DSSR

Discussion Paper No. 147

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July, 2025

Data Science and Service Research
Discussion Paper

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Location advantages and sorting in high school education

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ABSTRACT

This study examines how the neighborhood socioeconomic status differentiates school quality. To address this issue, we exploit the elimination of school zones in public high schools in Nagasaki City, Japan. Before the elimination in 2002, the local government assigned students to each school depending on test scores and residence to equalize the educational level across schools. While the reform enabled the students to choose a school on their own, the gap in academic performance across schools has widened. We found that one possible reason for this gap is the concentration of students from highly educated areas to schools with location advantages in terms of accessibility.

Keywords: school zone, spatial sorting, accessibility

JEL code: I24, I28, R12, R23

1. Introduction

During these two decades, a series of policies encouraging freedom of school choice by eliminating or relaxing the school zone system have been implemented across OECD countries (Govid, 2019). The policies are expected to enable students and parents to apply and choose a school depending on their preference. In addition, the increase in the number of choices can enhance competition across schools and thus improve the quality and effectiveness of education. In particular, the empirical literature in economics of education has examined how the quality of provided educational service governs the school choice decision and thus contributes to the improvement of outcomes measuring students' educational attainments (Hoxby, 2000; Campos & Kearns, 2024; Ogawa et al., 2024).

The expected positive mechanism brought by freedom of school choice can work appropriately if the students and parents regard the quality of provided educational service as a factor of the highest priority and choose a school relying (only) on it. However, some recent empirics have shown that the freedom of school choice does not necessarily improve the educational quality and outcomes (Cullen et al., 2005; Cullen et al., 2006; Angrist et al., 2013; Abdulkadiroğlu et al., 2018; Abdulkadiroğlu et al., 2020). This evidence implies that they often choose a school based on various factors within and surrounding the school, not limited to the quality of the educational service.

A school choice determinant of interest in this research is the location environment. Students and parents generally prefer a school with better accessibility to avoid the loss from a long commute (Chumacero et al., 2011; Burgess et al., 2015; Herskovic, 2020). Their preference determines the spatial extent of each school's commuting zone. In parallel, each school's educational attainment reflects the socioeconomic status (SES) of households within its commuting zone (Burgess et al., 2015; Matsuoka, 2018). Therefore, the geographical barrier in commute defines neighborhood SES for each school and thus educational attainment.

Despite the importance of the location environment, it is often empirically challenging to investigate its impacts on school choice decisions and educational outcomes in a causal sense. One of the identification threats is the difficulty of controlling for various observable and unobservable characteristics that affect school quality. To precisely evaluate the impact, the attributes other than the location environment should be equalized or randomized across schools, ideally. However, it is unrealistic to implement some experiments that satisfy these preconditions. While some empirics evaluate the impact of neighborhood racial composition as a location environment on school quality (Reber, 2005; Baum-Snow & Lutz, 2011), it is arguable whether we can merely apply their implications when interpreting the stratification across public schools in nations with homogeneous ethnic makeup, such as Japan and Korea.

Another threat is the reverse causality that the school quality determines the SES of its commuting zone. A vast amount of empirical literature in urban economics has provided the evidence supporting the capitalization hypothesis that a school with high quality attracts households with high SES, which raises land price and rent around the school (e.g., Machin, 2011; Nguyen-Hoang & Yinger, 2011; Kuroda, 2018; Kuroda, 2022). This mechanism makes it difficult to identify the impacts of neighborhood SES on school quality from data.

This research empirically investigates how the neighborhood SES determines school quality and leads to stratification across schools by exploiting the elimination of school zones in public high schools in Nagasaki City, Japan. Before the policy reform in 2002, the school zone system, based on a centralized assignment mechanism for prefectural academic track schools, was operated. Under this system, students who passed the admission test were allocated to one of five schools, Nagasaki Five Schools (*Nagasaki Gokoh*), depending on their residential locations and test scores to equalize the educational attainment across schools. It aimed to reduce the gaps in educational achievement across schools, and the assignment was irrespective of applicants' preferences. However, in response to the growing demand for freedom of school choice from students and parents, the prefectural government enabled them to select their desired school directly at the time of application. While the reform eliminated the geographical constraints in choosing a school, the disparity in educational outcomes, such as university acceptance performance, has widened across schools.

The institutional environments surrounding public high schools in Nagasaki City have several advantages to mitigate the identification concerns described above. First, up to the present, it is unrealistic for individual schools to take unique and continued initiatives to improve the quality of educational services because a teacher can hardly work at a specific school for a long time due to the high frequency of personnel transfers under the administrative system governing public schools. This feature enables us to treat a large part of the quality of the provided educational service as a randomized factor. Second, the quality of each school was ex-ante homogeneous before the reform because the centralized assignment mechanism equalized the educational attainment across schools. In this sense, we can focus on the stratification in educational attainment caused only by the reform. Finally, there is no guarantee that students can enroll in a specific high school regardless of their residence because they cannot enroll in one of five schools unless they pass a high-stakes admission test. Due to this feature, the households hardly have any incentive to reside in a block aiming to enroll their children in a specific high school. Therefore, we can expect that high school choice does not strongly affect households' residential choice.

To address this issue, we newly construct block-school level panel data of commuting flows from 1994 to 2018 and empirically evaluate the impact of the policy reform on commuting behaviors using the fixed-effect (FE) difference-in-differences (DID) method. In addition, based on the discrete choice model derived from the random utility framework, we analyze the commuters' preferences underlying the school choice decisions. Based on the equilibrium analysis using developed model, we integrate the findings from the reduced-form analysis using FE-DID and conduct the counterfactual and welfare analysis.

Our main findings are summarized as follows. First, we found that the students' commuting time significantly increased after the reform, and they bear the burden of longer commuting at the same level across schools. Second, in conjunction with this change, we also observed the emergence of a sorting of students based on their potential educational levels. Specifically, the students from blocks with higher levels of education enrolled in schools with location advantages, whereas the opposite relation was observed for those from blocks with lower educational attainment. Interestingly enough, this pattern of stratification cannot be replicated if the location environment is homogeneous across schools. These results imply that the spatial extent of commuting zones and thus the composition of neighborhood SES were altered after the reform for each school, driven by location advantages. Finally, we found that the stratification in educational level caused the gap in welfare across schools, and the reform did not equally improve welfare in all schools. In particular, a school with higher location advantages could enjoy higher welfare, at the expense of a loss of welfare in others.

This study contributes to several strands of literature. The first one is the impact evaluation of the reform of the school zone system (Hoxby, 2000; Hoxby, 2003; Söderström & Uusitalo, 2010; Schneider et al., 2012; Campos & Kearns, 2023). Through the progress of reform in various countries over the past two decades, researchers have pointed out that freedom of choice has advantages and disadvantages. Therefore, the debate regarding the pros and cons of the reform is still one of the central topics in the field of economics of education. The empirical investigation most relevant to this study is Ogawa et al. (2024), which evaluated the impacts of the elimination of school zones in Japanese prefectures during the early 2000s. They showed that the reform significantly increased university enrollment rates through the competitive effect. Their finding also suggests that the role of stratification across schools was limited in the improvement, perhaps because many students did not alter their school choices even after the reform. We complement their finding by utilizing a locational feature of prefectural academic track schools in Nagasaki City. In Nagasaki, the distance between schools subject to the school zone system is quite small. Therefore, the likelihood of changing school choice is relatively high. In addition, with commuting flow data, we can directly observe the change in students' school choice behaviors.

Similar to this research, there are also empirical investigations that examined the impact of the reform on segregation. The primary sources of segregation are, for example, ability (Hsieh & Urquiola, 2006), race (Ladd & Fiske, 2001; Bifulco & Ladd, 2007), and household background (Söderström & Uusitalo, 2010; Böhlmark et al., 2016). However, particularly in the cases in Western countries, it is challenging to separately distinguish the impacts of individual factors that affect school choice decisions due to the complexity of SES by race. In this regard, the cases in (eastern) Asian countries characterized by the homogeneity of race have a desirable setting to examine the impacts of each factor independently.

The research closest to this study is Oh et al. (2019), which examined the effects of replacing random assignment of high schools with school choice in Seoul, Korea, on segregation by educational attainment. They found that the differences in educational attributes within schools, such as test scores, amount of funds, and class size, drove the popularity of schools after the reform. We extend the scope of analysis by considering location characteristics and the composition of students by potential academic performance as alternative drivers of segregation. Another relevant study is Moriguchi et al. (2024), which evaluated the impacts of the reform regarding college admission system in Japan during the prewar period from the decentralized system where applicants could only apply to one school to the meritocratic centralized system where they were assigned to a school given their preference rankings and exam scores. They found that the students applying and enrolling in schools further away from their original prefecture increased after the reform and that the applicants in urban prefectures who were rejected by their first-choice schools but admitted to those in rural prefectures crowded out rural applicants. We complement their findings by showing that this spatial crowding-out can similarly be observed at the within-city level and in the case of an alternative reform, such as the transition from a centralized system aiming at equalization to a decentralized system. In addition, we empirically evaluate the distributional impacts of the crowding-out on welfare in detail based on discrete choice analysis.

The second one is the empirical analysis of students' commuting behaviors. Long-time commuting not only incurs an increase in pecuniary costs but also several problems in students' mental and physical conditions (Ding et al., 2023), the decline of quality of school life through the increase in absence and dropout (Dustan et al., 2016; Gottfried, 2017), and the stagnation of academic performances (Falch et al., 2013; Tigre et al., 2016). In addition, these costs also limit freedom of school choice, particularly for lower SES households. Therefore, economic agents concerning education are motivated to reduce commuting costs. The empirics in the economics of education and urban economics examined the effectiveness of various initiatives to eliminate students' burden of commuting, such as the introduction of school buses (Trajkovski et al., 2021) and the extension of mass transit (Dustan & Ngo, 2018; Herskovic, 2020; Asahi & Pinto, 2022). Nevertheless, the costs of commuting are sometimes offset by the advantages of gaining access to schools that offer a higher standard of education. For instance, students with higher SES tend to accept a long commute, aiming to receive a better quality of education and to spend school life with peers with high educational attainment (Yoshida et al., 2009; Glazerman & Dotter, 2017; Hastings et al., 2008; Parra-Cely, 2023).

This paper contributes to this literature by empirically examining how the trade-off between commuting costs and educational attainment governs the spatial pattern of commuting, focusing on the reform of the school zone system. The most relevant study is Gortázar et al.

(2023). They found that the reform in Madrid, Spain, conducted in 2013 led to an increase in the number of families receiving out-of-district school assignments, as well as assignments to schools located at greater distances from their residential addresses. They also showed that the highest 20% of households in terms of SES reacted to the reform the most. We complement their analysis by examining the compositional change of students after the reform with explicit consideration for the roles of each school's location advantages as pull factors attracting students, and by discussing the consequences of the change in relation to educational outcomes.

The third one is the capitalization of the quality of education and, more generally, the economic geography of school choice. In the field of urban economics, the reform of the school zone system has been discussed based on the framework of the capitalization hypothesis. In general, the quality of education provided in a school is positively associated with property prices in neighboring regions (e.g., Machin, 2011; Nguyen-Hoang & Yinger, 2011; Kuroda, 2018; Kuroda, 2022). Nevertheless, it has been empirically shown that this relation is weakened by the increase in choices through the reform of the school zone system and the entry of a new school irrelevant to the residence of students (Fack & Grenet, 2010; Schwartz et al., 2014; Chan et al., 2020). The potential mechanism underlying the attenuation of capitalization brought by the reform is the change in students' school choices, which subsequently affects commuting patterns. However, there is still limited understanding of whether and how the reform influences commuting behaviors. In addition, the empirics of the capitalization hypothesis generally treat school quality as a given factor, and the discussion regarding the mechanism driving stratification across schools in each context is often scant.

Following the recent development of the quantitative urban model (QUM), an empirical framework based on spatial general equilibrium analysis (e.g., Ahlfeldt et al. 2015), there are a few studies that conducted a structural estimation of school choice (Mun et al. 2023; Park & Hahm, 2023; Agostinelli et al., 2024). The analysis based on QUM is remarkably valuable because it enables researchers to explicitly map theoretical urban models to granular data and conduct a counterfactual analysis. However, perhaps due to the scant longitudinal variation in data, their inference regarding the elimination of the school zones is based on the counterfactual simulation. In addition, it is challenging to infer the actual process of the evolution of stratification and its mechanism from scratch since the quality of education in each school is ex-ante heterogeneous in their cases. This paper contributes to this literature by examining the actual change in commuting behaviors and its consequence on school quality based on longitudinal panel data covering before and after the reform under the ex-ante homogeneity across schools, and by structurally validating the reduced-form results.

The remainder of this paper proceeds as follows. Section 2 details the Japanese education system and the school zone system in Nagasaki. Section 3 introduces the data used in the analysis and illustrates its patterns. Section 4 presents the empirical strategy. Section 5 presents the main results and discussion. Section 6 integrates the reduced-form findings in Section 5 by the discrete choice analysis, and Section 7 concludes.

2. Institutional Background

2.1 The Japanese Education System

The Japanese education system consists of 9 years of compulsory education including six years of primary school (from age 6 to 12) and three years of junior high school (up to age 16)[1]. After graduating from junior high school, 98.9% of all graduates enrolled in high school (up to age 18) as of 2021. About 55% of all high schools are privately funded. As of 2021, 58.1% of all high school graduates are enrolled in university and approximately 76.8% of all universities are privately funded.

Especially in local regions, the selection of students responding to their academic achievement is conducted at the time of the admission test for high school. Candidates are typically permitted to take the admission tests for only one public high school, as the examinations within the same prefecture are held on the same day. Although there are several differences between public school and private school, the test tends to consist of a problem set of Japanese, English, social studies, science, and mathematics. Students who do not succeed in passing the test often seek admission to lower-ranked high schools where additional openings may be available. The majority of students are ultimately placed in one of the high schools, with only a small number opting not to pursue high school or choosing to reapply in the following year. Once the students enroll in a high school, they seldom transfer to another school unless they relocate to another prefecture in a unit of family.

The administrative system regarding public schools in Japan is characterized by limited discretion given to each school. Unlike private schools, the management of a school, the hiring, and personnel reshuffling are under the authority of the prefectural government. In general, a teacher works at a school for ten years at most due to the high frequency of personnel transfers, and it is unrealistic to concentrate the high achieving teachers only to academic track schools

[1] Section 2 is largely based on Matsumori (2008), Kuroda (2023), and Ogawa et al. (2024).

because it interrupts the operation in other public high schools. Therefore, it is quite difficult for individual schools to take unique and continued initiatives to improve the quality of educational service. In this sense, the quality of educational service provided by teachers in each public school is almost randomized for students. In addition, since the payoffs of teachers do not depend on the academic performance of their students, there is no pecuniary incentive for teachers and schools to enhance the competition across schools.

Japanese high schools can be generally divided into two main types: those focused on preparing students for higher education through general courses and those that offer vocational training in areas such as industry, commerce, and agriculture. The competitive nature and challenges associated with university admissions create a situation where access to higher education is significantly restricted for students who do not attend traditional academic track schools, which offer specialized programs aimed at preparing for entrance exams. Our paper covers public academic track schools with full-time general courses. Typically, the level of preparation required for entrance exams is more rigorous for national universities, as these exams encompass a wide range of subjects. Although the system of entrance exams for universities has diversified recently, 49.0% of candidates took the general entrance exam which requires the candidates to take achievement tests.

