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Abstract

The difference-in-differences (*DID*) approach that identifies the capitalization of amenities through changes in housing prices has been widely used in the literature of hedonic estimation in the past decade. However, concerns have been raised about how to interpret the estimated capitalization effects as changes in welfare. Following an approach developed by Banzhaf (2021), we estimate the capitalization of school redistricting in a generalized *DID* framework that incorporates general equilibrium effects. When comparing estimates from our generalized *DID* model to the conventional *DID* model, we find significant differences in both the capitalization effects and welfare changes associated with the school redistricting.

JEL-Codes: H400, I200, R200.

Keywords: difference-in-differences, hedonics, welfare, school quality.

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1 Introduction

Hedonic models, specifically those focused on the determinants of housing prices, have been used extensively to elicit estimates of the value of goods and services in the absence of explicit prices for these goods. Within this literature, there has been a growing trend of implementing difference-in-differences (*DID*) models to value quality-differentiated goods, such as air quality (Chay and Greenstone, 2005), water quality (Muehlenbachs, Spiller, and Timmins, 2015), brownfield (Ma, 2019), flood risk (Bakkensen, Ding, and Ma, 2019), and school quality (Collins and Kaplan, 2022). However, in contrast to the framework for hedonics outlined in Rosen (1974), the *DID* estimand that identifies the changes in housing prices associated with changes in amenities, the "capitalization effect," is not the same as the marginal willingness to pay (*MWTP*) (Klaiber and Smith, 2013; Kuminoff and Pope, 2014). These are not the same because the changes in prices mix information from two cross-sectional hedonic price functions. This may not become an issue if the hedonic price function is stable over time and changes in house attributes and shocks to amenities are small or if a small share of the housing market is "treated."[1] However, if the shocks or the treatment group are large, general equilibrium spillovers are likely to exist and the stable unit treatment assumption (SUTVA) is violated – there is a shift of the hedonic price functions that results in *DID* estimates in which capitalization does not equal *MWTP*. This means we cannot interpret coefficient estimates of the *DID* as welfare measures.

In this paper, we embrace the challenges around estimating both the capitalization and welfare effects in *DID* hedonics, focusing on recent school redistricting reform in Fayette County, Kentucky that changed school boundaries and opened a new high school. In addition to being a example of a discrete revision in local policy well-suited for *DID* as seen in studies including Ries and Somerville (2010); Collins and Kaplan (2022), changes in school catchment areas (boundaries) and the opening of new schools occur frequently, with over 1,000 schools changing boundaries and 258 new schools opening in 2020-21 alone. These changes in schooling can mean significant

[1] Koster and van Ommeren (2022) examine the neighborhood changes in Netherlands and argue the percentage of treated houses is only 4-5%, which is less likely to bias the results.

changes in school quality, housing prices, and welfare for households directly affected by the changes – and, possibly other households in the same housing market. Importantly for this study, these boundary changes often affect a large share of the households in the housing market – in the application here, the revision of high school catchment areas and the opening of a new high school in Fayette County (Lexington), Kentucky over twenty percent of all households in the county were redistricted to a different high school with forty percent of households in one high school redistricted to other high schools.

To understand the implications of these general equilibrium effects on both estimates of capitalization and welfare, we engage in two alternative exercises. First, we construct a simple general equilibrium model of household location choices when districts differ in their provision of a public good (educational quality). Our analysis reveals that the assumptions underlying a *DID* hedonic model—particularly concerning property values in districts that do not change their policies (the comparison group)—are not always stable. From this model we also generate a sufficient statistic that we operationalize to obtain our welfare estimates that arise due to redistricting. Although our policy involves altering the boundaries (geographical area) of school catchment zones, which differs from the policy examined by Banzhaf (2020) — focused on changes in public services within a single jurisdiction — our sufficient statistic demonstrates that aggregate, general equilibrium welfare effects can be calculated by summing the changes in house values within the area directly affected by the policy.

To obtain welfare estimates of these boundary changes and the new high school we follow the methodology proposed by Banzhaf (2021) to control for changes in house attributes and amenities whenever possible. We employ a discrete, non-parametric approach to measure a school quality. Specifically, we utilize school dummies both before and after the school redistricting to capture the general equilibrium effects, which encompass a bundle of amenities that home buyers value in a school zone. We include a set of interactions between time, house attributes, and school characteristics to account for potential endogenous changes in these variables. The differences between two school dummies post-redistricting would imply the capitalization effect associated with switching schools while considering potential general equilibrium effect. We observe significant increases in property values in areas that have been rezoned from lower-performing schools to better-performing ones, with the magnitude of these changes aligning with school rankings based on test scores. Conversely, we find a similar but opposite effect for homes rezoned to less-performing schools. To calculate the welfare effects, we multiply the number of homes, average home values, and the capitalization effect for each school-rezoning pair. These results constitute our baseline for assessing the general equilibrium welfare effects.

In addition, we also estimate a standard *DID* model without time-varying coefficients and compare the resulting estimates to those obtained using our non-parametric approach. We observe substantial differences in the estimates of capitalization and their associated impacts on welfare, particularly concerning the new high school.

