of departmentalized and self-contained organization structures and their effects on student achievement in elementary schools. The results of those studies have shown no evidence that one organizational structure is more effective than the other in improving students' academic achievement (Des Moines Public Schools, 1989). To date, a summary of available studies published after the 1990s still has not supported the beliefs that departmentalization (or content specialization) improves the learning process of students.

[3] For details on classroom structures see Appendix A.

In the following sections, I first review the school organizational patterns used to organize elementary schools. Second, I summarize the results of recent studies on the relationship between elementary school organization (i.e., departmentalized and self-contain classrooms) and student test scores.

1. Elementary School Organization Structures

A survey conducted among 41 elementary schools in the Des Moines School District asked principals to describe the organization structures in their schools. Self-contained structures were mainly used at the primary grade levels while both semi-departmentalized and departmentalized structures occurred at the upper elementary grade levels. Results of this survey indicated that departmentalization was gradually introduced at the upper elementary grade levels (Des Moines Public Schools, 1989). Table 1 reproduced from the results of this survey displays the percentage of elementary schools at each grade level for three organization structures, respectively. Other findings of this survey indicate that, in the opinion of principals, (1) larger schools would prefer using a departmentalized structure and (2) the organizational structure in a school should depend on student needs and the expertise of their teachers.

Table 1
Percentages for 41 elementary schools at each grade level by three organization structures

	Elementary school organization structures		
Grade levels	Self-contained	Semi-departmentalized	Departmentalized
1	87%	13%	---
2	90%	10%	---
3	64%	23%	13%
4	33%	28%	39%
5	33%	26%	41%

Source: Des Moines Public Schools, 1989.

Results from another survey conducted among 125 randomly selected schools in each of six southeastern states also reveal a similar tendency for schools to have semi-departmentalized and total departmentalized structures in each elementary grade (Roger and Palardy, 1987).[4] Different from the prior survey study, Roger and Palardy analyze the organizational patterns in grades, Kindergarten (K) to 6, and they also include a partial self-contained structure as one of the organization structures.[5] The percentage of the surveyed schools to have self-contained classrooms remarkably decreases from grades 3 through 4 (i.e., a 17 percent decrease). The major increase in the number of semi-departmentalized and total departmentalized classrooms at those surveyed schools happens in grades 4 and 6, respectively. There are nine percent more semi-departmentalized and total departmentalized classrooms in grade 4 compared to grade 3; and 10 percent more in grade 6 compared to grade 5.

[4] Six states include Alabama, Florida, Georgia, Louisiana, Mississippi, and Tennessee.
[5] "Partial self-contained children remain with the same teacher for most instruction, but are leveled in one or more of the basic curriculum areas and move to another teacher or teachers for such instruction" (Roger and Palardy, 1987, p. 115).

McPartland et al. (1987) survey principals in the schools that participated in the Educational Quality Assessment administrated by Pennsylvania's State Department of Education. Results of their study for schools in Pennsylvania show that mixed teacher assignments between self-contained and departmentalized assignments are found at all elementary grade levels and that the fully departmentalized assignment does not occur until grade 4.

One way to describe the degree of specialization within schools is to count the number of different teachers who provide academic instruction in major academic subjects for a student within grades. When all teachers have self-contained classrooms, the number of different teachers per student is one; when a school is fully departmentalized (i.e., one teacher only teaches one subject), the number of different teachers per student is the number of academic subjects students have. McPartland et al. (1987) compute the percentage of schools within grades with one, two, and three (or more) different teachers per student. Their results suggest that the number of surveyed schools where students have three and more teachers in the four core academic subjects increases from 20 percent in grade 4 through 48 percent in grade 6. In addition, the percentage of schools with one teacher per student drops from 48 percent in grade 4 through 22 percent in grade 6. There are no schools where students are taught by one and only one teacher in all academic subjects in grade 7 and higher.

2. Organization Structures and Student Test Scores

Early investigations of the impact of elementary organization structures on student achievement are based on both results of research studies and educators' opinions and observations. With the limitations and contradictory results of these prior studies as well as sometimes inconsistent definitions about departmentalization used in those published studies, the literature does not establish the superiority of either self-contained or departmentalized structures in delivering effective instruction (Des Moines Public Schools, 1989). In recent decades, more attention has been paid to school organization structures at upper elementary grade levels. My review of the literature focuses on comparing student achievement in grades 4 through 6 in self-contained and departmentalized classrooms.

In 1990, Harris compared student achievement in mathematics and reading in grades 5 and 6 between self-contained and departmentalized classrooms. This study focuses on students in three K-6 elementary schools in a small suburban school district over a five-year span (i.e., 1985 to 1989). In grades 5 and 6, two schools have self-contained classrooms and the third school (i.e., the largest of the three schools) has departmentalized classrooms. There are a total of 396 fifth graders and 449 sixth graders in five years in all schools. The student test data are analyzed using a multivariate analysis of covariance with multiple mathematics/reading tests as dependent variables and grade levels, organization structures, year dummies as independent variables. The findings of this study indicate that there is no significant effect on student test scores at either grade levels of either organizational structure.

Harris' study suffers from some weaknesses. He only focused on two of many organization structures.[6] The analytical sample is limited to a small student population at two grade levels. His study only examined the effects of instructional organizations on student test scores in mathematics and language arts. Instead, my study includes students from more than one hundred districts and analyzes the effects of organization structure in four core

[6] This issue is also present in the recent studies when comparing student achievement between different organization structures.

academic subjects.[7] More important, I consider hybrid structures since not all elementary teachers/schools are fully either self-contained or departmentalized.

Harris (1996) uses a cross-sectional pre-post-test design to study the growth of the reading achievement for two randomly selected samples of 30 sixth graders. One sample of 30 students as a control group receives instructions in self-contained classrooms; the other sample of 30 students as an experimental group receives instructions in a departmental program. All of those students attend the same school located in a predominantly lower socioeconomic area. Harris first shows that there is no significant difference in the pretest scores for two groups. Using a two-sample T-test based on the mean test scores, this study then reports that the students in the control group perform better in the posttest than the ones in the experimental group.

This experimental study focuses on a small group of students at one school in grade 6 in reading scores. It is interesting to know whether the similar results can be found when other researchers can expand Harris' study to examine test score changes between self-contained and departmentalized instruction programs in other subjects and other elementary grades using a large number of students. Although it is difficult to replicate this experiment on a large scale, it is possible to use non-experimental designs to answer whether departmentalization (or subject specialization) in elementary schools raise student test scores. Instead of comparing the mean difference, an application of regression analysis can also be used to evaluate the effects of specialization on student test scores in a large-scale study.

More studies that find support for the self-contained structure are found in Garner and Rust (1992) and McGrath and Rust (2002). The first study examines 96 fifth graders' test scores in departmentalized and self-contained rural schools in a lower middle socioeconomic

7 Student test scores in science and social studies were not studied in Harris (1990).

county in Tennessee. The second study uses a slightly bigger sample (i.e., 197 fifth and sixth graders) in one school district in Tennessee. Both studies use the same analytical method, analysis of variance (ANOVA).

In Garner and Rust (1992), all students attend self-contained classrooms in grade 4. In grade 5, there are 45 students attending four departmentalized classrooms and 51 students in three self-contained classrooms. Garner and Rust find that (1) there is no significant difference in terms of test scores in grade 4 and (2) observable student characteristics are balanced in two organization structures in grade 5 except that there are more boys in the self-contained classrooms than in the departmentalized classrooms. They analyze percentile scores using analysis of variances by organization structure, grade level, and gender. The results of their study show that percentile scores in all subject areas are significantly higher for the self-contained groups than the ones for the departmentalized groups at < 0.05 significance level. The differences of the group means in two structures are 15.14 for reading, 12.87 for mathematics, 24.83 for science, and 12.39 for social studies.

These findings support those of McGrath and Rust (2002). However, the significant effect of self-contained classrooms may not be consistent across all subjects studied. McGrath and Rust (2002) indicates that students in self-contained classrooms perform better than the ones in departmentalized classrooms in language and science, but no differences are found in reading, mathematics, and social studies.

Those two studies further extend the existing literature by examining the effects of school organization structure in other upper elementary grades (i.e., grades 4 and 5) and all other academic subjects (i.e., science and socials studies). The scale of those studies are still considered as small, they focus on students at rural schools, and none of those studies consider variation within self-contained and departmentalized categories (i.e., partially self-contained and semi-departmentalized structures).

Contreras (2009) conducts a critical review of literature studying the benefits of departmentalization on student achievement in elementary schools. Those studies used in Contreras' research span over 50 years (i.e., from 1956 to 2008). The finding of Contreras' study indicates that departmentalization does not appear to significantly improve student academic achievement in elementary schools.

Building upon Contreras' review and prior research, I summarize a number of studies that address the effects of departmentalized and self-contained structures on student achievement over 90 years. Table 2, reproduced from three studies, displays the results of 33 articles on the relationship between elementary organization structures and student achievement. The result shows that few studies provide clear support for either elementary organizational structure on student achievement.

The mixed findings regarding the effects of self-contained and departmentalized elementary schools in the literature may be due to the contradictory views about specialization. Specialization could be useful simply because it allows teachers to focus on one subject; therefore, they become better at teaching that subject than they would if their efforts were spread over several subjects. If specialization has not raised student test scores, the reason may be that self-contained classrooms provide teachers with more flexibility to organize instruction across subjects and better opportunity to integrate all subjects.

Table 2
Comparative studies of student achievement in self-contained and departmentalized classrooms

Study by	Year	Favorite structure	Grade and/or subject area studied
Otto	1923	Self-contained	Grades 5-8 (Otto, 1950)
Stewart	1927	Self-contained	Grades 5-8
Miller and Otto	1930	No significant difference	Grades 4-6
Gerberich and Prall	1931	Departmentalized	Grades 4 and 6, Math
			Grade 4, English
		Self-contained	Grade 4, Reading
			Grades 4 and 5, Geography
		No significant difference	Grades 4-6, All other comparisons
Woods	1949	Non-departmentalized	Grade 8, Stanford Achievement Test
Jackson	1953	No significant difference	Grades 5, 7, and 8 (Morrison, 1967)
Hosley	1954	No significant difference	Grade 6 (Morrison, 1967)
		Self-contained	Grade 6 (Slavin, 1988)
Spivak	1956	Self-contained	Grades 7 and 8
Snyder	1957	Self-contained	Grade 6
Woods	1959	Self-contained	Grades 8 and 9
Coffin	1961	Departmentalized	Grades 5 and 6, All except Math
		No significant difference	Grade 4
		No significant difference	Grades 4-6, Math
Stoddard	1961	No significant difference	Grades 1-5
Gibb and Matala	1962	No significant difference	Grades 5 and 6 Math, All ability levels
		Departmentalized	Grades 5 and 6, Science, All ability levels
Zimmerman	1962	No significant difference	Grade 7, English and Social studies
Coffin	1963	No significant difference	Grades 4-6, All areas
Elseroad	1965	Self-contained	Grades 4 and 6, Math and Reading
		No significant difference	Grades 4 and 6, All other subjects
		Self-contained	Grades 4 and 6, Pupils with IQs 75-89
Gibb and Matala	1967	Departmentalized	Grade 5, Social Studies
		No significant difference	Grade 6
Grooms	1967	No significant difference	Grades 4 and 6 Reading and Science
		No significant difference	Grade 4, Math
		Self-contained	Grades 4 and 6, All other comparisons
Morrison	1967	Self-contained	Grades 6 and 7, Middle socioeconomic, Math
		No significant difference	Grades 6 and 7, Lower socioeconomic, Math
		Contradictory	Grades 6 and 7,

			High socioeconomic, Math
Cleavinger	1968	Departmentalized Self-contained	Grade 6, Word meaning Grade 5 Social studies and Language Grade 6, Social studies and Math
Ward	1970	Self-contained No significant difference	Grades 4-6, Reading and Science Grades 4-6, Social Science and Math
Case	1972	Departmentalized	Grade 5, Reading and Math
Gould	1973	No significant difference Departmentalized	Grades 4-6, Work-study section Grade 6 Social studies composite score
Caliste	1975	No significant difference	Grades 7 and 8, Grade point average (GPA)
Bowser	1984	Self-contained No significant difference No significant difference	Grade 4, Social studies Grade 4, Science Grade 5, Social studies
Becker	1987	Departmentalized Self-contained	Grade 6, High socioeconomic levels Grade 6, Low socioeconomic levels (Slavin, 1988)
Harris	1990	No significant difference	Grades 5 and 6, Math and Language arts
Walker	1990	Departmentalized	Grades 1, 2, and 5, Stanford Diagnostic Math
Garner and Rust	1992	Self-contained	Grade 5, Stanford Achievement Test
Harris	1996	Self-contained	Grade 6, Reading
McGrath and Rust	2002	Self-contained No significant difference	Grades 5 and 6, Language and Science Grades 5 and 6, Reading, Math, and Social studies
Patton	2003	No significant difference	Grade 5, Math
Butzin et al.	2006	Non-self-contained	Grades 3 to 5, All standardized tests

Sources: Des Moines Public Schools, 1989; Garrigan, 1992; Contreras, 2009.

Overall, there are a couple of limitations in those studies that examine the benefits of departmentalized and self-contained elementary schools. They include ignoring variation within a particular organization structure, relatively small sample size, relatively short time period of analysis, and a limited set of academic subjects available for study. In addition, none of the recent studies discuss the importance of teacher job performance when comparing self-contained to departmentalized classrooms/schools.

Clearly, there is a need for some evidence about how teacher assignments in upper elementary grades raise student test scores. My study revisits the question relating to the effects of various degrees of departmentalization on student test performance in elementary schools and overcomes the limitations mentioned above. In particular, it may be that the benefits of specialization largely depend on the criteria used to make decisions on subject specialization. Specialization may not have been made on a manner associated with higher student test scores. I further extend this analysis to determine whether subject specialization based on teaching effectiveness affects the effects of subject specialization on student test performance.

Research Questions

This study examines the impacts of specialization of elementary school teachers on student test performance but with some substantial differences compared to the existing literature on the impact of school organization structures on student learning. This study is the first to empirically test whether specialization in upper elementary grades is associated with increasing student test performance in the all core academic subjects of mathematics, English/language arts, science, and social studies, using student- and teacher-level data from an entire state of Tennessee over nine school years. Secondly, this study differs from any available studies because of my specialization measure that describes hybrid structures of classrooms/schools. Thirdly, this study considers whether subject specialization based on teaching effectiveness affects student test performance. This study asks two research questions:

> Research question 1: Has specialization, in upper elementary grades 4 through 6 in Tennessee, raised student test performance in the core subjects of mathematics, English/language arts, science, and social studies, respectively?
>
> Research question 2: Does subject specialization based on teaching effectiveness in a subject raise student test performance in that subject?

Many prior studies have compared achievement outcomes between those students who are taught in self-contained classrooms and those who are taught in departmentalized classrooms in elementary schools. This may be due to the fact that those studies only focus on a handful group of schools. The organization structure can be predetermined in a grade in the selected schools for study. Unfortunately, when looking at school organization structures across more than one hundred districts in a state, it is likely that there is a great variation in school organization structures in elementary schools.

As noted above, some teachers could teach more students in some subjects while they teach fewer students and/or do not teach in other subject(s) in upper elementary grades 4 through 6. The description of teacher assignments in upper elementary grades 4 through 6 is presented in Section 4 in Chapter II on page 18 – 24. The complex pattern of teacher assignments across different subjects often involves elements of self-contained and departmentalized classrooms.

Instead of identifying self-contained and departmentalized classrooms for students, I use a continuous measure qualifying the degrees of specialization in a subject for elementary school teachers. Often, teachers are not fully departmentalized in elementary schools. For example, they teach different classes of students in one subject and the same class of students in other subjects. In this study, subject specialization is measured as the percent of students in a subject taught by a teacher in a grade.[8] This measure describes teacher assignments in elementary schools that are not limited only to self-contained and departmentalized classrooms. To the best of my awareness, my measure of subject

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[8] The majority of teachers (about 95 percent) in grades 4 through 6 taught in one and only one grade; some (2.6 to 3.34 percent) taught the same subject(s) in multiple grades; and others (1.5 to 2.31 percent) taught different subjects in multiple grades in each year.

specialization has not been implemented in any existing literature on the effects of school organization structures on student achievement in elementary schools. This measure is also used in Chapter II as the dependent variable that describes teacher assignments in a subject.

Different from Chapter II, I further average this measure to form the school-grade average share of students in a subject for all teachers in that subject. The weighted average share of a teacher's students in a subject in a grade in a school describes whether that school is highly specialized or mildly specialized in that subject in that grade. The weight is the ratio of the number of students taught by a teacher in a subject to all the students in that subject in a grade in a school (i.e., $n_k^s / \sum_k n_k^s$). This study then uses the weighted average share of a teacher's students in a subject to predict average student performance in that subject.

My regression analyses examine the impact of the weighted average share of students in a subject on average test scores in that subject at the school-grade level. While teaching effectiveness in a subject is correlated with student test scores in that subject, it is not certain that increasing the share of a teacher's students in a subject would also raise student test scores. There are two reasons that explain whether there is a possible effect of specialization by teachers in a subject on average test performance in that subject. First, teachers improve their own effectiveness through specialization. Specialization allows teachers to concentrate on fewer subjects instead of spreading their efforts to all subjects. Such change on teaching effectiveness may quickly plateau. Second, specialization based on teaching effectiveness in a subject allows relatively more effective teachers in that subject to teach students rather than the less effective teachers within schools.

In short, this chapter first examines the relationship between specialization by teachers in a subject and average test scores in that subject at the school-grade level; and then considers a variety of issues related to specialization in a subject in schools that also influence average test scores in that subject. More important, I consider prior value-added among teachers who specialize as a factor determining the gains from specialization in Tennessee's public elementary schools.

Empirical Methodology

1. The School-Grade Level Achievement Model

The average of student test scores in a subject is a function of specialization by teachers who taught in that subject in a school, a set of school characteristics, and dummy variables for grade, school year, and the interaction terms between grades and school years. My analyses use schools with tested students in all grades 4 through 6 (Model 1). I also consider the possible difference of specialization effects on average test scores separately in each grade (Model 2). The concern for the second set of analyses is with the fact that specialization has become widespread and broadly accepted in grade 6 over time and there is still a great deal of controversy over the consequences of specialization in grades 4 and 5 in most elementary schools. It is possible that self-contained classrooms provide teachers with more flexibility to response specific needs for students when learning focuses mostly on literacy development across different subjects. This specific advantage of self-contained classrooms gradually disappears with increasing skill sets and competencies required for teaching and learning non-verbal subjects. The effects of subject specialization are likely to be different on average test performance as the grade level goes up. This study further tests the difference of specialization effects on average test performance between Models 1 and 2. I use the analysis of specialization by mathematics teachers on average mathematics scores as an example to discuss my school achievement models. My model 1 for the mathematics analysis in grades 4 through 6 is presented below:

$$\bar{A}_{mt} = \beta_0 + \beta_1\bar{\theta}_{mt} + \beta_2 S_{mt} + \pi + \phi_m + e_{mt}, \tag{1}$$

where $\bar{A}_{mt}$ is the average of student test scores in mathematics in school *m* in school year *t*; $\bar{\theta}_{mt}$ is specialization by mathematics teachers in school *m* in school year *t*; S_{mt} is a vector of time-variant school-level characteristics; ϕ_m is school fixed effects for school *m*; π is a matrix of dummy variables for grades, school years, and the interaction terms between grades and school years; and e_{mt} is the error term clustered at the school level.[9]

This study controls for school fixed effects and time-variant school characteristics. The fixed effects capture the effects of time-invariant and unobservable characteristics that are correlated with school average performance. Those factors refer to the quality of principals and school contexts such as school size, location, and teachers' attitudes on students (e.g., motivation and expectation). The time-variant school characteristics include the percentage of students who are female; the percentage of minority students in each race/ethnicity category (e.g., Black, Hispanic, Asian, and American Indian); and a set of percentages of students who receive free/reduced-price school lunch (FRL) and special education service (SPED), and who are English language learner (ELL), gifted students, and migrant students. Research has shown that students with specific characteristics (i.e., sex, race/ethnicity, FRL, SPED, and gifted and migrant status) perform differently on their tests in schools and those student characteristics variables are often used to predict student test scores. In this study, the average of student test scores is then influenced by student composition within a school. Controlling time-variant school characteristics also increases the precision of the estimates and reduces the potential of omitted variable bias.[10]

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[9] The superscripts for subject and grade are omitted for notation clarity.

[10] For instance, the degree of specialization in a subject may be relatively high in affluent and high achieving schools than their counterparts or vice versa.

My mathematics model further includes dummy variables for grades, school years, and the interaction terms between grades and school years. Those dummy variables capture changes on the test contents, concentration of teaching and practice in a subject, and test difficulty across grades and school years.

I standardize student test scores within subject, grade, and year, and then average the standardized scores separately in each subject and each grade within schools. All students with valid test scores in all Tennessee's public elementary schools are used to estimate the standardized scores. The coefficient on $\bar{\theta}_{mt}$ can be interpreted as changes on average performance in a subject by β_1 standard deviation points with one standard deviation increase in the weighted average percent of students taught by teachers in that subject.

To estimate the effects of subject specialization separately in each grade, I further control for the interaction terms between subject specialization and grade dummy variables. This study then reports the marginal effects of subject specialization on average test scores separately in each grade. I perform F-test on the coefficients of the interaction terms between specialization and grade dummy variables to learn whether the grade-specific effects are different from the pooled effects across all grades.

This study uses a sample of average test scores in grades 4 through 6 separately in each subject in Tennessee's public elementary schools over nine school years 2003-04 through 2011-2012. In each analysis, the analytical sample includes all schools with average student test scores in a subject. When estimating average test scores within schools, I restrict the sample to students who attended a teacher's classroom for at least 150 calendar days. My analytical sample does not include the same number of schools in a subject. The different number of schools across subject-specific models is due to the fact that the student-teacher links are not available for all four core academic subjects in some schools. For example, students' teachers in mathematics, English/language arts, and science are identifiable in a grade in a school but not the students' teachers in social studies.[11]

2. Threats to Validity

While my analytical model controls for time-variant school characteristics, it is possible that some factors kept in the error term not only influence average test scores but also are correlated with subject specialization within schools. The effects of specialization on average test scores may be biased depending on the correlation between specialization by teachers in a subject in a school and the omitted variables. To explore such bias on subject specialization, this study compares the coefficient estimates before and after controlling for some potential omitted variables.

This study considers whether specialization might be a response to a negative trend of average school performance in a subject. I test a hypothesis whether the increase in subject specialization in a school results from the increase in the pressure to raise average school performance in that school. If this trend continues but is not controlled in the model, specialization appears to be ineffective.

I use school NCLB accountability status levels in a prior year to control for this negative trend. Under NCLB, school status levels are determined by Adequate Yearly Progress (AYP) and schools' history of NCLB accountability status levels. Schools were subject to a variety of NCLB sanctions depending on how many years those schools have failed to meet AYP. To achieve AYP every year, one of important criteria is that schools

[11] This is a data quality concern where the student-teacher links are not available in a subject in a grade for all students in a school. For the number of schools with no student-teacher links separately in each subject, see Appendix C. Overall, there are 1.7 percent of schools where all students in a grade are not linked to teachers in a subject over nine school years.

meet the performance benchmarks or make sufficient progress to the benchmarks in tested grades and subjects (i.e., mathematics and English/language arts).

Schools have continuously faced accountability pressures due to the fact that student test performance has not met AYP over time. Managing teacher assignments could have been used for school improvement. Specialization may be one of the managerial strategies implemented either at the sanctioned schools (i.e., low achieving schools) to boost student test performance or in good standing schools to sustain student test performance.

This study controls for a matrix of dummy variables for one-year lagged NCLB status levels in the model. Schools are grouped in three NCLB status levels, good standing, target, and sanction as well as an indicator for schools without NCLB accountability status.[12] The omitted category for NCLB dummy variables is the schools that were subject to NCLB sanctions in a prior year.

Data

This study uses longitudinal data on students and teachers in grades 4 through 6 in Tennessee's public elementary schools in nine school years 2003-04 through 2011-2012. Students are linked to their teachers through student-course records extracted from Tennessee's Oracle Education Information System. This course-record data file is prepared by Tennessee Consortium Research, Evaluation, and Development (TNCRED). A total number of three million students in nine school years are included in this study.[13] Table 3 displays descriptive statistics of standardized test scores and subject specialization by teachers separately in each subject and each grade in Tennessee's public elementary schools in schools years 2003-04 through 2011-2012.

[12] For detail on school NCLB accountability measure, see Section 4 in Chapter II on page 18.
[13] For detail information on the data used in this study, see Section 4 in Chapter II on page 16 through 18.

In Panel 1 of Table 3, the average of standardized test scores separately in each subject and each grade in my analytical samples are slightly above zero varying from 0.01 to 0.05. This is because my analytical sample excludes students who are not linked to any teachers in a subject and who have not attended their schools for at least 150 calendar days. It is likely that those students (mostly transfer students) appear to have lower test scores than the ones used in the regression analysis. The exclusion of those students is less than two percent of the overall students separately in each subject in my data and does not likely alter the effect of subject specialization on average test scores.[14]

In Panel 2 of Table 3, I present descriptive statistics of specialization by teachers separately in each subject and each grade at the school level. The average percent of students taught by teachers in a subject gradually increases over time. These averages of subject specialization are quantitatively similar in grade 4 and 5 but the ones in grade 5 are always slightly higher with roughly twice large of standard deviations. In the opposite, subject specialization is much higher in grade 6 compared to other grades across all subjects. Those facts suggest that schools have paid more attention to subject specialization in recent years than before and specialization has been made more frequently in grade 6 than in other elementary grades.

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[14] Appendix D presents the percent of students not included in my sample separately in each grade in school years 2003-04 through 2011-2012. The number of omitted students is trivial compared to the overall number of students in nine school years in three grades; moreover, I average test scores for individual students to the grade by school level.