2.2 School Zone System for High Schools in Nagasaki

The school zone system in Nagasaki Prefecture was first implemented in 1948 by the General Headquarters (GHQ). The Board of Education of Nagasaki aimed to maintain an education system that focused on developing certain schools into elite institutions, continuing a tradition from the prewar era. However, similar to other prefectures in Japan, the GHQ mandated the establishment of multiple school zones, placing them under the jurisdiction of the prefectural boards of education. Nagasaki City had two academic track schools, Nagasaki

Nishi High School and Nagasaki Higashi High School. To bridge the disparities among these schools, the Board of Education standardized the quality and number of teachers, facilities, and students. The initial school zone system was abolished in 1958 due to the significant demand for unrestricted school choice and the successful attainment of equalization.

The school zone system in Nagasaki City, however, was revived in 1961 because of the sequential establishment of new academic track schools, Nagasaki Minami High School (in 1961) and Nagasaki Kita High School (in 1964). This initiative aimed to address the rapidly growing demand for high school education resulting from the postwar baby boom. The Board of Education sought to prevent the disparities between these newly established schools and existing ones, Nishi and Higashi. With the establishment of Nagasaki Hokuyodai High School in 1978, the group of prefectural academic track schools around Nagasaki City was accomplished. Up to the present, the educators and students around Nagasaki call this school group "Nagasaki Five Schools" (*Nagsaki Gokoh*). Figure 2.1 shows the location of these five public high schools. While four schools (Higashi, Kita, Minami, and Nishi) are concentrated around the central area of Nagasaki City, only Hokuyodai is on the fringe of the city.

The school zone system for high schools in Nagasaki City operated on a centralized assignment mechanism. Applicants submitted their applications to the school group, treating it as a single school. If an applicant passed the test, he or she was assigned to one of five schools depending on their residential block (*ohaza* or *chochomoku*) and performance on the admission test. Consequently, candidates had no opportunity to select their desired school. The blocks in Nagasaki were divided into fixed blocks (*koyu chiku*) and adjustment blocks (*chosei chiku)*.

The fixed blocks consisted of the neighborhood of each high school. The candidates residing in these blocks were automatically assigned to the nearest school. The adjustment blocks were typically located in the central area of Nagasaki City, providing convenient access to all high schools. Candidates living within these adjustment blocks played a crucial role in the coordination process aimed at balancing the educational standards across schools. Consequently, they remained unaware of their assigned high school until the results of the entrance examinations were disclosed[2]. The extremely high achiever was assigned to a school with a relatively low level of education and vice versa.

2.3 Reform of School Zone System

The school zone system implemented in Nagasaki endured for three decades. This initiative effectively diminished disparities across schools by standardizing the educational attainment of students and their success rates for admission to universities. Nevertheless, evolving educational demands in Nagasaki rendered the continuation of the system in its original form impractical. The intrinsic features of this system limited candidates' ability to apply to their preferred schools for enrollment. This restriction hindered their opportunity to select a school that aligned with their preferences and qualifications. Furthermore, as urban expansion, propelled by advancements in the transportation network, led to an increase in the "potential" school choices, the original school zones established at the inception of the system became increasingly inadequate.

To address these issues, in 2000, the Board of Education of Nagasaki resolved to modify the school zone system, enabling applicants to select their desired school directly at the time of application. Concurrently, educational reform bills, which included the elimination of the school zone system, received approval from the Diet in 2001. As a result, the limitations on school choice that had been in place for thirty years were almost lifted in 2002[3].

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[2] Owing to this coordination system, the school was sometimes different even among brothers although they applied to the same school group from the same address.
[3] Following the educational reform bills, the school zone system for high schools was abolished in other Japanese prefectures. See, for example, Ogawa et al. (2024) for detail.

3. Data

3.1 Specification of Each Data

We digitize the commuting flow data for first-year students at each high school included in the Nagasaki Five Schools. This data is derived from the Annual School Directory (*Gakkou Youran*) of each high school, spanning the years 1994 to 2018. Note that the directory was not published during the period from 1999 to 2002 due to some reasons[4]. The flow data provides insights into the number of students traveling from specific blocks to their respective schools. Thereby, we can examine commuting patterns at the block-school level. The blocks are categorized into three distinct groups: (a) blocks located in Nagasaki City prior to a large municipal merger in 2005; (b) blocks that were incorporated into Nagasaki post-2005; and (c) blocks located in separate towns. The primary focus of our analysis is on the 297 blocks in group (a) as the data aggregation unit varies for the other groups depending on the schools[5].

Since the commuting time is unavailable in the digitized data, we calculate it using shortest time path search through Google Maps. This method yields the shortest commuting duration that takes into account public transportation options, such as buses and trains, which serve as the primary mode of transport for high school students in Nagasaki[6]. Due to the absence of personal characteristics such as a student's capabilities and socioeconomic

[4] To interpolate the part of missing data, we might use the commuting flow observations for third-year students because it is uncommon for the students to transfer to another school or repeat a year in the case of the Nagasaki Five Schools.

[5] Some schools count the number of students separately for each block in a town, the others treat the town as a single block.

[6] The path search using Google Maps has a notable limitation in that it does not support route searches based on historical transportation networks. Although the transportation infrastructure in Nagasaki City was well-established before the reform of the school zone system and has remained largely unchanged after the 1990s, it is important to recognize that there have been specific alterations in bus routes and enhancements to roadways that could potentially decrease commuting times. Note that the shortest time path has almost the same trend as the shortest distance searched by using the Open Source Routing Machine powered by OpenStreetMap. Appendix A shows the comparison between them. Another constraint is that it cannot account for the frequency of service on each route.

background in our flow data, we utilize block-level educational status data sourced from the National Census. This dataset provides information on the number of graduates categorized by their academic history. We employ this variable to assess the average educational attainment within each block.

To assess the university acceptance performance for each high school, we utilize two data sources: the university hensachi (deviation) scores, which serve as a widely recognized metric for evaluating the difficulty in enrollment of universities in Japan, and the number of graduates from each high school accepted by various universities. By combining these data, we can derive the average hensachi score of the universities that accept graduates from each high school.

We use the scores published by Kawaijuku. Kawaijuku is recognized as one of the leading preparatory schools in Japan, and the data presented here aligns with the information utilized by high school students aspiring to enroll in universities. This data encompasses nearly all universities that mandate academic achievement assessments as part of their admission criteria[7]. The scores are displayed in intervals of 2.5, with a range extending from 35 to 72.5.

The annual data regarding the number of students accepted from each high school to various universities is sourced from the "Extra issue of Sunday Mainichi, High School Achievement" published by Mainichi Shimbun Publishing Inc[8][9]. This dataset is derived from a yearly survey conducted on four-year universities by the firm DAIGAKUTSUSHIN Corporation. The number of high schools and universities included in the survey varies slightly from year to year, with data collected from around 5,000 high schools and 500 universities.

[7] The overall hensachi score of the university is determined by the average hensachi scores from the initial examinations, which are the foundational assessments across all departments. It is important to note that hensachi scores vary among different departments and types of entrance examinations.

[8] The presented data reflect the total count of students who have been accepted, rather than the actual number of enrollments. Consequently, if an individual student is admitted to multiple universities, they are counted multiple times.

[9] The number of students accepted to universities by high school does not differentiate among various departments or types of entrance examinations.

The accuracy of the data is notably high and representative, encompassing approximately 99% of high schools and 95% of national and public universities in Japan.

3.2 Data Patterns

3.2.1 Geographical Distribution of Commuters

The geographical distribution of the first-grade commuters for each high school is summarized according to three distinct groups of blocks, both before (1998) and after (2018) the school zone reform, as illustrated in Figure 3.1. The total number of commuters decreased in all schools, which can be due to the decline in number of children. Most students commute from the neighborhoods within Nagasaki City. An exception to this trend is Hokuyodai, where over 60% of its students reside outside Nagasaki City, as Hokuyodai is not located in the city but neighboring Nagayo Town.

Figure 3.2 shows the share of commuters to the Nagasaki Five Schools by block level. Rather than the central area, the suburb blocks where the new town development proceeded from the 1970s has large share of commuters. We also summarize the change in commuting time before and after the reform by using density plot in Figure 3.3. The mode value was 15-20 minutes before the reform (1994-1998), while it rose to 35-40 minute in the post-reform period (2003-2018). This increase in commuting time suggests that some changes in the geographical distribution of commuting flow happened after the reform.

3.2.2 Academic Performance of Each School

We assess the change in the university acceptance performance for each high school with several measurements. Figure 3.4 denotes the change in the average hensachi score of the universities that accept graduates from each high school. Before and soon after the reform, the hensachi scores distributed around 51 for all schools and we cannot observe the remarkable difference across schools. However, after 2005, when the first students after the reform graduated from high school, the gap between schools began to expand. While the performance stagnated in Minami, Kita, and Hokuyodai, Nishi and Higashi experienced a notable improvement that persisted particularly until the early 2010s. This trend of polarization has continued to intensify to the present day. Due to this polarization, the average hensachi across the Nagasaki Five Schools exhibited little to no change.

For in-depth understanding of this trend, we show the detailed distributional features of the university acceptance performance in Figure 3.5 utilizing violine plot. In Minami, Kita, and Hokuyodai, high-achieving graduates vanished after 2010 and the share of graduates who enrolled in universities with lower hensachi scores increased. While Higashi marginally improved the performance, Nishi remarkably succeeded in increasing the share of outstanding graduates after 2005. The variation in hensachi scores within schools has increased after the reform, a trend observed across all schools.

This Nishi's outstanding achievement is observed more explicitly focusing on the number of graduates accepted by competitive universities as illustrated in Figure 3.6. Overall, the number of graduates accepted by prestigious universities has increased only in Nishi. Higashi stayed with the status quo while Minami, Kita, and Hokuyodai lost most of these high-achieving graduates in these two decades. Regarding the national/public universities, the decline of Minami and Kita was conspicuous.

Furthermore, in Figure 3.7, we compare the change in the university acceptance performance of Nagasaki Five Schools with that of private high schools around Nagasaki City that offer general education programs for students aiming for higher education. Prior to the reform, there was no overlap in the performance between public and private. After 2010, the performance of the top private school, Seiun, declined to the same level as Nishi due to some reason. The hensachi scores for Minami, Kita, and Hokuyodai also decreased, approaching the average scores of most private schools. Notably, despite the stagnation observed in these three high schools, the overall performance of private high schools remained stable on average.

3.2.3 Socioeconomic Environment Surrounding Students and Schools

While the level of education and thus the performance in university acceptance was standardized across schools under the school zone system, the disparity has widened after the reform as discussed above. To interpret this consequence, we assess the change in composition of students in terms of their surrounding socioeconomic environment. In addition, we illustrate the differences in the local environmental context surrounding each school.

By combining the commuting flow data and block-level educational status data, for each school, we calculate the weighted average of the share of university graduates using the number of students residing in each block as a weighting factor. The geographical distribution of university graduates is illustrated in Figure 3.8. Overall, the blocks with a higher share of university graduates are concentrated in a limited plain area. However, some high-educated blocks are neighboring low-educated ones. Therefore, the spatial segregation by the level of education is not necessarily perfect in Nagasaki City. Figure 3.9 shows the change in the average before and after the reform. Because the educational status data is only available in 2000 and 2010 while the observations of commuting flow are unavailable in 2000, we connect the educational status data in 2000 to the commuting flow data in 1998. To eliminate the macroeconomic factor such as the rise of the university entrance ratio overall Japan in a decade, we standardize the average for each year. The general pattern depicted in Figure 3.8 highlights Nishi's notable success in attracting the students from the blocks with a high level of education in contrast to the stable status of Higashi and the stagnation experienced by other schools. This trend is quite similar to the illustrations presented in Figures 3.4, 3.5, and 3.6, despite some variations in the ranking of the schools.

We focus on several accessibility measurements to summarize the local environmental context surrounding each school. Using these indices, we quantify how easily each school can attract economic activities from the blocks in Nagasaki. To measure the accessibility to population, we calculate three indices. Using the block-level population data, we introduce the population market access defined in Equation (3.1):

$$Population\ Access_j = \sum_i pop_i \exp(-\alpha \times time_{ij}), \tag{3.1}$$

where pop_i is population in block i, $time_{ij}$ is duration from block i to school j, $\alpha > 0$ is a distance decay parameter. We set $\alpha = 0.011552$ following Rosic et al. (2020). In this setting, the size of economic activities A located in 60 minutes away from origin is reduced to 0.5A[10]. In a similar vein, we also introduce two indices by using the number of students commuting to NFS in 1998 and 10–14-year-old population in 1995 respectively. One is the student access defined in Equation (3.2):

$$Students\ Access_j = \sum_i students_i \exp(-\alpha \times time_{ij}), \tag{3.2}$$

where $students_i$ is the number of the total NFS commuters in block i. The other is 10-14 population access defined in Equation (3.3):

$$10 - 14\ Population\ Access_j = \sum_i 10 - 14\ pop_i \exp(-\alpha \times time_{ij}), \tag{3.3}$$

where $10 - 14\ pop_i$ is the population aged 10 to 14 in block i.

In Figure 3.10, we compare the values of these accessibility indices across schools. For the sake of convenience in comparison, we take the logarithm for all indices and standardize them. As a general trend, the ranking of the indices is almost the same across the schools. Nishi has the highest accessibility, while that of Minami is the lowest. In Figure 3.11, we show the change in the geographical distribution of commuters to Nishi before and after the reform using cartograph maps. The size of each block in the central pane (in 1998) and the right pane (in 2010) is expanded by the number of commuters. Each block is colored by the share of university graduates in 2000. After the reform, we can observe the number of commuters

[10] To check the robustness of the obtained results, we also try different distance decay parameters corresponding to 30, 45, 60, 75, and 90 minutes. A series of estimation results are summarized in Appendix B.

increased in the northern suburb blocks and the central area with a higher value of the share of university graduates. In addition, new blocks with relatively high value of the share emerged in the eastern region.

4. Empirical Strategy

In Section 3, we found several changes in the commuting behaviors after the reform of the school zone system in 2002 through exploratory data analysis. The commuting time to the Nagasaki Five Schools has increased, indicating a shift in the geographical distribution of commuting flows. In addition, this shift in commuting patterns has coincided with an expansion of the disparity across schools in educational outcomes measured with the university acceptance. Behind this expansion of the disparity, the composition of students in terms of the level of education that their neighborhood has changed among the schools. In particular, the concentration of the commuters from highly educated blocks to a school with better accessibility concurs with the outstanding performance of the school.

To empirically validate these findings, we firstly evaluate the impact of the reform on students' commuting behaviors based on the following model using the Poisson-Pseudo Maximum Likelihood (PPML) estimation:

$$E(com_{ijt}) = \exp[\eta_{it} + \delta_{jt} + \kappa_{ij} + \theta longTime_{ij} \times after_t], \tag{4.1}$$

where com_{ijt} is the number of first-grade commuters from block i to school j in year t, η_{it} is the block-year fixed effect, δ_{jt} is the school-year fixed effect, κ_{ij} is the block-school fixed effect, $longTime_{ij}$ a dummy variable taking 1 if commuting time from block i to school j, $time_{ij}$, exceeds 30 minutes, and $after_t$ is a dummy variable taking 1 if $t > 2002$. Standard errors are clustered at the block-school level. The coefficient of our main interest is θ, which represents the impact of the reform on commuting behaviors by commuting time. We expect that $\theta > 0$ because the candidates have the opportunity to seek out a school that fits their abilities and preferences, rather than being limited to the nearest one after the reform. τ captures the intrinsic association between commuting flows and commuting time, which is expected to be negative. In line with Equation (4.1), we also estimate the following event-study model:

$$E\left(com_{ijt}\right) = \exp\left[\eta'_{it} + \delta'_{jt} + \kappa'_{ij} + \sum_{t \neq 1998} \theta'_t longTime_{ij} \times \gamma_t\right], \tag{4.2}$$

where γ_t is year dummy. This model enables to examine evolving relation between commuting patterns and duration of commutes. The change in commuting flows can differ depending on the school. To consider the heterogenous impacts of the reform across schools, we estimate the following model:

$$E\left(com_{ijt}\right) = \exp\left[\eta''_{it} + \delta''_{jt} + \sum_{t=1994}^{2018} \tau_{jt} \ln time_{ij} \times \gamma_t \times \mu_j\right], \tag{4.3}$$

where μ_j is the school dummy. The coefficient τ_{jt} captures the school-specific association between commuting flows and commuting time for each year.