In contrast to our non-parametric approach to characterize school quality (school dummy variables), numerous hedonic studies of schooling have measured quality in terms of test scores, school report cards, or racial composition (Figlio and Lucas, 2004; Clapp, Nanda, and Ross, 2008; Ries and Somerville, 2010). We, too, follow this approach using a mean ACT score as our measure of school quality. Analogous to our non-parametric approach, we allow the coefficient on ACT as well as coefficients on other house attributes to vary between the pre- and post-redistricting periods. Subsequently, we calculate changes in welfare associated with redistricting across schools with varying ACT scores. Our findings show significant discrepancies in the welfare effects compared to our model using school dummy variables. In an effort to reconcile these differences, we introduce specifications that incorporate additional school characteristics, including student demographics, graduation rates, student-to-teacher ratios, and behavioral events — factors frequently used in other studies to assess school quality (Downes and Zabel, 2002). After incorporating these factors, our welfare estimates align more closely with those derived using school dummy variables.

We see three important contributions. First, we contribute to the literature addressing issues related to using of difference-in-difference models in hedonic estimation by showing that failure to account for the general equilibrium effects of large policy changes will result in inaccurate measures of capitalization. Second, complementing the discussions found in Klaiber and Smith (2013), Kuminoff and Pope (2014), and Banzhaf (2021), we construct a simple general equilibrium model and use it to demonstrate how and when imprecise welfare evaluations are obtained when using conventional *DID* methods. Finally, our application on education quality is an important local policy and significant expenditure that has been the focus of a voluminous literature. Specific to the literature that employs hedonic estimation to evaluate school quality, we uncover substantial disparities in welfare estimates when comparing our non-parametric approach to quantifying school quality with methods relying on test scores.

In the next section, we provide a review of related literature and offer some key distinctions between the approaches in these studies and the approach we take. Following that, in Section 3, we offer background information on school redistricting in Fayette County, Kentucky. We provide a discussion of the issues that arise in estimating *DID* hedonic models as well as a simple example of when they occur in Section 4. Section 5 summarizes our data on housing and schooling and discusses our empirical strategy. We present our results of estimation and discussion of welfare estimates in Section 6. Section 7 concludes.

2 Related Literature

Difference-in-Differences Hedonics Pioneered by Black (1999), a large strand of literature has utilized boundary discontinuities to study the capitalization of school quality (Kane, Riegg, and Staiger, 2006; Dhar and Ross, 2012). One issue that arises in the estimation of boundary fixed effect models is the sorting of home buyers across district boundaries (Bayer, Ferreira, and McMillan, 2007). More recently, another strand of literature that utilizes exogenous changes in educational quality to identify differences in property values between those areas subject to the reforms and those areas that are not to alleviate the concerns of residential sorting has emerged. Bogart and Cromwell (2000) study the impact of redistricting schools on house values in Ohio and find that school closings resulted in dramatic decreases in house values. Ries and Somerville (2010) use a

DID hedonic with repeated sales and find significant effects of the redistricting for top-quartile of homes. In a recent work, Collins and Kaplan (2022) look into school redistricting in Shelby County, Tennessee and they find that homes rezoned to higher-quality schools has a 2-3% appreciation in sale prices under one standard deviation increase in test scores.

Even though *DID* hedonics have distinct advantages in overcoming several empirical challenges in cross-sectional hedonic estimation and boundary fixed effect models, two issues remain concerns about when interpreting the estimated effects of redistricting. First, the timing and the scope of redistricting matters when estimating capitalization.[2] If redistricting is a lengthy process, with possibly years between its announcement and implementation, a simple two-period *DID* hedonic estimation may underestimate the true effect (Ding et al., 2022). [3] Second, while small adjustments along the existing school boundaries may not affect how homes capitalize school quality (Koster and van Ommeren, 2022), large changes in school catchment areas may affect the stable unit treatment assumption (SUTVA) as highlighted in Banzhaf (2021). If redistricting results in a large percent change of homes being assigned to different schools, the failure to account for shifts in hedonic models and spillover effects from redistricted areas to original areas will introduce bias into the results, causing the estimates from the hedonic model to deviate from the *MWTP*. Second, it is difficult to make welfare interpretations through quasi-experimental methods. *DID* estimations are informative to understand the average treatment effect, but it is unclear about the welfare benefits from the *DID* estimand. Banzhaf (2021) shows the *DID* estimates represent a lower bound on the total welfare effects of the policy for all households and researchers should account for non-marginal changes in amenities and general equilibrium price effects, mobility responses, and endogenous responses to house attributes. We provide a more complete discussion of Banzhaf's explanation of the shortcomings of traditional *DID* in hedonics in Section 4.2 and follow his application in changes in toxic air emissions to examine changes in school quality in this paper.

[2] Bishop and Murphy (2019) discuss forward-looking hedonic models.

[3] In the case of the redistricting in Fayette County considered in both (Ding et al., 2022) and here, the interval between the announcement of redistricting and its implementation was over three years.

What School Characteristics Affect House Values In contrast to estimating the value of a bundle of services and attributes of public schools using discrete changes (Ding et al., 2022), many studies relate school quality to specific school characteristics. One of the attributes receive a great deal of attention is racial and ethnic composition. Bogart and Cromwell (2000) includes percent of nonwhite students in school as a control variable. Boustan (2012) investigates desegregation of public schools and find housing prices fell by 6 percent relative to neighboring suburbs.

Test scores are another widely used measure to represent school quality. Figlio and Lucas (2004) utilize school report cards that provide grades to represent the quality of schools. In a recent paper, Beracha and Hardin (2018) also use school grade to study the impact of school quality on the premium of renters and owners. They find that the price premium for school quality for owners exceeds the premium for renters. Liu and Smith (2023) uses Criterion-Referenced Competency Test (CRCT) scores in Georgia to construct both normalized test scores and percent of students did not meet the standard to represent school quality. Clapp, Nanda, and Ross (2008) shows that both test scores and racial composition affect property values. Gibbons, Machin, and Silva (2013) use English and Math scores to represent school quality and find one standard deviation increases house prices by 3% utilizing boundary discontinuities.