Table 3
Descriptive statistics of standardized test scores and subject specialization in school years 2003-04 through 2011-2012 in upper elementary grades 4 through 6 in Tennessee

	School year								
	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-2010	2010-2011	2011-2012
Panel 1: Standardized test scores									
Grade 4									
Mathematics	0.0376	0.0261	0.0416	0.0417	0.0405	0.0379	0.0195	0.0200	0.0213
	(0.9931)	(0.9934)	(0.9896)	(0.9897)	(0.9891)	(0.9918)	(0.9962)	(0.9903)	(0.9842)
English/	0.0352	0.0248	0.0436	0.0408	0.0392	0.0372	0.0188	0.0186	0.0211
language arts	(0.9930)	(0.9933)	(0.9809)	(0.9908)	(0.9867)	(0.9850)	(0.9955)	(0.9902)	(0.9855)
Science	0.0311	0.0236	0.0423	0.0447	0.0444	0.0393	0.0201	0.0192	0.0215
	(0.9906)	(0.9951)	(0.9890)	(0.9902)	(0.9864)	(0.9892)	(0.9964)	(0.9911)	(0.9852)
Social studies	0.0340	0.0272	0.0442	0.0419	0.0434	0.0391	0.0329	0.0241	0.0168
	(0.9908)	(0.9854)	(0.9856)	(0.9851)	(0.9868)	(0.9858)	(0.9879)	(0.9890)	(0.9839)
Grade 5									
Mathematics	0.0404	0.0338	0.0427	0.0401	0.0413	0.0380	0.0230	0.0216	0.0250
	(0.9933)	(0.9904)	(0.9875)	(0.9849)	(0.9921)	(0.9959)	(0.9922)	(0.9848)	(0.9791)
English/	0.0405	0.0300	0.0454	0.0403	0.0422	0.0376	0.0207	0.0207	0.0232
language arts	(0.9898)	(0.9884)	(0.9789)	(0.9782)	(0.9818)	(0.9905)	(0.9911)	(0.9860)	(0.9811)
Science	0.0346	0.0280	0.0412	0.0384	0.0448	0.0403	0.0231	0.0217	0.0242
	(0.9950)	(0.9919)	(0.9850)	(0.9888)	(0.9875)	(0.9887)	(0.9927)	(0.9861)	(0.9808)
Social studies	0.0402	0.0331	0.0432	0.0399	0.0438	0.0411	0.0341	0.0210	0.0159
	(0.9882)	(0.9844)	(0.9791)	(0.9886)	(0.9876)	(0.9840)	(0.9874)	(0.9872)	(0.9838)
Grade 6									
Mathematics	0.0424	0.0473	0.0445	0.0470	0.0423	0.0425	0.0287	0.0261	0.0239
	(0.9893)	(0.9863)	(0.9832)	(0.9839)	(0.9861)	(0.9866)	(0.9824)	(0.9785)	(0.9814)
English/	0.0403	0.0431	0.0435	0.0467	0.0408	0.0405	0.0262	0.0234	0.0219
language arts	(0.9909)	(0.9833)	(0.9852)	(0.9840)	(0.9818)	(0.9835)	(0.9836)	(0.9799)	(0.9827)
Science	0.0373	0.0397	0.0362	0.0447	0.0431	0.0391	0.0279	0.0252	0.0233
	(0.9834)	(0.9816)	(0.9822)	(0.9806)	(0.9819)	(0.9859)	(0.9837)	(0.9795)	(0.9827)
Social studies	0.0401	0.0411	0.0380	0.0429	0.0405	0.0396	0.0305	0.0128	0.0133
	(0.9792)	(0.9728)	(0.9813)	(0.9749)	(0.9779)	(0.9803)	(0.9812)	(0.9843)	(0.9878)
Panel 2: Subject specialization									
Grade 4									
Percent of students taught in									
Mathematics	26.01	27.19	26.93	26.63	26.57	26.80	26.75	27.08	27.47
	(8.32)	(11.71)	(10.99)	(9.91)	(9.66)	(10.89)	(10.61)	(11.89)	(13.68)
English/	29.85	30.38	29.75	30.54	31.11	31.53	32.11	31.71	33.19
language arts	(17.82)	(18.86)	(17.40)	(18.57)	(19.56)	(20.53)	(21.46)	(20.79)	(22.70)
Science	26.04	26.64	26.19	25.58	25.70	25.73	25.90	26.08	26.09
	(8.43)	(10.90)	(9.74)	(7.26)	(8.35)	(7.95)	(8.26)	(9.21)	(9.90)
Social studies	25.37	26.09	25.72	25.22	25.12	25.47	25.60	25.82	25.84
	(5.03)	(8.86)	(7.81)	(5.74)	(6.19)	(7.17)	(7.30)	(8.77)	(9.48)
Grade 5									
Percent of students taught in									
Mathematics	28.10	29.39	28.51	28.81	28.97	29.22	29.46	30.54	32.30
	(14.57)	(16.91)	(14.92)	(15.42)	(15.36)	(16.65)	(17.04)	(19.08)	(22.18)
English/	34.94	36.11	34.09	36.10	35.74	36.93	37.75	37.03	39.42
language arts	(24.14)	(25.52)	(23.10)	(25.33)	(25.07)	(26.60)	(27.10)	(26.49)	(28.59)
Science	28.35	28.95	28.35	28.01	28.17	27.96	28.31	28.72	30.09
	(14.45)	(16.70)	(14.36)	(14.04)	(14.34)	(14.36)	(14.87)	(15.77)	(18.21)
Social studies	27.19	27.82	27.40	27.23	27.45	27.48	27.61	28.43	29.17
	(12.22)	(14.19)	(12.57)	(13.24)	(13.37)	(13.74)	(13.88)	(15.65)	(16.82)
Grade 6									
Percent of students taught in									
Mathematics	41.14	45.47	46.56	47.24	49.67	51.18	51.57	56.19	59.00
	(34.21)	(35.07)	(34.90)	(35.21)	(35.99)	(37.53)	(37.40)	(38.28)	(39.44)
English/	49.35	53.35	54.39	56.91	59.13	61.69	61.40	65.06	65.98
language arts	(36.17)	(36.57)	(36.60)	(36.75)	(37.04)	(37.43)	(37.55)	(37.49)	(37.87)
Science	39.68	43.61	44.34	44.36	46.10	47.24	47.99	51.30	51.64
	(32.86)	(33.58)	(33.39)	(33.41)	(34.10)	(35.27)	(36.23)	(36.54)	(36.97)
Social studies	37.84	39.70	41.36	40.97	43.17	44.65	44.70	48.89	50.25
	(31.82)	(31.32)	(31.83)	(31.74)	(33.09)	(34.45)	(34.78)	(35.76)	(36.63)

Results

1. Key Findings

The effects of specialization by teachers within schools on average test performance are reported in Table 4 separately for each subject. Those analyses use schools in nine years from 2003-04 through 2011-2012. The upper panel presents the effects of subject specialization in a sample of pooling all grades; and the lower panel presents the effects separately in each grade.

For each set of model specifications, I present two sets of regression coefficients using the models with and without controlling for school fixed effects, respectively. For example, in mathematics in the upper panel, the effect of specialization is positive and insignificant (i.e., 0.011) in the school fixed-effect (SCH-FE) model but negative (i.e., -0.018) in the Ordinary Least Square (OLS) model.[15] The OLS models are likely to suffer from an omitted variable bias which is specific to a school and fixed over time. The omitted variables may include principal managerial efforts and their knowledge about teaching effectiveness for individual teachers that not only influence school performance but also positively correlates with teacher assignments.[16] Unfortunately, this type of variables are not observable for this study.[17] By controlling school fixed effects, the models may substantially reduce the omitted variable bias from the time-invariant unobserved influence. The results reported below are from the school fixed-effect models.

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[15] A significant difference can be found in the lower panel for the grade-specific effects in the models of science and social studies where the fixed-effect model reports significant effects but not the OLS models.

[16] A good leader knows which teachers can effectively raise student test scores in a subject and keeps those teachers in the classrooms for that subject.

[17] Teaching effectiveness measured by teacher value added is estimable in this study. The discussion about controlling teachers' value-added in school-achievement models is addressed after reporting the main results.

Table 4
Effects of specialization on average test scores in Tennessee's public elementary schools in school years 2003-04 through 2011-2012

Average test scores	Mathematics		Englissh/language arts		Science		Social studies	
	OLS	SCH-FE	OLS	SCH-FE	OLS	SCH-FE	OLS	SCH-FE
	Model specification 1: Using all schools in grades 4 through 6							
Subject specialization	-0.0175	0.0109	-0.0227	0.0135	0.0162	0.0199	-0.0054	-0.0077
	(0.0181)	(0.0173)	(0.0152)	(0.0153)	(0.0179)	(0.0191)	(0.0193)	(0.0199)
Observations	20,353	20,353	20,421	20,421	20,352	20,352	20,341	20,341
R-squared	0.4521	0.6281	0.5451	0.6848	0.5778	0.7077	0.5308	0.6842
Adjusted R-squared	0.4511	0.6000	0.5442	0.6610	0.5770	0.6856	0.5299	0.6602
	Model specification 2: Using all schools in grades 4 through 6 and interacting specialization with grade dummy variables							
Subject specialization in grade 4	0.0730	0.0233	0.0538	0.0427	-0.0043	-0.0822†	-0.1170	-0.1670*
	(0.0496)	(0.0528)	(0.0331)	(0.0307)	(0.0477)	(0.0434)	(0.0720)	(0.0730)
Subject specialization in grade 5	-0.0320	-0.0080	-0.0159	0.0049	0.0255	0.0092	0.0341	-0.0059
	(0.0247)	(0.0226)	(0.0195)	(0.0189)	(0.0276)	(0.0285)	(0.0295)	(0.0293)
Subject specialization in grade 6	-0.0305	0.0198	-0.0540**	0.0101	0.0146	0.0468*	-0.0105	0.0153
	(0.0221)	(0.0215)	(0.0202)	(0.0191)	(0.0212)	(0.0223)	(0.0213)	(0.0230)
Observations	20,353	20,353	20,421	20,421	20,352	20,352	20,341	20,341
R-squared	0.4524	0.6282	0.5454	0.6849	0.5778	0.7079	0.5311	0.6845
Adjusted R-squared	0.4513	0.5999	0.5445	0.6610	0.5770	0.6858	0.5301	0.6606
F-test in model specification 2								
H_0: Interaction terms between specialization and grade dummy variables are jointly equal to zero.								
P-value (*df* = 2)	0.1120	0.4803	0.0164	0.4213	0.8112	0.0301	0.0789	0.0606

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Samples include schools with student test scores in grades 4 through 6 in nine school years 2003-04 through 2011-2012. All models control for time-variant school characteristics and dummy variables for grades, school years, and interaction terms between grades and school years. The models labeled as "SCH-FE" control for school fixed effects.

In the upper panel of Table 4, the results from the school fixed-effect model separately in each subject suggest that specialization has no effects on average test scores in mathematics, English/language arts, science, and social studies. In the lower panel of Table 4, I report the marginal effects of subject specialization separately in each grade. The results of F-test statistics suggest that the difference between the pooled specialization effects across all grades and the ones separately in each grade is not statistically significant in mathematics and English/language arts, and social studies at $p < 0.05$. Instead, the F-test statistics in the science model rejects the null hypothesis in which the interaction terms between specialization and grade dummy variables are jointly equal to zero at $p < 0.05$. I find no effects of specialization on average science scores in grade 5. In the opposite, specialization by science teachers is statistically significant to predict the average science scores in grades 4 (i.e., -0.08 at $p < 0.1$) and 6 (0.05 at $p < 0.05$).

A plausible explanation for the negative effects in science in grade 4 is that specialization makes teachers less likely to know their students well, which is crucial to raise student science scores in grade 4. Science teaching in grade 4 is highly likely to focus on how effectively students can read and learn through a variety of science-related reading materials. Self-contained classrooms provide the opportunity where teachers can combine some learning activities across different subjects and be flexible about their teaching emphasis based on what they learn about their students' strength and weakness.[18]

[18] The effect of specialization in social studies in grade 4 in the fixed-effect model is also negative and statistically significant, but the F-test statistics fails to reject the null hypothesis where none of the interaction terms between specialization and grade dummy variables is statistically different from zero at $p < 0.05$. As being said above, this may be due to the fact that self-contained classroom teachers are likely to response to specific needs for students with more flexibility while social studies specialists cannot. It is possible that students who read better perform well in the social studies test in grade 4 since teaching in elementary social studies centers on the knowledge of history. Students may score better in social studies if they have learned how to read effectively.

To the contrary, the advanced science skills are normally introduced in later grades where teaching science centers beyond how effectively students can read. Students may score higher in science if they have been taught by science specialists instead of self-contain classroom teachers who cannot provide enough subject-related teaching.

2. Threats to Validity

This study further examines the internal validity of the effects of subject specialization on average test performance. The threats to validity (i.e., an omitted variable bias) can be found if those estimates are changed after controlling for the factors that are correlated with specialization and test scores. I have controlled for dummy variables for one-year lagged NCLB status levels in the school average performance models. Since test scores in science and social studies are not used to estimate school AYP results, any change is not expected in those subjects.

Column (3) of Table 5 presents the effects of subject specialization on average test performance in the models that control for lagged NCLB dummy variables. Those analyses use five school years 2007-08 through 2011-2012 where the lagged NCLB data are available. In order to reveal changes on the effects of subject specialization, the column (1) reports the school fixed-effect findings from Table 4 using the samples in nine school years; and I also re-estimate those models in the column (2) using only five school years where lagged NCLB data are available for schools but not controlling for those dummy variables. Furthermore, I also estimate the grade-specific effects of subject specialization and report the marginal effects separately in each grade in the lower panel of Table 5.

Table 5
Effects of specialization on average test scores in Tennessee's public elementary schools

Average test scores	Mathematics			English/language arts			Science			Social studies		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Model specification 1: Using all schools in grades 4 through 6												
Subject specialization	0.0109	0.0190	0.0185	0.0135	0.0150	0.0175	0.0199	0.0265	0.0284	-0.0077	0.0039	0.0058
	(0.0173)	(0.0201)	(0.0198)	(0.0153)	(0.0172)	(0.0171)	(0.0191)	(0.0228)	(0.0225)	(0.0199)	(0.0235)	(0.0236)
Schools in good standing			-0.1427***			-0.1250***			-0.1678***			-0.1249***
under NCLB in year t - 1			(0.0196)			(0.0203)			(0.0253)			(0.0197)
Schools in target under			-0.0981***			-0.1035***			-0.1365***			-0.0997***
NCLB in year t - 1			(0.0181)			(0.0193)			(0.0233)			(0.0180)
Schools without NCLB			-0.1773***			-0.1381***			-0.1562***			-0.1427***
status levels in year t - 1			(0.0366)			(0.0358)			(0.0411)			(0.0367)
Observations	20,353	11,735	11,735	20,421	11,787	11,787	20,352	11,725	11,725	20,341	11,724	11,724
R-squared	0.6281	0.6375	0.6421	0.6848	0.6857	0.6892	0.7077	0.7137	0.7182	0.6842	0.7187	0.7211
Adjusted R-squared	0.6000	0.5893	0.5944	0.6610	0.6441	0.6479	0.6856	0.6756	0.6806	0.6602	0.6813	0.6839
Model specification 2: Using all schools in grades 4 through 6 and interacting specialization with grade dummy variables												
Subject specialization in	0.0233	-0.0249	-0.0265	0.0427	-0.0095	-0.0060	-0.0822†	-0.0857†	-0.0806	-0.1670*	-0.0926†	-0.0889†
grade 4	(0.0528)	(0.0419)	(0.0412)	(0.0307)	(0.0324)	(0.0322)	(0.0434)	(0.0519)	(0.0514)	(0.0730)	(0.0516)	(0.0518)
Subject specialization in	-0.0080	0.0116	0.0108	0.0049	0.0116	0.0139	0.0092	-0.0068	-0.0037	-0.0059	0.0231	0.0260
grade 5	(0.0226)	(0.0257)	(0.0250)	(0.0189)	(0.0210)	(0.0209)	(0.0285)	(0.0294)	(0.0290)	(0.0293)	(0.0312)	(0.0312)
Subject specialization in	0.0198	0.0381	0.0381	0.0101	0.0276	0.0300	0.0468*	0.0680**	0.0687**	0.0153	0.0083	0.0093
grade 6	(0.0215)	(0.0242)	(0.0241)	(0.0191)	(0.0218)	(0.0217)	(0.0223)	(0.0257)	(0.0254)	(0.0230)	(0.0275)	(0.0276)
Observations	20,353	11,735	11,735	20,421	11,787	11,787	20,352	11,725	11,725	20,341	11,724	11,724
R-squared	0.6282	0.6376	0.6422	0.6849	0.6857	0.6892	0.7079	0.7141	0.7186	0.6845	0.7189	0.7212
Adjusted R-squared	0.5999	0.5894	0.5945	0.6610	0.6441	0.6479	0.6858	0.6759	0.6809	0.6606	0.6814	0.6840
F-Test in model specification 2												
H_0: Interaction terms between specialization and grade dummy variables are joinly equal to zero.												
P-Value (df = 2)	0.4803	0.3893	0.3618	0.4213	0.5939	0.6092	0.0301	0.0081	0.0099	0.0606	0.0751	0.0779

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Samples in Column (1) include schools with student test scores in grades 4 through 6 or separately in each grade in nine school years 2003-04 through 2011-2012; and Columns (2) and (3) use the samples restricted to the school years 2007-08 through 2011-2012 where the lagged school NCLB data are available. All models control for time-variant school characteristics and dummy variables for school years. The pulled models using schools in grades 4 through 6 control for dummy variables for grades and interaction terms between grades and school years. All models control for school fixed effects. In column (3), additinal covariates include dummy variables for two NCLB status levels, good standing and target and a dummy variable that indicates schools with no NCLB status levels. The omitted category for NCLB status levels is the schools that were subject to NCLB sanctions.

There is no evidence that the effect of subject specialization is significantly changed before and after controlling for lagged NCLB status levels – comparing the coefficients between columns (2) and (3). This is also true when I examine the grade-specific effects. The pooled effects indicate that specialization has no effects on average test scores in any subjects in elementary schools in those five-year analyses. The results of F-test statistics show that the pooled results are not statistically different from the grade-specific effects in all subjects except science.

An interesting finding in Table 5 is that all significant effects found in the column (1) are smaller than the ones in the column (2) and the direction of the relationship between specialization and test scores has remained the same. One fact that may be related to this difference is that specialization separately in each subject and each grade has been growing in elementary schools over time (See Panel 2 of Table 3). One speculation would be that schools have been learning how specialization could help improve school performance over time. In recent years, since more specialization has been observed in schools, there is a better opportunity for schools to learn how specialization needs to be done with the aim to raise student test scores.

As worth noting, the effects of lagged school NCLB accountability status levels are negative and statistically significant to predict average test performance in all subjects and grades. Table 6 presents the number of schools with students in grades 4 through 6 by school NCLB accountability status. Over time, fewer schools have met the requirements for good standing from 1,115 in 2006-07 to 648 in 2010-2011; and more schools have been placed in target status and subject to NCLB sanctions.

Table 6
NCLB accountability status for schools with students in grades 4 through 6 in school years 2006-07 through 2010-2011

NCLB status	2006-07	2007-08	2008-09	2009-2010	2010-2011
Good Standing	1,115	1,072	1,024	982	648
Target	66	116	141	157	426
School Improvement 1	25	28	49	83	112
School Improvement 2	10	6	12	27	68
Corrective Action	9	7	2	6	23
Restructuring 1	4	4	3	2	4
Restructuring 2	1	0	2	3	3
State/LEA Reconstitution	7	1	0	2	4
N<10 - Small School	1	0	0	0	0
Pending	0	0	0	2	2
Schools without NCLB status	6	12	23	29	17
Total	1,244	1,246	1,256	1,293	1,307

3. Why No Effects on Average Scores in Grades 4 through 6

This study then explores four possible explanations why subject specialization may have differentiated effects or no effects on average test scores by subject and grade. Specialization would have little effects on average test scores if (1) the variation in teaching effectiveness in a subject is equal to zero or small within schools; (2) the factors used to make decisions on subject specialization are unrelated to student test scores; (3) specialization by teachers in a subject does not improve teaching effectiveness for those teachers in that subject; and (4) the relatively more effective teachers have not been selected to specialize within schools instead of the less effective teachers. The explanations (1), (3) and (4) are related to teaching effectiveness. When teachers are equally effective in teaching a subject within schools, specialization does not matter to student test scores. If teaching effectiveness are not improved through specialization, teaching a subject in multiple classrooms does not change average test scores. If the variation in teaching effectiveness is large, selecting the least effective teachers to specialize does not lead to better test scores. The explanation (2), instead, concerns the factors other than teaching effectiveness. It is clear that, if those factors are not strongly related to teaching effectiveness or unrelated to student test scores, specialization determined by those factors does not matter to student test scores.

This study first examines whether the variation in teaching effectiveness in a subject is relatively small for teachers within schools and whether the variation is small within those highly specialized schools. Second, I present whether the factors other than teaching effectiveness determine teacher assignments. Third, I test whether teachers increase their own teaching effectiveness in a subject through specialization in that subject. Lastly, I examine whether subject specialization based on teaching effectiveness has raised student test scores in Tennessee's elementary schools. I elaborate each of those in turn.

I first consider the variation in teacher value added within schools separately in each subject and each grade. If all teachers are equally effective in teaching a subject or all subjects, there is no need to manage teacher assignments. Instead, the larger the variation of teaching effectiveness in a subject, the more likely specialization will make an effect on average test scores.

Table 7 reports descriptive statistics of standard deviations of teacher value added for teachers within schools by subject, grade, and school year. The average standard deviations for teachers separately in each subject and each grade vary from 0.11 through 0.22. Teaching effectiveness in English/language arts within schools has the smallest variation among all subjects in all years separately in each grade with a few exceptions in the most recent two years.[19] I also find that variations of value added have been declining over time separately in each subject mostly in grades 4 and 5. The largest decline was seen for specialization by mathematics teachers (35 percent) over six school years 2006-07 through 2011-2012.[20]

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[19] The average standard deviations in science in 2010-2011 in grade 6 and in 2011-2012 in grades 5 and 6 are smaller than the ones in English/language arts.

[20] In grades 4 and 5, variations of value added for mathematics teachers dropped from 0.2 standard deviation in the 2006-07 school year to 0.13 standard deviation in 2011-2012.

Table 7
Descriptive statistics of standard deviations of teachers' history of value added for teachers within schools separately in each subject and each grade in Tennessee's public elementary schools in school years 2006-07 through 2011-2012

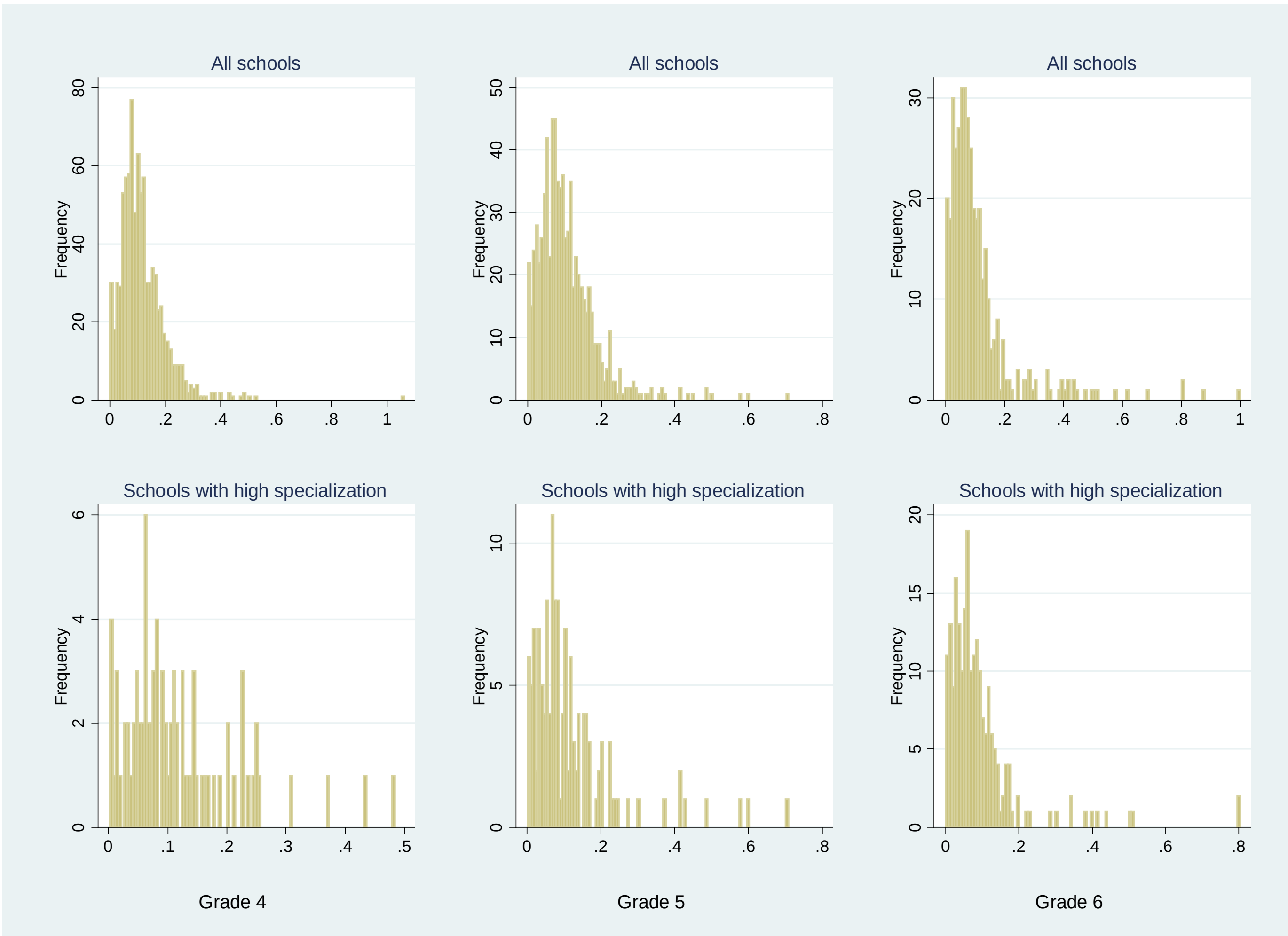
Subject		School year					
	Grade	2006-07	2007-08	2008-09	2009-2010	2010-2011	2011-2012
Mathematics	4	0.2004	0.1949	0.1963	0.1797	0.1544	0.1277
		(0.0875)	(0.0824)	(0.0924)	(0.0821)	(0.0723)	(0.0712)
	5	0.2004	0.2002	0.1930	0.1856	0.1611	0.1334
		(0.0838)	(0.0800)	(0.0743)	(0.1016)	(0.0924)	(0.0825)
	6	0.1781	0.1746	0.1779	0.2171	0.1949	0.1718
		(0.0755)	(0.0754)	(0.0816)	(0.1732)	(0.1701)	(0.1480)
English/ language arts	4	0.1508	0.1448	0.1456	0.1553	0.1345	0.1178
		(0.0779)	(0.0645)	(0.0633)	(0.0937)	(0.0708)	(0.0716)
	5	0.1529	0.1485	0.1440	0.1607	0.1450	0.1241
		(0.0687)	(0.0626)	(0.0596)	(0.1165)	(0.0983)	(0.0865)
	6	0.1413	0.1381	0.1416	0.1940	0.1906	0.1591
		(0.0644)	(0.0606)	(0.0692)	(0.1776)	(0.1694)	(0.1416)
Science	4	0.1858	0.1781	0.1783	0.1705	0.1446	0.1203
		(0.0820)	(0.0793)	(0.0758)	(0.0790)	(0.0668)	(0.0622)
	5	0.1887	0.1831	0.1820	0.1747	0.1496	0.1201
		(0.0803)	(0.0778)	(0.0719)	(0.1007)	(0.0808)	(0.0646)
	6	0.1880	0.1856	0.1800	0.1969	0.1597	0.1386
		(0.0763)	(0.0776)	(0.0723)	(0.1547)	(0.1416)	(0.1224)
Social studies	4	0.1953	0.1973	0.1954	0.2032	0.1912	0.1718
		(0.0869)	(0.0834)	(0.0899)	(0.0935)	(0.0840)	(0.0762)
	5	0.1968	0.1986	0.1980	0.2055	0.1905	0.1708
		(0.0831)	(0.0785)	(0.0781)	(0.0902)	(0.0877)	(0.0820)
	6	0.1880	0.1833	0.1806	0.2013	0.1836	0.1594
		(0.0742)	(0.0750)	(0.0834)	(0.1311)	(0.1220)	(0.1059)

Notes: DOLS value-added estimates for teachers are estimated over a four-year window separately in each subject in grades 4 through 6.