If the change in the geographical distribution of commuting flows can be confirmed, we turn to the examination of the shift in the composition of commuters after the reform. Through the exploratory analysis in Section 3, we observed that potential high achievers residing in blocks with a high level of education tended to enroll in a school that offered superior accessibility whereas a school with limited accessibility experienced a decline in their enrollment of such students. To test this change in composition, we first construct the commuting flow data divided by the level of education measured with the share of university graduates in the origin blocks, specifically commuting flows from the highest 25% blocks, and those from the lowest 25% blocks. Then we estimate the following model for each group:

$$E\left(com_{ijt}\right) = \exp\left[\zeta_{ij} + \mu_{it} + \phi Access_j \times after_t\right], \tag{4.4}$$

where ζ_{ij} is the block-school fixed effect and μ_{it} is the block-year fixed effect. $Access_j$ is one of the accessibility indices introduced in Section 3.2.3: the number of university graduates within an hour from each school, the commuter market access, the number of employees in the commercial sectors within 15 minutes on foot, the urbanization index, the number of preparatory schools within 15 minutes, and the preparatory school accessibility. As with Section 3.2.3, we take the logarithm for all indices and standardize them. We also estimate the following event-study model to capture the dynamism of the association:

$$E\left(com_{ijt}\right) = \exp\left[\zeta'_{ij} + \mu'_{it} + \sum_{t\neq 1998} \phi'_t Access_j \times \gamma_t\right], \tag{4.5}$$

As discussed in Section 1, the level of tolerance for long-time commuting is heterogeneous across the SES of students and their families. Specifically, a student with high SES tends to accept a long commute aiming to receive a better quality of education and to spend school life with peers with high educational attainment. Once high SES students concentrate on a school with better accessibility, this might attract students residing in faraway blocks. To test this hypothesis, we estimate the following model for each group:

$$\begin{aligned} E\left(com_{ijt}\right) = \exp\big[&\xi_{ij} + \lambda_{it} + \phi_1 longTime_{ij} \times after_t \\ &+ \phi_2 Access_j \times longTime_{ij} \times after_t\big], \end{aligned} \tag{4.6}$$

Given the differences in demographics and the geographical separation from other schools included in the Nagasaki Five Schools, it may not be appropriate to analyze Hokuyodai in conjunction with the others. Consequently, the subsequent sections of this paper will exclude observations related to Hokuyodai[11]. To construct the balanced panel data, we excluded the observations in 2006, 2007, and 2013 because the school directory was not completely published by all the Nagasaki Five Schools in these years.

[11] A large part of our main results is not altered even after including the observations regarding Hokuyodai. A series of estimation results are summarized in Appendix C.

5. Result

5.1 Geographical Distribution of Commuting Flows

We test the change in the commuting patterns of first-grade students after the reform. Table 5.1 shows the estimation results of Equation 4.1, changing the selection of the sample. The value of coefficient θ is consistent and positively significant across the results. We also examine the change using an alternative treatment variable $\ln time_{ij}$. This change in the definition of the treatment variable does not alter the results. These results imply that the reform of the school zone system increased the commuting time.

The result of the event-study estimation of Equation 4.2 is provided in Figure 5.1. The magnitude of estimated coefficient increases progressively shortly after the reform, reaching its highest point in 2012, and continues to persist thereafter. Importantly, the coefficient is almost insignificant before the reform. Therefore, there is no convincing evidence that there is a potential alternative factor shifting the geographical distribution of flows before the reform. The disadvantage of our data is that we cannot observe the commuting flows of first-grade students from 1999 to 2002. To compensate for the lack of data, we estimate the same model using the observations of third-grade students. Since the coefficient value is around 0 as shown in Figure 5.2, we cannot find strong evidence of the violation of the parallel trend assumption.

Figure 5.3 depicts the change in the association between commuting flows and duration by school estimated by Equation 4.3. The association was heterogeneous in prior to the reform. The magnitude of the coefficient is larger in Kita, which suggests that Kita is a school more localized regarding commuting behaviors. After the reform, however, the deviation across schools was gradually reduced and converged to a certain level. This suggests that the disparity in commuting time decreased after the reform and all the students bear the burden of longer commuting at the same level across schools.

5.2 Change in Composition of Students

We empirically examine if the differences in accessibility across schools are related to the change in the composition of students in terms of the level of education after the reform. The commuting flow data in this analysis is divided based on the university graduate rate of blocks, separating it into two groups: one comprising the highest 25% of the university graduate rate and the other consisting of the lowest 25%. Table 5.2 summarizes the estimation results for each group in terms of the level of education. All the accessibility indices are positively associated with the commuting flows for the highest 25% group, whereas the opposite relation is observed for the lowest 25% group[12].

We also test this association with the event-study model specified with Equation 4.5. The results are provided in Figure 5.4. Soon after the reform, a positively significant association is observed for the highest 25% group and continues to persist thereafter[13]. We can observe a negative relation for the lowest 25% group but not necessarily significant due to large standard errors. Interestingly enough, the commuting patterns changed reacting to the accessibility soon after the reform for the highest 25% group, while there was a gap of three years until the change in the patterns emerged for the lowest 25% group.

As discussed above, a positive association exists between accessibility and commuting flows for students from blocks with high levels of education. This implies the concentration of

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[12] The alternative drivers to attract students are each school's traditional attributes, which might be the confounding factors with location advantages. To address this concern, we test if the observed associations between location advantages and commuting behavior are robust even after controlling for the tradition by using a dummy variable taking one if a school originated from the prewar middle school (*kyusei chugaku*). As shown in Appendix D, we confirmed that the results were not largely altered.

[13] One identification threat is that being adopted to the special program to prioritize a specific educational field (e.g., science, mathematics, English) is an alternative driver to attract students to a school. Specifically, Minami was adopted to the Super English Language High School in 2004, and Nishi was adopted to the Super Science High School in 2005, respectively. However, the results obtained from the event-study analysis suggest that the change in commuting behaviors largely happened in advance of these adoptions. In this regard, it cannot be said that the adoptions remarkably contributed to the shift in the commuting patterns.

students who are likely to achieve high educational outcomes in geographically advantageous schools. We examine if this concentration attracts students from distant blocks with high educational attainment by estimating Equation 4.6. Table 5.3 summarizes the estimation results. For all the accessibility indices, the interaction terms with the baseline treatment variable $longTime_{ij} \times after_t$ are positively correlated with commuting flows from the highest 25% group. This suggests a snowballing concentration of students with potentially high educational attainments from distant blocks after the reform. For comparison, we also estimate the same model for commuting flows from the lowest 25% group. Except for several results, the interacted treatment variables are insignificant.

5.3 Discussion

The principal findings derived from the analysis presented in Section 5 can be summarized as follows: (i) the reform of the school zone system has resulted in an increase in the commuting duration for students, (ii) students living in blocks characterized by higher educational attainment tend to enroll in schools with a better accessibility, whereas a contrasting trend is observed among students from neighborhoods with lower educational levels, and (iii) the concentration of students likely to attain high educational outcomes attracts peers from more remote locations. Although our data and identification strategy do not enable us to conclusively determine the precise mechanism driving these findings and the relation among them, we consider the potential mechanisms to deepen our comprehension of them.

Long-time commuting has several negative impacts on students, as discussed in Section 1. Concurrently, the university admission outcomes, as indicated by the average hensachi, exhibited little to no change across the Nagasaki Five Schools, as detailed in Section 3.2.2. In this regard, it is arguable whether the negative aspects driven by the increase in commuting time were sufficiently offset by enhancements in educational achievement.

The opposite consequence in commuting patterns between the higher-educated and lower-educated blocks in response to location advantages is consistent with the disparity in the university acceptance performance across schools after the reform. Since the quality of supplied educational service is randomized and there is little incentive for competition across schools, each public high school serves as just a box whose quality is determined by the level of education of its students. The educational potential of students is significantly influenced by the educational achievements and norms of their parents and neighbors. Consequently, the quality of each box might be a function of the neighborhood quality, which tends to be greater in urban regions that require sufficient housing affordability. While the literature points out that the underlying mechanism of the urban-rural gap in educational quality is the difference in the competitive environment among the providers of educational service (e.g., Gibbons & Silva, 2008), our findings suggest an alternative mechanism, spatial sorting driven by neighborhood quality as discussed in Couture et al. (2024).

In addition, we observed the gap of three years between the higher-educated and lower-educated blocks regarding the change in commuting behaviors after the reform. While students in the higher-educated blocks altered their choices soon after the reform, those in the lower-educated did not. This result implies that the university acceptance performance of the first generation after the reform served as an indicator of educational attainment in each school, visible to all economic agents demanding education. The students and their parents in lower-educated blocks knew that they were crowded out only after the expansion of the disparity. This suggests the existence of information disparity among different SES.

Our final finding (iii) is consistent with the tendency that a student from a high SES is likely to endure a long time commuting in pursuit of superior educational opportunities and to engage with peers who have higher levels of academic achievement. In addition, this association might be magnified by the preference for the homogeneity of a group (Reber, 2005;

Baum-Snow & Lutz, 2011). However, considering the difficulty of admission tests for the Nagasaki Five Schools, we also should note the likelihood that this concentration of potential high achievers crowds out the students who originally could enroll in their nearest school under the school zone system, which ends up forcing undesirable school choices.

6 Preference in School Choice Decision

6.1. Model

We integrate the findings in the reduced-form analysis, particularly (ii), by estimating the students' preference in the school choice decision. Following the equilibrium analysis of commuting behavior (e.g., Monte et al., 2018) and university choice (Mun et al., 2023), we first derive the commuting probability based on the random utility framework.

Suppose that there are I blocks and N high schools. Student ω living in block i faces a choice regarding which high school n to apply for and enroll in. The residences of students and the locations of high schools are exogenous. We assume that $V_{in}(\omega)$, the utility of student ω living in block i and commuting to school n, depends on the level of location advantage of school n, B_n, disposable leisure time T_{in}, and idiosyncratic utility $b_{in}(\omega)$.

$$V_{in}(\omega) = B_n T_{in} b_{in}(\omega). \tag{6.1}$$

A student chooses a school subject to the following time constraint, where 24 hours are allocated to round-trip commuting time to the school CT_{in}[h], study hours in the school ST, minimum required sleep hours SL, disposable leisure T_{in}, and self-motivated study hours SE_{in}.

$$24 = CT_{in} + ST + SL + T_{in} + SE_{in}. \tag{6.2}$$

$b_{in}(\omega)$ is assumed to be drawn from the following independent Fréchet distribution:

$$Prob[b_{in}(\omega) \leq b] = e^{-A_n b^{-\epsilon}}, \tag{6.3}$$

where A_n is a scale parameter reflecting the average level of amenity from commuting to school n, and ϵ is a dispersion parameter.

Using the property of Fréchet distribution in Equation (6.3), the probability that a student living in block i commutes to school n under the utility maximization is

$$\lambda_{in} = \frac{A_n [B_n T_{in}]^{\epsilon}}{\sum_{r=1}^{I} \sum_{s=1}^{N} A_s [B_s T_{rs}]^{\epsilon}}. \tag{6.4}$$

The probability of commuting to n conditional on living in block i, $\lambda_{in|i}$ is derived as follows:

$$\lambda_{in|i} = \frac{\lambda_{in}}{\lambda_i^{Residence}} = \frac{A_n [B_n T_{in}]^{\epsilon}}{\sum_{s=1}^{N} A_s [B_s T_{is}]^{\epsilon}}, \lambda_i^{Residence} = \frac{\sum_{s=1}^{N} A_s [B_s T_{is}]^{\epsilon}}{\sum_{r=1}^{I} \sum_{s=1}^{N} A_s [B_s T_{rs}]^{\epsilon}}. \tag{6.5}$$

This commuting probability yields the expected value of commuting flows from block i to school n, c_{in}, expressed as follows:

$$c_{in} = \lambda_{in|i} L_i = \frac{A_n [B_n T_{in}]^{\epsilon}}{\sum_{s=1}^{N} A_s [B_s T_{is}]^{\epsilon}} L_i, T_{in} = 24 - (CT_{in} + ST + SL + SE_{in}), \tag{6.6}$$

where $L_i = \sum_{s=1}^{N} c_{is}$ is the total number of students residing in block i.

6.2 Parameter Estimation

To map the model to data, we first formulate the location-specific amenities B_n and the self-motivated study hours SE_{in}. We define each school's location advantages as accessibility from (or to) potentially high-achieving students. To express this, we assume that B_n is a constant elasticity function of an accessibility index $\mathbb{B}_n$, the weighted sum of the number of students in block r, L_r, with respect to the share of university graduates α_r defined as follows[14]:

$$B_n = \mathbb{B}_n^{\delta}, \mathbb{B}_n = \sum_{r=1}^{I} \alpha_r L_r \exp(-0.00924 \times time_{rn}). \tag{6.7}$$

The distance-decay parameter, 0.00924, takes off half the size of economic activities located 75 minutes away from the origin.

It is assumed that higher educational attainment (hensachi) required to enroll in school n, E_n, increases SE_{in}, while the efficiency of a student's self-motivated study increases as the academic background of the surrounding adult neighbors is higher. To express this, we formulate SE_{in} as an increasing function of hensachi E_n and a decreasing function of the share of university graduates α_i. To match the scale of α_i to E_n, we use $\tilde{\alpha}_i$, a standardized variable of α_i, so that it has a mean of 10 and a standard deviation of 50[15].

[14] The value of the distance-decay parameter, 0.00924, is chosen from a series of parameters corresponding to 30, 45, 60, 75, 90, 105, and 120 minutes to minimize the negative pseudo log-likelihood given in Equation (5.11).

[15] This formulation of SE_{in} yields the desirable results in terms of the fitting to data evaluated with negative log-likelihood and replicability in the equilibrium analysis, while we also try

$$SE_{in} = \left(\frac{E_n}{\tilde{\alpha}_i}\right)^{\beta}, \tilde{\alpha}_i = \left(\frac{\alpha_i - \bar{\alpha}}{s_\alpha}\right) \times 10 + 50, \tag{6.8}$$

where $\bar{\alpha}$ is an arithmetic mean of α_i, and s_α is a standard deviation of α_i.