Teacher quality also affects how parents value schools. Jacob and Lefgren (2007) examines the outputs that parents value education using information on parent requests for individual teachers. They find that parents strongly prefer primary school teachers who are good at promoting student satisfaction while they place relatively less value on a teacher's ability to raise standardized test scores.

While not relevant to our examination of educational policy in Fayette County, Kentucky, school choice policies also affect property values.[4] Reback (2005) studies how open enrollment policies affect capitalization in Minnesota by looking at the percentage of students transferring between school districts. Related to the impact of school choice, Brunner, Imazeki, and Ross (2010) find universal vouchers affect racial and ethnic segregation.

[4]See Brunner (2014) for a summary of school quality and school choice.

3 Background of Redistricting in Fayette County

We utilize a recent school redistricting happened in Fayette County, Kentucky to examine the welfare effects of changes in school catchment areas (zones) on the local housing market. Fayette County has only one school district, Fayette County Public Schools that administrates school assignment policies. Fayette County has no open enrollment program nor any charter schools meaning that most students attend schools that are assigned based on the residence location. It does, however, have magnet programs that allow a limited number of students to attend schools other than the school to which they are zoned.[5] Prior to 2014, there had been an average increase in enrollment of 600 to 750 students a year for the existing five high schools with Figure A1 plotting the annual enrollment for each high school. From the figure, the upward trend of increasing enrollment in most of the public high schools prior to 2016 is evident. Given these enrollment increases, a redistricting process and planning for a new high school began in late 2013. The year-long work of determining new school boundaries that would be adopted in August 2017 began in spring 2014 with a committee of members from the county, including parents, teachers, Fayette County Public Schools administrators, two school board members, a district Equity Council representative, a city planning official, a home builder and other community stakeholders. The committee met three times to review some initial demographic information and community growth trends. In April 14, 2015, the committee presented a plan to the Fayette County Board of Education with a summary of its draft proposals. The school board then met with the redistricting committee on April 21st for a joint work session. At their June 3, 2015 meeting, The Fayette County Board of Education approved the redistricting plan. On August 16, 2017, the new high school was opened and the new zones were in effect. We summarize the timeline of the rezoning process in Table 1. As we show in Ding et al. (2022), the timing of the approval and implementation of the redistricting plan had a significant impact on when capitalization occurred. As we have addressed these timing issues in Ding et al. (2022), in this study we restrict our sample

[5] Only extreme cases are permitted for out-of-area requests such as family moving out of the current school catchment area in the middle of a school year.

to property sales that occurred prior to the announcement of redistricting (April 29, 2014) and that followed the implementation of the plan (August 2017).

Figure 1 presents the map of the school catchment areas or hence force, the school "zones" before and the after the redistricting. Panel 1a shows the original school zones and Panel 1b shows the proposed school zones. Under the new plan, the southeast part of the original Bryan Station High School was redistricted to the proposed school, Frederick Douglass.[6] There are small geographical changes in the other four high-school zones. Figure 2 shows these changes in school boundaries where the dashed lines represent the old catchment boundaries (pre-2017) and red solid lines represent changes (post-2017) in the catchment boundaries from the redistricting. Based on these changes, we are able to determine the school catchment area for each house sold before and after the redistricting process. Appendix Table B1 reports the share of redistricted homes in each original high school zone using 2013 housing stock information from Fayette County assessment. Almost forty percent of Bryan Station homes were rezoned to a different school. Other high schools are also affected with vary degrees of homes affected by this change.

4 Hedonics in General Equilibrium

In this section we first summarize the discussion from Banzhaf (2021) on *DID* in hedonic models when the stable unit treatment assumption (SUVTA) is violated, that is, when there are general equilibrium effects from policy changes in a single jurisdiction. Specifically, changes in policies in one jurisdiction or, in our case, school zone, affect housing prices in other zones, in which there were no changes in policies. These change in housing prices are a violation of SUTVA. Following our summary Banzhaf's discussion, we present a simple model that provides an example of when and how estimates of the impact of policy changes on housing prices cannot be interpreted as marginal willingness to pay (*MWTP*).

[6]The name for the proposed high school was not announced until November 10, 2016 and approved by the Fayette County School Board until November 21, 2016 over a year after the approval and districting for the proposed high school see Spears, Valarie Honeycutt (November 10, 2016) "Frederick Douglass recommended as name for new Lexington high school, *The Lexington Herald Leader, https://www.kentucky.com/news/local/education/article114008613.html.*

4.1 Interpreting Difference-in-Differences Hedonics

Greenstone (2017), among others, notes there are a number of advantages of employing quasi-experimental techniques such as regression discontinuity, border fixed-effects, or as done here, difference-in-difference estimations with hedonics. However, as noted by a number of studies, including Kuminoff, Parmeter, and Pope (2010), Klaiber and Smith (2013), Kuminoff and Pope (2014), and Banzhaf (2021), the coefficient on the difference-in-difference term, that is the interaction of the variable denoting the treatment group and the treatment period in a regression on, in our case, log of sale price, cannot be directly interpreted as an estimate of marginal willingness to pay (*MWTP*). As Banzhaf (2021) notes, in terms of the vocabulary of the program evaluation literature, the "stable unit treatment value assumption" is likely to be violated – even properties whose amenities, specifically school zones, are not changed will incur changes in their value. In our case, for example, the opening of Frederick Douglass in August 2017 high school resulted in significant reductions in enrollments in Bryan Station and Henry Clay high schools.