By and large, the variation in teaching effectiveness for teachers in the same subject within schools is considered as large enough to make substantial differences on student test performance. However, variations in teaching effectiveness vary across schools and grades. Figure 1 presents a set of histograms of variations in teaching effectiveness in mathematics in the 2011-2012 school year separately in each grade.[21] The upper panel plots variations in teaching effectiveness in mathematics using all schools; and the lower panel only uses the schools where the percent of students taught in mathematics within schools is above its average within grades. Those graphics do not show a systematic pattern where the variation in teaching effectiveness is relatively small in schools with high specialization across grades or vice versa. This is also true in other subject separately in each grade. Therefore, little specialization effects on average test scores do not result from small or zero variations in teaching effectiveness within schools.

[21] The number of bins is set to 100 in all histograms. The high number of bins allows me to identify whether schools are clustered in any specific regions of the distribution of standard deviations of value added.

Figure 1
Histograms of standard deviations of value added in mathematics within schools in the 2011-2012 school year separately in each grade



This study then considers whether teacher credentials (i.e., education levels and years of teaching experience) influence teacher assignments.[22] The analytical models in Essay 1 control for teacher credentials and their interaction terms with lagged absolute advantages in teaching that subject. Those findings support this discussion. I first analyze how much of the variation in teacher assignments can be explained by teachers' education level and teaching experience. I use teacher credentials to predict teacher assignments in school years 2009-2010 through 2011-2012 and then report R-square in Table 8. All models separately in each subject and each grade only control for years of teaching experience in all schools and dummy variables for education levels. The reported R-squares vary across subjects and grades. The explained variation in teacher assignments by teacher credentials is extremely small (i.e., less than one percent). The highest R-square is seen in the assignments for science in grade 4 (i.e., 0.55 percent). These results suggest that teachers' education levels and years of teaching experience are less likely to be influential in making teacher assignments and there are much greater unexplained variations in teacher assignments by factors other than teacher credentials.

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[22] This study only considers two specific credentials for teachers due to the data availability constraints. Specifically, I have no information about the number of mathematics credits studied by teachers in college or whether they specialize in mathematics education. Certification is another concern. Since all elementary school teachers hold the same generalist certificate, there is little chance that the certificate will explain variation in assignments. The analyses in the following discussion are limited to two teacher credential variables.

Table 8
Variation in teacher assignments that can be explained by teacher charatersitics and value added

	Mathematics			English/language arts			Science			Social studies		
	Grade 4	Grade 5	Grade 6	Grade 4	Grade 5	Grade 6	Grade 4	Grade 5	Grade 6	Grade 4	Grade 5	Grade 6
Teacher charactersitics	0.01%	0.03%	0.12%	0.29%	0.14%	0.12%	0.55%	0.16%	0.06%	0.09%	0.06%	0.09%
Observations	8,430	8,898	9,917	8,430	8,898	9,917	8,430	8,898	9,917	8,430	8,898	9,917
Value added	0.12%	0.61%	0.72%	0.10%	0.46%	0.30%	0.16%	0.38%	1.09%	0.16%	0.10%	0.18%
Observations	8,471	8,952	9,955	8,471	8,952	9,955	8,471	8,952	9,955	8,471	8,952	9,955

Notes: Teacher charactersitics include years of teaching experience and dummy variables for education levels.Value-added measures include absolute advantages of teaching each of four subjects. The variables for teacher characteristics are also used in the regression analyses in Chapter II. Each model is preformed separately for each subject and each grade. Samples include teachers with value added at least in a subject in three school years 2009-2010 through 2011-2012.

Table 9 then presents marginal effects of both education levels and years of teaching experience on teacher assignments separately for each subject and each grade. Those estimates are obtained from the analyses in Chapter II. The effects of teacher credentials on teacher assignments vary with subjects and grades. The mathematics result shows that teaching experience is negative and statistically significant in predicting the percent of students taught in mathematics in grade 6. Similarly, negative effects are found for teacher assignments in science in grades 4 and 5. One possible explanation is that veteran teachers may have more influence over assignments especially in mathematics and science (i.e., two hard-to-staff positions). They may intend to teach fewer share of students in those subjects and more share in other subjects. In addition, I find positive and statistically significant effects of teaching experience for teachers in English/language arts in grades 4 and 6 and in social studies in grade 5. All those significant effects are very small varying from -0.12 to 0.08 percent. The negative effect in mathematics assignments is the largest among all significant effects on specialization in mathematics. For example, teachers with 10 years of teaching experience higher have had 1.2 percent less of students taught in mathematics in grade 6.

Table 9
Marginal effects of education levels and years of teaching experience on teacher assignments separately in each grade in Tennessee's public elementary schools in school years 2009-2010 through 2011-2012

Percent of students	Mathematics			English/language arts		
	Grade 4	Grade 5	Grade 6	Grade 4	Grade 5	Grade 6
Education level (Omitted: Bachelors)						
Masters	-0.0051	-0.8034	-0.9342	2.0375***	1.835**	1.5408†
	(0.3940)	(0.5099)	(0.7160)	(0.5058)	(0.6686)	(0.8839)
Education doctoral	-0.3631	-1.0887	1.2113	2.3765*	3.342*	0.8949
and above	(0.9774)	(1.0988)	(1.4017)	(1.1652)	(1.4103)	(1.7441)
Years of teaching experience in all schools						
	-0.0057	-0.0401	-0.1194**	0.0791**	0.02501	0.0766†
	(0.0226)	(0.0335)	(0.0377)	(0.0293)	(0.0373)	(0.0463)
Percent of students	Science			Social studies		
	Grade 4	Grade 5	Grade 6	Grade 4	Grade 5	Grade 6
Education level (Omitted: Bachelors)						
Masters	-1.0531**	-0.9007†	-0.3721	-1.0322**	-0.1676	-0.1710
	(0.3305)	(0.4642)	(0.7072)	(0.3290)	(0.4865)	(0.7833)
Education doctoral	-1.0081	-1.5571	-0.3634	-1.0504	-0.8325	-1.8627
and above	(0.7677)	(0.9924)	(1.3431)	(0.8423)	(1.2435)	(1.3042)
Years of teaching experience in all schools						
	-0.0596**	-0.0463†	-0.0249	-0.0120	0.0646*	0.0626
	(0.0202)	(0.0278)	(0.0372)	(0.0215)	(0.0327)	(0.0394)

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Models control for school fixed effects and dummy variables for school year and the number of years taught by subject. Additional teacher and school controls include dummy variables for education degree, school NCLB status in year t - 1, and mobility status; years of teaching experience at all schools and dummy variables for the number of years taught at the current school; school size of tested students in grade 4; and their interaction terms with absolute advantages in the subject under study. Samples include teachers who are assigned to teach at least one subject to six and more students who have been to their teachers' classrooms for at least 150 calendar days in their current school years. Samples exclude four teachers from schools that were subject to "N<10 - Small School Review" under the NCLB accountability system (two teachers from the 2009-2010 school year and the other two from the 2010-2011 school year).

The significant effects of education levels are also small but larger than the ones found in teaching experience by subject and grade. In mathematics, there is no evidence that acquiring advanced education levels is statistically associated with specialization in any grade. In contrast, teachers with Master degree are likely to teach more percent of students in English/language arts than the ones with Bachelor degree in all grades. Those positive and statistically significant effects are slightly higher for teachers with Education Doctoral and above in grades 4 (2.4 percent at $p < 0.05$) and 5 (3.3 percent at $p < 0.05$) but not statistically significant in grade 6. Some negative and significant results are found for teachers with Master degree but not with Education Doctoral and above in science and social studies. The results show that teachers with Master degree has taught one percent less of students in science in grades 4 and 5 and in social studies in grade 4 than the ones with Bachelor degree.

All findings from Tables 8 and 9 suggest that education levels and years of teaching experience are associated with teacher assignments but not in all subjects and grades. More important, their impact on teacher assignments is significant but trivial. The select teacher credentials only explain a very small portion of variation in teacher assignments. In addition, literature has found that education levels and years of teaching experience are not strongly correlated with student test performance (Goldhaber and Brewer, 2000; Hanushek, 1971 & 1997; Wayne and Youngs, 2003).[23] In other words, teacher assignments were based on the factors weakly related to student test scores. Overall, there is no evidence that the select teacher credentials explain why specialization has little effect on student test performance.

In addition, in Chapter II, I have shown that teachers' value added is correlated with teacher assignments. Table 8 presents the variation of teacher assignments that can be

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[23] Some studies have found positive effects of teacher credentials, especially in teacher experience, on student test scores (Rivkin, et al., 2005; Rockoff, 2004).

explained by teachers' value added separately in each subject and each grade. I regress teacher assignments $\mathrm{TA}_{k,t+1}^{s}$ in subject *s* for teacher *k* in school year $t + 1$ on absolute advantages in teaching each of four subjects X_{kt}^{mth}, X_{kt}^{ela}, X_{kt}^{sci}, and X_{kt}^{soc}.[24] The explained variation in teacher assignments across all models is small ranging from 0.1 to one percent across subjects and grades. Table 8 suggests that the explained variation in teacher assignments by teachers' value added is much higher than the one due to teacher credentials. These results also suggest that a substantial amount of variation in teacher assignments may be explained by factors other than teachers' value added.

Now, I consider whether teachers improve their own teaching effectiveness through specialization. Some teachers may be asked to focus on teaching one or fewer subjects. Instead of spreading their efforts to all subjects, they have concentrated on one or select subjects and have been likely to teach multiple classrooms in those subjects over time. I test whether changes on teaching effectiveness in a subject result from changes on the number of other subjects taught by teachers. I estimate this relationship using a teacher-level model where changes on value added in two school years *t* and $t - 1$ is a function of dummy variables for changes on the number of other subjects taught by teachers in two school years *t* and $t - 1$, grades, and school years; and school fixed effects. The equation is presented below:

$$\Delta E_{k,(t,t-1)}^{s} = \beta_0 + \beta_1 \Delta \psi_{k,(t,t-1)}^{-s} + \pi + \phi_m + e_{mt}, \tag{2}$$

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[24] The superscript *s* separately indicates each subject, mathematics (MTH), English/language arts (ELA), science (SCI), and social studies (SOC). The absolute advantage in teaching a subject is set to zero if teachers did not have a value-added score in that subject.

where $\Delta E^{s}_{k,(t,t-1)}$ is the difference of teachers' value added in subject *s* for teacher *k* in two school years *t* and *t* – 1 (i.e., $A^{s}_{kt} - A^{s}_{k,t-1}$);[25] $\Delta\psi^{-s}_{k,(t,t-1)}$ is a matrix of dummy variables for changes on the number of other subjects -*s* (*s* $\neq$ -*s*) taught by teacher *k* in two school years *t* and *t* – 1; π is a matrix of dummy variables for grades and school years; ϕ_{m} is school fixed effects for school *m*; and e_{mt} is the error term clustered at school level.[26]

Table 10 presents marginal effects of changes on teacher assignments in subjects -*s* on changes of value added in subject *s*. The key regression coefficients are dummy variables for teachers who taught fewer subjects in year *t* than in year *t* – 1. For those teachers, the differences in the number of subjects -*s* include -1, -2, and -3. Those numbers indicate the number of subjects teachers did not teach in year *t*, but they taught those subjects in year *t* – 1. The omitted category for assignment dummy variables is the teachers who taught the same number of subjects in two school year.

[25] A^{s}_{kt} and $A^{s}_{k,t-1}$ are the effectiveness measures in subject *s* for teacher *k* in years *t* and *t* – 1, respectively, using the Dynamic Ordinary Least Square model in Chapter II.
[26] The superscripts for grades are suppressed for notation simplicity.

Table 10
Marginal effects of teacher assignments in a subject on effective teaching in that subject separately in each grade in Tennessee's public elementary schools

Changes on teachers' value added in two years *t* and *t* - 1	Mathematics		Englissh/language arts		Science		Social studies	
	OLS	SCH-FE	OLS	SCH-FE	OLS	SCH-FE	OLS	SCH-FE
	Model specification 1: Using all schools in grades 4 through 6							
Dummy variables (DV) for changes on the number of other subjects taught in two years *t* and *t* - 1								
DV#$_{-3}$	0.0005	-0.0019	0.0084	0.0035	0.0039	0.0087	-0.0062	-0.0029
	(0.0100)	(0.0111)	(0.0069)	(0.0067)	(0.0097)	(0.0122)	(0.0125)	(0.0137)
DV#$_{-2}$	0.0031	-0.0015	0.0116	0.0003	-0.0003	0.0047	0.0025	-0.0034
	(0.0084)	(0.0092)	(0.0075)	(0.0068)	(0.0096)	(0.0091)	(0.0083)	(0.0089)
DV#$_{-1}$	0.0133	0.0203**	0.0088	0.0087	0.0006	0.0029	0.0148†	0.0089
	(0.0080)	(0.0071)	(0.0084)	(0.0060)	(0.0070)	(0.0070)	-0.0083	(0.0081)
DV#$_{1}$	0.0088	0.0155	0.0090	0.0113	0.0001	0.0041	0.0001	-0.0127
	(0.0090)	(0.0087)	(0.0097)	(0.0067)	(0.0078)	(0.0087)	(0.0087)	(0.0095)
DV#$_{2}$	0.0104	0.0133	0.0017	-0.0039	0.0010	0.0070	0.0228*	0.0213†
	(0.0137)	(0.0120)	(0.0089)	(0.0084)	(0.0118)	(0.0118)	(0.0108)	(0.0115)
DV#$_{3}$	0.0188	0.0109	-0.0038	-0.0124	-0.0192	-0.0077	-0.0020	-0.0080
	(0.0118)	(0.0136)	(0.0072)	(0.0080)	(0.0119)	(0.0147)	(0.0104)	(0.0161)
Observations	24,094	24,094	27,941	27,941	23,493	23,493	23,856	23,856
R-squared	0.0064	0.0983	0.0020	0.0864	0.0017	0.1006	0.0090	0.1046
Adjusted R-squared	0.0059	0.0459	0.0016	0.0409	0.0012	0.0468	0.0085	0.0519
	Model specification 2: Using all schools in grades 4 through 6 and interacting dummy variables for changes on the number of other subjects with grade dummy variables							
Dummy variables for changes on the number of other subjects taught in year *t* and *t* - 1								
DV#$_{-3}$ in grade 4	-0.0322	-0.0467	-0.0124	-0.0199	-0.0041	0.0056	-0.0474	-0.0912
	(0.0358)	(0.0315)	(0.0265)	(0.0193)	(0.0573)	(0.0428)	(0.0433)	(0.0571)
DV#$_{-3}$ in grade 5	-0.0205	-0.0171	-0.0005	-0.0056	-0.0325	-0.0263	-0.0120	-0.0253
	(0.0272)	(0.0251)	(0.0126)	(0.0134)	(0.0226)	(0.0313)	(0.0265)	(0.0351)
DV#$_{-3}$ in grade 6	0.0106	0.0091	0.0147	0.0120	0.0105	0.0152	-0.0035	0.0070
	(0.0105)	(0.0133)	(0.0074)	(0.0084)	(0.0101)	(0.0138)	(0.0148)	(0.0153)
DV#$_{-2}$ in grade 4	0.0171	0.0291	0.0248	0.0108	-0.0058	0.0008	-0.0210	-0.0362
	(0.0288)	(0.0229)	(0.0161)	(0.0159)	(0.0337)	(0.0227)	(0.0236)	(0.0227)
DV#$_{-2}$ in grade 5	-0.0037	-0.0096	0.0012	-0.0138	0.0031	0.0090	0.0082	0.0017
	(0.0139)	(0.0142)	(0.0100)	(0.0103)	(0.0129)	(0.0145)	(0.0129)	(0.0137)
DV#$_{-2}$ in grade 6	0.0039	-0.0057	0.0159	0.0117	-0.0013	0.0020	0.0045	0.0031
	(0.0102)	(0.0138)	(0.0119)	(0.0105)	(0.0123)	(0.0133)	(0.0127)	(0.0134)
DV#$_{-1}$ in grade 4	0.0325	0.0478**	0.0526*	0.0458**	0.0069	0.0054	0.0439†	0.0359†
	(0.0311)	(0.0176)	(0.0206)	(0.0134)	(0.0246)	(0.0174)	(0.0244)	(0.0193)
DV#$_{-1}$ in grade 5	0.0133	0.0213†	0.0096	0.0112	-0.0013	0.0055	0.0038	0.0003
	(0.0101)	(0.0118)	(0.0123)	(0.0101)	(0.0110)	(0.0117)	(0.0140)	(0.0134)
DV#$_{-1}$ in grade 6	0.0072	0.0113	-0.0108	-0.0085	-0.0002	0.0005	0.0118	0.0059
	(0.0100)	(0.0099)	(0.0112)	(0.0088)	(0.0086)	(0.0097)	(0.0098)	(0.0116)
DV#$_{1}$ in grade 4	0.0503†	0.0551**	0.0253	0.0138	0.0083	0.0023	0.0020	-0.0227
	(0.0222)	(0.0200)	(0.0215)	(0.0151)	(0.0225)	(0.0210)	(0.0199)	(0.0219)
DV#$_{1}$ in grade 5	-0.0074	0.0017	0.0179	0.0206†	0.0035	0.0068	0.0093	0.0016
	(0.0147)	(0.0141)	(0.0156)	(0.0106)	(0.0133)	(0.0148)	(0.0145)	(0.0156)
DV#$_{1}$ in grade 6	0.0052	0.0112	-0.0058	0.0026	-0.0048	0.0025	-0.0085	-0.0194
	(0.0092)	(0.0126)	(0.0116)	(0.0099)	(0.0097)	(0.0120)	(0.0106)	(0.0138)
DV#$_{2}$ in grade 4	-0.0081	0.0090	-0.0252	-0.0244	-0.0380	-0.0251	0.0529†	0.0379
	(0.0322)	(0.0283)	(0.0255)	(0.0212)	(0.0438)	(0.0327)	(0.0302)	(0.0313)
DV#$_{2}$ in grade 5	0.0271	0.0188	0.0012	-0.0107	0.0248	0.0305	0.0403*	0.0396*
	(0.0249)	(0.0212)	(0.0158)	(0.0147)	(0.0206)	(0.0202)	(0.0190)	(0.0198)
DV#$_{2}$ in grade 6	0.0062	0.0107	0.0090	0.0072	-0.0046	-0.0001	0.0050	0.0074
	(0.0182)	(0.0166)	(0.0104)	(0.0114)	(0.0140)	(0.0160)	(0.0130)	(0.0154)
DV#$_{3}$ in grade 4	0.0188	-0.0115	-0.0472	-0.0519	---	---	0.0163	0.0112
	(0.0401)	(0.0524)	(0.0271)	(0.0224)	---	---	(0.0463)	(0.0725)
DV#$_{3}$ in grade 5	0.0458	0.0477	0.0071	-0.0046	-0.0094	-0.0050	0.0059	-0.0189
	(0.0409)	(0.0363)	(0.0148)	(0.0192)	(0.0231)	(0.0333)	(0.0398)	(0.0441)
DV#$_{3}$ in grade 6	0.0138	0.0074	0.0004	-0.0063	-0.0215	-0.0080	-0.0050	-0.0067
	(0.0126)	(0.0152)	(0.0083)	(0.0095)	(0.0137)	(0.0162)	(0.0112)	(0.0175)
Observations	24,094	24,094	27,941	27,941	23,493	23,493	23,856	23,856
R-squared	0.0069	0.0989	0.0032	0.0873	0.0019	0.1008	0.0094	0.1051
Adjusted R-squared	0.0059	0.0461	0.0023	0.0414	0.0010	0.0466	0.0084	0.0519
F-test in model specification 2								
H_0: Interaction terms between dummy variables for changes on the number of other subjects and grade dummy variables are jointly equal to zero.								
P-value (df = 12)	0.5568	0.2450	0.0787	0.0115	0.8522	0.9543	0.7915	0.4456

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. Samples include teachers in five school years 2007-08 through 2011-2012. The omitted variable for changes on the number of other subjects taught by teachers in two years *t* and *t* - 1 is the teachers who taught the same number of other subjects in two years. All models control for dummy variables for grades and school years. The models labeled as "SCH-FE" control for school fixed effects. The degree of freedom for F-test statistics is equal to 11 in science analyses.

The significant effects of education levels are also small but larger than the ones found in teaching experience by subject and grade. In mathematics, there is no evidence that acquiring advanced education levels is statistically associated with specialization in any grade. In contrast, teachers with Master degree are likely to teach more percent of students in English/language arts than the ones with Bachelor degree in all grades. Those positive and statistically significant effects are slightly higher for teachers with Education Doctoral and above in grades 4 (2.4 percent at $p < 0.05$) and 5 (3.3 percent at $p < 0.05$) but not statistically significant in grade 6. Some negative and significant results are found for teachers with Master degree but not with Education Doctoral and above in science and social studies. The results show that teachers with Master degree has taught one percent less of students in science in grades 4 and 5 and in social studies in grade 4 than the ones with Bachelor degree.

All findings from Tables 8 and 9 suggest that education levels and years of teaching experience are associated with teacher assignments but not in all subjects and grades. More important, their impact on teacher assignments is significant but trivial. The select teacher credentials only explain a very small portion of variation in teacher assignments. In addition, literature has found that education levels and years of teaching experience are not strongly correlated with student test performance (Goldhaber and Brewer, 2000; Hanushek, 1971 & 1997; Wayne and Youngs, 2003).[27] In other words, teacher assignments were based on the factors weakly related to student test scores. Overall, there is no evidence that the select teacher credentials explain why specialization has little effect on student test performance.

In addition, in Chapter II, I have shown that teachers' value added is correlated with teacher assignments. Table 8 presents the variation of teacher assignments that can be

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[27] Some studies have found positive effects of teacher credentials, especially in teacher experience, on student test scores (Rivkin, et al., 2005; Rockoff, 2004).

explained by teachers' value added separately in each subject and each grade. I regress teacher assignments $\mathrm{TA}_{k,t+1}^{s}$ in subject *s* for teacher *k* in school year $t + 1$ on absolute advantages in teaching each of four subjects X_{kt}^{mth}, X_{kt}^{ela}, X_{kt}^{sci}, and X_{kt}^{soc}.[28] The explained variation in teacher assignments across all models is small ranging from 0.1 to one percent across subjects and grades. Table 8 suggests that the explained variation in teacher assignments by teachers' value added is much higher than the one due to teacher credentials. These results also suggest that a substantial amount of variation in teacher assignments may be explained by factors other than teachers' value added.