Using these formulations, the commuting flow in Equation (5.6) is expressed as follows:

$$c_{in} = \frac{A_n \mathbb{B}_n^{\delta\epsilon} T_{in}^{\epsilon}}{\sum_{s=1}^{N} A_s \mathbb{B}_s^{\delta\epsilon} T_{is}^{\epsilon}} L_i, T_{in} = 24 - \left\{CT_{in} + ST + SL + \left(\frac{E_n}{\tilde{\alpha}_i}\right)^{\beta}\right\}. \tag{6.9}$$

Specifying $ST = 7, SL = 6, \gamma = \delta\epsilon$ and taking the logarithm, Equation (5.9) is

$$\begin{aligned} \ln c_{in} = \ln A_n + \gamma \ln \mathbb{B}_n + \epsilon \ln\{11 - CT_{in} - (E_n/\tilde{\alpha}_i)^{\beta}\} \\ - \ln \sum_{s=1}^{N} A_s \mathbb{B}_s^{\gamma} \{11 - CT_{is} - (E_s/\tilde{\alpha}_i)^{\beta}\}^{\epsilon} + \ln L_i. \end{aligned} \tag{6.10}$$

Since c_{in} takes non-negative integer value and often zero, we assume that c_{in} follows Poisson distribution where $E(c_{in}) = \mu_{in}$. Thus, we estimate the model which minimizes the following negative pseudo log-likelihood function $-l(\boldsymbol{\theta})$ with respect to the parameters $\boldsymbol{\theta}' = (\beta, \gamma, \epsilon)$:

$$\begin{aligned} -l(\boldsymbol{\theta}) = -\sum_{r=1}^{I}\sum_{s=1}^{N} \rho_{rs}(\boldsymbol{\theta}) = -\sum_{r=1}^{I}\sum_{s=1}^{N} (c_{rs} \ln \mu_{rs} - \mu_{rs}), \\ \ln \mu_{in} = \ln A_n + \gamma \ln \mathbb{B}_n + \epsilon \ln\{11 - CT_{in} - (E_n/\tilde{\alpha}_i)^{\beta}\} \\ - \ln \sum_{s=1}^{N} A_s \mathbb{B}_s^{\gamma} \{11 - CT_{is} - (E_s/\tilde{\alpha}_i)^{\beta}\}^{\epsilon} + \ln L_i. \end{aligned} \tag{6.11}$$

We expect that all parameters included in $\boldsymbol{\theta}$ are positive. In advance of the parameter estimation, we specify the initial values of parameter estimates $\widehat{\boldsymbol{\theta}}$ satisfying $11 - CT_{in} - (E_n/\tilde{\alpha}_i)^{\beta} > 0$ under the following ranges:

$$-30 \le \beta \le 30, -30 \le \gamma \le 30, -30 \le \epsilon \le 30 \tag{6.12}$$

We conduct the optimization by the L-BFGS-B method using the R package "optimx." Based on Hansen (2022), we numerically estimate the standard errors for parameter estimates $\widehat{\boldsymbol{\theta}}$ by

$$\begin{aligned} Var(\widehat{\boldsymbol{\theta}}) = \mathbf{Q}(\widehat{\boldsymbol{\theta}})\boldsymbol{\Omega}(\widehat{\boldsymbol{\theta}})\mathbf{Q}(\widehat{\boldsymbol{\theta}})', \\ \mathbf{Q}(\widehat{\boldsymbol{\theta}}) = \sum_{r=1}^{I}\sum_{s=1}^{N} \nabla^2 \rho_{rs}(\widehat{\boldsymbol{\theta}}), \boldsymbol{\Omega}(\widehat{\boldsymbol{\theta}}) = \sum_{r=1}^{I}\sum_{s=1}^{N} \nabla \rho_{rs}(\widehat{\boldsymbol{\theta}}) \nabla \rho_{rs}(\widehat{\boldsymbol{\theta}})', \end{aligned} \tag{6.13}$$

where $\nabla \rho_{rs}(\widehat{\boldsymbol{\theta}})$ is the gradient of ρ_{rs} with respect to $\widehat{\boldsymbol{\theta}}$.

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other forms of SE_{in}, such as $(E_n/\alpha_i)^{\beta}$. Although we should rely on a more flexible formulation of SE_{in}, such as $\left(\beta_1 E_n^{\beta_2}/\alpha_i^{\beta_3}\right)^{\beta_4}$, the parameter estimation becomes infeasible in most cases.

The average utility A_n is recovered from the residuals when estimating the model in Equation (6.11) under the setting of $A_n = 1$. In this sense, A_n captures the unobservable amenities (e.g., tradition, curriculum) isolated from location environments captured by B_n. The steps of iterative calculation to recover A_n is as follows by setting the initial value $A_{n(0)} = 1$:

1. Calculate the predicted value of the commuting flow $\hat{\mu}_{in(t)}$ using $A_{n(t)}$, the value of average amenity obtained in *t* th iteration.
2. Calculate the total predicted number of commuters for each school $\sum_r \hat{\mu}_{rn(t)}$.
3. Update $A_{n(t)}$ to $A_{n(t+1)}$ by the value $A_{n(t+1)} = 0.25\{A_{n(t)} \times (c_{in}/\hat{\mu}_{in(t)})\} + 0.75A_{n(t)}$ if the condition $\sum_n \left|\sum_r c_{rn} - \sum_r \hat{\mu}_{rn(t)}\right| < 10$ is not satisfied. Return to Step 1.
4. Break the iteration if the condition $\sum_n \left|\sum_r c_{rn} - \sum_r \hat{\mu}_{rn(t)}\right| < 10$ is satisfied.

To estimate the model in Equation (6.11), we use the variables observed around 2007 when the hensachi scores E_n at the beginning of stratification for each school are available. The hensachi scores E_n in 2007 is obtained from the National Overview of High School and Junior High School Hensachi Scores (*Zenkoku Koukou Chugaku Hensachi Soran*) published by Kanjuku Co., Ltd. Since the number of first-grade commuters from block i to school j, c_{in}, is not completely observed for every school in 2007, we use that of second-grade commuters in 2008 instead. As the share of university graduates α_i in 2007, we use the linear-interpolated value of α_i between 2000 and 2010 because the share is only observed decennially. The round-trip commuting time to the school CT_{in} is obtained by calculating $(time_{in}/60) \times 2$.

The estimation result of the parameters $\boldsymbol{\theta}' = (\beta, \gamma, \epsilon)$ is summarized in Table 6.1. All parameters are positive and statistically significant. The implied value of $\delta = 0.824$. We also show the estimated value of location advantage $B_n = \mathbb{B}_n^{\delta}$ and the recovered value of average amenity A_n for each school together with the hensachi score E_n in Table 6.2. The order of B_n is consistent with that of E_n but not with A_n. From the estimated values of B_n, it is implied that

Nishi is the most advantageous in terms of location environment, while Minami is the least, which has one-to-one correspondence with the rank of the educational attainment.

6.3 Equilibrium Analysis

We assess whether the developed model can replicate the actual variation and order in educational attainment. Specifically, using $\widehat{\boldsymbol{\theta}}' = (\hat{\beta}, \hat{\gamma}, \hat{\epsilon})$ and the recovered A_n, we investigate the equilibrium hensachi score E_n^* for each school when we set the identical value $E_{n(0)} = 63$. To get the equilibrium values, we implement the following algorithm:

1. Given $\widehat{\boldsymbol{\theta}}, CT_{in}, \alpha_i, L_i, B_n, A_n$, and the hensachi score obtained in t th iteration $E_{n(t)}$, calculate the predicted value of the commuting flow $\hat{\mu}_{in(t)}$.
2. Calculate the total predicted number of commuters for each school $\sum_r \hat{\mu}_{rn(t)}$.
3. Calculate $gap_n = \sum_r \hat{\mu}_{rn(t)} - \sum_r c_{rn}$ to get the excess and deficient number of students.
4. Update $E_{n(t)}$ to $E_{n(t+1)}$ by the value $E_{n(t+1)} = E_{n(t)} + 0.001 \times gap_n$ if the condition $\max\left(\sum_r \hat{\mu}_{rn(t)} - \sum_r c_{rn}\right) < 10$ is not satisfied. Return to Step 1.
5. Break the iteration if the condition $\max\left(\sum_r \hat{\mu}_{rn(t)} - \sum_r c_{rn}\right) < 10$ is satisfied.

Figure 6.1 summarizes the results of equilibrium analysis. To evaluate the importance of each element included in the commuting flow represented by Equation (5.10), we implement the analysis under the following multiple conditions:

1. w/B_n & A_n: Consider both location advantage B_n and average utility A_n.
2. w/B_n: Consider only B_n (set $A_n = 1$ for all schools).
3. w/A_n: Consider only A_n (set $\mathbb{B}_n = \mathbb{B}_G$ for all schools. $\mathbb{B}_G$ is the geometric mean of $\mathbb{B}_n$).
4. w/o B_n & A_n: Ignore both B_n and A_n (set $A_n = 1$ and $\mathbb{B}_n = \mathbb{B}_G$ for all schools).

Naturally, the equilibrium hensachi scores considering both B_n and A_n replicate the actual scores shown in Table 6.2 such that Nishi has the highest hensachi while Minami has the lowest.

The result of particular importance is that the pattern of stratification in the hensachi score is also replicable even if only considering B_n, but not if only considering A_n or if ignoring both elements. Interestingly enough, the stratification per se hardly emerges in these two cases ignoring B_n. This implies that the primary driver of the gap in educational attainment is the difference in location environment across schools, rather than other school-specific factors. As shown in Figure 6.2, a similar trend is also observable when using the value adding 12.5 to the average hensachi score of the universities that accept graduates from each school in 2002 as the initial value[16].

6.4 Welfare Analysis

Based on the developed model, we evaluate the welfare impacts brought by freedom of school choice. Specifically, we compare the value of the deterministic term in the utility function represented by Equation (5.1) between cases with and without differences in location environment B_n and educational attainment E_n across schools. For the case with differences in B_n and E_n, we calculate the per capita welfare function following the condition "w/B_n" in the equilibrium analysis $\sum_r \sum_s \hat{\mu}_{rs}^1 B_s \{11 - CT_{rs} - (E_s^*/\tilde{\alpha}_r)^\beta\} / \sum_r \sum_s \hat{\mu}_{rs}^1$, where $\hat{\mu}_{rs}^1$ is the predicted number of commuters from block r to school s, and E_s^* is the equilibrium hensachi score of school s. We also calculate the welfare function for the case without differences in B_n and $\sum_r \sum_s \hat{\mu}_{rs}^2 B_G \{11 - CT_{rs} - (E^*/\tilde{\alpha}_r)^\beta\} / \sum_r \sum_s \hat{\mu}_{rs}^2$, where $\hat{\mu}_{rs}^2$ is the predicted number of commuters when the hensachi score is E^* for all schools, and $B_G = \mathbb{B}_G^\delta$. We set $E^* = 63.197$, the weighted average of the hensachi scores E_s^* with respected to $\hat{\mu}_{rs}^1$. We eventually investigate the change in welfare by calculating the ratio between these functions:

[16] As a matter of convention in the entrance exam industry, a high school hensachi is roughly equivalent to the university hensachi of a STEM department by adding 15, and comparable to that of a non-STEM department by adding 10.

$$\frac{PW_1}{PW_2} = \frac{\sum_r \sum_s \hat{\mu}_{rs}^1 B_s\{11 - CT_{rs} - (E_s^*/\tilde{\alpha}_r)^\beta\}/\sum_r \sum_s \hat{\mu}_{rs}^1}{\sum_r \sum_s \hat{\mu}_{rs}^2 B_G\{11 - CT_{rs} - (E^*/\tilde{\alpha}_r)^\beta\}/\sum_r \sum_s \hat{\mu}_{rs}^2}. \tag{6.14}$$

To examine the welfare impacts across schools and blocks, we also introduce the welfare function by school and block as follows:

$$\frac{PW_{1,n}}{PW_{2,n}} = \frac{\sum_r \hat{\mu}_{rn}^1 B_n\{11 - CT_{rn} - (E_n^*/\tilde{\alpha}_r)^\beta\}/\sum_r \hat{\mu}_{rn}^1}{\sum_r \hat{\mu}_{rn}^2 B_G\{11 - CT_{rn} - (E^*/\tilde{\alpha}_r)^\beta\}/\sum_r \hat{\mu}_{rn}^2}, \tag{6.15}$$

$$\frac{PW_{1,i}}{PW_{2,i}} = \frac{\sum_s \hat{\mu}_{is}^1 B_n\{11 - CT_{is} - (E_s^*/\tilde{\alpha}_i)^\beta\}/\sum_s \hat{\mu}_{is}^1}{\sum_s \hat{\mu}_{is}^2 B_G\{11 - CT_{is} - (E^*/\tilde{\alpha}_i)^\beta\}/\sum_s \hat{\mu}_{is}^2}. \tag{6.16}$$

The value of the welfare ratio for all commuters given by Equation (6.14) is 1.083. This result suggests that the freedom of school choice marginally improves welfare overall. Table 6.3 summarizes the value of the welfare ratio by school. While the welfare for commuters to Nishi significantly increases, that for commuters to Minami decreases remarkably. Interestingly enough, the welfare for Higashi and Kita's commuters also increases.

In the same table, we also show the ratios for other variables. Except for Nishi, the self-motivated study hours SE_{in} decrease. The average commuting time for Higashi and Kita increases, while that of Minami and Nishi decreases. The share of long commuters increases in all schools except for Nishi. From these results, it is implied that the relative welfare gain in Higashi and Kita is due to the offset of other negative factors affecting the welfare by the reduction of learning costs. The results for Nishi that contradict those in the reduced-form analysis might be because the hensachi score E_n is introduced in our model as merely a cost factor, and the model does not illustrate the situation that the higher hensachi score on its own attracts the high-achieving students. The consideration for such a situation is needed to be rigorously addressed in future studies.

The block-level welfare ratio using a cartogram where the area of each block is expanded proportional to the number of students in Figure 6.3. The remarkable trend observed from this cartogram is that the welfare for commuters residing around Minami decreases. These results regarding the welfare change by school and block suggest that the policy reform aiming to introduce the freedom of school choice sometimes has a distributional impact due to the winner-takes-all by locationally advantageous schools and the crowding-out of potential low achievers, and it does not equally improve welfare for all students as a consequence.

6. Conclusion

This study empirically investigated the impact of the reform of the school zone system on students' commuting behaviors and the change in the composition of students based on their potential educational achievements. To address this issue, we focused on the reform aimed at public high schools in Nagasaki City in 2002. We examined the changes in commuting behaviors utilizing the block-school level commuting flow data.

We found that the reform significantly increased the students' commuting time. Along with this change, we also observed the emergence of a stratification of students based on their potential educational levels measured by the educational attainment within their residential blocks. Specifically, the students from blocks with higher levels of education enrolled in schools that offered location advantages in terms of accessibility, whereas we observed the opposite relation for those from blocks with lower educational attainment. We also found that this spatial sorting of students had a distributional welfare impact by school and block. In addition, our analysis suggested that the concentration of potential high achievers attracted peers residing in distant blocks. At the same time, this concentration might have crowded out students who originally could have enrolled in their nearest school.

This study has several future tasks. The first one is to develop a framework that explicitly incorporates the change in the university acceptance performance as a final outcome. While the present identification strategy in this study reveals the change in commuting patterns and thus the composition of students after the reform, we have yet to directly associate this change with an academic outcome. To close the identification framework, it might be necessary to extend the equilibrium model. The second one is the comparison across the cities. In the case of Nagasaki, we showed that location advantages could be a driver of spatial sorting and thus the disparity in academic performance across schools. Nevertheless, the impact of the reform may vary across cities due to distinct local characteristics, including socioeconomic conditions, geographical features, and the educational administration system. For example, if the distance across schools is too remote, the number of choices virtually does not increase, and the reform affects nothing in the first place. Along with this task, it is beneficial to evaluate the relative importance of each factor that may play a role in the stratification of students.