As these studies point out, *DID* estimates confound *MWTP* estimates, movements along hedonic frontiers as in Rosen (1974), with shifts between hedonic frontiers caused by general equilibrium changes within the housing market. This point is nicely illustrated in Figure 3, a replication of Figure 1 in Banzhaf (2021).[7] In Figure 3, a treated (rezoned) and matched control property both start at a price of p_A and have identical amenities, including schools. With the rezoning the price of the untreated house (not rezoned) falls to p_B (distance IE), the indirect effect. This represents the shift in the hedonic function, that is the general equilibrium effects on housing prices in Fayette County, due to the rezoning. As the indirect effect is a change in housing price without any change in housing characteristics or amenities, it is simply a transfer between owner and renter with no associated welfare effects. However, for the treated (rezoned) property the public service (quality of schooling) increases from $g^{a'}$ to g^{a^*}, the distance DE (direct effect) along the new hedonic frontier. The distance DE is the partial equilibrium effect or utility-constant price change,

[7] Appendix Figure A2 shows pre- and post-approval hedonic functions of housing prices and school ACT composite scores using local polynomial regressions. It is closely related to what Banzhaf (2021) argued a shift in hedonic price function.

the change in price that provides a lower bound on the welfare measure, *Hicksian equivalent surplus*. The total effect (TE) is what is estimated by standard *DID* techniques and includes both the direct effect and the indirect or general equilibrium effect. As both Kuminoff and Pope (2014) and Banzhaf (2021) demonstrate, the estimate of capitalization based on the difference-in-difference can severely underestimate the welfare effects of the treatment as it confounds the direct and indirect effects.

4.2 A Simple Model of General Equilibrium Price Changes

To see an example in which general equilibrium effects result in the coefficients from a hedonic not being interpreted as marginal willingness to pay, let utility of (identical) residents of two districts be given by

$$U(x_i, e_i, h_i, \alpha) = x_i + \alpha ln(e_i) + \gamma ln(h_i) \tag{1}$$

where x_i is a private good, e_i is a public good (education quality) provided by district i, and h_i is housing consumption of residents of district i. The term α is a "taste" parameter for education quality with the term γ a taste parameter for housing. The budget constraint is given by $y = x_i + p_i h_i$ with demand for housing given by $h_i = \frac{\gamma}{p_i}$ making the indirect utility function

$$V(e_i, p_i, \alpha) = y - \gamma + \alpha ln(e_i) + \gamma ln(\gamma) - \gamma ln(p_i) \tag{2}$$

We further assume a fixed amount of housing (land) in each community, L_i and a total population of N.

4.2.1 Equilibrium Conditions and Comparative Statics

We consider the interpretation of hedonic estimates, $\frac{dp_i}{de_i}$, when districts are not small and "utility takers". In this case, as all individuals are identical and mobile between the two districts, equilibrium requires individuals receive the same level of utility in each of the two districts,

$$\alpha ln\left(e_1\right) - \gamma ln\left(p_1\right) = \alpha ln\left(e_2\right) - \gamma ln\left(p_2\right) \tag{3}$$

In addition to the equal utility condition, the housing market needs to clear in both districts or,

$$L_1 = n_1 \frac{\gamma}{p_1} \text{ and } L_2 = \left(N - n_1\right)\frac{\gamma}{p_2}, \tag{4}$$

where n_1 is the population of district 1. Differentiating (3) with respect to e_1 yields

$$\frac{dp_1}{de_1} = \frac{\alpha/e_1}{\gamma/p_1} + \frac{p_1}{p_2}\frac{dp_2}{de_1} \tag{5}$$

and differentiating (4) we obtain

$$\frac{dp_2}{de_1} = -\frac{L_1}{L_2}\frac{dp_1}{de_1} \tag{6}$$

Then from (5) and (6)

$$\underbrace{\frac{dp_1}{de_1}}_{TE} = \underbrace{\frac{\alpha/e_1}{\gamma/p_1}}_{DE} + \underbrace{\frac{\frac{L_1}{L_2}\frac{p_1}{p_2}}{\left[1 + \frac{L_1}{L_2}\frac{p_1}{p_2}\right]}\left(\frac{\alpha/e_1}{\gamma/p_1}\right)}_{IE} = \frac{\alpha/e_1}{\gamma/p_1} + \frac{n_1}{N}\left(\frac{\alpha/e_1}{\gamma/p_1}\right) \tag{7}$$

In (7) we can see that the slope of the hedonic, $\frac{dp_1}{de_1}$, depends on two components. The first is the slope when districts are atomistic, that is, $\frac{L_1}{L_2} \longrightarrow 0$ or, equivalently, the slope along a public good/housing indifference curve, $\frac{\alpha/e_1}{\gamma/p_1}$, while the second is the element resulting from districts having a non-zero share of the housing market or "market power", $\frac{\frac{L_1}{L_2}\frac{p_1}{p_2}}{\left[1+\frac{L_1}{L_2}\frac{p_1}{p_2}\right]}\left(\frac{\alpha/e_1}{\gamma/p_1}\right)$, or the shift between indifference curves. Then, as seen in (7) in the terms of Banzhaf (2021), the direct effect (DE) is the term $\frac{\alpha/e_1}{\gamma/p_1}$ and the term $\frac{\frac{L_1}{L_2}\frac{p_1}{p_2}}{\left[1+\frac{L_1}{L_2}\frac{p_1}{p_2}\right]}\left(\frac{\alpha/e_1}{\gamma/p_1}\right)$ is the indirect effect (IE) with the magnitude of the indirect effect depending on how large the share of the housing market is in district 1.