Now, I consider whether teachers improve their own teaching effectiveness through specialization. Some teachers may be asked to focus on teaching one or fewer subjects. Instead of spreading their efforts to all subjects, they have concentrated on one or select subjects and have been likely to teach multiple classrooms in those subjects over time. I test whether changes on teaching effectiveness in a subject result from changes on the number of other subjects taught by teachers. I estimate this relationship using a teacher-level model where changes on value added in two school years *t* and $t - 1$ is a function of dummy variables for changes on the number of other subjects taught by teachers in two school years *t* and $t - 1$, grades, and school years; and school fixed effects. The equation is presented below:

$$\Delta E_{k,(t,t-1)}^{s} = \beta_0 + \beta_1 \Delta\psi_{k,(t,t-1)}^{-s} + \pi + \phi_m + e_{mt}, \qquad (2)$$

[28] The superscript *s* separately indicates each subject, mathematics (MTH), English/language arts (ELA), science (SCI), and social studies (SOC). The absolute advantage in teaching a subject is set to zero if teachers did not have a value-added score in that subject.

where $\Delta E^{s}_{k,(t,t-1)}$ is the difference of teachers' value added in subject *s* for teacher *k* in two school years *t* and *t* – 1 (i.e., $A^{s}_{kt} - A^{s}_{k,t-1}$);[29] $\Delta\psi^{-s}_{k,(t,t-1)}$ is a matrix of dummy variables for changes on the number of other subjects -*s* ($s \neq -s$) taught by teacher *k* in two school years *t* and *t* – 1; π is a matrix of dummy variables for grades and school years; ϕ_m is school fixed effects for school *m*; and e_{mt} is the error term clustered at school level.[30]

Table 10 presents marginal effects of changes on teacher assignments in subjects -*s* on changes of value added in subject *s*. The key regression coefficients are dummy variables for teachers who taught fewer subjects in year *t* than in year *t* – 1. For those teachers, the differences in the number of subjects -*s* include -1, -2, and -3. Those numbers indicate the number of subjects teachers did not teach in year *t*, but they taught those subjects in year *t* – 1. The omitted category for assignment dummy variables is the teachers who taught the same number of subjects in two school year.

These analyses show that teachers who taught two or three subjects fewer (i.e., -2 and -3) in year *t* than in year *t* – 1 did not improve their own teaching effectiveness in the subject(s) they have taught for two years. However, I find that teachers' value added in teaching mathematics is increased by 0.02 standard deviation ($p < 0.01$) in grades 4 through 6 when they taught one non-mathematics subject fewer (i.e., -1) compared to the ones who taught the same number of non-mathematics subjects in two school years. This pooled effect across all grades is not statistically significant to predict changes in teaching effectiveness in any other subjects.

[29] A^{s}_{kt} and $A^{s}_{k,t-1}$ are the effectiveness measures in subject *s* for teacher *k* in years *t* and *t* – 1, respectively, using the Dynamic Ordinary Least Square model in Chapter II.
[30] The superscripts for grades are suppressed for notation simplicity.

I then estimate whether the effects of changes on teacher assignments in other subjects are independent of grade level. The F-test statistics fails to reject the null hypothesis that the pooled effects across all grades are the same as the grade-specific effects on teaching effectiveness in all subjects except English/language arts. Teachers in English/language arts in grade 4 increase their own teaching effectiveness by 0.05 standard deviation ($p < 0.01$) when they taught one subject fewer compared to the ones who taught the same number of other subjects in two years in grade 4.

While these analyses find some significant results about the relationship between changes on teaching effectiveness and changes on the number of subjects taught by teachers in two years, there are more than 90 percent of the key regression coefficients that are not statistically significant. Therefore, these analyses do not provide strong evidence (or a consistent pattern) that specialization measured by changes on the number of subjects taught by teachers has significantly raised teachers' value added. In addition, there is no evidence that teachers who taught more subjects in year t than in year $t-1$ lower their own value added.

Lastly, I turn to the discussion about how teachers' value added has been used to make decisions on teacher assignments in grades 4 through 6 in Tennessee's public elementary schools. This discussion becomes important since I find that subject specialization has no effects on average test scores in any subjects in upper elementary grades 4 through 6 in Tennessee.

This study re-constructs the measure of subject specialization at the school-by-grade level as follows:[31]

[31] The subscripts for subject, grade, and school are omitted for notation simplicity.

$$\bar{\theta}_{va,t} = \sum_k \frac{n_{kt}}{\sum_k n_{kt}} * \frac{n_{kt}}{\sum_s n_{kt}} * A_{kt}, \quad (3)$$

where $\bar{\theta}_{va,t}$ is the specialization weighted by value added in a subject in a grade in a school in school year *t*; $\frac{n_{kt}}{\sum_k n_{kt}}$ is the weight equal to the number of students taught by teacher *k* in a subject divided by the total number of students taught by all teachers in that subject in a grade in a school in school year *t*; $\frac{n_{kt}}{\sum_s n_{kt}}$ is the share of students in a subject for teacher *k* in school year *t*; A_{kt} is teaching effectiveness in a subject for teacher *k* in school year *t*.[32] This specialization weighted by value added is constructed separately in each subject in a grade within schools.

This subject specialization weighted by value added describes how students are distributed from more to less effective teachers in a subject in a grade in a school. The more students taught by specialist teachers in a subject, the more weights will be assigned to those teachers' value added in teaching that subject. This measure in a subject is positive and large when the high-performing teachers specialize in that subject. In short, the variable $\bar{\theta}_{va,t}$ allows me to test whether the effect of specialization on student test performance depends on which teachers specialize, the high-performing or the low-performing ones.

Using the school mathematics model as an example, I control for subject specialization weighted by value added for mathematics teachers, $\bar{\theta}_{va,mt}$, in school *m* in school year *t* in the equation (1) instead of $\bar{\theta}_{mt}$. Table 11 presents the estimates of subject specialization, column (1), and subject specialization weighted by value added, columns (2) and (3), separately in each subject on average test performance. Instead of using nine school years, the analytical sample is restricted to six school years 2006-07 through 2011-2012 where teachers' average value added data are available. I also consider the grade-specific

[32] Teaching effectiveness is estimated in Chapter II using the DOLS model separately in each subject.

effects of specialization measures on average performance by adding the interaction terms between specialization measures and grade dummy variables.

In column (1), all findings are consistent with the nine- and six-year analyses. In column (2), the pooled and grade-specific effects are positive and statistically significant in all models. The F-test statistics suggests that the positive effects vary across grades in all subjects except English/language arts. In three other subjects, the highest impact of specialization weighted by value added is found in grade 4; and this impact reduces as the grade level goes up.

The interpretation of this specialization measure weighted by value added is not straightforward since this variable depends on the values of both the weighted specialization and teachers' value added. To interpret the effects on average test score, I use the following hypothetical example that is presented in Appendix D. Suppose there are two schools with two mathematics teachers in each school in grade 4. Separately in each school, one of two teachers has a weighted specialization 0.6 and the second teacher has a weighted specialization 0.2. In school A, the teacher who specialized more has a value-added score equal to 0.1 and another teacher has that score equal to 0.2. In the opposite, in school B, the teacher who specialized more has a value-added score equal to 0.2 and another teacher has that score equal to 0.1. The specialization weighted by value added is 0.1 in school A and 0.14 in school B. The difference of average mathematics achievement between two schools is $1.86 \times 0.04 = 0.07$ standard deviation.

Table 11
Effects of specialization based on teaching effectivenesson average scores in Tennessee's public elementary schools

Average test scores	Mathematics			English/language arts			Science			Social studies		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Model specification 1: Using all schools in grades 4 through 6												
Subject specialization	0.0164	1.2421***	1.8127***	0.0132	1.0422***	2.3545***	0.0094	1.2317***	1.8223***	0.0006	1.4203***	2.0357***
	(0.0191)	(0.0474)	(0.0692)	(0.0162)	(0.1152)	(0.1007)	(0.0220)	(0.0552)	(0.0814)	(0.0214)	(0.0551)	(0.1000)
Observations	14,029	14,029	14,029	14,092	14,092	14,092	14,026	14,026	14,026	14,018	14,018	14,018
R-squared	0.6417	0.6997	0.6930	0.6925	0.7293	0.7285	0.7223	0.7628	0.7588	0.7170	0.7751	0.7684
Adjusted R-squared	0.6023	0.6666	0.6592	0.6588	0.6996	0.6987	0.6917	0.7367	0.7323	0.6859	0.7504	0.7429
Multiplied by value added	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Model specification 2: Using all schools in grades 4 through 6 and interacting specialization by teachers and teachers' average value added in a subject with grade dummy variables												
Subject specialization in	0.0039	1.8557***	3.1532***	0.0073	1.1937***	4.2363***	-0.0973*	1.7527***	3.4369***	-0.0958†	2.1240***	4.0028***
grade 4	(0.0427)	(0.0947)	(0.2098)	(0.0312)	(0.2563)	(0.3483)	(0.0443)	(0.1057)	(0.3661)	(0.0499)	(0.0936)	(0.2301)
Subject specialization in	0.0075	1.4622***	1.9767***	0.0072	1.0385***	2.4688***	-0.0248	1.4697***	2.1362***	0.0039	1.6018***	2.0798***
grade 5	(0.0249)	(0.0826)	(0.1402)	(0.0205)	(0.1654)	(0.1560)	(0.0294)	(0.0897)	(0.1546)	(0.0305)	(0.1130)	(0.2370)
Subject specialization in	0.0261	0.8800***	1.2066***	0.0208	0.9556***	1.7203***	0.0495*	0.9255***	1.2437***	0.0131	1.0271***	1.4124***
grade 6	(0.0228)	(0.0478)	(0.0744)	(0.0207)	(0.0516)	(0.0965)	(0.0246)	(0.0571)	(0.0773)	(0.0250)	(0.0511)	(0.0697)
Observations	14,029	14,029	14,029	14,092	14,092	14,092	14,026	14,026	14,026	14,018	14,018	14,018
R-squared	0.6418	0.7064	0.7010	0.6925	0.7296	0.7335	0.7227	0.7664	0.7652	0.7172	0.7812	0.7773
Adjusted R-squared	0.6023	0.6740	0.6680	0.6587	0.7000	0.7042	0.6921	0.7406	0.7393	0.6860	0.7571	0.7528
Multiplied by value added	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
F-test in model specification 2												
H_0: Interaction terms between specialization by teachers and grade dummy variables are jointly equal to zero.												
P-value (*df* = 2)	0.7904	0.0000	0.0000	0.8446	0.2972	0.0000	0.0038	0.0000	0.0000	0.1072	0.0000	0.0000

Notes: Clustered standard errors in parentheses; significant levels based on clustered standard errors at school level; and †p-value <0.1, *p-value <0.05, **p-value <0.01, and ***p-value <0.001. The columns (1) through (3) use the samples restricted to the six school years 2006-07 through 2011-2012 where the data on teaches' average value added are available. All models control for time-variant school characteristics, dummy variables for grades and school years, the interaction terms between grade and year dummy variables, and school fixed effects. In the columns (2) and (3), for a given subject, the weighted specialization for a teacher is multiplied by her/his teaching effectiveness, and then sum this measure over all teachers who taught that subject in a grade in a school to construct the subject specialization variable for that school in that grade. Teaching effectiveness is measured by DOLS in column (2) and by Empirical Bayesian (i.e., shrinakge estimates) in column (3).

In short, this section provides several analyses that attempt to explain why specialization by teachers in a subject has no positive effects on average student performance in that subject. I find that (1) there is a substantial amount of variation of teaching effectiveness in the same subject for teachers within schools, but no evidence that variations of teaching effectiveness are small in schools with high specialization; (2) teacher credentials and teacher value added explain a tiny percent of variation in specialization and a great deal of the variation in specialization remain unexplained; and (3) teaching effectiveness has not been changed as the number of subjects taught goes down. Most important, this study finds consistent, large, and positive effects of subject specialization weighted by teachers' value added on average test performance in mathematics, English/language arts, science, and social studies. Those analyses provide strong empirical evidence that specialization matters to student test scores when the relatively more effective teachers have been assigned to specialize in upper elementary grades 4 through 6 in Tennessee.

4. Additional Analyses Using Shrinkage Estimates

I also perform a set of additional analyses using shrinkage teacher estimates instead of DOLS estimates. Those results are presented in column (3) of Table 11 using six school years. The effects of subject specialization weighted by shrinkage estimates are much stronger than the ones reported in column (2) in predicting average student scores separately in each subject. The magnitude of regression coefficients in column (3) varies from 1.8 to 2.4 in the pooled analyses and from 0.9 to 4.2 in the grade-specific analyses. As a result, the difference in mathematics achievement is much higher when using the regression coefficients from column (3) of Table 11. In the above hypothetical example, the difference in mathematics achievement between two schools is 0.13 standard deviation.

Conclusion

This study provides empirical evidence whether specialization by teachers in a subject influences average test performance in upper elementary grades 4 through 6 in Tennessee. Subject specialization has no effects on average test scores in mathematics, English/language arts, and social studies; and have some small effects in grades 4 and 6 in science. This study then examines several reasons why the effects of specialization by teachers have no positive impacts on average school performance across subjects and grade. More important, I find that subject specialization based on teachers' value added in all core academic subjects has a significant and positive effect on average test scores. These positive effects are much stronger when using the precise measure of teaching effectiveness (i.e., shrinkage estimates). In addition, this study shows that there is a great deal of potential in using teachers' value added to make decisions on specialization in all subjects. The next chapter will discuss the maximum potential gains that could be achieved through specialization in upper elementary grades in Tennessee.

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APPENDIX

Appendix A
Definition of terms on school organization structures

The definitions of classroom structures used in this study are identical to the ones presented in the report *Elementary School Organization: Self-Contained and Departmentalized Classroom Structure* (1989).

Self-contained: This elementary school organization structure with one teacher teaching a group of students for the majority of the day in all four academic subjects, math, reading/language arts, science, and social studies. Students in a self-contained classroom may receive art, music, and physical education from specialized teachers.

Semi-departmentalized: This classroom structure with two or three teachers sharing the responsibility of teaching a group of students in all four academic subjects. Students may also receive art, music, and physical education from specialized teachers.

Departmentalized: This classroom structure is most popular in middle and high schools. Teachers teach in their area of specialization, and students receive instruction from subject-area specialist teachers for all four academic subjects. Students may also receive art, music, and physical education from specialized teachers.

Appendix B
Table B - 1
Number of schools with no student-teacher links separately in each subject and each grade in school years 2003-04 through 2011-2012

			Number of schools without student-teacher links			
School year	Grade	All schools	Mathematics	English/ language arts	Science	Social Studies
2003-04	4	660	2	1	0	1
2003-04	5	620	3	2	3	6
2003-04	6	397	3	1	3	1
2004-05	4	724	1	0	1	1
2004-05	5	685	4	2	2	5
2004-05	6	459	2	2	2	4
2005-06	4	904	2	1	1	1
2005-06	5	840	1	0	0	1
2005-06	6	546	4	1	4	10
2006-07	4	936	5	2	3	4
2006-07	5	879	3	1	2	3
2006-07	6	584	10	4	8	10
2007-08	4	943	5	1	5	3
2007-08	5	882	5	1	5	1
2007-08	6	583	3	1	3	4
2008-09	4	950	1	0	1	1
2008-09	5	884	13	0	13	11
2008-09	6	571	12	4	12	13
2009-2010	4	946	4	0	3	4
2009-2010	5	893	5	1	8	11
2009-2010	6	579	3	1	6	5
2010-2011	4	973	1	0	1	0
2010-2011	5	912	2	1	3	3
2010-2011	6	596	2	0	5	5
2011-2012	4	981	0	1	1	0
2011-2012	5	926	3	2	4	4
2011-2012	6	602	3	1	3	1
Total		20,455	102	31	102	113

Notes: Some schools do not have student-teacher links in more than one core subject. There is no systematic pattern in schools where student-teacher links are always not avialable in a grade over time.

Appendix C
Table C - 1
Number of students excluded from analytical samples due to no student-teacher links separately in each grade in school years 2003-04 through 2011-2012

		Percent of students excluded from analytical samples			
School year	Grade	Mathematics	English/ language arts	Science	Social Studies
2003-04	4	0.32%	0.22%	0.07%	0.15%
2003-04	5	1.96%	1.03%	0.96%	1.14%
2003-04	6	3.30%	2.21%	2.24%	2.58%
2004-05	4	0.37%	0.25%	0.05%	0.12%
2004-05	5	1.84%	1.33%	1.24%	1.72%
2004-05	6	4.30%	2.66%	2.37%	3.08%
2005-06	4	0.40%	0.15%	0.19%	0.21%
2005-06	5	1.19%	0.75%	0.56%	0.45%
2005-06	6	3.42%	1.92%	0.99%	2.29%
2006-07	4	0.29%	0.16%	0.20%	0.26%
2006-07	5	1.05%	0.35%	0.66%	0.64%
2006-07	6	3.82%	2.13%	1.87%	2.56%
2007-08	4	0.79%	0.26%	0.54%	0.55%
2007-08	5	1.38%	0.58%	1.05%	0.71%
2007-08	6	2.84%	2.00%	1.73%	2.53%
2008-09	4	0.88%	0.16%	0.83%	0.78%
2008-09	5	1.72%	1.05%	1.78%	1.24%
2008-09	6	3.70%	1.96%	2.56%	3.10%
2009-2010	4	0.99%	0.18%	0.84%	0.93%
2009-2010	5	2.04%	1.33%	1.72%	1.72%
2009-2010	6	3.64%	3.40%	2.68%	3.20%
2010-2011	4	0.87%	0.38%	0.64%	0.47%
2010-2011	5	0.69%	0.65%	0.97%	0.85%
2010-2011	6	3.15%	2.60%	1.96%	2.77%
2011-2012	4	0.27%	0.24%	0.18%	0.09%
2011-2012	5	1.25%	0.85%	0.45%	0.62%
2011-2012	6	1.88%	1.95%	1.03%	0.87%
Total		1.82%	1.16%	1.14%	1.34%

Appendix D

Table D - 1

Gains in mathematics achievement between two schools in a hypothetical example

	School A	
Teachers	(1)	(2)
Weighted specialization	0.6	0.2
DOLS value added	0.1	0.2
	School B	
Teachers	(3)	(4)
Weighted specialization	0.6	0.2
DOLS value added	0.2	0.1
Difference in mathematics specialization		0.040
Difference in average mathematics achievement		0.074
	School A	
Teachers	(1)	(2)
Weighted specialization	0.6	0.2
EB value added	0.1	0.2
	School B	
Teachers	(3)	(4)
Weighted specialization	0.6	0.2
EB value added	0.2	0.1
Difference in mathematics specialization		0.040
Difference in average mathematics achievement		0.126

Notes: The degree of mathematics specialization is equivalent in two schools, but the more effective teacher in school B specialized in teaching mathematics.

CHAPTER IV

THE MAXIMUM POTENTIAL GAINS IN MATHEMATICS ACHIEVEMENT THAT COULD BE ACHIEVED THROUGH SPECIALIZATION IN ELEMENTARY SCHOOLS

Introduction

Research on teacher value added on student achievement (Aaronson et al., 2007; Ballou, 2005; Braun et al., 2010; Koedel and Bett, 2007; Rockoff, 2004; Rothstein, 2009) has concluded that (1) some teachers are more effective than others at raising student test scores; and (2) teacher value-added estimates are subject to noise, arising from measurement error and other sources of imprecision, which results in a high level of instability in the estimated teacher effects. The first set of research findings suggests the possibility of using the estimated teacher effects to raise student test scores. This can simply be done by taking teachers with the highest value-added estimates and having them to teach. The second set of research findings, however, poses a major concern to the implementation of teaching effectiveness related policies. This concern is with making school personnel decisions (i.e., promotion, retention, salary, and assignment) on the basis of the noisy estimates of teacher effects.

Given the growing interest on the potential of using teacher effectiveness measures, there is definitely a need for appropriate discussion to determine how to make the best school personnel decisions to raise student test scores with the information provided by the estimated teacher effects. The current research on policy use of the estimated teacher effects, instead, focuses on which school personnel decisions can be made on the basis of the estimated teacher effects. Several studies have explored the possibility of using teacher value-added estimates in making tenure decisions, promotion to administrative positions, and reassignments to high/low-stakes positions (Chingos and West, 2011; Goldhaber and Hansen, 2010a). Although those studies find the association between the estimated teacher effects and school personnel decisions, there is a lack of discussion about how to use teacher value-added estimates to make those personnel decisions.

This study, to the best of my awareness, is the first to investigate how to use estimated teacher effects optimally in making school personnel decisions. The personnel decision discussed in this study refers to making teacher assignments for subject specialization in elementary schools. Other researchers have also paid attention to managing teacher assignments. Jacob and Rockoff (2011) suggests allowing teachers to specialize in teaching the subject where they are most effective can substantially raise student test scores. They have further proposed that the benefits for students could be sufficiently large relative to the cost of managing teacher assignments. My study takes this one step further by asking: what is the maximum gain in a subject that could be achieved through specialization.

While many teachers teach self-contained classrooms in elementary schools, some are served as specialist teachers who have one or some subjects specialized to different classes of students. Research has shown that there have been an increasing number of content-specific specialist teachers in the core academic subjects at the upper grade levels in elementary schools. The variation of elementary school organization structures provides opportunities to have teacher effectiveness measures play an important role in managing teacher assignments.

As noted above, this study focuses on how to use the estimated teacher effects to make decisions on teacher assignments in elementary schools. The objective of this study is to maximize the potential gains in mathematics achievement that could be achieved through specialization in elementary schools if teacher value-added estimates are used to make assignment decisions. This study estimates teaching effectiveness for mathematics teachers using value added modeling.

I focus on mathematics for the following reasons: (1) student mathematics performance is often a bigger problem for schools than performance in other subjects; and (2) the variation of value-added estimates for teachers is larger in mathematics than other subjects. If specialization is positively correlated with student achievement, potential gains are greater in mathematics than other subjects.

This study determines the optimization-based selection of teachers to specialize in teaching mathematics within schools. The teachers with the highest absolute advantage in teaching mathematics within schools are assigned to fully specialize in teaching mathematics. I do not consider assignments that require teachers to change schools.

Since teacher value-added estimates are always subject to imprecision, I implement the empirical Bayesian approach to adjust the estimated teacher effects. In the literature, this approach also refers to the Best Linear Unbiased Prediction (BLUP) first developed in Searle (1971). These shrinkage estimates are then used to determine who specializes in teaching mathematics within schools. I then calculate the expected gains in mathematics achievement. In addition, I estimate achievement changes in other subjects that would result from this policy if the students released from the new specialists' classes were relocated among teachers of other subjects, holding teachers' workloads the same before and after this hypothetical policy. While mathematics specialization can increase student achievement in mathematics, it is uncertain how such specialization would also affect student achievement in other subjects.

To demonstrate the assignment procedure and the maximum potential gains in mathematics achievement that could be achieved through specialization, I use data from the Tennessee's public elementary schools. This study focuses on teachers in upper elementary grades 4 through 6 who taught mathematics in the 2010-2011 school year and who have stayed at the same schools for at least two years (i.e., the 2010-2011 school year and forward).[1]

Under the hypothetical policy for mathematics specialization, the number of mathematics specialists is determined by the number of students divided by the average workload for teachers within schools. The reminder of this division is then rounded to the nearest whole number. When the number of students divided by the average workload for teachers is smaller than 1 in a school, there is one and only one mathematics specialist needed in that school. When one teacher specializes, that teacher is assigned to teach mathematics to all students. When there is more than one mathematics specialist, each teacher is assigned to teach the same number of students.[2]

My hypothetical achievement gains in mathematics are always higher than the actual gains as long as the less effective mathematics teachers actually taught more students than the more effective mathematics teachers. The goal of this hypothetical policy for specialization is to allow the best mathematics teacher(s) to specialize in teaching mathematics. I assume this hypothetical policy always makes students move from less effective to more effective mathematics teachers; therefore, mathematics specialization can further improve student mathematics scores. If the relatively more effective teachers have

[1] To obtain the estimated teacher effects in a subject, a teacher has to teach that subject at the same school for at least two years prior to a new school year.
[2] The number of students assigned to each mathematics specialist could be somewhat either lower or higher than average teaching load within schools.

already taught more students, the reassignment of students to those teachers is not necessary. In the 2010-2011 school year, there are a total number of four schools with eight mathematics specialists (i.e., two teachers per school) where mathematics specialization is not necessary because the two teachers separately in each school taught the same number of students.

This study simultaneously calculates achievement changes in other subjects. To do so, the students who were taught by the new mathematics specialist(s) in other subjects are reassigned to the non-mathematics specialists whose assignments are altered under the hypothetical policy for mathematics specialization. The reassignment between those students and teachers is random. This random assignment is neither ideal nor practical, but it is one of the assignment strategies that can be easily implemented with minimum administrative efforts within schools. In practice, the reassignments of students in other subjects can also follow the similar optimal process used for mathematics specialization within schools. This study does not discuss any sophisticated assignment process for those students and teachers in other subjects since the key focus is on the maximum potential gains in mathematics achievement through specialization.

The achievement changes may or may not be positive under the random assignments. If the new mathematics specialists are relatively more effective in teaching non-mathematics subjects in a school, student scores in those subjects are likely to be not as good as before the hypothetical assignments would have taken place. In the opposite, if the mathematics teachers who do not become mathematics specialists under the hypothetical policy are relatively more effective in teaching other subjects, student test scores in those subjects are likely to be higher.

This study reports achievement gains in mathematics and achievement changes in other subjects if this hypothetical policy for mathematics specialization would have taken place within schools in the 2010-2011 school year. The average of the maximum gains in mathematics achievement is about 0.16 standard deviation points in schools where mathematics can be fully specialized. In 75.9 percent of those schools, the maximum gains are greater than 0.1 standard deviation. The achievement changes in English/language arts and science are centered on -0.1. The average achievement change in social studies is equal to zero.

This study further reports average maximum achievement gains in mathematics by school characteristics. The average gains through mathematics specialization are larger in schools with high poverty levels (i.e., the percent of students eligible for free/reduced-price school lunch) and low prior test performance compared to their counterparts. The schools in the lowest performance quintile of average prior test performance (quintile 1) and the ones with more than 87 percent of students eligible for free/reduced-price school lunch (quintile 5) can raise average test performance in mathematics by 0.17 and 0.18 standard deviation, respectively. I then report achievement gains in mathematics in schools grouped by school accountability status under NCLB and the Tennessee's new school accountability system implemented in the 2011-2012 school year.[3] Under either accountability system, schools are held for accountable for their performance in recent years instead of just one year prior. I find that the average of maximum achievement gains in mathematics and achievement changes in other subjects are not different across school groups based on

[3] For details on the exemplary districts, see Appendix A.

accountability indicators. The average achievement gains in priority and non-priority schools are 0.16 and 0.15, respectively.[4]

This chapter is organized in the following fashion. In Section 2, I explain the possibility of generating postdecision surprises during the process of selecting the high-performing teachers to specialize in mathematics and then discuss the way of using teacher value-added estimates to overcome the postdecision surprise when making teacher assignments. Section 3 states my research questions. Section 4 illustrates my method. Data used for this study are presented in Section 5. I display my findings in Section 6. This chapter concludes in Section 7.