Acknowledgments

We thank Kentaro Nakajima and Atsushi Yamagishi for their comments and suggestions at the earliest stage of this study. We thank the participants of the Urban Economics Workshop in Kyoto University (Tomohiro Machikita, Tomoya Mori, Se-il Mun, and Minoru Osawa, especially), the 2024 Mini Conference on Machine Learning, Urban Economics and Economic History, the 38th Applied Regional Science Conference (Miwa Matsuo, especially), the Musashi Research Workshop (Ryo Kambayashi and Reiji Kasamatsu, especially), the 18th Workshop on Empirical Moral Science (Katsuo Kogure, especially), and the JEA Meeting Spring 2025 (Ryuichi Tanaka, especially) for their helpful comments and suggestions. We are grateful to (junior) high school teachers in Nagasaki Prefecture for their advice based on an in-depth understanding of the high school education in Nagasaki to conduct this research.

Declaration of Interest Statement

This study was supported by the Japan Society for the Promotion of Science (JSPS) under KAKENHI Grant Numbers 21K13315, 22K13411, and 23K25529.

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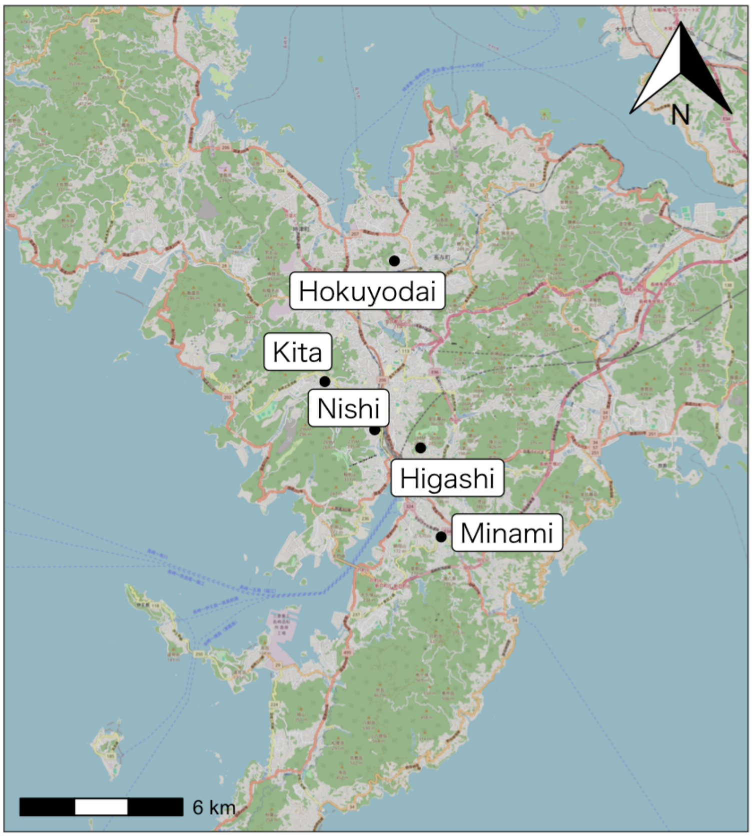

Figure 2.1: Location of Public High Schools included in Nagasaki Five Schools
Notes: OpenStreetMap contributes. The areas depicted in gray indicate urbanized regions. The regions shown in green signify mountainous terrain. The orange and red lines represent the primary roads.

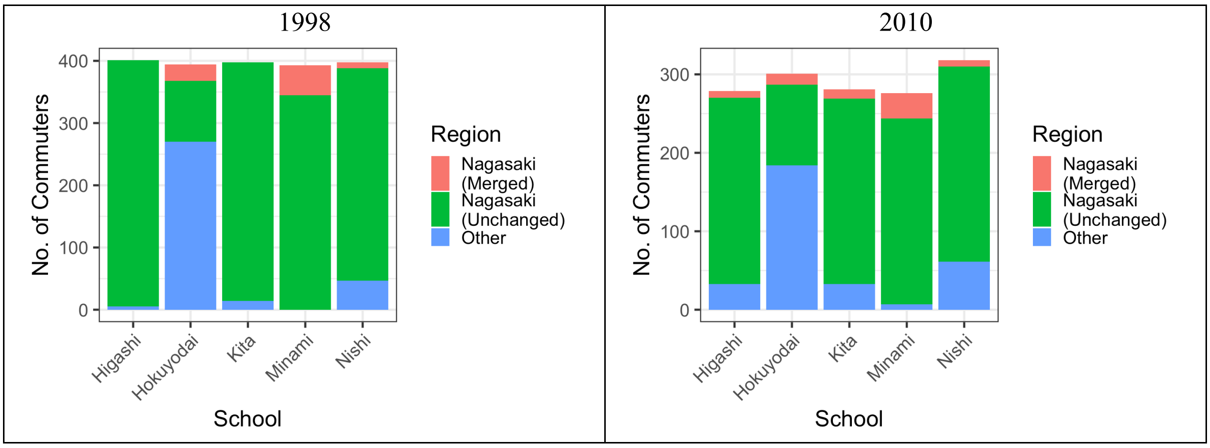

Figure 3.1 Geographical Distribution of the First-grade Commuters

Notes: Nagasaki (Unchanged) denotes the number of commuters in the first-grade originating from the blocks within Nagasaki City since before 2005. Nagasaki (Merged) represents the number of commuters from the blocks that were integrated into Nagasaki after 2005. The category labeled Other illustrates the number of commuters outside Nagasaki City.

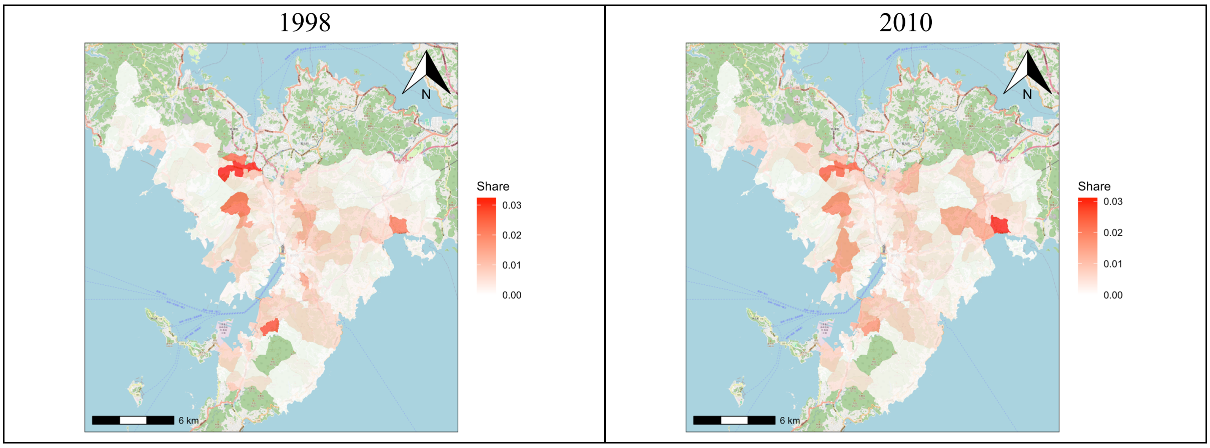

Figure 3.2 Geographical Distribution of the First-grade Commuters

Notes: OpenStreetMap contributes. The blocks within Nagasaki City since before 2005 are shown. The share is calculated by dividing the number of students in the first-grade in each block by total number of students in Nagasaki Five Schools.

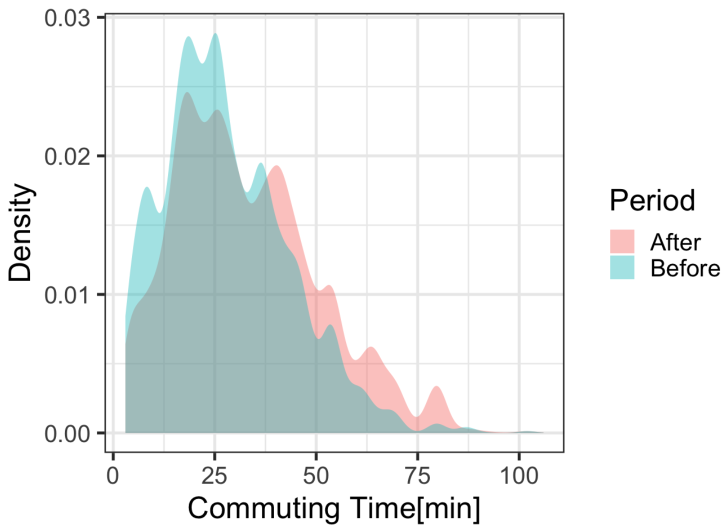

Figure 3.3 Distribution of Commuting Time

Notes: Commuting flows to Hokuyodai High School are excluded. Only the flows from blocks within Nagasaki City since before 2005 are included.

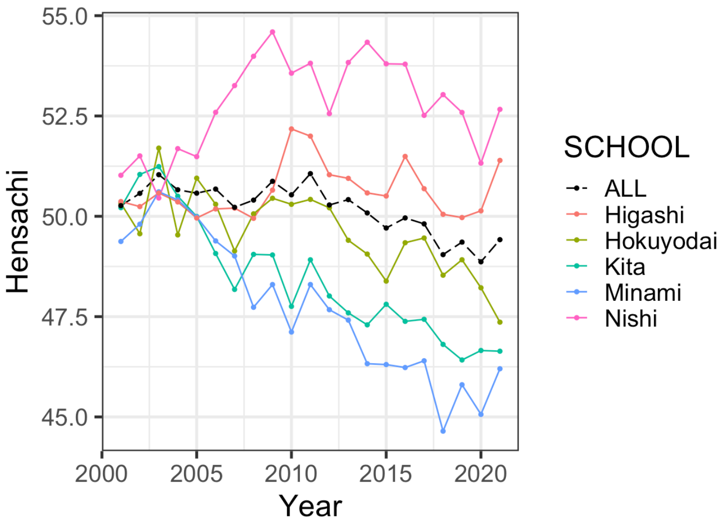

Figure 3.4 Average Hensachi Score of the Universities that Accept Graduates from Each School
Notes: University acceptance data are based on a survey by DAIGAKUTSUSHIN Corporation, and hensachi scores are based on reports from Kawaijuku.

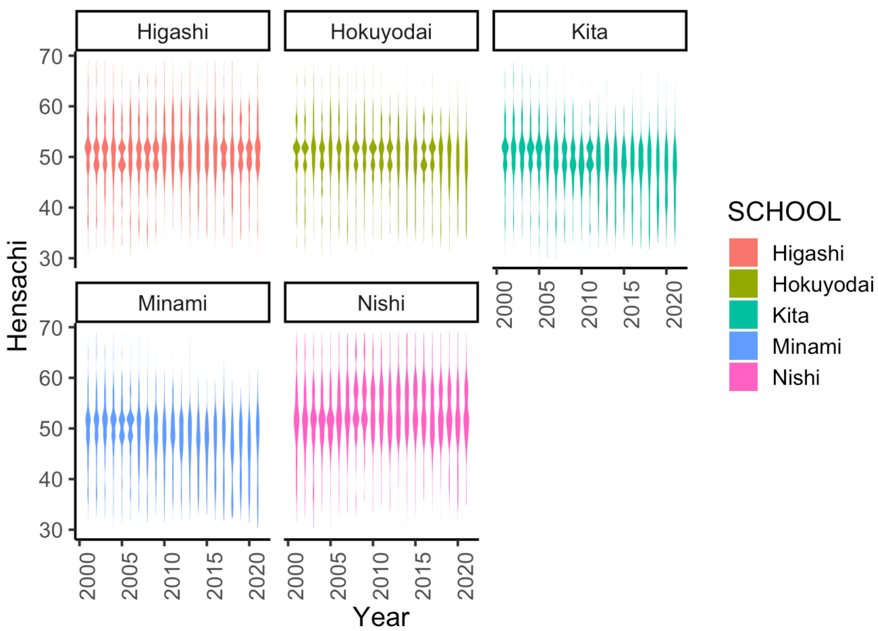

Figure 3.5 Distribution of Hensachi Scores of the Universities that Accept Graduates from Each School
Notes: University acceptance data are based on a survey by DAIGAKUTSUSHIN Corporation, and hensachi scores are based on reports from Kawaijuku.

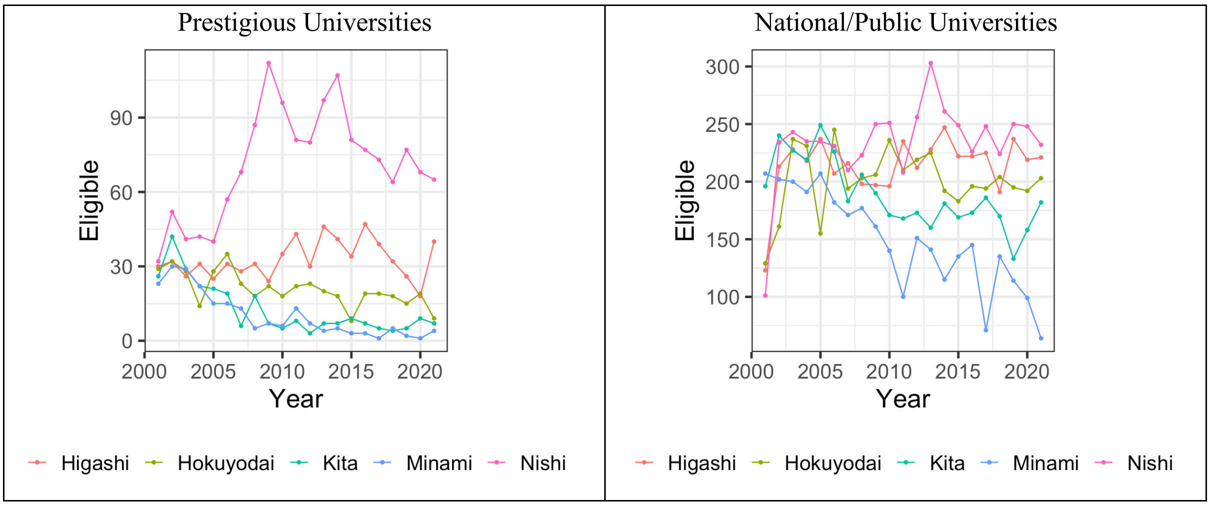

Figure 3.6 The Number of Graduates Accepted by Competitive Universities

Notes: Prestigious Universities consist of the former Imperial Universities (University of Tokyo, Kyoto University, Tohoku University, Kyushu University, Hokkaido University, Osaka University, Nagoya University), Hitotsubashi University, Tokyo Institute of Technology, Waseda University, and Keio University. University acceptance data are based on a survey by DAIGAKUTSUSHIN Corporation, and hensachi scores are based on reports from Kawaijuku.

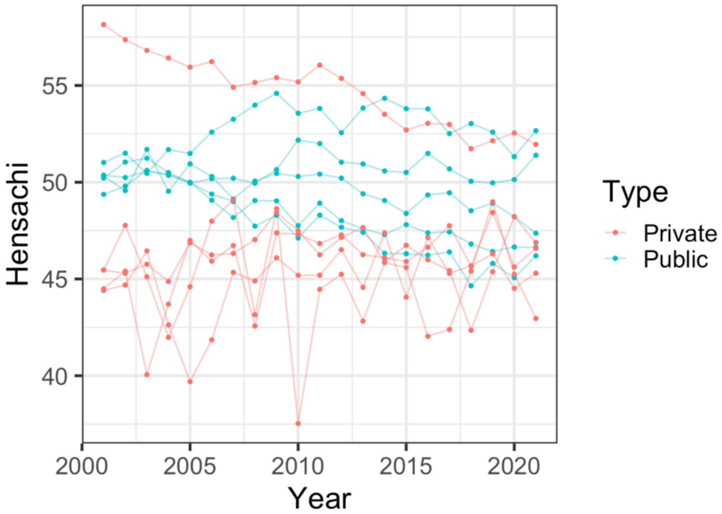

Figure 3.7 Comparison of Average University Hensachi Score with Private High Schools

Notes: Private High Schools consists of Kwassui, Kaisei, Nagasaki Nanzan, Junshin, and Seiun. University acceptance data are based on a survey by DAIGAKUTSUSHIN Corporation, and hensachi scores are based on reports from Kawaijuku.