4.3 A Numerical Example

We illustrate the differences between the hedonic obtained with atomistic districts and those with significant market shares with a simple numerical example for the case of a change in educational quality in one of the districts. We employ the framework described in the preceding section with the following values: $\gamma = 1$ and $\alpha = 1$ with both districts having equal shares of land, $\rho_1 = \rho_2 = .5$. We set $e_2 = 1$ and vary e_1 in the range [0.4, 1.8], solving for the equilibrium values of p_1 and p_2. We can see the results of these simulations in Table 2 and Figure 4a. In the figure, the dark blue line represent prices when district 1 is atomistic $\frac{\rho_1}{\rho_2} = 0$ or, equivalently, utility is constant. The gray lines are the prices when the two districts have equal land shares and, as seen in Table 2 utility varies with the level of e_1. The lighter blue line gives the constant utility price/public service curve for utility when $p_1 = 1.09$ and $q_1 = 1.4$, $p_1(U')$. As is evident from the figure, changes in p_1 with changes in e_1 are of a greater magnitude along the constant utility price lines, $p_1\left(U^0\right)$ and $p_1(U')$ than when the two districts have are of equal size and utility is not constant, $p_1(ES)$. As well, when the two districts are of equal size, changes in e_1 changes in e_1 also change in p_2 in the opposite direction of the change in p_1 as shown with the line $p_2(ES)$. Consider the increase in e_1 from 1 to 1.4. In Banzhaf's terms, the observed change in price, the total effect, TE, is found along the line $p_1(ES)$, the direct effect, DE, is the change in p_1 along the line $p_1(U')$ and the distance between the two lines at $q_1 = 1.4$ is the indirect effect, IE.[8] And, as shown by both Kuminoff and Pope (2014) and Banzhaf (2021), the total effect on prices, TE, is less than the direct effect on price, DE, the change in welfare.

In fact as seen in the figure, the change in prices in the two districts, $\Delta p_1 - \Delta p_2$ is virtually the same in both cases – the decrease in p_2 in the case of equal land shares equals the difference in p_1 in the two cases. Then to capture the direct effect of the change in public service quality, empirically we need to allow for and employ changes in both p_1 and p_2, $\frac{\Delta p_1}{\Delta q_1} - \frac{\Delta p_2}{\Delta q_1}$, to derive welfare estimates when we believe the SUVTA conditions are violated. This is the intuition behind the

[8]As utility is quasi-linear in this example, there are no income effects for housing or public service demand. This being the case, the lines $p_1\left(U^0\right)$ and $p_1\left(U'\right)$ are parallel making the difference between the prices at $e_1 = 1$ and $e_1 = 1.4$ the same on both lines.

estimation strategy discussed in Section 5.2.

In Figure 4b, we provide the price gradients for both p_1 and p_2 for different population shares of the two districts – providing intermediate cases to the cases shown in Figure 4a, $n_1 = 0$ (atomistic) and $n_1 = .5$. We can see that when district 1 has a small share of the population, 10% or less, the price lines are quite close to the atomistic case ($n_1 = 0$) particularly for relatively small changes in e_1 with much more pronounced differences with the atomistic case when the population of district 1 is above 20%.

4.4 A Sufficient Statistics Approach to Welfare Estimation

Our discussion of Banzhaf (2021) and the example in the preceding subsections that the appropriate measure of the welfare effect of a change in school quality is based on differences in property values along an utility-constant hedonic. However, in contrast to most hedonic applications, the change in the amenity, educational quality [9], we examine does not arise because of a change in the quality within a given school district (zone) but in changes in the boundaries of school zones. To formally derive the welfare effects of these changes in school boundaries, we posit a social welfare function that includes both renter and landowner utility. Then we show how a change in boundaries (land in school zone) affects social welfare and, in doing so, obtain a sufficient statistic. In Section 6.2, we operationalize our sufficient statistic to obtain welfare estimates of the opening of a new school and changing of school boundaries in Fayette County, Kentucky.

The model we use here is a generalizaton of that used in 4.2 with a more general (indirect) utility function, $V(e_i, p_i, \alpha) = y + \alpha ln(e_i) - \gamma(p_i)$ and housing demand given by $h(p_j)$. Again, there is a fixed population and land area for the two districts and, again, equilibrium again characterized by the equal utility condition, (3), and clearing in the housing markets, (4). As housing prices are housing prices in both districts are simultaneously determined, both prices are a function of the amount of

[9]In fact, the quality of schools is likely to change as a result of changes in the number and characteristics of students as a result of the boundary changes. As we discuss, our welfare estimates implicitly include these quality changes across the school zones.

land and educational quality in both zones, that is, we have $p_i = p_i\left(e_i, e_j, L_1, L_2\right), i, j = 1, 2$ and, of course, utility is a function of land and educational quality as well, with $U = U(e_1, e_2, L_1, L_2)$. As equilibrium utility is a function of education quality and land in both zones, we can express the housing price in a zone by $p_i = p(e_i, U)$.