Literature Review

It is obvious that teacher value-added estimates are always subject to random estimation error. Research has shown that not only teacher value-added estimates are not stable for a given teacher over time but also the differences on value-added estimates are not explained by observable teacher characteristics (Aaronson et al., 2007; Ballou, 2005; Goldhaber and Hansen, 2010b; Koedel and Betts, 2007; McCaffrey et al., 2008 and 2009). A teacher's ranking of value-added estimates will not be always the same from one year to the next. This can be an important reason that teacher value-added estimates are less attractive to the educators and researchers who believe that true teaching effectiveness is stable over time. Particularly, concerns are raised when teacher value-added estimates are used to make decisions on teacher assignments.

This study seeks to provide a mathematical solution to resolve postdecision surprises in an optimization-based selection process for subject specialization in schools. I consider

[4] Schools are placed on the priority list if they are in the bottom five percent of overall performance across tested grades and subjects.

two important issues in understanding the proposed strategy to assign the relatively more effective mathematics teachers to fully specialize in teaching mathematics. The first issue concerns the expected surprise built into the optimization-based selection process where selection is on the basis of some uncertain estimates of the true values. The second issue relates to the statistical technique to adjust teacher value-added estimates to overcome the postdecision surprise discussed in the first issue.

1. Postdecision Surprises

Postdecision surprises refer to the difference between what a decision-maker expects and what actually happens after a decision is made. The hypothetical policy I am considering for subject specialization can result in such surprise when the value estimates used to make decisions are subject to error.

Postdecision surprises can be observed in competitive situations. Several examples of auctions are often used to describe such surprise. According to Thaler (1998), an auction winner is unsatisfied (or perhaps even "cursed") when the winning bid exceeds the value of the object for sale or when the profit the winner gains from winning the bid is less than the winner's expectation. Postdecision surprises will occur when the estimates of the value of the object for sale from the bidders are subject to some random error (i.e., commonly associated with positive estimation errors during actions). The competition among auction bidders further amplifies the degree of surprises since the bidders have to bid aggressively to win the auction. The higher the bidders bid, the larger postdecision surprises will be if the estimates of the value of the object for sale are over what the value of that object truly is.

Marks (2008) and Smith and Winkler (2006) have also observed such surprise in an optimization-based selection process. Similar to the auction examples, choosing the best among the estimated values that are subject to some random error will result in unsatisfactory results on average. In a simulation example, a researcher selects the maximum value from three estimates. Those estimates are independent and identically distributed with an identical true value of zero and a standard deviation of one. In each iteration, the researcher generates three random estimates and selects the highest value estimate V_i. Repeat that data simulation and selection process hundreds or thousands times. The researcher then compares the average of the maximum value estimates selected over all iterations to the average of the known true value v_i. While the true value for each value estimate V_i is always known as zero, the average of the maximum value estimates over all iterations is 0.85. Therefore, the expected postdecision surprise $E(\hat{V}_i - v_i)$ is 0.85.

Smith and Winkler (2006) has further found that the expected surprise becomes larger as the number of the estimates for selection rises. The expected postdecision surprise $E(\hat{V}_i - v_i)$ will reach 1.54 when selecting the highest value estimate among 10 value estimates. Column 1 of Table 1 presents evidence of the expected surprise when selecting one and only one highest value estimates as the number of alternatives increases. I further extend this simulation analysis by asking whether the expected surprise will be varying when selecting multiple highest value estimates as the number of alternatives increases. I find that, holding the number of alternatives constant, the expected surprise decreases as the number of select highest value estimates increases. However, when holding the ratio of the number of select highest value estimates to the number of alternatives constant, the more alternatives, the higher is the expected surprise. For example, when this ratio is 1:4 (i.e., a quarter of alternatives is selected from each iteration), the expected surprise increases from

1.03 with four alternatives to 1.13 with eight alternatives (See the numbers highlighted in gray).[5] Such increase disappears when the total number of alternatives reaches 24.

This simulation example presented above closely mirrors subject specialization for teachers in my study. Assume that all mathematics teachers have an identical true value of teaching effectiveness in a given school, but their value-added estimates are different. Teachers with positive estimation error will look more effective than the ones with negative estimation error. While the optimization-based selection process determines the mathematics teacher with the highest value estimate to specialize in teaching mathematics, true effectiveness, by assumption, is the same across all mathematics teachers. The expected student test score gains from specialization are higher than what actually will be achieved. The difference between the two test score gains (expected versus actual) is the estimated postdecision surprise.

[5] A Stata program for this simulation analysis is available from the author by request.

Table 1
Expected surprise in a process of selecting the highest value estimate(s) as the number of alternatives increases

Number of alternatives	Expected surprise when selecting {a number of} highest value estimate(s)														
	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}	{14}	{15}
1	0.00														
2	0.56	0.00													
3	0.84	0.42	0.00												
4	1.03	0.66	0.34	0.00											
5	1.17	0.83	0.56	0.29	0.00										
6	1.27	0.96	0.71	0.48	0.25	0.00									
7	1.35	1.05	0.82	0.61	0.42	0.22	0.00								
8	1.42	1.13	0.91	0.72	0.54	0.37	0.20	-0.01							
9	1.48	1.21	1.00	0.82	0.65	0.50	0.34	0.18	0.00						
10	1.54	1.27	1.06	0.89	0.74	0.59	0.46	0.32	0.17	0.00					
11	1.59	1.32	1.12	0.96	0.81	0.68	0.55	0.42	0.29	0.16	0.00				
12	1.63	1.37	1.18	1.02	0.87	0.75	0.62	0.51	0.39	0.27	0.15	0.00			
13	1.67	1.42	1.23	1.07	0.94	0.81	0.70	0.58	0.48	0.37	0.26	0.14	0.00		
14	1.70	1.45	1.27	1.12	0.98	0.86	0.75	0.65	0.55	0.45	0.34	0.24	0.13	0.00	
15	1.73	1.49	1.31	1.16	1.03	0.91	0.81	0.71	0.61	0.51	0.42	0.33	0.23	0.12	0.00
16	1.76	1.52	1.35	1.20	1.07	0.96	0.86	0.76	0.67	0.58	0.49	0.40	0.31	0.22	0.12
17	1.79	1.55	1.38	1.23	1.11	1.00	0.90	0.80	0.71	0.63	0.54	0.46	0.38	0.29	0.20
18	1.82	1.59	1.41	1.27	1.15	1.04	0.94	0.85	0.77	0.68	0.60	0.52	0.44	0.36	0.28
19	1.85	1.61	1.44	1.30	1.18	1.08	0.98	0.89	0.81	0.73	0.65	0.57	0.50	0.42	0.35
20	1.87	1.64	1.47	1.33	1.22	1.11	1.02	0.93	0.85	0.77	0.69	0.62	0.55	0.48	0.41
21	1.89	1.66	1.49	1.36	1.24	1.14	1.05	0.96	0.88	0.80	0.73	0.66	0.59	0.52	0.46
22	1.91	1.68	1.51	1.38	1.27	1.17	1.08	0.99	0.91	0.84	0.77	0.70	0.63	0.57	0.50
23	1.93	1.71	1.54	1.41	1.30	1.20	1.11	1.02	0.95	0.87	0.81	0.74	0.67	0.61	0.55
24	1.95	1.73	1.57	1.44	1.32	1.23	1.14	1.06	0.98	0.91	0.84	0.77	0.71	0.65	0.59
25	1.97	1.75	1.58	1.46	1.35	1.25	1.16	1.08	1.01	0.94	0.87	0.80	0.74	0.68	0.62
26	1.98	1.77	1.61	1.48	1.37	1.27	1.19	1.11	1.04	0.97	0.90	0.84	0.78	0.72	0.66
27	2.00	1.78	1.62	1.49	1.39	1.29	1.21	1.13	1.06	0.99	0.92	0.86	0.80	0.75	0.69
28	2.02	1.80	1.64	1.52	1.41	1.32	1.23	1.15	1.08	1.01	0.95	0.89	0.83	0.78	0.72
29	2.03	1.82	1.66	1.53	1.43	1.33	1.25	1.18	1.11	1.04	0.98	0.92	0.86	0.81	0.75
30	2.05	1.83	1.68	1.55	1.45	1.35	1.27	1.20	1.13	1.06	1.00	0.94	0.88	0.83	0.78

Notes: Value estimates are drawn from a normal distribution with mean of zero and standard deviation of one. Each row is simulated by 30,000 times. Averages of the expected surprise are reported as the number of highest value estimates increases for a given number of alternatives.

2. Using Shrinkage Estimates in the Optimization-Based Selection Process

There is an increasing interest of using shrinkage estimates to improve the prediction of regression parameters due to the noise in the process of regression estimation. The shrinkage estimate is the solution for the problem of postdecision surprises in this study. To show the proof, let k^* be the teacher with the highest teacher estimate; and the optimal selection process chooses the teacher k^* to fully specialize in teaching mathematics. When selecting teachers based on the estimated teacher effects V_{km} in school *m*, the expected postdecision surprise conditional on $V = (V_1, \dots, V_n)$ is $E[\mu_{k^*} - V_{k^*}|V]$.[6] Such postdecision surprise is not equal to zero based on the simulation analysis mentioned above. The key to overcome this postdecision surprise is to choose "proper conditioning" (Smith and Winkler, 2006). Using the empirical Bayesian approach, the shrinkage estimate for teacher *k* is the posterior means $\hat{v}_k = E[\mu_k|V]$ for $k = 1, \dots, n$ from the posterior distribution for $\mu|V$ where $\mu = (\mu_1, \dots, \mu_n)$. Now rank $\hat{v}_k$ for all teachers and choose the maximal posterior value estimate for mathematics specialization. Given teacher k^* with the highest posterior value $\hat{v}_{k^*}$, the conditional expectation of $\mu_{k^*} - \hat{v}_{k^*}$ is

$$E[\mu_{k^*} - \hat{v}_{k^*}|V] = E[\mu_{k^*} - E[\mu_{k^*}|V]|V] = E[\mu_{k^*}|V] - E[\mu_{k^*}|V] = 0. \quad (1)$$

After integrating the conditional expectation over all estimated teacher effects in school *m*, the postdecision surprise $E[\mu_{k^*} - \hat{v}_{k^*}]$ is equal to zero.

A generalized form of a shrinkage estimator is $\hat{\beta} = \alpha \mathrm{B} + (1-\alpha)\bar{\beta}$ (Sander and Horn, 1994; Searle, 1971). The term α refers to the reliability of parameter estimates, a ratio of signal to the overall variance. The shrinkage estimator $\hat{\beta}$ depends on the reliability α, the

[6] There are a total number of n mathematics teachers in school *m*. The subscript for school is omitted for notation simplicity.

parameter estimate B, and the shrinking target $\bar{\beta}$ which normally is the grant mean of all true parameters. When the reliability is equal to one, the shrinkage estimate is the same as the raw estimate. When the reliability is approaching to zero, the parameter estimate is shrunk toward the grant mean of the true parameters.

To build shrinkage estimates for this study, consider my value-added estimates V_{km}, true teacher effects μ_{km}, and average value-added estimates V_m in school *m* in the following equations:

$$V_{km} = \mu_{km} + e_{km}, \tag{2}$$

$$\mu_{km} = \delta_{km} + \delta_m, \tag{3}$$

$$V_m = \mu_m + e_m, \tag{4}$$

where μ_m is the average true teacher effects in school *m*; δ_{km} is the difference between μ_{km} and μ_m for teacher *k* in school *m*; δ_m is the difference between μ_m and the grand mean effects for all teachers which is set to zero (i.e., $\mu = 0$).[7] With some algebra, one can then decompose V_{km} into three components as follows:

$$V_{km} = (V_{km} - V_m) + (V_m - \bar{V}) + (\bar{V} - \mu), \tag{5}$$

where the third component $(\bar{V} - \mu)$ is equal to zero since the true grand mean μ is equal to zero and the estimated grand mean $\bar{V}$ is approximately equal to zero. Quantitatively, V_{km} is the sum of the first two components.

The first two components are estimated with random error. I apply the generalized form for shrinkage estimator as mentioned above to calculate the shrinkage estimates for teacher *k*. The parameter estimate B is now replaced by the teacher-level component

[7] The grand mean of true teacher effects can be set to any number in a regression analysis. Conventionally, researchers estimate teachers' value-added estimates that follow a normal distribution with a mean of zero and a standard deviation of one.

$(V_{km} - V_m)$ and the school-level component $(V_m - \bar{V})$. The equation of my shrinkage estimator is presented below

$$\hat{v}_{km} = \alpha_1(V_{km} - V_m) + \alpha_2(V_m - \bar{V}) + (1 - \alpha_1 - \alpha_2)V_m, \tag{6}$$

where α_1 and α_2 are two reliability coefficients; and α_1 is not equal to α_2. Prior research by Sander and his colleagues has also used a similar version of shrinkage estimator but with one distinction. Their shrinkage estimator allows α_1 to be equal to α_2.

Instead, my shrinkage estimator in the equation (6) assumes that the amount of noise when estimating each of the first two components is different in this study. This assumption is true because the amount of noise comes from different sources separately for each component. The reliability of the teacher-level component depends on the amount of data used to estimate teachers' value added. The more data on student test scores and the less measurement error on test scores, the more accurate teachers' value-added estimates would be. Instead, for the school-level component, average value added depends on the number of teachers within schools. One teacher with an extremely high/low value-added estimate will largely influence average value added in small schools. Usually, the reliability coefficient in the teacher-level component is smaller than the one in the school-level component. It is easier to learn and more accurate to predict how effectively a school raises student test scores based on teaching effectiveness from individual teachers than how effectively individual teachers raise student test scores in that school based on student-level achievement data.

In this study, my primary focus is on the teacher-level component. Within schools, I select the most effective teacher(s) to fully specialize in teaching mathematics based on teachers' absolute advantage in teaching mathematics (i.e., $\hat{v}_{km} - \hat{v}_m$). The magnitude of these absolute advantages for individual teachers depends on the teacher-within-school effect $\alpha_1(V_{km} - V_m)$. The teacher-within school effects are then used to determine which mathematics teacher(s) will fully specialize in teaching mathematics in a school.

Research Questions

This study resolves a mathematical question of postdecision surprises to estimate achievement changes in each of four academic subjects in a school year if mathematics would have been fully specialized by the most effective mathematics teacher(s). I am asking two research questions:

> Research question 1: What would be the maximum gains in mathematics achievement that could be achieved through mathematics specialization in upper elementary grades 4 through 6 in Tennessee?
>
> Research question 2: What would be the achievement changes in other subjects while mathematics have been fully specialized in upper elementary grades 4 through 6 in Tennessee?

There are three things that need to be clear before calculating the achievement gains in mathematics or the achievement changes in other subjects. First, the number of mathematics specialists depends on the size of the school. When the school size is large, it might require the second and third best mathematics teachers to fully specialize in teaching mathematics. Second, this study uses a mixed-model equation to estimates the shrinkage of teaching effectiveness. Lastly, this study uses the shrinkage estimates to calculate absolute advantages in teaching mathematics among all mathematics teachers within schools. The decision on specialization by mathematics teachers is then based on within-school absolute advantages in teaching mathematics.

Empirical Methodology

1. Shrinkage Estimates for Teachers

This study uses the same setup including variables and sample specifications as the DOLS model presented in Chapter II to estimate the shrinkage of value added for teachers. Instead of estimating teacher effects in the DOLS model, I use the mixed-model equation in this essay to estimate school and teacher random effects within a fixed time period. My estimation equation for the BLUP estimator of teacher value added is presented below:

$$S_{it} = \beta_0 + \beta_1 S_{i,t-1} + \beta_2 X_{it} + \beta_3 P_t + \beta_4 \pi + \delta_m + \delta_{km} + v_{it}, \quad (7)$$

where δ_m is the random effects for school *m*; and δ_{km} is the random effects for teacher *k* in school *m*; and v_{it} is the error term clustered at the school level. According to Sander and Horn (1994) and Searle (1971), the BLUP estimator of random teacher effects is the shrinkage of value added.[8] This study estimates the shrinkage of value added for teachers separately in each of six hybrid districts over a rolling four-year window. In the Tennessee's value-added model, Sander and other researchers also pool schools with similar attributes from different districts to create a set of large hybrid districts and then estimate the shrinkage value added for teachers within each of those newly formed districts. I group schools based on school region and urbanicity categories.[9]

Teachers' shrinkage estimates are measured as teacher within school effects over a four-year period. I choose not to estimate teacher random effects using one year of data for two reasons. First, not all teachers have taught for four years. Even if one year of data on student test scores is missing, it is still possible to estimate teacher value added using data in other years available. Second, one year of data on student test scores is considered not being

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[8] For detailed information on the mixed-model equation, see Sanders and Horn (1994) on page 305.
[9] For more information about the hybrid districts, see Chapter II on page 14.

sufficient to estimate teacher random effects that are used for making decisions on teacher assignments. My estimation method allows me to use as many years of data as are available up to four years. The more years of data on student test scores for individual teachers increase the precision of shrinkage estimates for teaching effectiveness.

2. Subject Specialization and Teacher Assignments

In this analysis, teachers are regarded as eligible to fully specialize in teaching mathematics if they have shrinkage estimates in mathematics in schools where there were at least two mathematics teachers. The hypothetical policy for subject specialization targets on (1) self-contained classroom teachers and (2) teachers who were partially and/or fully specialized in teaching mathematics. Although two or more teachers have specialized in teaching mathematics in some schools, it is possible that previous specialization is not optimal. All eligible teachers at the same school are ranked based on their absolute advantages in teaching mathematics and the teacher with the highest absolute advantage is selected first for mathematics specialization. The teacher's absolute advantage in teaching mathematics is the difference between the shrinkage estimate $\hat{\delta}_{km}$ and the average of the shrinkage estimates $\hat{\delta}_{m}$ among all mathematics teachers at the same school. Those teachers are selected from each school to fully specialize in teaching mathematics at their own schools.

The number of mathematics specialists in a given school depends on the average teaching load within schools across all mathematics teachers. The teaching load is the total number of students in all subjects taught by a teacher in a school year. For example, a teacher taught three subjects, 25 students in mathematics and 20 in both English/language arts and science. The teaching load for that teacher is 25 + 20 + 20 = 65 students. The teaching loads for individual mathematics teachers are then averaged to the school level. The number of mathematics specialist teachers is equal to the total number of students divided by the average teaching load and this number is then rounded to integers. For example, if this number is less than 1.5 in a school, there is one and only mathematics specialist teacher required in that school. If there are more than one mathematics specialists in a school, the teachers with the highest absolute advantages are chosen first for mathematics specialization. All selected teachers fully specialize in teaching mathematics. The number of students assigned to each specialist is equal to the total number of students divided by the number of mathematics specialists. The mathematics specialists not only teach the students they actually taught in the 2010-2011 school year but also some additional students from other mathematics teachers who no longer teach mathematics under the new assignments for mathematics specialization.

The focus of the maximum gains in mathematics achievement is on those additional students taught by the mathematics specialists under the hypothetical policy for mathematics specialization since those students are reassigned to the mathematics specialists. The gains in mathematics are equal to the difference of the weighted average of teaching effectiveness before and after teacher assignments for mathematics specialization take place. The equation of estimating achievement gains in mathematics is as follows:

$$GAIN = W_{as} * T_{as} - W_{bs} * T_{bs}, \quad (8)$$

where T_{as} is a vertical vector of teacher shrinkage estimates for hypothetical mathematics specialists; T_{bs} is a vertical vector of teacher shrinkage estimates for the teachers who actually taught mathematics in the 2010-2011 school year;[10] and the horizontal vectors of weights W_{bs} and W_{as} are the proportion of students taught by mathematics teachers within

[10] The subscripts as and bs represent "after the reassignments for mathematics specialization" and "before the reassignments for mathematics specialization", respectively.

schools before and after mathematics specialization, $n_{bs,kt}/\sum_k n_{bs,kt}$ and $n_{as,kt}/\sum_k n_{as,kt}$, respectively.[11] If there is one and only one mathematics specialist in a school, W_{as} is a scalar vector of one and the weighted average of teaching effectiveness is the shrinkage estimate for that specialist teacher.

The estimation of the maximum gains in mathematics is rather straightforward. A mathematical example is presented below. This example further emphasizes which groups of students actually receive the benefits from mathematics specialization. Assume there are eight self-contained classroom teachers with 20 students per teacher in each of four subjects. Two mathematics specialists are needed for a total number of 160 mathematics students (80 student per specialist). When I estimate the maximum gains in mathematics, the target students are those 120 students who were taught by six other self-contained classroom teachers who no longer teach mathematics after the hypothetical policy for subject specialization takes place. The weights W_{as} for the mathematics specialists are equal to the ratio of 60 to 120 (i.e., each mathematics specialist teaches 60 more students who come from the other six teachers). The weights W_{bs} for the teachers who will no longer teach mathematics are equal to the ratio of 20 to 120 (i.e., each of those teachers taught 20 students in mathematics and the total number of those students is 120).

Those teachers who are eligible for reassignments also include the ones within schools where mathematics has already been fully specialized. It is not clear whether more effective specialist teachers have always been assigned to teach more students than other less effective specialist teachers in mathematics. In other words, if the existing assignments for mathematics specialization has not been optimal, there is a room to further improve the

[11] The subscript for subject and school is omitted for notation clarity.

average mathematics performance through mathematics specialization. Specifically, I allow the students from less effective specialist teachers to flow to more effective specialist teachers. For example, there are two specialists who taught one and only one subject, mathematics, in a schools. Teacher A taught 90 students with the highest value added; and teacher B taught 110 students. The average teaching load for mathematics teachers is 100 students. Since the current assignment for mathematics teachers was not optimal, it is possible to raise average mathematics scores by letting teacher A teach 10 more students who originally were taught by teacher B. In this particular case, all specialist teachers continue teaching mathematics but the number of students assigned separately to each teacher is set to the average teaching load for mathematics teachers.

After determining mathematics specialists and the maximum gains in mathematics, the number of students mathematics specialists who would have had in other subjects are randomly assigned to other non-mathematics specialist teachers who originally taught mathematics before mathematics specialization. The way to calculate the changes for those students in each of non-mathematics subjects is similar to the way I estimate the maximum gains in mathematics through specialization. In the equation (8), $W_{as} * T_{as}$ is the weighted average of teaching effectiveness in a non-mathematics subject after the random reassignment occurs; and $W_{bs} * T_{bs}$ is the weighted average of teaching effectiveness in the same non-mathematics subject before the random reassignment occurs.[12] In the above example, the achievement changes are centered on those 120 students who will be randomly reassigned to different teachers in each of three non-mathematics subjects after mathematics specialization.

[12] When the reassignments happen within schools where mathematics has already been fully specialized, the estimation of changes in achievement in other subjects is not available.

Data

This study uses student and teacher longitudinal data to estimate the shrinkage of value added for teachers in grades 4 through 6 in Tennessee's public elementary schools. Shrinkage estimates in the 2010-2011 school year are then used to make decisions on mathematics specialization within schools. I estimate the maximum gains in mathematics through specialization and the changes in achievement in other subjects.

This study also considers school-level characteristics to understand the variation of the maximum gains in mathematics that could be achieved through specialization. I group schools based on school poverty level; the average test scores in schools and school NCLB accountability status levels in the 2009-2010 school year; and the Tennessee's own accountability indicators in the 2011-2012 school year. I then compare achievement gains across different groups separately in each subject.

In the 2011-2012 school year, Tennessee replaces the NCLB accountability system with its own accountability system; and focuses on growth of achievement for all students and on closing achievement gaps. Under this new system, the state of Tennessee will provide a list of schools/districts under different achievement categories. For this new school accountability, schools are placed in three categories, reward, priority, and focus. Each of those categories represents a group of schools. For example, the top 5 percent of high performing schools in Tennessee are listed on the reward school list. The bottom 5 percent of schools on overall achievement performance are placed on the priority school list. The 10 percent of schools with the largest achievement gaps are placed on the focus school list. In addition to the school accountability, Tennessee further classifies districts in three categories, exemplary, in need of improvement, and need of subgroup improvement. Districts are placed on each category based on (1) the district overall proficiency levels; (2) progress on closing achievement gaps; and (3) improvement for minority students, students with disabilities, limited English language learners, and socioeconomically disadvantaged students. In this study, I group schools based on the Tennessee's own accountability measures in the 2011-2012 school year in order to understand the variation of the maximum gains in mathematics across different school/district categories as well as the changes in achievement in other subjects.[13]

Results

Previous Chapters II and III have shown that (1) there is a great deal of potential to increase the degree of specialization in upper elementary grades 4 through 6 in Tennessee and (2) the variation of teachers' value added in mathematics is the highest among all other subjects. This section then presents the maximum gains in mathematics and the changes in achievement in other subjects after the hypothetical policy for mathematics specialization would have taken place in the 2010-2011 school year.

There are a total number of 1,212 schools with mathematics teachers in grades 4 through 6 in the 2010-2011 school year. The number of schools that meet the requirements to implement the hypothetical policy for mathematics specialization is 874. Those schools have a total number of 6,211 mathematics teachers. Among those teachers, there are 1,811 mathematics specialists selected under the hypothetical policy holding their average teaching load constant within schools. Tables 2a and 2b presents the number of teachers separately in each grade by teacher assignments before and after mathematics specialization has taken place.

[13] The use of the Tennessee's own accountability system starts in the 2011-2012 school year; therefore, the Tennessee's school and district accountability statuses are not available in the 2010-2011 school year. I use the estimated teaching effectiveness data in the 2010-2011 school year because the school poverty and NCLB data from TDOE report cards are only available in the 2010-2011 school year for the public use.

Specifically, Table 2a shows the number of mathematics specialists by their actual assignments in the 2010-2011 school year. As expected, a large proportion of mathematics specialists (i.e., 96 percent in grade 4 and 86 percent in grade 5) taught self-contained classrooms in the 2010-2011 school year. In grade 6, there are 51 percent of mathematics specialists assigned to continue specializing in teaching mathematics and there are 22 percent of mathematics specialists who actually were self-contained classroom teachers in the 2010-2011 school year.