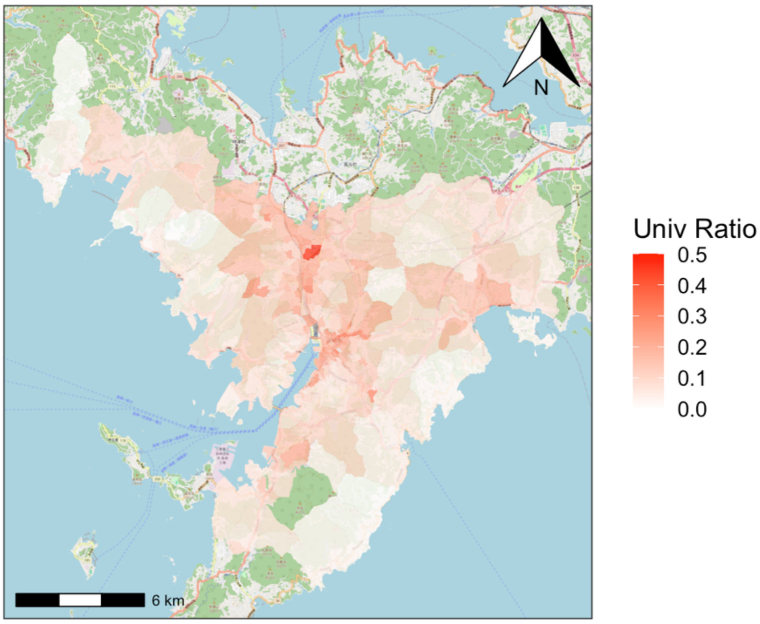

Figure 3.8 Geographical Distribution of the Share of University Graduates
Notes: OpenStreetMap contributes. The share is calculated by dividing the number of university graduates by that of all graduates for all blocks.

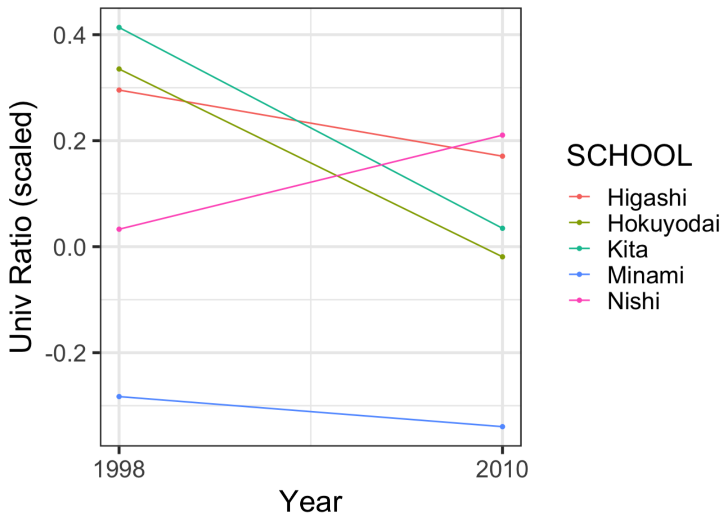

Figure 3.9 Weighted Average of Share of University Graduates
Notes: A weighting factor is the number of students in the first grade in each block. We connect the educational status data in 2000 to the commuting flow data in 1998. We standardize the weighted average for each year.

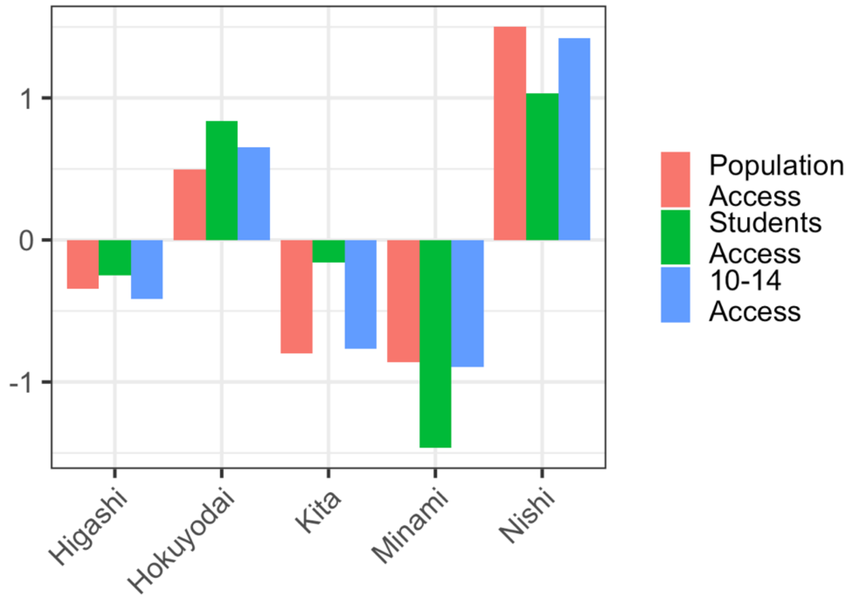

Figure 3.10 Accessibility Indices

Notes: Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. We take the logarithm for all indices and standardize them.

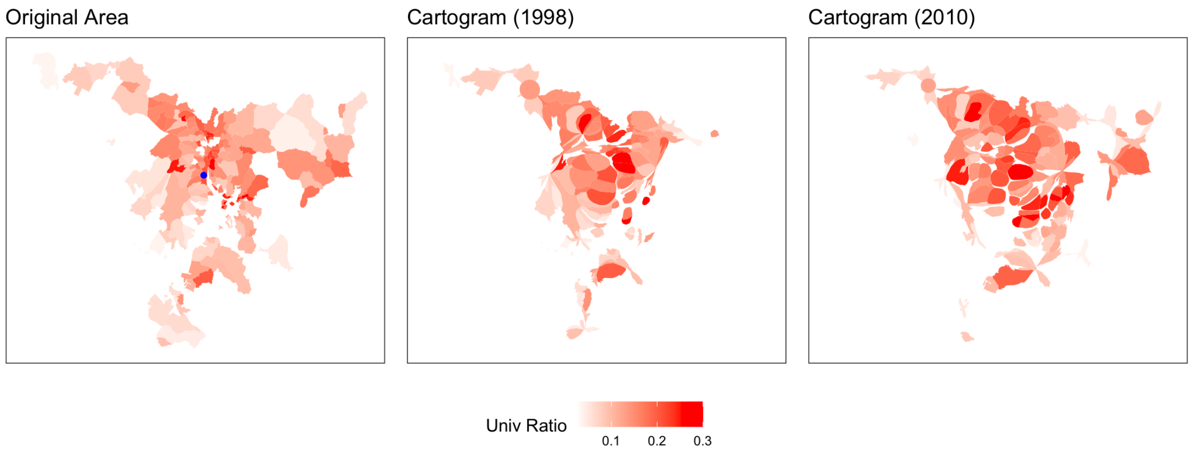

Figure 3.11 Geographical Distribution of the First-grade Students in Nishi High School

Notes: The left pane is a choropleth map regarding the share of university graduates for blocks having commuter(s) to Nishi High School in 1998 or 2010. A blue point represents the location of Nishi High School. The central panel presents a cartogram in which the geographic size of each block is modified to reflect the number of students commuting to Nishi High School in 1998. The right panel displays a cartogram regarding the number of commuters in 2010.

Table 5.1 Association between Commuting Time and Flows after the Reform

	(1)	(2)	(3)
	Baseline	Nagasaki	Nagasaki (Unchanged)
longTime x after	1.19*** (0.150)	1.20*** (0.150)	1.25*** (0.152)
ln(time) x after	2.26*** (0.199)	2.22*** (0.197)	2.24*** (0.198)
Observations	14,528	14,280	14,013

Notes: The estimation results of PPML estimation formulated in Equation 4.1 are reported. The dependent variable is the number of commuters in the first grade. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. *time* is commuting time between a block and a school. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE, SCHOOL-YEAR FE, and ADDRESS-SCHOOL FE. Column (1) shows the result using all observations. Column (2) shows the result using the observations in blocks in Nagasaki City. Column (3) shows the result using the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

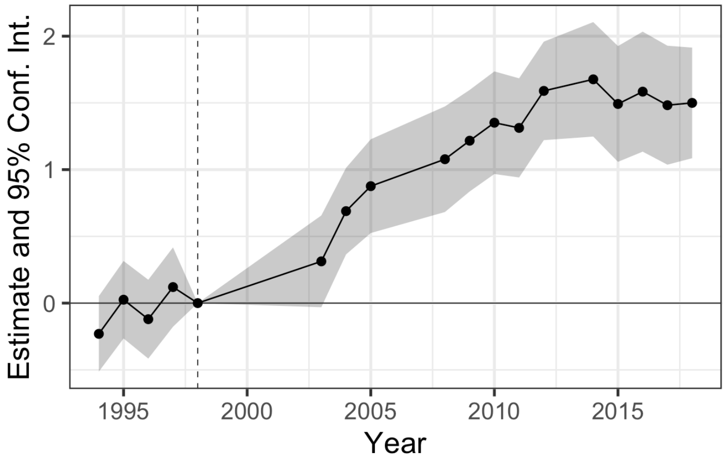

Figure 5.1 Association between Commuting Time and Flows after the Reform (Event Study)

Notes: The estimation result of PPML estimation formulated in Equation 4.2 is reported. The dependent variable is the number of commuters in the third grade. Each point represents a point estimate of the regression coefficient of the interaction term between *longTime* and year dummies. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE, SCHOOL-YEAR FE, and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

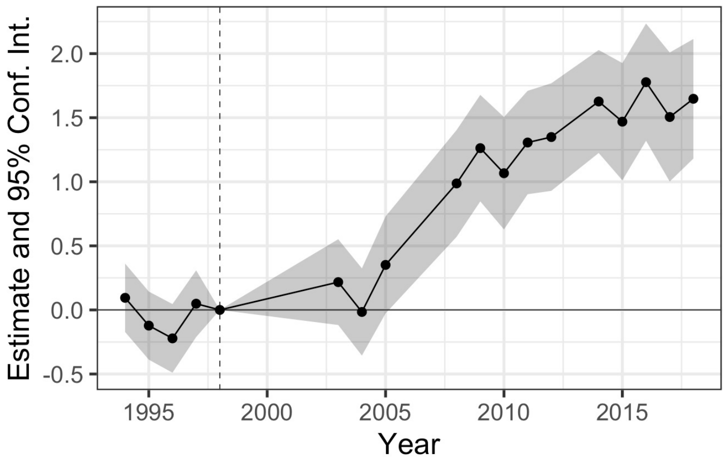

Figure 5.2 Association between Commuting Time and Flows after the Reform (Event Study, Third Grade)
Notes: The estimation result of PPML estimation formulated in Equation 4.2 is reported. The dependent variable is the number of commuters in the third grade. Each point represents a point estimate of the regression coefficient of the interaction term between *longTime* and year dummies. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE, SCHOOL-YEAR FE, and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

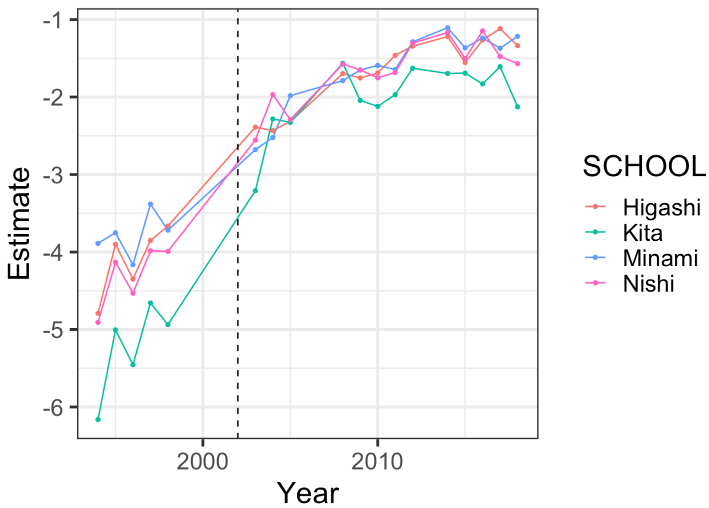

Figure 5.3 Association between Commuting Time and Flows after the Reform by School
Notes: The estimation result of PPML estimation formulated in Equation 4.3 is reported. The dependent variable is the number of commuters in the first grade. Each point represents a point estimate of the regression coefficient of the interaction term between ln(*time*), year dummies, and school dummies. *time* is commuting time between a block and a school. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Table 5.2 Association between Accessibility Indices and Commuting Flows after the Reform

	(1)	(2)	(3)
	Highest 25%	Highest 25%	Highest 25%
Population Access x after	0.390*** (0.102)		
Students Access x after		0.404*** (0.104)	
10-14 Population Access x after			0.395*** (0.102)
Observations	3,807	3,807	3,807
	(4)	(5)	(6)
	Lowest 25%	Lowest 25%	Lowest 25%
Population Access x after	−0.278** (0.119)		
Students Access x after		−0.257** (0.116)	
10-14 Population Access x after			−0.275** (0.118)
Observations	2,502	2,502	2,502

Notes: The estimation results of PPML estimation formulated in Equation 4.4 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