Let social welfare be given by the sum of renter and landlord utility in both school zones,

$$SWF = n_1\left[y - \gamma(p_1) + \alpha(e_1)\right] + n_2\left[y - \gamma(p_2) + \alpha(e_2)\right] + L_1(p_1) + (1 - L_1)p_2 \tag{8}$$

where, of course, it follows that social welfare depends on land and educational quality, $SWF(e_1, e_2, L_1, L_2)$. Then differentiating with respect to L_1 gives

$$\begin{aligned}\frac{dSWF}{dL_1} = & \underbrace{\frac{\partial n_1}{\partial L_1}\left[y - \gamma\left(p_1\right) + \alpha\left(e_1\right)\right] + \frac{\partial n_2}{\partial L_1}\left[y - \gamma\left(p_2\right) + \alpha\left(e_2\right)\right] +}_{(a)} \\ & \underbrace{-\left(n_1 h_1 \frac{\partial p_1}{\partial L_1} + n_2 h_2 \frac{\partial p_2}{\partial L_1}\right) + \left(L_1 \frac{\partial p_1}{\partial L_1} + (1 - L_2)\frac{\partial p_2}{\partial L_1}\right)}_{(b)} + \underbrace{p_1 + \frac{\partial L_2}{\partial L_1} p_2}_{(c)}\end{aligned} \tag{9}$$

In (9) there are three distinct effects on social welfare: a) the change in utility for households moving from zone 2 to zone 1; b) the change in rents paid by residents and received by landlords as a result of change in housing prices; and c) the change in rents received by landlords in the area rezoned from zone 2 to zone 1. As utility is the same in both districts, term (a) of (9) must equal zero. Term (b) also equals zero – the changes in rents to residents is also the change in income to landlords $\left(n_j h_j = L_j\right)$. With $e_1 \neq e_2$, housing prices in the two districts are not equal and therefore term (c) does not equal zero. Then it follows that the change in social welfare simplifies to

$$\frac{dSWF}{dL_1} = p_1 - p_2 \tag{10}$$

where we again use the condition $\frac{\partial L_2}{\partial L_1} = -1$ to obtain (10). Then integrating over the change in the size of the district 1 gives

$$\Delta SWF = \int_{L_1^o}^{L_1'} (p_1 - p_2)\, dL_1 = (p_1 - p_2)\, \Delta L_1 \tag{11}$$

where L_1^o and L_1' are, respectively, the land in district 1 before and after redistricting and $\Delta = L_1' - L_1^o$.

The interpretations of (11) is quite straightforward and intuitive – it is equal to the product of the amount of land (number of houses)[10] rezoned from district 1 to district 2 and the difference in the prices of houses in the two zones.

Equation (10) is the change in social welfare from a marginal change in land (housing) distribution evaluated at a given distribution of housing and educational quality. With discrete changes in the amount of land (housing) in each school zone, this could be the either the distribution of housing and educational quality either prior to or following the redistricting. Letting the superscript o and ' refer values before and after the redistricting, estimation of the welfare effects of this redistricting requires we estimate the difference in prices at same equilibrium, that is, we either estimate $p(E_1, U^o)$ - $p(E_2, U^o)$ or $p(E_1, U')$ - $p(E_2, U')$ and not use estimates of $p(E_1, U^o)$ - $p(E_2, U')$ or $p(E_1, U')$ - $p(E_2, U^o)$.

5 Data and Empirical Strategy

As explained in Section 4, standard *DID* estimates cannot be used to obtain meaningful measures of welfare and capitalization when *SUVTA* is violated. In this section, we outline the empirical strategy we employ, following Banzhaf (2021), to obtain estimates of capitalization and the welfare effects of school redistricting in Fayette County, Kentucky. We first discuss the data on housing and school used in this study. Then we discuss a simple two-period *DID* model frequently used in the literature of school boundary changes and housing prices and its limitations in addressing the general equilibrium effects. Next, we address the issues discussed in Banzhaf (2021) and our

[10]Given the structure of the model, we can easily convert from land area to number of houses using $n_j = \frac{L_j}{h_j}$

theoretical model by a non-parametric *DID* model and compare it with alternative specifications. Last, we also show the hedonic *DID* with continuous school quality measures.

5.1 Data

5.1.1 Housing Data

Our housing sales data are obtained from Fayette County Property Valuation Administrator (PVA) office. They have detailed information about the sale date, sale price, parcel identifier, and structure characteristics such as the number of bathrooms, square footage, and exterior finish for the years between 2010 and 2020. We restrict our sample to arm's length transactions of single-family residential houses.

Table 3 shows the summary statistics for major house attributes. Columns (1) and (2) present the averages for houses in rezoned and nonrezoned areas prior to the announcement of redistricting respectively and column (3) shows the differences. Important for identification, it is clear from this table that the redistricting did not select certain types of houses given that we do not find any statistically significant or economically large differences between the two groups of homes. The only exception is distance to schools where rezoned homes are 1.1 mile farther away from schools compared to homes in nonrezoned areas, which is consistent with the idea that houses that are distant from schools and close to the boundaries have more uncertainty in changing school boundaries (Cheshire and Sheppard, 2004).

5.1.2 Measures of School Performance and Environment

ACT Scores Our data on Fayette County public high schools are from Kentucky Department of Education and National Center for Education Statistics (NCES) Common Core Data (CCD). The school level average ACT scores are accessed from School Report Card Datasets for school years of 2011-2012 through 2018-2019.[11] Since 2008, ACT tests are required state-wide and around 98% of high school students took ACT tests. Hence it is less a concern that ACT scores will bias

[11] See https://openhouse.education.ky.gov/Home/SRCData.

towards schools that encourage students to take the test. There are four subjects including English, Reading, Math, and Science reported in the data set, along with a composite score that is the average of all four sections. We use the composite ACT score to measure the performance of high schools. Figure A3 plots the average ACT composite score for each school by year. We do not see significant changes in scores across the existing five high schools. Paul Dunbar, Henry Clay, and Lafayette have similar test scores, the highest in the district. Tates Creek follows these schools and Bryan Station has the lowest ACT scores. Frederick Douglass only has two data points and performs slightly higher than Bryan Station following its opening.