Instead, Table 2b indicates assignments for teachers who no longer teach mathematics due to the hypothetical policy for mathematics specialization. Most self-contained classroom teachers now only teach three non-mathematics subjects. In addition, I find that some mathematics specialists (i.e., 112 in grades 4 through 6) in the 2010-2011 school years do not teach any subject under the hypothetical policy for mathematics specialization while those teachers fully specialized in teaching mathematics in the 2010-2011 school year.[14] The number of mathematics specialists is small in grades 4 and 5 in schools, but not all of those teachers had high value added so that they can be chosen to continue specializing fully in teaching mathematics.

[14] Some of those teachers do not have value-added data in any non-mathematics subjects if they have specialized fully in teaching mathematics for at least three school years. This hypothetical policy for mathematics specialization does not mean to lay off this small group of teachers. Instead, there are several possible reassignments for those teachers within schools. They may teach in the lower elementary grades 1 and 2; teach non-academic subjects; and take non-instructional positions (e.g., student counselor). It is important to acknowledge that the policy for specialization does not intend to fire the less effective teachers in a subject within schools.

Table 2a

Number of mathematics teachers who will specialize in teaching mathematics separately in each grade by their actual assignments in the 2010-2011 school year

Subject scheme before reassignments	Grade level					
	4		5		6	
	Number	Percent	Number	Percent	Number	Percent
MTH	8	1.2%	35	5.1%	237	50.7%
MTH and ELA	6	0.9%	17	2.5%	51	10.9%
MTH and SCI	2	0.3%	8	1.2%	26	5.6%
MTH and SOC	3	0.5%	6	0.9%	22	4.7%
MTH, ELA, and SCI	4	0.6%	3	0.4%	4	0.9%
MTH, ELA, and SOC	3	0.5%	9	1.3%	9	1.9%
MTH, ELA, SCI, and SOC	636	96.1%	585	85.8%	101	21.6%
MTH, SCI, and SOC	0	0.0%	19	2.8%	17	3.6%
Total number of teachers	662		682		467	

Notes: Sample includes teachers who taught matheamtics in grades 4 through 6 and some teachers who taught more than one grade in schools. There are 874 schools (out of 1,212) eligible for this hypothetical policy for mathematics specialization in the 2010-2011 school year.

Table 2b

Number of mathematics teachers who no longer teach mathematics separately in each grade by their new assignments due to mathematics specialziation

Subject scheme after reassignments	Grade level					
	4		5		6	
	Number	Percent	Number	Percent	Number	Percent
Do NOT teach	13	0.7%	30	1.6%	69	12.1%
ELA	17	0.9%	24	1.3%	62	10.9%
ELA and SCI	12	0.6%	18	1.0%	9	1.6%
ELA and SOC	16	0.8%	14	0.8%	19	3.3%
ELA, SCI, and SOC	1,931	96.7%	1,672	91.1%	330	58.1%
SCI	3	0.2%	25	1.4%	25	4.4%
SCI and SOC	3	0.2%	46	2.5%	33	5.8%
SOC	1	0.1%	7	0.4%	21	3.7%
Total number of teachers	1,996		1,836		568	

Notes: Sample includes teachers who taught matheamtics in grades 4 through 6 and some teachers who taught more than one grade in schools. There are 874 schools (out of 1,212) eligible for this hypothetical policy for mathematics specialization.

Figures 1 through 4 display the achievement gains or losses for individual schools separately in each subject. On average, those figures suggest there are gains in mathematics, less than 0.1 losses in both English/language arts and science, and almost no changes in social studies.

In mathematics, there are 24.1 percent (211) schools with the maximum gains less than 0.1 standard deviation; 51.8 percent (453) with the gains between 0.1 and 0.2; and 24 percent (210) with the gains greater than 0.2. The average of the maximum gains in mathematics is about 0.155 standard deviation.

The changes in achievement due to mathematics specialization could be either positive or negative in other subjects within schools. There are about 89 percent of schools (639) with the changes in achievement smaller than zero standard deviation in English/language arts, 89.6 percent (635) in science, and 50.7 percent (356) in social studies. The average changes in achievement is -0.086 in English/language arts, -0.097 in science, and 0.001 in social studies. The negative changes in achievement in both English/language arts and science may be due to the fact that the mathematics specialists were also relatively effective in teaching other non-mathematics subjects in the 2010-2011 school year compared to the ones who no longer teach mathematics but other non-mathematics subjects.

In addition to reporting the gains/losses in achievement for individual schools, this study is also interesting in how school characteristics are associated with the maximum gains in mathematics through specialization and the changes in achievement in other subjects after reassignments. This is a policy-related concern regarding whether the potential maximum gains in mathematics and the changes in achievement in other subjects are substantially higher in one particular group than another.

Figure 1
Maximum achievement gains in mathematics that could be achieved through specialization in upper elementary grades 4 through 6

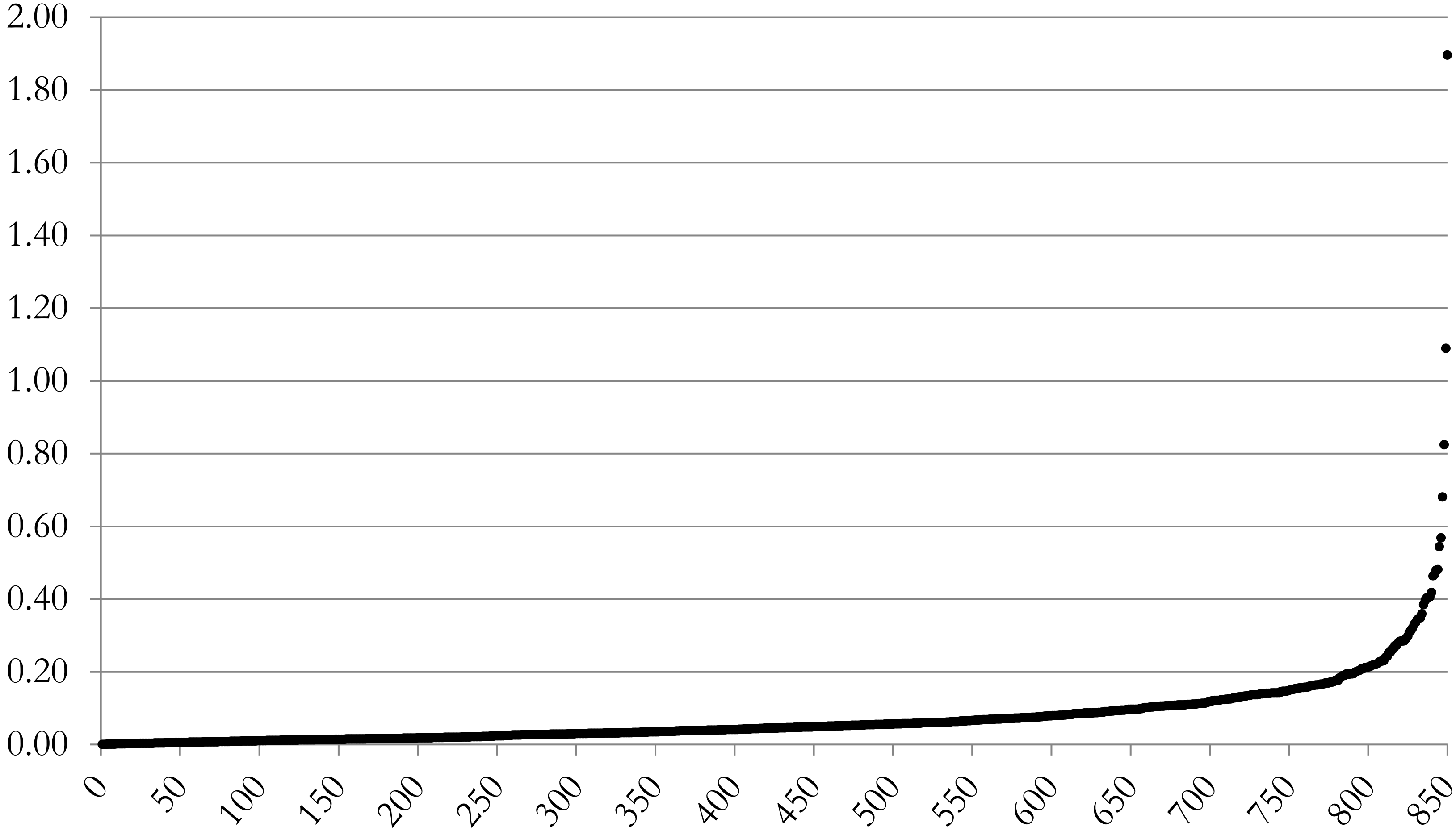

Figure 2
Achievement changes in English/language arts in upper elementary grades 4 through 6 after reassignment

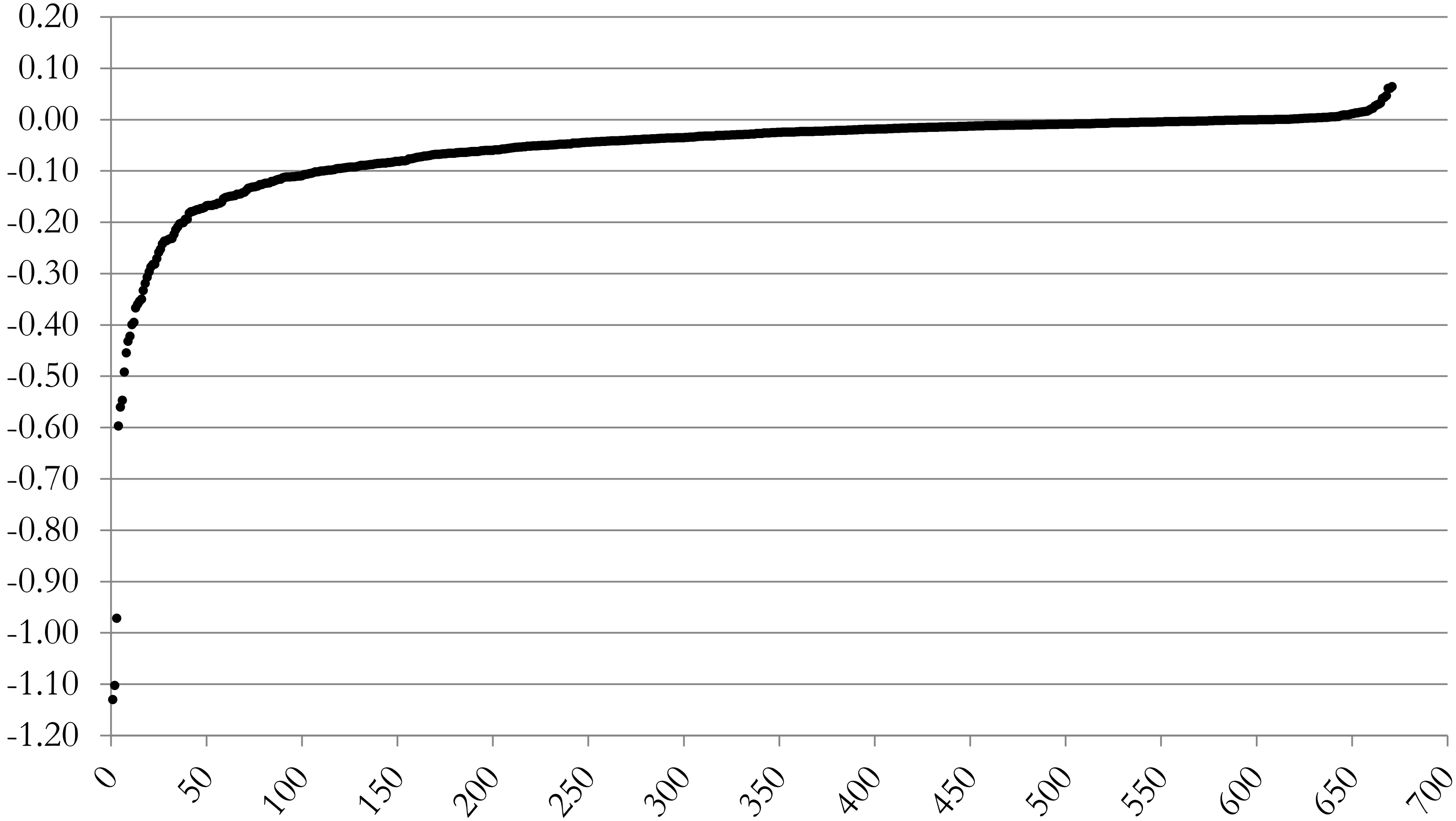

Figure 3
Achievement changes in science in upper elementary grades 4 through 6 after reassignment

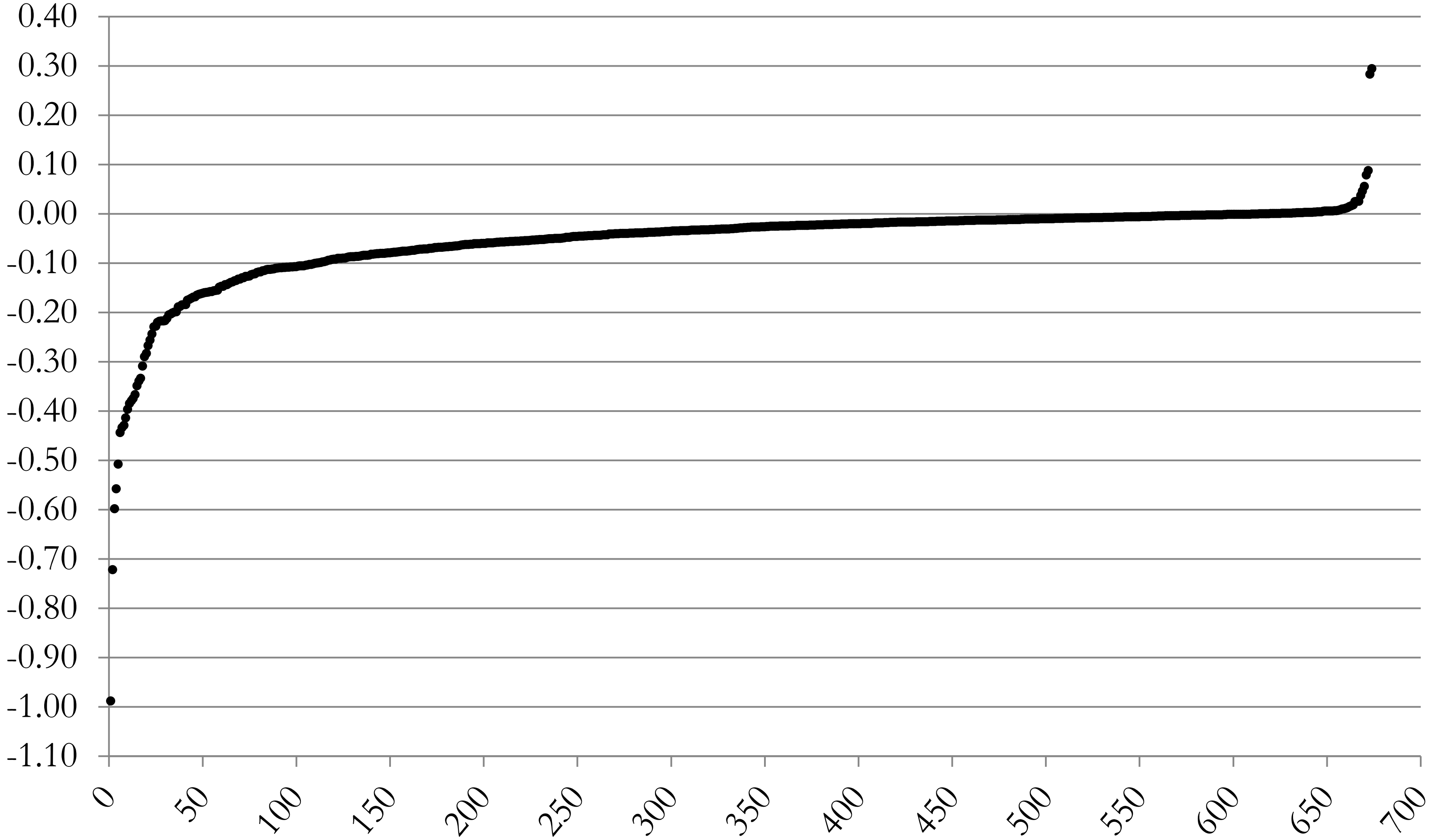

Figure 4
Achievement changes in social studies in upper elementary grades 4 through 6 after reassignment

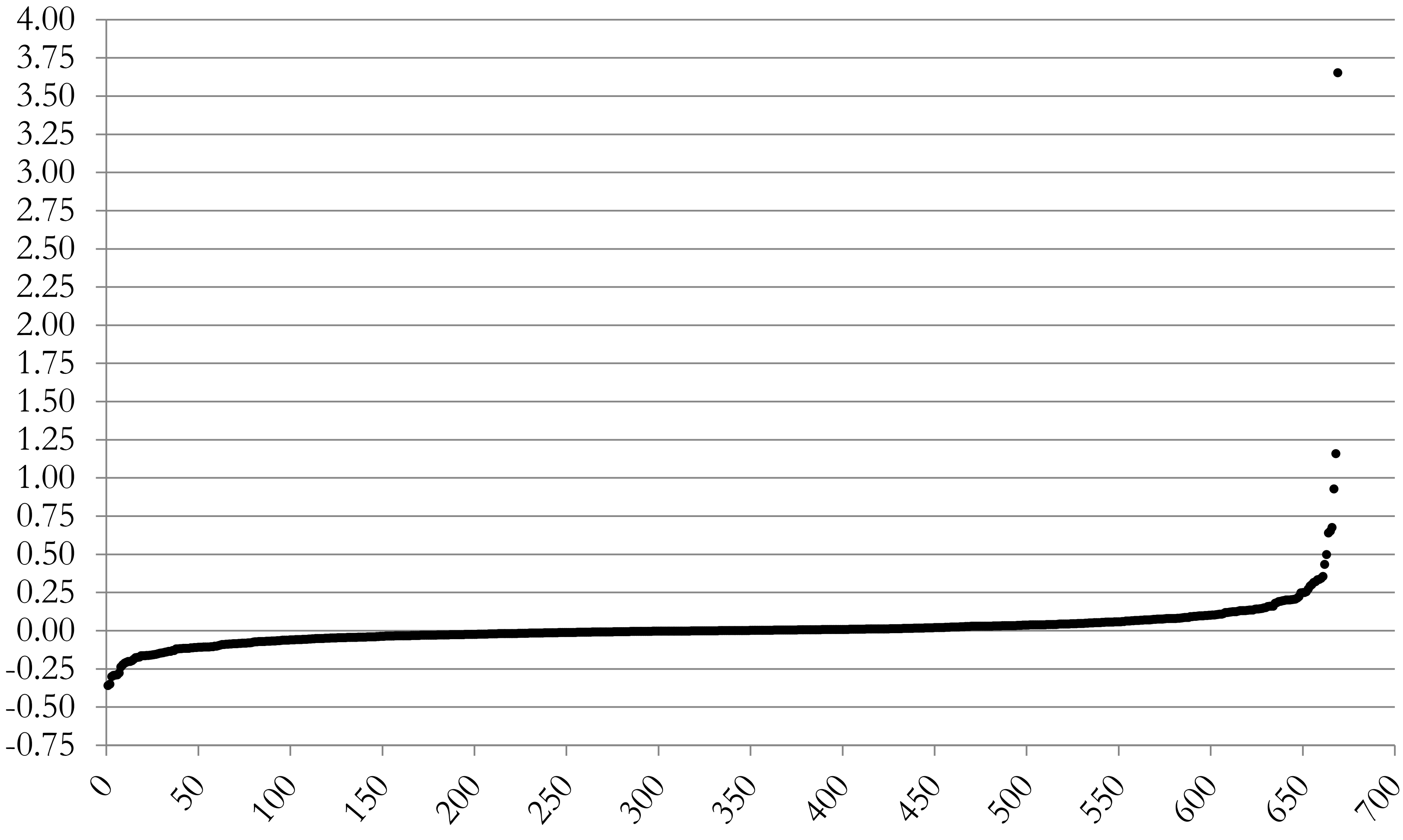

Table 3 presents the aggregated maximum gains in mathematics and the changes in achievement separately in each non-mathematics subject by school characteristics.[15] I consider three types of school characteristics (i.e., percent of students eligible for free/reduced price school lunch – FRL, average of prior test performance – ATP, and school NCLB accountability statuses) and five school grouping strategies (i.e., priority, focus, reward, exemplary, and subgroup improvement classifications under Tennessee's own accountability system).

Average gains/losses in achievement are reported for schools within each of five FRL quintiles, each of five ATP quintiles, and three NCLB accountability status levels (i.e., good standing, target, and sanctions). Using Tennessee's own accountability system, I also report average gains/losses in achievement based on a set of binary accountability status indicators (i.e., priority versus non-priority, focus versus non-focus, reward and non-reward, exemplary and non-exemplary, and subgroup improvement versus non-subgroup improvement).

[15] For the graphic illustration of average gains/losses in each subject separately by school characteristics, see Appendix B.

Table 3

Achievement gains/losses in each subject separately through specialization and after reassignments in the 2010-2011 school year in upper elementary grades 4 through 6 in Tennessee

		Mathematics		English/ language arts		Science		Social studies	
		Average gains	Number of schools	Average changes	Number of schools	Average changes	Number of schools	Average changes	Number of schools
Percent free/reduced price school lunch in schools									
Quintile 1	1.20 - 46.21%	0.1457	203	-0.0766	164	-0.0863	161	-0.0102	163
Quintile 2	46.24 - 61.68%	0.1537	151	-0.0714	120	-0.0839	113	-0.0074	112
Quintile 3	61.68 - 72.75%	0.1519	177	-0.0888	144	-0.1046	143	-0.0045	143
Quintile 4	72.81 - 87.14%	0.1531	178	-0.0902	151	-0.0941	146	0.0080	143
Quintile 5	87.15 - 100%	0.1748	156	-0.1009	135	-0.1138	142	0.0250	137
Total		0.1551	865	-0.0857	714	-0.0968	705	0.0021	698
Average achievement score at school									
Quintile 1		0.1846	135	-0.1054	119	-0.1227	128	0.0020	128
Quintile 2		0.1612	191	-0.1048	148	-0.1000	156	-0.0051	141
Quintile 3		0.1606	187	-0.0868	148	-0.0837	130	-0.0175	138
Quintile 4		0.1414	174	-0.0735	148	-0.0995	139	-0.0003	153
Quintile 5		0.1349	187	-0.0623	155	-0.0809	156	0.0279	142
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
School NCLB status									
Good standing		0.1543	449	-0.0801	385	-0.0957	379	0.0009	379
Target		0.1587	282	-0.0907	235	-0.0999	230	-0.0057	226
Sanctions		0.1506	143	-0.0947	98	-0.0939	100	0.0203	97
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
Grouping schools (1)									
Non-priority		0.1549	842	-0.0851	691	-0.0965	681	0.0003	675
Priority		0.1601	32	-0.0969	27	-0.1039	28	0.0319	27
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
Grouping schools (2)									
Non-focus		0.1549	784	-0.0846	639	-0.0987	634	0.0036	626
Focus		0.1571	90	-0.0932	79	-0.0807	75	-0.0163	76
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
Grouping schools (3)									
Non-reward		0.1561	790	-0.0868	646	-0.1005	635	0.0015	630
Reward		0.1460	84	-0.0743	72	-0.0649	74	0.0010	72
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
Grouping schools (4)									
Non-exemplary		0.1547	782	-0.0855	640	-0.0973	636	0.0008	631
Exemplary		0.1589	92	-0.0863	78	-0.0926	73	0.0079	71
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702
Grouping schools (5)									
Non-subgroup improvement		0.1548	555	-0.0868	445	-0.0981	443	0.0047	441
Subgroup improvement		0.1557	319	-0.0836	273	-0.0946	266	-0.0040	261
Total		0.1551	874	-0.0856	718	-0.0968	709	0.0015	702

Notes: Schools with the lowest average mathematics scores are grouped in the first quintile; and schools with the highest average mathematics scores are grouped in the fifth quintile.

Those results show that the proportional changes across school FRL and ATP groups are large but strikingly similar across accountability groups. In comparison of average gains in achievement between the first (< 46 percent) and the fifth (> 87 percent) FRL percent quintiles, schools with higher percent of FRL students achieve higher gains in mathematics (a 20 percent increase) and much greater gains in social studies (from – 0.1 to 0.02 standard deviation). At the same time, average losses in achievement increase by 31.8 percent in both English/language arts and science between the first and fifth FRL percent quintiles. These findings suggest that schools with more poverty students are likely to make much higher gains in mathematics through specialization compared to their counterparts. This may be due to the fact that the variation of value added for mathematics teachers is large in schools with more poverty students. While the losses in achievement become larger in schools with more poverty students in English/language arts and science, there are much higher gains in social studies in schools with more than 72.8 percent of FRL students.

The proportional changes are even stronger across schools grouped by average of prior achievement performance. Comparing the lowest (quintile 1) to the highest (quintile 5) groups of average prior test performance, average gains in mathematics steadily decrease from 0.18 to 0.13 standard deviation. There is a 40.8 and 34 percent decrease in average losses in English/language arts and science, respectively. Average losses drop from -0.11 to -0.06 standard deviation in English/language arts and from -0.12 to -0.08 in science. These findings suggest that average gains in mathematics through specialization are inversely associated with average prior test performance in schools. In other words, more achievement gains in mathematics can be achieved through specialization in schools with lower prior mathematics achievement. The higher prior achievement in English/language arts and science, the less achievement losses in those subjects. In the opposite, there is no systematic pattern of the changes in social studies across ATP groups and the average gain is almost zero in social studies.

Average gains in mathematics are not significantly different across accountability groups. This is also true about average achievement losses in English/language arts and science. However, the schools with poor accountability status have higher achievement gains in social studies. For example, those schools that were subject to NCLB sanctions and classified as priority schools have 0.02 and 0.03 standard deviation, respectively. While achievement changes in social studies are different across accountability groups based on each accountability indicator, average achievement changes in social studies are small less than 0.05 standard deviation. Over all, these findings suggest that the gains in mathematics and the changes in other subjects are not affected by school accountability status assessed one year before (2009-2010) and after (2011-2012).