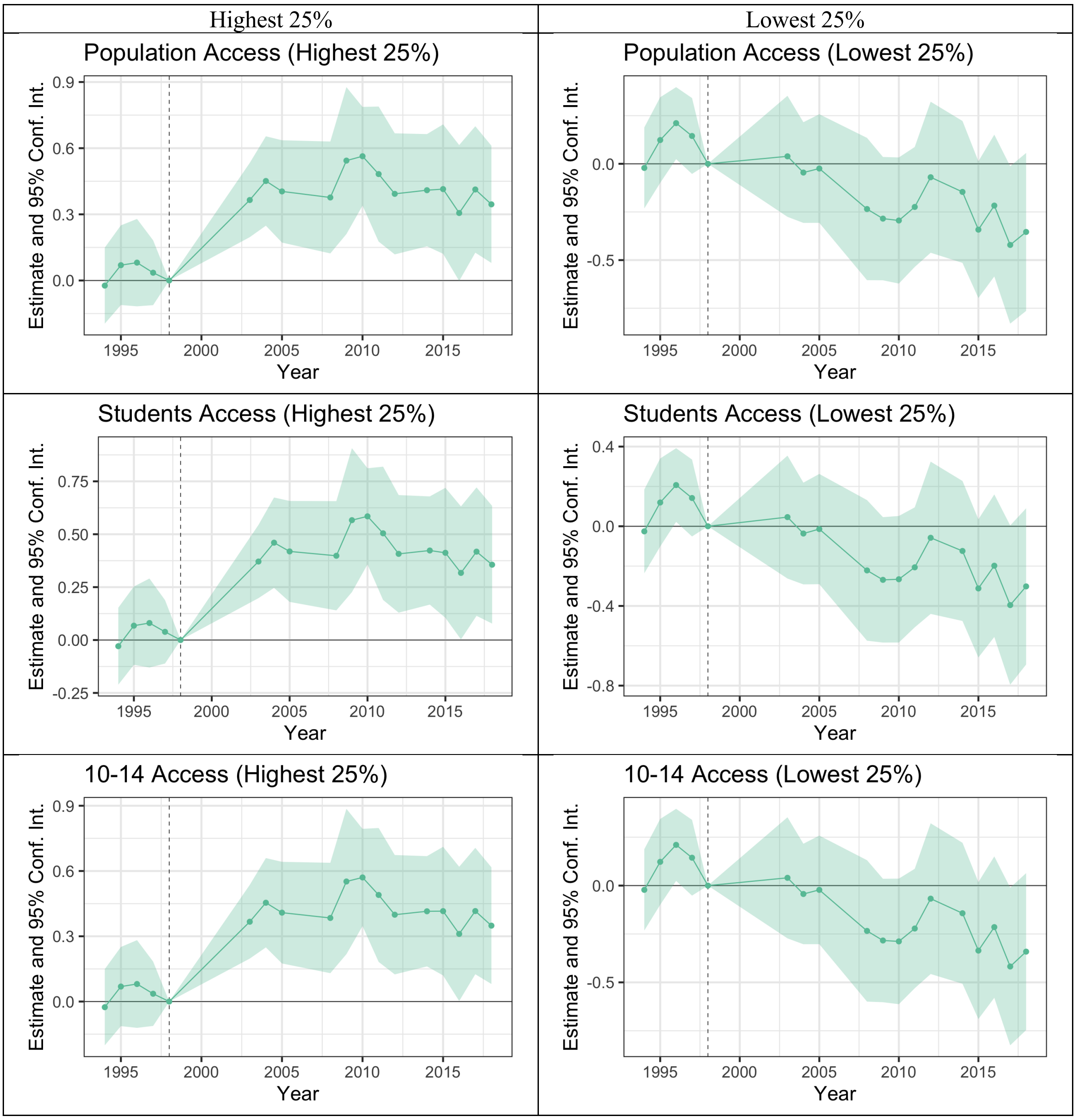

Figure 5.4 Association between Accessibility Indices and Commuting Flows after the Reform (Event Study)

Notes: The estimation results of PPML estimation formulated in Equation 4.5 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. Each point represents a point estimate of the regression coefficient of the interaction term between each access index and year dummies. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Table 5.3 Association between Accessibility Indices and Commuting Flows after the Reform by Commuting Time

	(1)	(2)	(3)
	Highest 25%	Highest 25%	Highest 25%
longTime x after	0.337* (0.179)	0.357** (0.178)	0.343* (0.178)
Population Access x longTime x after	0.484** (0.241)		
Students Access x longTime x after		0.493** (0.240)	
10-14 Population Access x longTime x after			0.491** (0.240)
Observations	3,807	3,807	3,807
	(4)	(5)	(6)
	Lowest 25%	Lowest 25%	Lowest 25%
longTime x after	2.43*** (0.348)	2.41*** (0.348)	2.43*** (0.348)
Population Access x longTime x after	−0.408*** (0.136)		
Students Access x longTime x after		−0.375*** (0.131)	
10-14 Population Access x longTime x after			−0.401*** (0.135)
Observations	2,502	2,502	2,502

Notes: The estimation results of PPML estimation formulated in Equation 4.6 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Table 6.1 Estimation Result of Preference Parameters

	(1)
ϵ	14.671*** (1.152)
β	2.166*** (0.163)
$\gamma = \delta\epsilon$	12.089*** (1.986)
NPLL	−78.699
Observations	888

Notes: The estimation results of PPML estimation formulated in Equation 5.11. The dependent variable is the number of commuters in the second grade in 2008. Statistically significant at ***1%, **5%, and *10% level. The robust standard errors are in parentheses.

Table 6.2 Values of Average Utilities, Location Advantages, and Hensachi Scores

	Higashi	Kita	Minami	Nishi
Average Utility A_n	1.107	1.041	0.93	0.947
Location Advantage B_n	55.247	55.044	53.063	57.123
Hensachi Score E_n	63	62	59	67

Notes: The values of A_n and B_n are obtained from the estimation results of PPML estimation formulated in Equation 5.11.

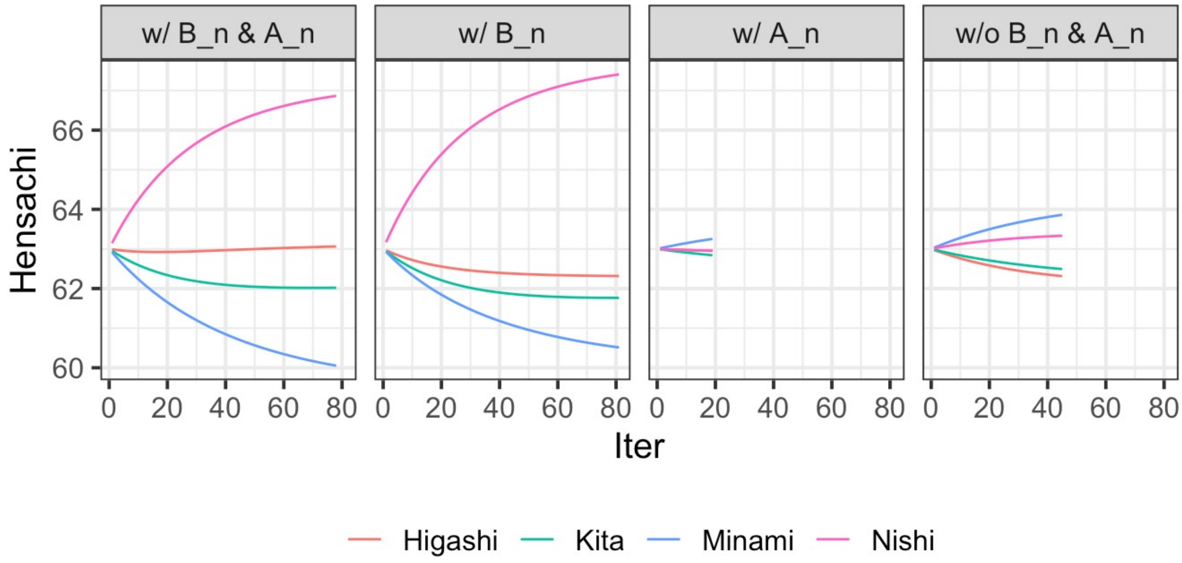

Figure 6.3 Equilibrium Hensachi Scores (Identical Initial Value)

Notes: The horizontal axis represents the number of iterations in equilibrium calculation. We set the identical initial hensachi score $E_{n(0)} = 63$ for all schools. "w/B_n & A_n" considers both location advantage B_n and average utility A_n, "w/B_n" considers only location advantage B_n, "w/A_n" considers only average utility A_n, and "w/o B_n & A_n" ignores both location advantage B_n and average utility A_n, respectively.

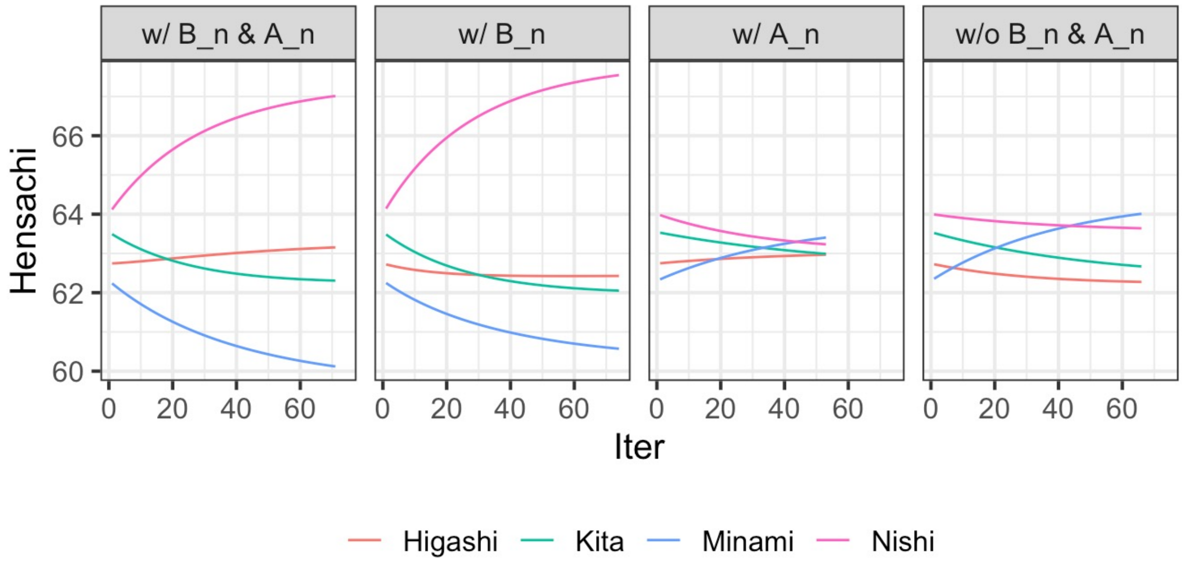

Figure 6.4 Equilibrium Hensachi Scores (Initial Value Proportional to Average University Hensachi)

Notes: The horizontal axis represents the number of iterations in equilibrium calculation. We set the value adding 12.5 to the average hensachi score of the universities that accept graduates from each school in 2002 as an initial hensachi score $E_{n(0)}$. "w/B_n & A_n" considers both location advantage B_n and average utility A_n, "w/B_n" considers only location advantage B_n, "w/A_n" considers only average utility A_n, and "w/o B_n & A_n" ignores both location advantage B_n and average utility A_n, respectively.

Table 6.3 Comparison of Welfare and Other Variables with/without Location Advantage by School

	Higashi	Kita	Minami	Nishi
Per Capita Welfare PW_n	1.049	1.005	0.645	1.444
Self-motivated Study Hours SE_{in}	0.991	0.979	0.956	1.079
Average Commuting Time CT_{in}	1.017	1.042	0.995	0.969
Share of Long Commuters	1.015	1.051	1.005	0.956

Notes: The long commuters are defined as students who spend more than an hour commuting. We use the equilibrium variables obtained from the "w/B_n" condition as a case with freedom of school choice where we consider differences in location environment B_n and educational attainment E_n across schools.

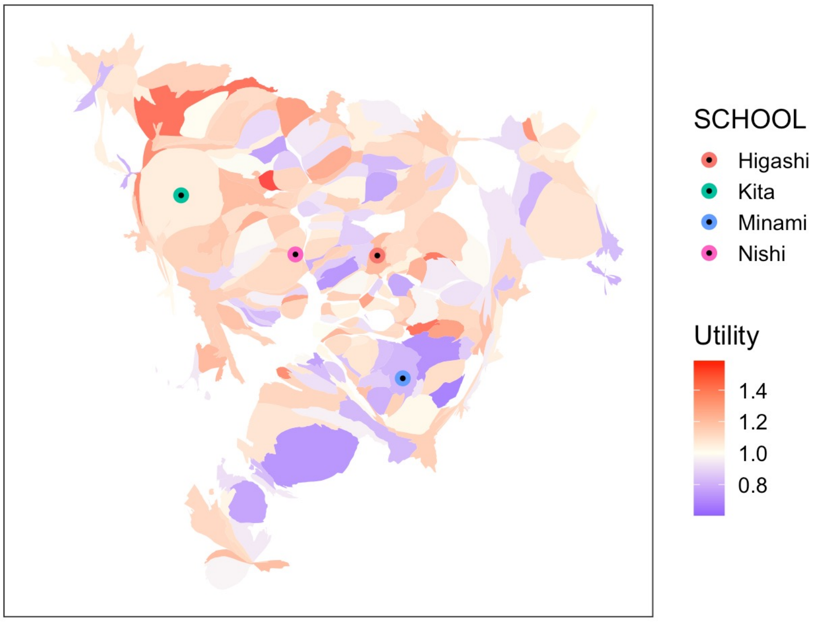

Figure 6.5 Welfare Ratio by Block

Notes: The area of each block is expanded proportionally to the number of students. We use the equilibrium variables obtained from the "w/B_n" condition as a case with freedom of school choice where we consider differences in location environment B_n and educational attainment E_n across schools.

Appendix A: Comparison between the Shortest Time Path and the Shortest Road Network Distance

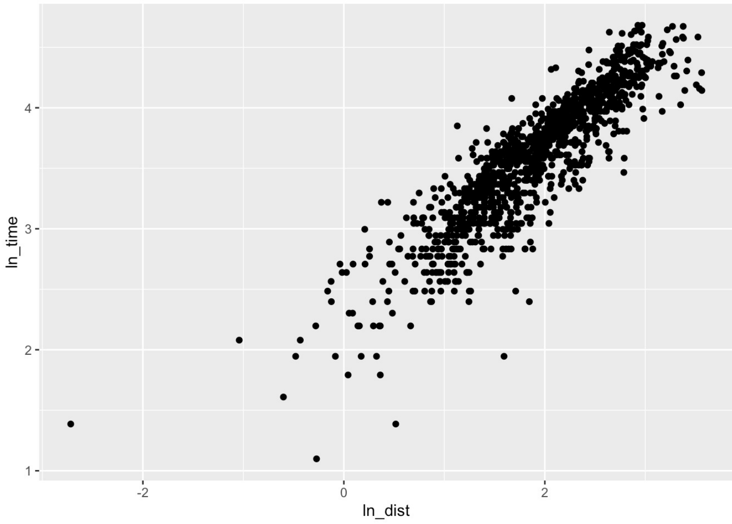

Figure A.1: Shortest Time Path and Shortest Road Network Distance

Notes: The vertical axis is the logarithm of the shortest time path obtained from Google Maps, and the horizontal axis is the logarithm of the shortest road network distance obtained from the Open Source Routing Machine (OSRM) powered by OpenStreetMap. The traffic mode in OSRM is car.