School Environment In addition to the test score data, we also collect information on school environment. Following Downes and Zabel (2002) among others. We measure the school environment using racial composition and percentage of free and reduced lunch participants. Figures A4 and A5 present selected school characteristics. As can be seen from the two figures, the percentage of white students steadily decreased over time without pronounced changes at the time of redistricting. The percentage of free and reduced lunch students gradually increased across over time and then began to decline in recent years. In our empirical analysis, we include these variables to account for school environment.

5.2 Empirical Strategy

5.2.1 A Two-Period Simple Difference-in-Differences Model

We take advantage of the recent school redistricting reform that resulted in changes in school boundaries to estimate the capitalization of school quality. Even though the redistricting process took more than three years to complete following the announcement of the intention to redraw school boundaries and the timing of the capitalization is important (Ding et al., 2022), we focus on a simple two-period *DID* model:

$$\ln P_{ijt} = \mathbf{X}_{it}\beta + \mathbf{Z}_{it}\delta + \phi Rezoned_i + \theta Rezoned_i \times Post_{it} + \zeta_j + \zeta_t + u_{ijt} \tag{12}$$

where $\ln P_{ijt}$ is log sale price of house i in location j at time t. $\mathbf{X}_{it}$ is a set of variables controlling for house attributes such as log of square footage, number of bathrooms, number of stories, house age and age square, whether the house is all brick, and whether the house is located in the urban area. $\mathbf{Z}_{it}$ represents a vector of location amenities including distance to parks, distance to the high school, and distance to urban service boundary. ζ_j and ζ_t denote location and time fixed effects respectively, accounting for the aggregate shocks and neighborhood heterogeneity. u_{ijt} is the error term.

$Rezoned_i$ is a binary variable that equals one if a house is located in an area that is expected to be redistricted to a different school or the new school. The binary variable $Post_{it}$ that equals to one if house i sold in time t was after the approval of the redistricting plan and zero if it was sold before. In essence, following Ries and Somerville (2010) we group the approval and opening periods into one stage that has been found yield the most significant appreciation in home values. To alleviate the concerns that failure to account for post-announcement stage effect will downward bias the estimate, in our empirical analysis we exclude sales that occurred between the announcement and approval of the redistricting. The term θ is the parameter of interest reflecting the effect of switching school zones on housing prices.

5.2.2 Identification

Key to identification in *DID* models is the parallel trend assumption, which implies that in the absence of the redistricting, the trend of log sale price for rezoned and nonrezoned homes would have behaved similarly. Figure 5 shows that the trend of sale prices for the two groups is parallel before the announcement/approval and starts to diverge after the approval of redistricting.

Equally important is the assumption of the exogeneity of school redistricting. As suggestive evidence of exogeneity, we compare neighborhood characteristics on both sides of the new boundaries under rezoning and find that they are not statistically different as seen in Table 4. In each column, we regress housing prices, percent of white, percent of bachelor degree holders, and median household income separately on a dummy indicating rezoning status. All regressions control for boundary fixed effect, school fixed effect, and year fixed effect. Within a quarter-mile of the new boundaries, homes in rezoned areas are 6.9 percent higher in value compared to those on the opposite side, although the difference is not statistically significant. Moreover, areas that have undergone rezoning display a 4.7 percentage point decrease in white households, an increase of 5.5 percentage points in bachelor's degree holders, and a minimal $74.9 gap in household income. Upon expanding our sample to include more locations farther from the new boundaries, the disparities in sale prices diminish.

We also perform a pairwise comparison for each new school zone boundary with the results are presented in Table 5. The first school is the high school of attendance following rezoning and the latter is high school prior to rezoning. The coefficient reports the differences in housing price and neighborhood demographics along the boundary. While there are some statistically-different, with the possible exception of the Tates Creek - Henry Clay boundary, in none of the boundaries is more than a single measure statistically-different along the border.

Finally, while we do not restrict our analysis to rezoning along "straight lines" as in Turner, Haughwout, and van der Klaauw (2014) where land regulations are examined, as can be seen in Figure A6, in fact, almost all the boundaries between school zones are straight lines along major arteries in Lexington. The exception is, again, the Tates Creek - Henry Clay boundary.

5.2.3 Difference-in-Differences Hedonics with Discrete School Effects

As suggested by our discussion of Banzhaf (2021) and our example in Section 4.2, because of potential general equilibrium effects of the redistricting, the returns to housing and locational characteristics may change along with the return to schooling. To consider this possibility we follow Banzhaf (2021) and estimate a generalized *DID* of the form

$$\ln P_{ijt} = \mathbf{X}_{it}\left(\beta + Post_t\tilde{\beta}\right) + \mathbf{Z}_{it}\left(\delta + Post_t\tilde{\delta}\right) + \sum_{j=2}^{5}\phi_j HS_j^{Old} + \sum_{j=2}^{6}\tilde{\phi}_j HS_j^{New} + \zeta_t + u_{ijt}. \tag{13}$$

where $Post_t$ equals one for sales after approval. HS_j^{Old} refers to the school catchment area for house i before the approval of redistricting and HS_j^{New} is the school catchment area after the approval. ϕ_j is the parameter that captures the relative difference between the base Bryan Station High School ($j = 1$) and high school j in the pre-redistricting period and $\tilde{\phi}_j$ is the parameter of interest that represents the difference in the post-redistricting period. The terms ϕ and $\tilde{\phi}$ can be interpreted as the fixed effects of schools; therefore, we do not include the usual locational fixed effect in this specification.[12] Then based on (13) the welfare effect (minimum bound on equivalent variation) of being redistricted from school a to school b is based on the post-redistricting coefficients, is $\tilde{\phi}_b$ - $\tilde{\phi}_a$.