Conclusion

This study estimates the shrinkage of value added for individual teachers. The shrinkage estimates are then used in the optimization-based selection process to determine mathematics specialist(s) within schools. I estimate the maximum gains in mathematics that could be achieved through specialization and the changes in achievement in other subjects. The results indicate that the gains in mathematics are higher in schools with higher poverty students and lower average prior test performance. At the same time, the gains in mathematics are not different across school groups defined by school accountability status under NCLB and the Tennessee's new school/district accountability system.

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APPENDIX

Appendix A

Table A - 1

Tennessee's district accountability results in the 2011-2012 school year

Exemplary	Need of improvement	Need of subgroup improvement	
(1)	(1)	(1)	(2)
Blount County Schools	Alamo City	Anderson County	Huntingdon
Claiborne County Schools	Richard City	Bedford County	Kingsport
Fayette County Schools	Union County	Bradley County	Lawrence County
Fayetteville Schools		Campbell County	Lebanon
Henry County Schools		Carter County	Lenoir City
Hollow Rock-Bruceton School District		Cheatham County	Lexington
Franklin Special School District		Cleveland	Macon County
Loudon County Schools		Cocke County	Madison County
Marshall County Schools		Coffee County	Manchester
McKenzie Special School District		Crockett County	Maryville
Milan Special School District		Cumberland County	Meigs County
Newport City Schools		Decatur County	Memphis
Rogersville City Schools		Dekalb County	Monroe County
Rutherford County Schools		Dyersburg	Murfreesboro
Sequatchie County Schools		Etowah	Oak Ridge
Sevier County Schools		Fentress County	Oneida
Smith County Schools		Gibson County SSD	Paris
South Carroll County Special School District		Greene County	Pickett County
Sweetwater City Schools		Greeneville	Polk County
Trousdale County Schools		Grundy County	Scott County
Union City Schools		Hamblen County	Stewart County
		Hancock County	Trenton
		Hardeman County	Van Buren County
		Hardin County	Washington County
		Hawkins County	Wayne County
		Houston County	Weakley County
		Humboldt	Wilson County

Source: Data retrived from http://www.tn.gov/education/accountability/ on September 10, 2013.

Appendix B
Figure B - 1
Average achievement changes in each subject separately by percent quintile of free/reduced price school lunch

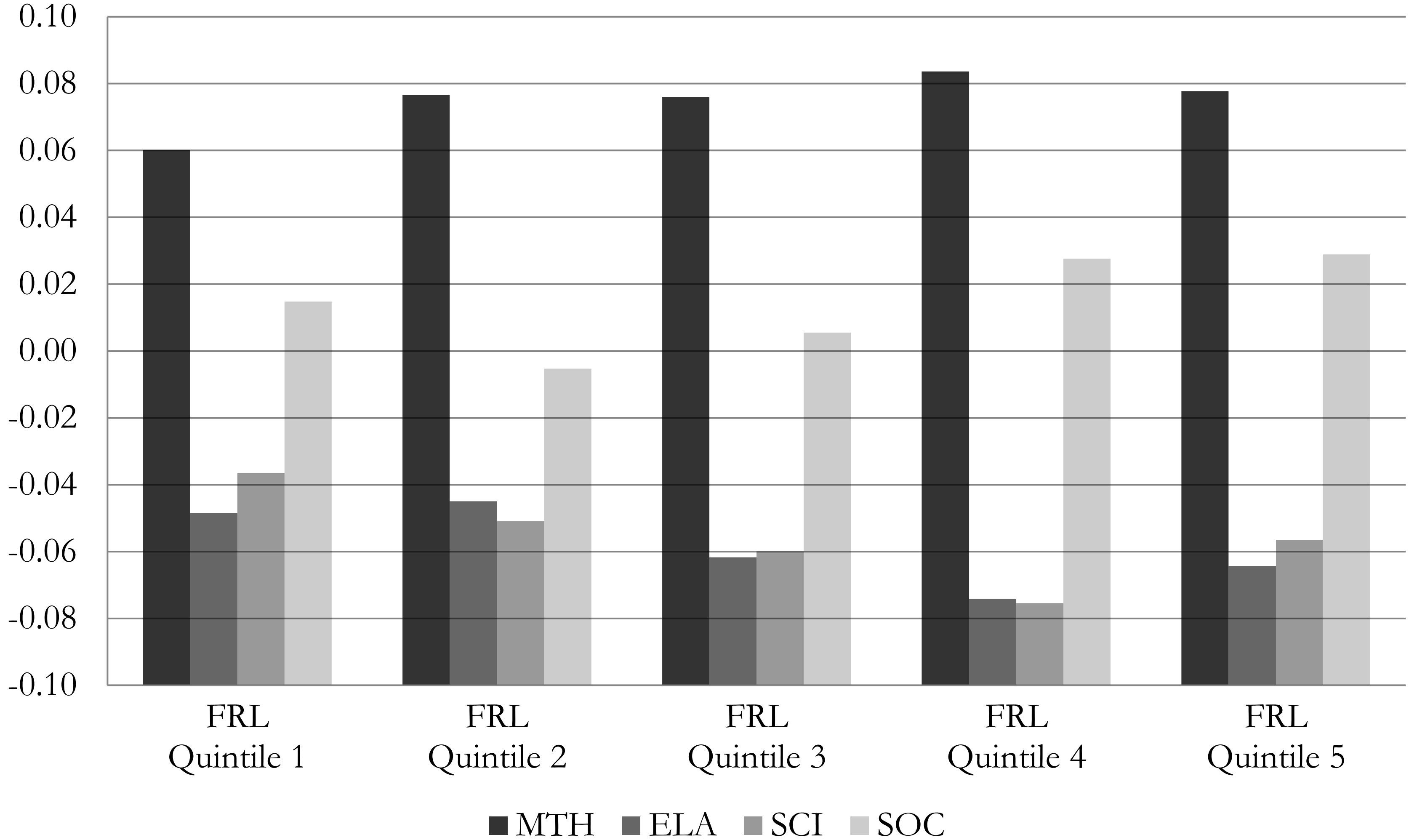


Figure B - 2
Average achievement changes in each subject separately by average achievement quintile

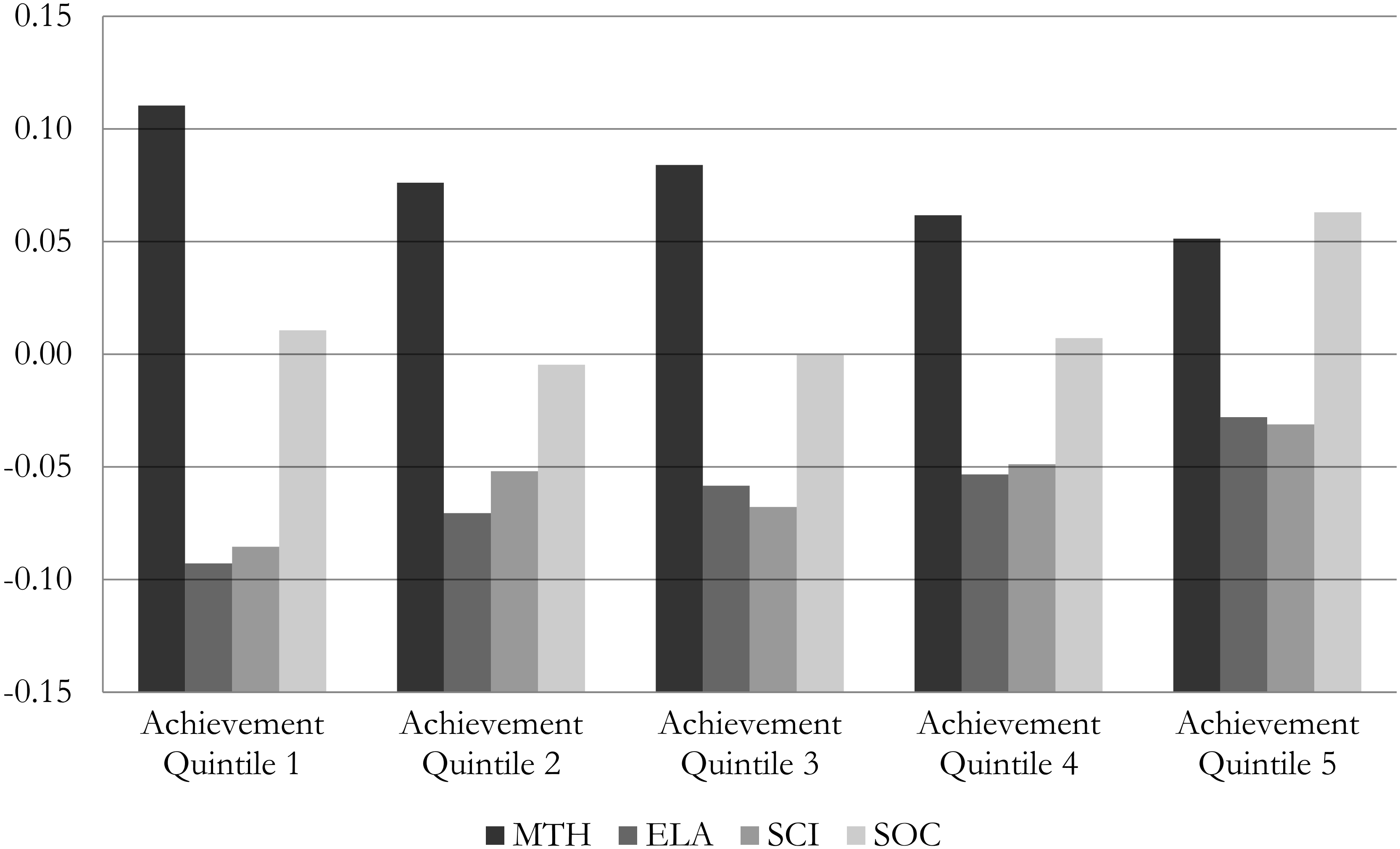


Figure B - 3
Average achievement changes in each subject separately by school NCLB status

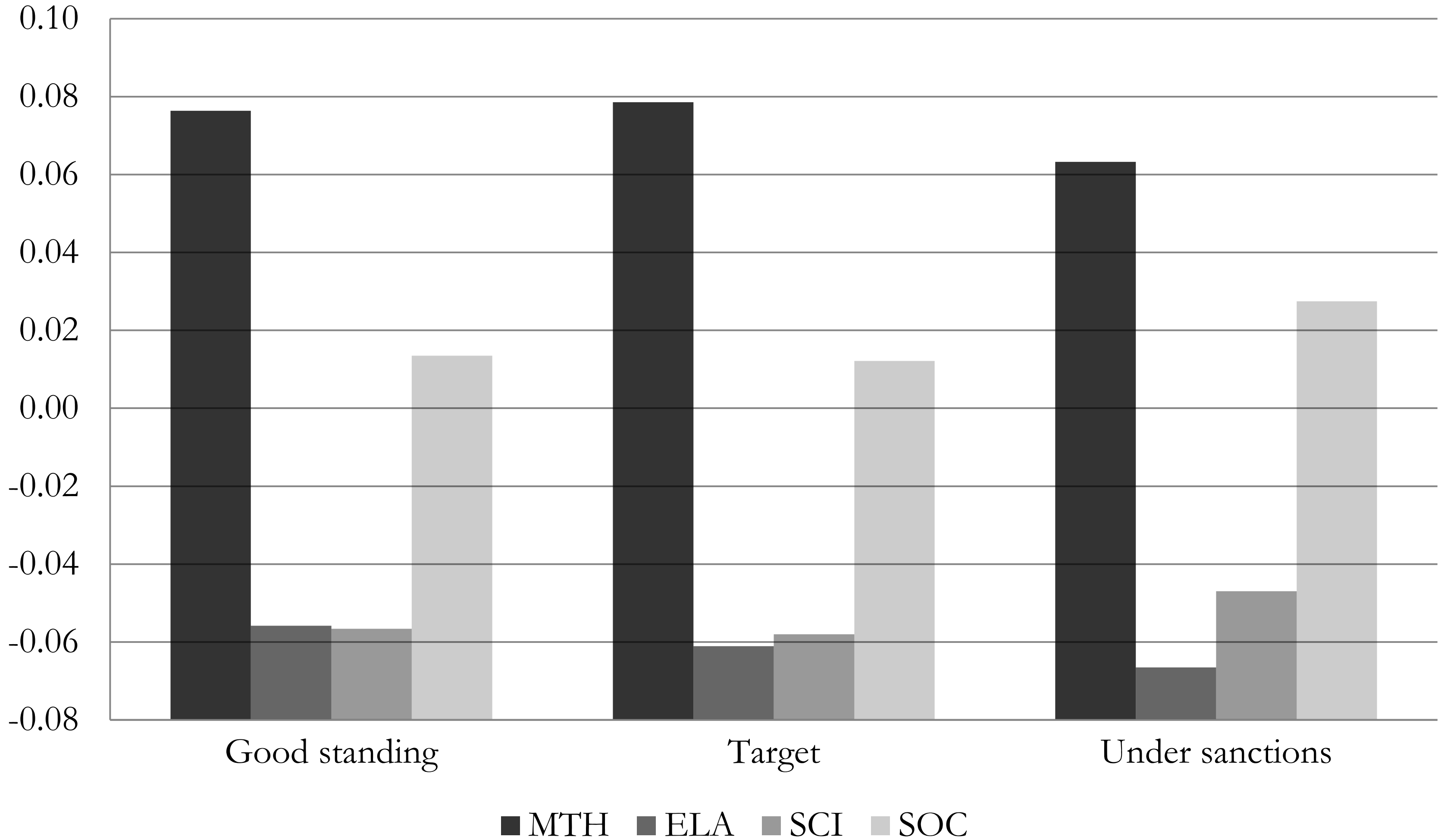


Figure B - 4
Average achievement changes in each subject separately between priority and non-priority schools

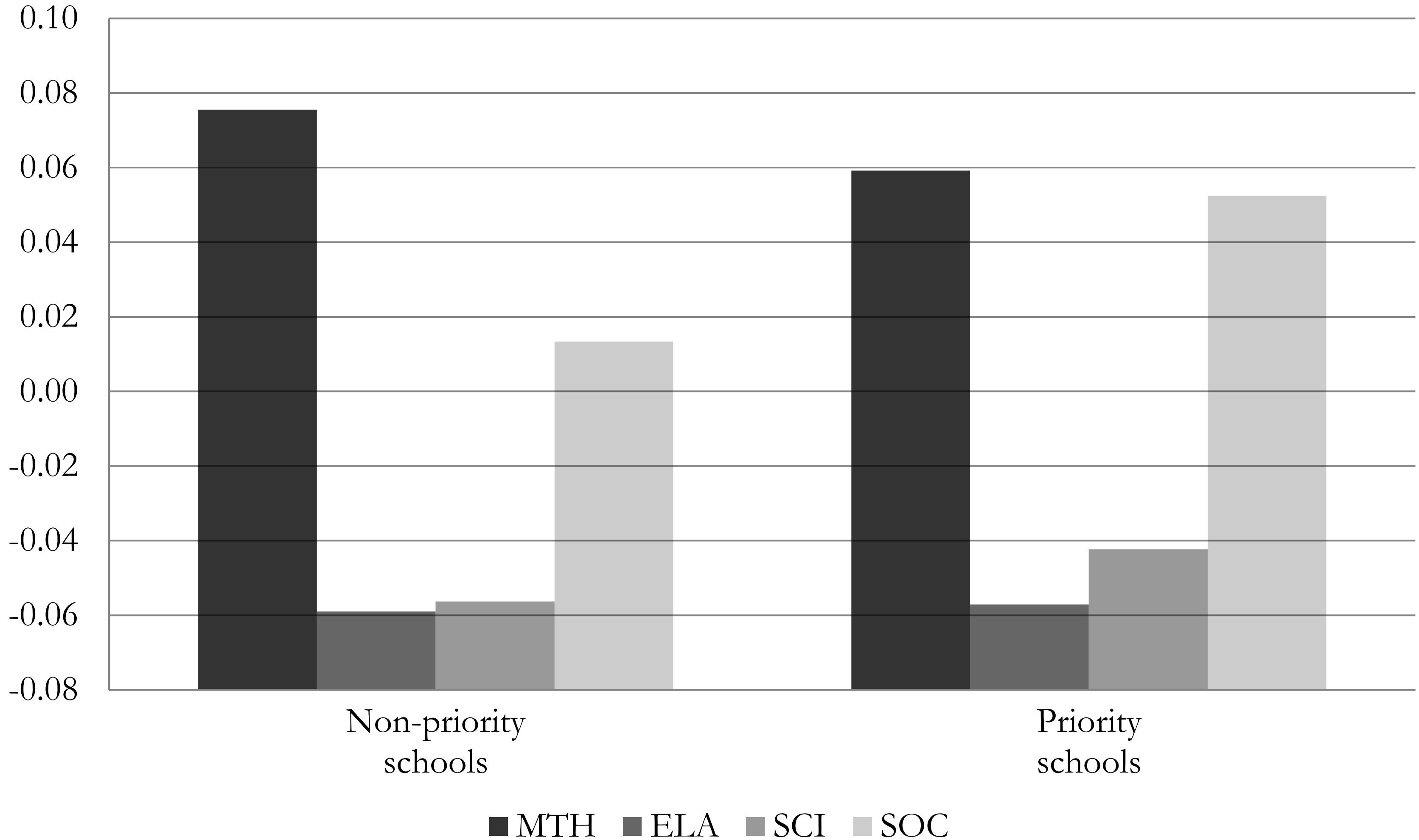


Figure B - 5
Average achievement changes in each subject separately between focus and non-focus schools

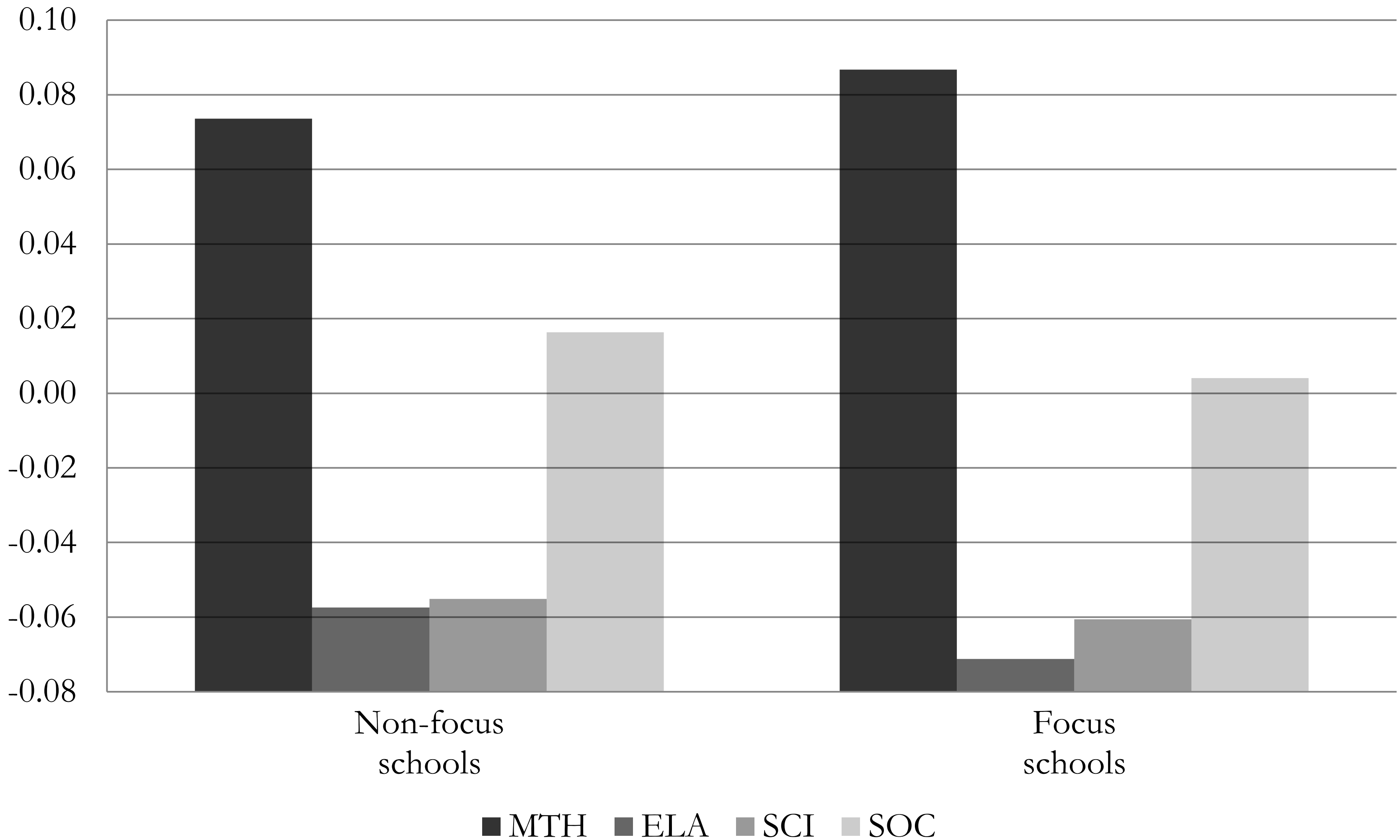


Figure B - 6
Average achievement changes in each subject separately between reward and non-reward schools

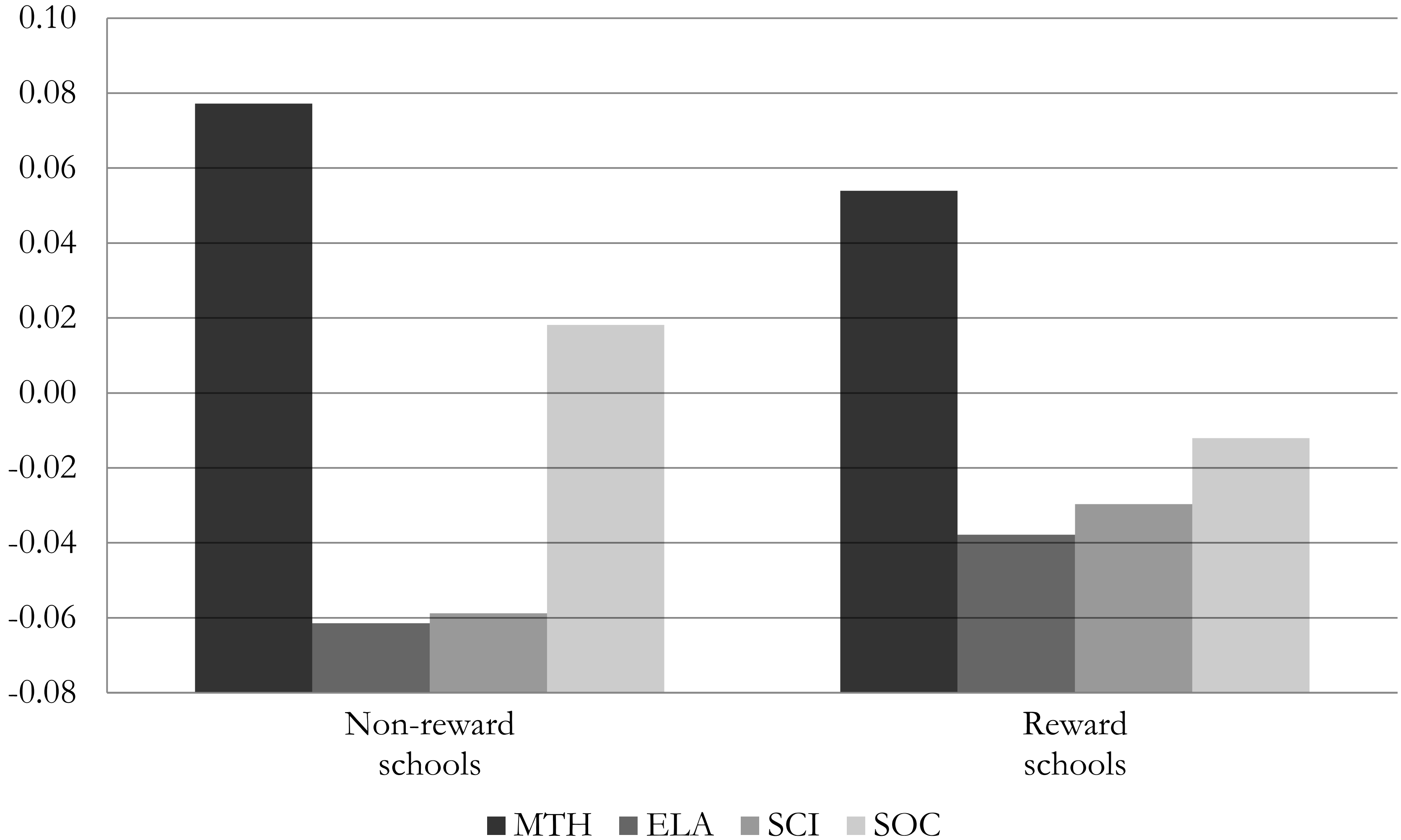
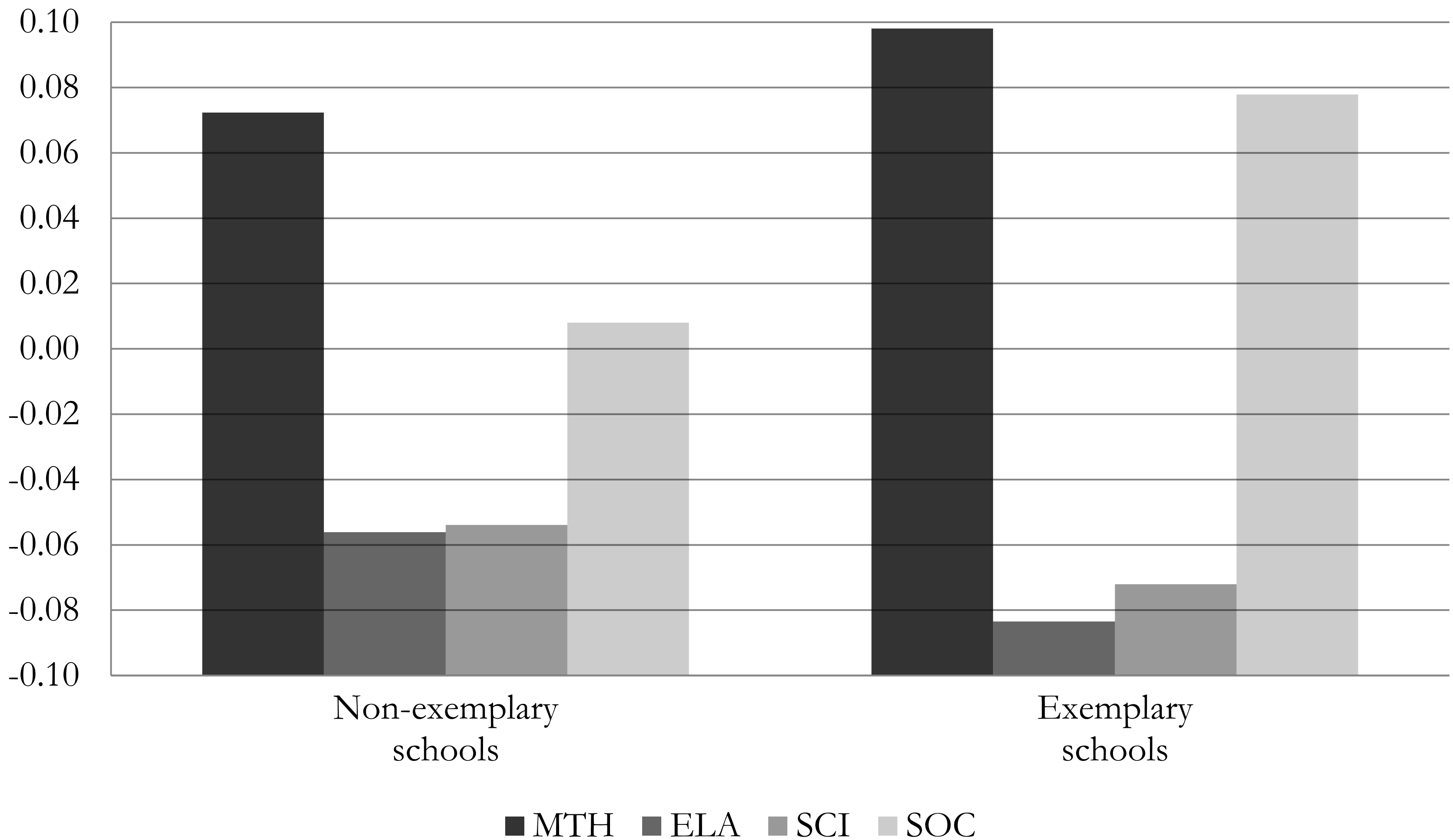


Figure B - 7
Average achievement changes in each subject separately between exemplary and non-exemplary schools



CHAPTER V

CONCLSION

This dissertation seeks to inform educators, researchers, and policy-makers who intent to use teacher value-added data to make decisions on teacher assignments in elementary schools. A particular focus is on subject specialization and its impact on average test performance. I develop models to provide evidence that teaching effectiveness measured by teacher value added is positively correlated with subject specialization and specialization based on teaching effectiveness raises average student scores in upper elementary grades 4 through 6 in Tennessee. I further estimate the maximum gains in mathematics that could be achieved through specialization.