Appendix B: Estimation Results Using Different Distance Decay Parameters

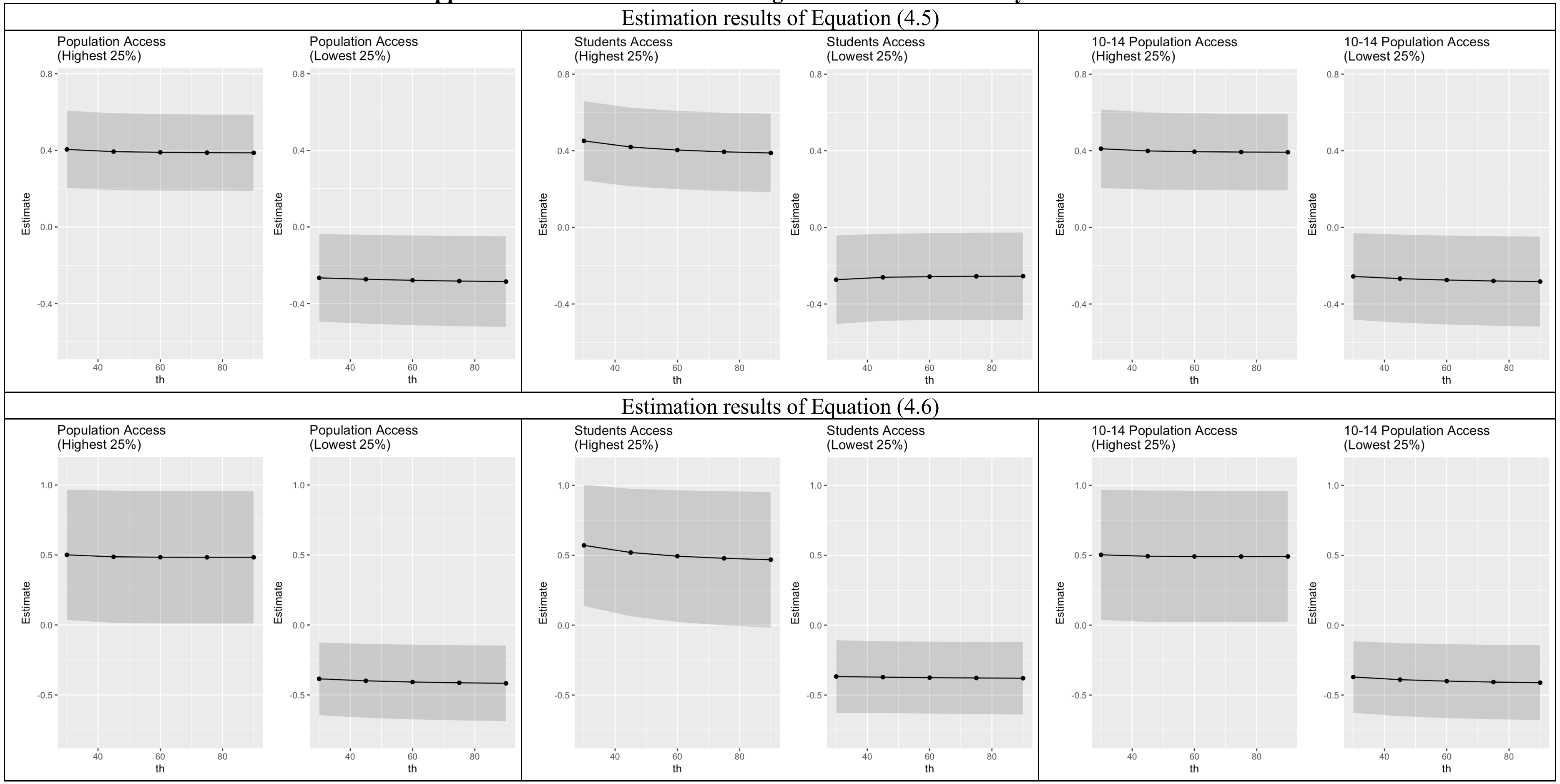

Figure B.1: Estimation Results regarding Treatment Variables Depending on Distance Decay Parameters

Notes: The estimation results of PPML estimation formulated in Equation 4.5 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. Each point represents a point estimate of the regression coefficient of the interaction term between each access index and year dummies. The ribbon for each point represents the 95% confidence interval for each point estimate corresponding to each distance decay parameter. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Appendix C: Estimation Results Including Observations Regarding Hokuyodai

Table C.1 Association between Commuting Time and Flows after the Reform

	(1)	(2)	(3)
	Baseline	Nagasaki	Nagasaki (Unchanged)
longTime x after	1.22*** (0.153)	1.09*** (0.131)	1.20*** (0.132)
ln(time) x after	2.00*** (0.169)	2.10*** (0.169)	2.12*** (0.169)
Observations	16,784	16,462	16,143

Notes: The estimation results of PPML estimation formulated in Equation 4.1 are reported. The dependent variable is the number of commuters in the first grade. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. *time* is commuting time between a block and a school. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and SCHOOL-YEAR FE. Column (1) shows the result using all observations. Column (2) shows the result using the observations in blocks in Nagasaki City. Column (3) shows the result using the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

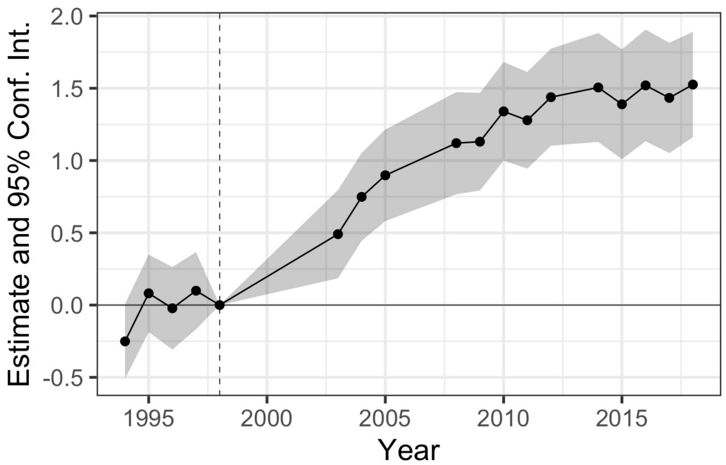

Figure C.1 Association between Commuting Time and Flows after the Reform (Event Study)

Notes: The estimation result of PPML estimation formulated in Equation 4.2 is reported. The dependent variable is the number of commuters in the third grade. Each point represents a point estimate of the regression coefficient of the interaction term between *longTime* and year dummies. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE, SCHOOL-YEAR FE, and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

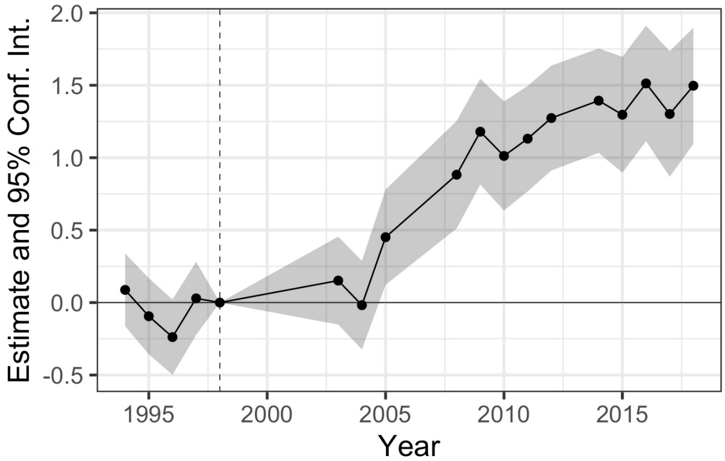

Figure C.2 Association between Commuting Time and Flows after the Reform (Event Study, Third Grade)
Notes: The estimation result of PPML estimation formulated in Equation 4.2 is reported. The dependent variable is the number of commuters in the third grade. Each point represents a point estimate of the regression coefficient of the interaction term between *longTime* and year dummies. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE, SCHOOL-YEAR FE, and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

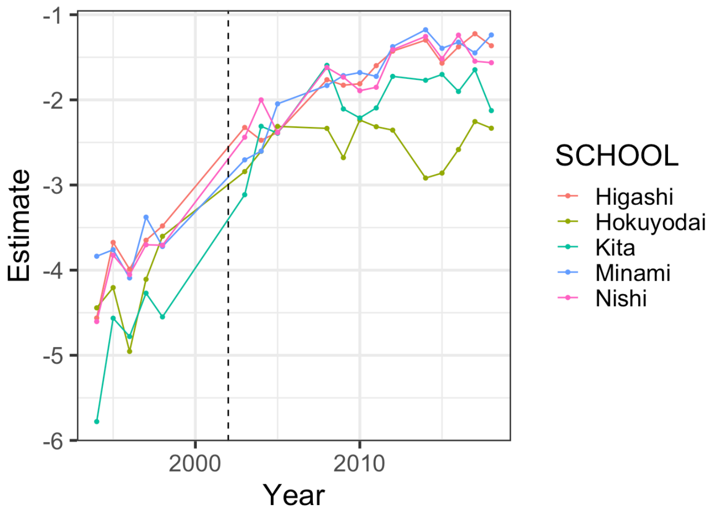

Figure C.3 Association between Commuting Time and Flows after the Reform by School
Notes: The estimation result of PPML estimation formulated in Equation 4.3 is reported. The dependent variable is the number of commuters in the first grade. Each point represents a point estimate of the regression coefficient of the interaction term between ln(*time*), year dummies, and school dummies. *time* is commuting time between a block and a school. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Table C.2 Association between Accessibility Indices and Commuting Flows after the Reform

	(1)	(2)	(3)
	Highest 25%	Highest 25%	Highest 25%
Population Access x after	0.372*** (0.090)		
Students Access x after		0.282** (0.133)	
10-14 Population Access x after			0.393*** (0.092)
Observations	4,467	4,467	4,467
	(4)	(5)	(6)
	Lowest 25%	Lowest 25%	Lowest 25%
Population Access x after	−0.246** (0.105)		
Students Access x after		−0.066 (0.109)	
10-14 Population Access x after			−0.243** (0.107)
Observations	2,735	2,735	2,735

Notes: The estimation results of PPML estimation formulated in Equation 4.4 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

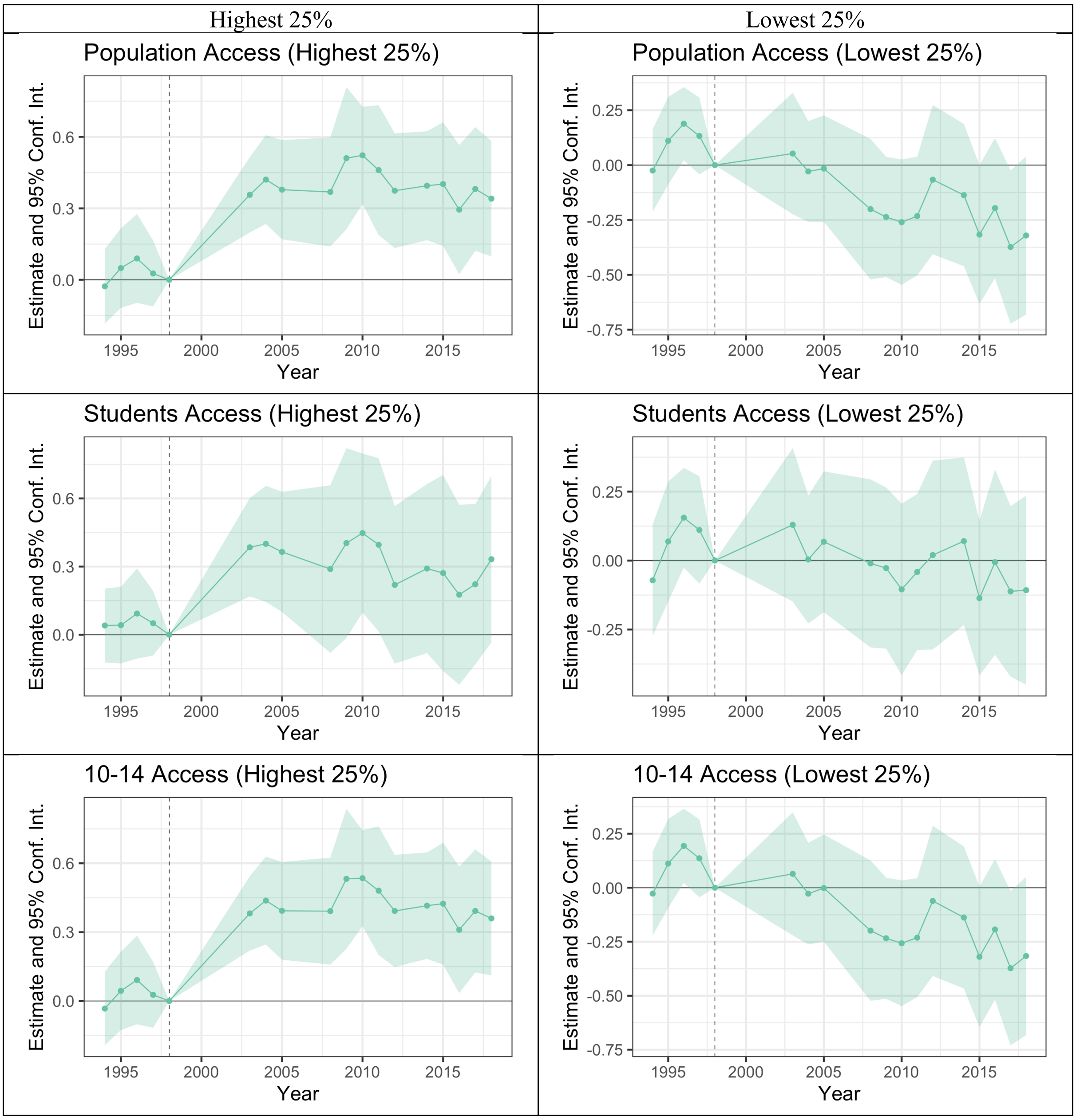

Figure C.4 Association between Accessibility Indices and Commuting Flows after the Reform (Event Study)

Notes: The estimation results of PPML estimation formulated in Equation 4.5 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. Each point represents a point estimate of the regression coefficient of the interaction term between each access index and year dummies. The ribbon for each point represents the 95% confidence interval for each point estimate. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Table C.3 Association between Accessibility Indices and Commuting Flows after the Reform by Commuting Time

	(1)	(2)	(3)
	Highest 25%	Highest 25%	Highest 25%
longTime x after	0.270* (0.158)	0.263 (0.172)	0.292* (0.160)
Population Access x longTime x after	0.467** (0.211)		
Students Access x longTime x after		0.170 (0.334)	
10-14 Population Access x longTime x after			0.489** (0.215)
Observations	4,467	4,467	4,467
	(4)	(5)	(6)
	Lowest 25%	Lowest 25%	Lowest 25%
longTime x after	2.38*** (0.332)	2.29*** (0.334)	2.36*** (0.332)
Population Access x longTime x after	−0.367*** (0.120)		
Students Access x longTime x after		−0.183 (0.125)	
10-14 Population Access x longTime x after			−0.364*** (0.121)
Observations	2,735	2,735	2,735

Notes: The estimation results of PPML estimation formulated in Equation 4.6 for commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. *longTime* takes a value of 1 if commuting time between a block and a school exceeds 30 minutes and 0, otherwise. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.

Appendix D: Change in Composition of Students (Controlling for Prewar Middle School Dummy)

Table D.1 Association between Accessibility Indices and Commuting Flows after the Reform

	(1)	(2)	(3)
	Highest 25%	Highest 25%	Highest 25%
Population Access x after	0.713*** (0.155)		
Students Access x after		0.657*** (0.147)	
10-14 Population Access x after			0.695*** (0.152)
Trad x after	−0.766*** (0.286)	−0.631** (0.268)	−0.723*** (0.280)
Observations	3,807	3,807	3,807
	(4)	(5)	(6)
	Lowest 25%	Lowest 25%	Lowest 25%
Population Access x after	−0.673*** (0.255)		
Students Access x after		−0.563** (0.237)	
10-14 Population Access x after			−0.641*** (0.249)
Trad x after	0.854* (0.483)	0.691 (0.463)	0.804* (0.474)
Observations	2,502	2,502	2,502

Notes: We estimate PPML regression formulated in Equation 4.4 by introducing the interaction term between *Trad*, a dummy variable taking a value of 1 if a school originated from the prewar middle school, and *after*, a dummy variable taking a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. We analyze commuting flows from the highest 25% blocks and those from the lowest 25% blocks in terms of the share of university graduates in each block. The dependent variable is the number of commuters in the first grade. Population Access is defined in Equation 3.1, Students Access is defined in Equation 3.2, and 10-14 Population Access is defined in Equation 3.3, respectively. *after* takes a value of 1 after the reform of the school zone system in 2002 and 0, otherwise. Statistically significant at ***1%, **5%, and *10% level. Standard errors are clustered at ADDRESS-SCHOOL level. All estimation results include ADDRESS-YEAR FE and ADDRESS-SCHOOL FE. The data consists of the observations in blocks in Nagasaki City excluding those integrated into Nagasaki after 2005.