The three essays in this dissertation are linked by three different focuses on teaching effectiveness measured by teacher value added, but they all connected to teacher assignments. This dissertation contributes to the line of research on improving student learning measured by test scores in the core academic subjects. Specifically, I focus on changes in teacher assignments and school organization structure in elementary schools.

The first essay centers on the relationship between teaching effectiveness and teacher assignments. It concludes that high value added in a subject increases the proportion of students taught by individual teachers in that subject. This evidence can be interpreted by the arguments that either teacher value added has been used to assign teachers to their area of specialty or the criteria used to make decisions on teacher assignments are correlated with the estimated teacher effects using value added modeling (i.e., DOLS and DOLS with teacher-within school effects). While this correlation between teacher assignments and teacher effectiveness is positive and statistically significant, there is a great deal of variation in teacher assignments explained by factors other than teaching effectiveness. This finding has raised the interest in measuring the impact of subject specialization on student test scores in elementary schools.

The second essay asks whether specialization assignments raise average student performance in elementary schools. This essay is interested in the consequence of subject specialization that has been growing in elementary schools over time. My findings suggest that specialization has not raised student test scores in all subjects except science in grade 6. Those findings are then followed by several analyses on why specialization does not matter to student achievement across subject and grades. I then conclude that specialization based on teacher value added has substantially raised average student scores. Combining the first two essays, I show that not only teacher value added is correlated with teacher assignments, but also the use of teacher value added to make teacher assignments has a strong and positive influence to school performance. Now, a new question arises what benefits can be achieved through specialization especially when specialization is optimally operated in elementary schools.

The third essay asks what maximum gains in mathematics could be achieved through specialization. Based on how specialization has been done in the past, the third essay asks how much gains a school can achieve if an optimal selection procedure is implemented to select the most effective teacher(s) to fully specialize in teaching mathematics within schools. To accurately estimate the maximum gains in mathematics, this study uses the BLUP estimator, also as known as shrinkage estimates, to quantify teaching effectiveness. The gains in mathematics are more substantial in schools with more students eligible for free/reduced-price school lunch and lower prior test scores.

I then pay attention to the changes in achievement in other subjects. The approach I take to assign students to teachers in non-mathematics subjects is not optimal. Clearly, taking the random assignment approach generates losses in achievement in English/language arts and science. This suggests that there is a need for a more sophisticated approach to further take the advantages of subject specialization.

Overall, this dissertation will raise more studies on the use of teacher value added and the practice of teacher assignments that aim to raise student test scores in the future. It would be very interesting to conduct a similar study based this dissertation in different States, especially the ones where schools and districts are less likely to favor teacher value added. In addition, taking a different approach, future studies may focus on experimental evidence for the use of teacher value added and the impact of subject specialization in elementary schools.[1] The goal of these future studies is to (1) help design the rigorous guidelines for school administrators to follow when they use value-added data to make teacher assignments; (2) evaluate the impact of subject specialization based on the proposed guidelines; (3) use the responses from teachers and administrators about the use of value added data to make teacher assignments to further develop better plans for school administrators; and (4) examine teacher mobility, retention, and recruitment under the influence of the new assignment policy that involves the use of value added data.

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[1] Appendix B presents the patterns of teacher assignments based on the Schools and Staffing Survey data collected from different states. Those descriptive statistics of teacher assignments serve a standing point for the purpose to replicate this dissertation in a different state.

APPENDIX

Appendix A

List of abbreviations and acronyms

MTH	Mathematics
RLA	Reading/Language Arts
SCI	Science
SOC	Social Studies
AYP	Adequate Yearly Progress
NCLB	No Child Left Behind
EVAAS	Educational Value-added Assessment System
TVAAS	Tennessee Value-Added Assessment System
MNPS	Metropolitan Nashville Public Schools
POINT	Project on Incentives in Teaching
SASS	Schools and Staffing Survey
TCAP	Tennessee Comprehensive Assessment Program
PIRS	Personnel Information Reporting System
TSLA	Tennessee State Library and Archives
SUR	Seemingly Unrelated Regressions
DOLS	Dynamic Ordinary Least Squares
RCA	“Revealed” Comparative Advantage

Appendix B
Patterns of Assignments for Public Upper Elementary Grade Level Teachers: Evidence from the 2003-04 Schools and Staffing Survey

May 2012

B – TABLE OF CONTENTS

B – LIST OF TABLES

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B – INTRODUCATION

We use data from the Schools and Staffing Survey (SASS) to demonstrate patterns of teacher assignments at upper elementary grades at public schools. The tables provided in this section examine how many subject(s) and grade(s) were taught by public elementary school-level teachers at grades 4 to 6. Our intention is to show whether the patterns of teacher assignments in Tennessee are generalizable across all other states in the United States. We address the following areas:

- The number of state-tested subject areas (i.e., mathematics, reading/language arts, science, and social studies) taught by public elementary school-level teachers in a selection of grades;
- The number of grades taught by public elementary school-level teachers in four state-tested subject areas;
- The percentage of public elementary school-level teachers by varying combinations of course subject areas.

Teachers' course subject areas are measured by teaching assignment and subject matter codes. All the surveyed teachers first answer a filter question in which they describe the way their classes are organized. For teachers who instruct the same group of students all or most of the day in multiple subjects (self-contained class), they reported how many hours they spent teaching each of four state-test subject areas during their most recent full week of teaching. The criterion to determine a subject taught by a teacher is whether the reported hours of teaching that subject are greater than zero. For teachers who instruct several classes of different students most or all of the day in one or more subjects (departmentalized instruction), they were asked to report subject matter and grade level codes for each class (or section) they currently taught. They were allowed to report no more than ten classes (or sections). We use the subject matter codes the teachers reported to determine which subject(s) they taught. The reported subject matter codes can then be grouped in one of four state-tested subject areas.

The grade(s) taught are also measured differently for the teachers teaching self-contained classes and the ones teaching departmental courses. The self-contained classroom teachers only reported in which grades students were taught by them while the teachers teaching departmental courses reported at what grade they taught a specific subject. For the latter, teachers' subject(s) and grade(s) taught are explicitly connected; therefore, we know what teachers taught at a grade.

The survey does not provide the information about what grades are taught in a specific subject by self-contained classroom teachers. The link between subject(s) and grade(s) might not be necessary if we assume that the self-contained classroom teachers always taught all four subject areas at most or all weeks at the same grade. However, it is possible that those teachers do not teach all four subject areas for some weeks or at the same grade (e.g., they taught two subjects at one grade and taught two other subjects at another grade). If they reported teaching multiple grades, we assert that they taught all subjects during their most recent full week of teaching in those grades. Alternatively, we may simply assume that the self-contained classroom teachers taught all four state-test subject areas to the same group of students all or most of the day in all grades the teachers reported.

To capture the number of grades taught, we measure whether teachers taught in multiple grades regardless of the subjects they taught. Some teachers reported teaching all subjects in multiple grades. Other teachers reported teaching some of the subjects in multiple grades, but teaching other subjects in one grade. Using a selection of three elementary grades, we create four grade combinations to classify teachers who taught in multiple grades in each of those groups (i.e., 4 and 5; 5 and 6; 4 and 6; and 4 to 6).

In the findings of this section, we show teacher assignments at public elementary school upper grade levels (i.e., 4 to 6) and the percentage of those teachers by different combinations of state-test subject areas and/or the number of grades taught. We then compare these findings with the ones described in our proposal, in which we use data from Tennessee public elementary school-level teachers. Table 1 presents the number and percentages of teachers who taught at grades 4 to 6 in public schools with varying combinations of subject areas taught by the number of grades. Table 2 further details the number and percentages of those teachers who taught at only one grade (i.e., 4, 5, and 6) and at multiple grades (i.e., with varying combinations of those grades). Finally, table 3 details the number and percentages of the teachers in the South region only by grades and subjects taught. Additional tables reported at national, regional, and state levels for patterns of teacher assignments can be found in detail in Appendix B – A.

B – DATA AND VARIABLES

Data used in this section come from the 2003-04 Schools and Staffing Survey Restricted-Used Public School Teacher Data File. We provide the details on the measure of four state-tested subject areas and indicators for groupings on various geographic (e.g., regions) characteristics. Additional information about the SASS data will be provided in detail in Appendix B – B.

Subject areas taught: Groupings of assignment and subject matter codes

Teacher assignments are considered as they self-reported subjects taught. For purposes of our analysis, we intend to identify the subjects taught in self-contained classrooms. While self-contained classroom teachers could teach all subjects to the same class of students at public elementary schools, this does not necessarily mean that they taught all state-tested subjects. In the SASS teacher questionnaire, each self-contained classroom teacher reported hours of teaching each of four subject areas (i.e., English/reading/language arts, arithmetic/mathematics, social studies/history, and science) during the most recent full week. Although the subjects taught in that full week again does not necessarily mean the subjects those teachers were actually assigned to teach in a school year, especially to the teachers who only reported teaching one or two of those subjects, this could be the best approximate assignments for the self-contained teachers in a school year. One possibility for the self-contained teachers who did not teach four state-tested subjects would be that those teachers instructed the same group of students in multiple subjects, but not all of the subjects taught were asked to report the number of hours of teaching during that week. We prefer using the hours for each subject reported by self-contained classroom teachers to determine whether they instruct the same class of students in multiple subjects. We argue that although teachers teach in self-contained classrooms at a school, it is not certain that they have to teach any or all subjects in mathematics, reading/language arts, science, and social studies. The SASS teacher data show that some of those teachers taught less than four state-tested subjects; and a few of those teachers only taught one subject during their most recent full week of teaching.

This analysis also includes teachers who instruct multiple classes of different students in one subject and/or multiple subjects. Each teacher self-reported subject matter codes for the classes (or sections). Since we are interested in four state-tested subject areas, the subjects within each broad subject area listed in the table 1 of the SASS teacher questionnaire are collapsed to mathematics, reading/language arts, science, and social studies. Addition information on the subjects used to form the four main subject areas can be found in Appendix B - C.

Groupings: Geographic variation and the state in South

This section addresses the patterns of teacher assignments by geographic variation. The surveyed schools are stratified in each of four regions: Northeast, Midwest, South, and

West. The region variable indicates where a district is located. We also present data on teacher assignments by state. To describe the patterns of teacher assignments by state, the indicator for Federal Information Processing Standard (FIPS) state codes can be found at the first two digits of the teacher control number. Tennessee with a FIPS code equal to 47 is one of the states in the South region.

B – FINDINGS

Findings for teacher assignments are presented below. This analysis uses the term "elementary school-level teachers" in all tables. Those teachers include traditional public and public charter school teachers who instructed at grades 4 to 6 at elementary schools and combined K-12 schools. The counts for those teachers by varying combinations of subjects and grades in all tables represent the target survey population. To adjust the sample totals to the population totals, the teacher final weight, TFNLWGT, is used for all analyses. The percentages reported in all tables represent the frequency of elementary school-level teachers at a given assignment at a given grade (or a combination of multiple grades) across all teachers. A Chi-square statistic is reported for tables 1, 2, and 3 that tests whether the distributions of teacher assignments across two samples of public elementary school-level teachers are equivalent. We present the patterns of teacher assignments in three samples. The samples of teachers include all teachers in the population, the teachers from the South region, and the teachers from Tennessee.

As shown in Table B – 1, the most frequently reported assignments for public elementary school-level teachers in 2003-04 was to teaching four subjects at only one grade with 223,700 teachers (41.18%). Among the assignments where teachers taught three subjects, the most frequently reported assignment was to teaching three subjects, mathematics, reading/language art, and social studies, at only one grade with 43,300 teachers (7.97%). Among the assignments where teachers taught two subjects, the most frequently reported assignment was to teaching reading/language arts and social studies at only one grade with 31,100 teachers (5.72%). Teaching reading/language arts (47,600 teachers or 8.76%) was the most frequently reported assignment when teaching one and only one subject at one grade. Across all subject-specific assignments, there were 482,000 teachers (88.76%) teaching one and only one grade, 48,500 teachers (8.94%) teaching two grades, and 12,500 teachers (2.31%) teaching three grades.

Table B – 1

Number and percentages of public elementary school-level teachers by subject and number of grades taught in the United States in the 2003-04 school year

Subject(s) Taught	Number of Grades Taught						Grade Levels 4 through 6	Tennessee
	1		**2**		**3**			
MTH, RLA, SCI, and SOC	223,651	41.18%	22,987	4.23%	6,100	1.12%	46.54%	36.12%
MTH	20,379	3.75%	1,548	0.29%	447	0.08%	4.12%	7.37%
MTH and RLA	17,641	3.25%	3,841	0.71%	1,750	0.32%	4.28%	3.38%
MTH and SCI	11,464	2.11%	357	0.07%	41	0.01%	2.18%	2.36%
MTH and SOC	2,253	0.41%	763	0.14%	811	0.15%	0.70%	1.95%
MTH, RLA, and SCI	24,842	4.57%	2,593	0.48%	1,455	0.27%	5.32%	3.91%
MTH, RLA, and SOC	43,300	7.97%	3,473	0.64%	591	0.11%	8.72%	4.00%
MTH, SCI, and SOC	4,599	0.85%	1,031	0.19%	11	0.00%	1.04%	2.77%
RLA	47,600	8.76%	4,937	0.91%	731	0.13%	9.81%	14.14%
RLA and SCI	11,178	2.06%	1,485	0.27%	187	0.03%	2.37%	3.14%
RLA and SOC	31,077	5.72%	1,883	0.35%	100	0.02%	6.09%	6.41%
RLA, SCI, and SOC	4,522	0.83%	1,251	0.23%	147	0.03%	1.09%	1.38%
SCI	18,631	3.43%	1,327	0.24%	168	0.03%	3.71%	5.26%
SOC	14,681	2.70%	742	0.14%	---	---	2.84%	5.05%
SCI and SOC	6,215	1.14%	309	0.06%	---	---	1.20%	2.75%
Total number of teachers	482,033	88.76%	48,528	8.94%	12,538	2.31%	100.00%	

Table B – 2 and B – 3 further expands the patterns of teacher assignments by grades and varying combinations of grades. As shown in table 2, the number of public elementary school-level teachers who taught four subjects decreased from 108,700 (20.01%) at grade 4 to 81,100 (14.93%) at grade 5. This number dropped sharply to 33,900 teachers (6.24%) at grade 6. There were about 34,000 teachers (6.26%) teaching at grades 4 and 5; 13,000 teachers (2.47%) teaching grades 5 and 6; and 1,100 teachers (.21%) teaching grades 4 and 6.

Table B – 3 focuses on the patterns of teacher assignments for teachers only in the South region. Compared to the data reported for all teachers, the percentage of teachers who taught four subjects in the South region was lower (46.54 vs. 39.76), but the percentages for teachers who taught one and only one subject in the South region were always higher (4.12 vs. 6.20 in mathematics; 9.81 vs. 15.51 in reading/language arts; 3.71 vs. 4.78 in science; and 2.84 vs. 3.89 in social studies).

Table B – 2

Number and percentages of public elementary school-level teachers by subject, grade, and combinations of grades taught in the United States in the 2003-04 school year

Subject(s) Taught	Grade Levels and Combination of Grades Taught														Grade Levels 4 through 6	Tennessee
	4		5		6		4 and 5		5 and 6		4 and 6		4, 5, and 6			
MTH, RLA, SCI, and SOC	108,695	20.01%	81,076	14.93%	33,880	6.24%	19,142	3.52%	3,509	0.65%	336	0.06%	6,100	1.12%	46.54%	36.12%
MTH	1,579	0.29%	1,913	0.35%	16,887	3.11%	635	0.12%	866	0.16%	47	0.01%	447	0.08%	4.12%	7.37%
MTH and RLA	4,902	0.90%	4,212	0.78%	8,527	1.57%	2,501	0.46%	1,271	0.23%	69	0.01%	1,750	0.32%	4.28%	3.38%
MTH and SCI	1,464	0.27%	3,679	0.68%	6,321	1.16%	205	0.04%	152	0.03%	---	---	41	0.01%	2.18%	2.36%
MTH and SOC	327	0.06%	22	0.00%	1,904	0.35%	269	0.05%	494	0.09%	---	---	811	0.15%	0.70%	1.95%
MTH, RLA, and SCI	9,988	1.84%	8,606	1.58%	6,249	1.15%	2,096	0.39%	436	0.08%	61	0.01%	1,455	0.27%	5.32%	3.91%
MTH, RLA, and SOC	19,761	3.64%	15,242	2.81%	8,297	1.53%	3,211	0.59%	213	0.04%	50	0.01%	591	0.11%	8.72%	4.00%
MTH, SCI, and SOC	1,170	0.22%	1,451	0.27%	1,978	0.36%	985	0.18%	45	0.01%	---	---	11	0.00%	1.04%	2.77%
RLA	7,445	1.37%	7,521	1.38%	32,634	6.01%	1,716	0.32%	2,708	0.50%	513	0.09%	731	0.13%	9.81%	14.14%
RLA and SCI	1,850	0.34%	3,846	0.71%	5,481	1.01%	669	0.12%	795	0.15%	21	0.00%	187	0.03%	2.37%	3.14%
RLA and SOC	5,224	0.96%	7,469	1.38%	18,384	3.39%	826	0.15%	1,057	0.19%	---	---	100	0.02%	6.09%	6.41%
RLA, SCI, and SOC	1,451	0.27%	1,407	0.26%	1,664	0.31%	1,207	0.22%	44	0.01%	---	---	147	0.03%	1.09%	1.38%
SCI	283	0.05%	2,503	0.46%	15,845	2.92%	347	0.06%	973	0.18%	8	0.00%	168	0.03%	3.71%	5.26%
SOC	214	0.04%	818	0.15%	13,649	2.51%	59	0.01%	662	0.12%	21	0.00%	---	---	2.84%	5.05%
SCI and SOC	1,231	0.23%	1,195	0.22%	3,789	0.70%	105	0.02%	204	0.04%	---	---	---	---	1.20%	2.75%
Total number of teachers	165,584	30.49%	140,960	25.95%	175,489	32.31%	33,974	6.26%	13,428	2.47%	1,125	0.21%	12,538	2.31%	100%	

Table B – 3

Number and percentages of public elementary school-level teachers in the South region by subject, grade, and combinations of grades taught in the United States in the 2003-04 school year

Subject(s) Taught	Grade Levels and Combination of Grades Taught														Grade Levels 4 through 6	Tennessee
	4		5		6		4 and 5		5 and 6		4 and 6		4, 5, and 6			
MTH, RLA, SCI, and SOC	34,741	17.12%	29,281	14.43%	9,538	4.70%	5,166	2.55%	704	0.35%	219	0.11%	1,032	0.51%	39.76%	36.12%
MTH	1,045	0.51%	1,332	0.66%	9,388	4.63%	348	0.17%	369	0.18%	---	---	103	0.05%	6.20%	7.37%
MTH and RLA	1,160	0.57%	1,026	0.51%	2,417	1.19%	1,023	0.50%	442	0.22%	26	0.01%	64	0.03%	3.03%	3.38%
MTH and SCI	1,235	0.61%	2,537	1.25%	2,831	1.40%	111	0.05%	107	0.05%	---	---	41	0.02%	3.38%	2.36%
MTH and SOC	327	0.16%	22	0.01%	758	0.37%	269	0.13%	80	0.04%	---	---	7	0.00%	0.72%	1.95%
MTH, RLA, and SCI	2,622	1.29%	2,345	1.16%	1,566	0.77%	234	0.12%	---	---	---	---	149	0.07%	3.41%	3.91%
MTH, RLA, and SOC	4,095	2.02%	4,910	2.42%	1,101	0.54%	59	0.03%	67	0.03%	---	---	73	0.04%	5.08%	4.00%
MTH, SCI, and SOC	608	0.30%	516	0.25%	1,264	0.62%	924	0.46%	---	---	---	---	11	0.01%	1.64%	2.77%
RLA	5,147	2.54%	5,472	2.70%	17,200	8.48%	1,659	0.82%	1,110	0.55%	484	0.24%	407	0.20%	15.51%	14.14%
RLA and SCI	789	0.39%	1,990	0.98%	1,458	0.72%	378	0.19%	151	0.07%	---	---	7	0.00%	2.35%	3.14%
RLA and SOC	4,242	2.09%	4,330	2.13%	4,708	2.32%	567	0.28%	272	0.13%	---	---	83	0.04%	7.00%	6.41%
RLA, SCI, and SOC	820	0.40%	151	0.07%	51	0.02%	993	0.49%	---	---	---	---	45	0.02%	1.01%	1.38%
SCI	275	0.14%	1,667	0.82%	7,129	3.51%	---	---	525	0.26%	---	---	112	0.06%	4.78%	5.26%
SOC	48	0.02%	159	0.08%	7,318	3.61%	53	0.03%	285	0.14%	21	0.01%	---	---	3.89%	5.05%
SCI and SOC	819	0.40%	996	0.49%	2,587	1.27%	---	---	137	0.07%	---	---	---	---	2.24%	2.75%
Total number of teachers	57,973	28.57%	56,734	27.96%	69,314	34.16%	11,784	5.81%	4,246	2.09%	751	0.37%	2,135	1.05%	100%	

B – REFERENCES

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Tourkin, S.C., Warner, T., Parmer, R., Cole, C., Jackson, B., Zukerberg, A., Cox, S., and Soderborg, A. (2007). Documentation for the 2003–04 Schools and Staffing Survey (NCES 2007–337). U.S. Department of Education. Washington, DC: National Center for Education Statistics.

Appendix B – A

List of the 2003-04 SASS public school teacher questionnaire used in this section.

Survey Section II: Class Organization

11. In which grades are the STUDENTS you currently teacher at THIS school?

12. Which statement best describes the way YOUR classes at this school are organized?

16. During your most recent FULL WEEK of teaching, approximately how many hours did you spend teaching each of the following subjects at THIS school?

19. For each class (or section) that you currently teach at THIS school, complete a row/line of information.

Appendix B – B

Codes for major field of study (Not all the codes listed below are used)

English and Language Arts (RLA)

151 Communications
152 Composition
153 English
154 Journalism
155 Language arts
158 Reading
159 Speech

Mathematics and Computer Science (MTH)

191 Algebra, elementary
192 Algebra, intermediate
193 Algebra, advanced
194 Basic and general mathematics
195 Business and applied math
196 Calculus and pre-calculus
197 Computer science
198 Geometry
199 Pre-algebra
200 Statistics and probability
201 Trigonometry

Natural Sciences (SCI)

210 Science, general
211 Biology/Life sciences
212 Chemistry
213 Earth sciences
215 Integrated science
216 Physical science
217 Physics

Social Sciences (SOC)

220 Social studies, general
221 Anthropology
225 Economics
226 Geography
227 Government/Civics
228 History
231 Native American studies
233 Psychology
234 Sociology