We compare the estimates from (13) to an alternative, commonly used *DID* that excludes time-varying effect for houses that are not redistricted:

$$\ln P_{ijt} = \mathbf{X}_{it}\beta + \mathbf{Z}_{it}\delta + \sum_{j=2}^{5} \phi_j HS_j^{Old} + \sum_{m=1}^{6} \eta_m Rezoned_m + \sum_{m=1}^{6} \rho_m Rezoned_m \times Post_t + u_{ijt}, \tag{14}$$

where the subscript m now denotes the school rezoning pairs that is different from single school fixed effect j. $Rezoned_m$ is a set of binary indicators of school rezoning pairs. The term η_m captures the effect of rezoning areas before the approval of redistricting plan and ρ_m delivers the *DID* estimate of the average treatment effect for each rezoning pair after approval as compared to nonrezoned areas.

5.2.4 Difference-in-Differences Hedonics with Continuous Measure of Quality

The advantage of the nonparametric estimation of school quality in the context of school redistricting is that we are able to identify the bundle of aggregate changes within a school while still incorporating general equilibrium effects happened across school catchment zones. However, it remains a question as to what extent does the change come from different aspects of the school.

[12]Following Banzhaf (2020) and Bishop and Timmins (2018), we can estimate demand curves under the assumptions that the distribution of demand types active in the market does not change over time and use the single-crossing property that households can be ordered by their *MWTP* for the amenity, and the ordering will be the same evaluated at any level of the amenity and under any equilibrium price function.

Test scores are commonly used value-added measures to evaluate changes in school quality and teacher effects. But under a large redistricting reform, the student body composition along with changes in other dimensions of school characteristics and neighborhood could potentially bias the valuation of school test scores. As seen in Figure 6, vertically switching between Bryan Station and Frederick Douglass will cause a change in housing prices but not ACT scores. Given the location of the new Frederick Douglass High School is in the original Bryan Station area, there must be changes in how people value other attributes of the school and homes in the area that lead to changes in housing prices.

We follow numerous studies that have examined the relationship between property values and characteristics of schools, in addition to estimating the "total" effect of redistricting from (12) to estimate equations of the form

$$\ln P_{ijt} = \mathbf{X}_{it}\left(\beta + Post_t\tilde{\beta}\right) + \mathbf{Z}_{it}\left(\delta + Post_t\tilde{\delta}\right) + \mathbf{S}_{jt}\left(\gamma + Post_t\tilde{\gamma}\right) + \zeta_t + u_{ijt} \tag{15}$$

where $\mathbf{S}_{jt}$ is a vector of school characteristics that includes measures of student performance (composite ACT score, graduation rate), student characteristics (racial composition, percent free or reduced lunch, percent of students reported having behavior incidents), and resources (student-teacher ratio). Letting S_j^k represent the value of characteristic k in school j, the change in welfare from a move from school a to school b is

$$\sum_{k=1}^{K}\left(S_b^k - S_a^k\right)\left(\gamma^k + Post\tilde{\gamma}^k\right), \tag{16}$$

the product of the difference in the two schools post-treatment attributes and the post-treatment coefficients on school attributes.

6 Results

We provide our estimation results of our empirical models in this section. First, we present the capitalization effects using hedonics *DID* models and discuss the violation of SUTVA. Next, we follow Banzhaf (2021) to show the welfare effects associated with different methodologies.

6.1 Capitalization with Difference-in-Differences Hedonics

6.1.1 Discrete Measures

A Simple *DID* We first report our results of the replication of a standard two-period *DID* model similar to a generalized version in Ding et al. (2022). The pairwise estimation of rezoning effects compares homes in the same school zones before redistricting but in different zones following redistricting. Table 6 shows the results for six school pairs. In the table the corresponding rankings of schools based on ACT scores are in the parentheses. As the estimates show, the direction of capitalization is generally consistent with the test score performance of the school. Homes moved from a school with lower scores, Bryan Station, to a school with slightly higher scores, the new school, Frederick Douglass, yields a 2.7 percent increase in housing prices compared to the homes that are staying in Bryan Station. In contrast, homes moved from Bryan Station to Paul Dunbar, a school with a much higher ACT results in a 6.3 percent appreciation in property values. Houses that are moving from Lafayette to Henry Clay have a 3.1 percent increase in property values. In general, houses that are rezoned to schools with lower ACT scores see a decrease in house values. Being rezoned from Henry Clay to the new Frederick Douglass causes a 0.9 percent decline and the point estimate is noisy. The rezoning effect is slightly higher for Henry Clay to Tates Creek, even though Tates Creek has a better ACT score. There is a negligible one percent decline in Paul Dunbar to Lafayette rezoning pair and is not statistically significant.

General Equilibrium *DID* As discussed in Section 5.2, following Banzhaf (2021) one way to account for the general equilibrium effects of rezoning is including dummies for pre- and post-rezoning schools as well as time-varying coefficients on house and neighborhood characteristics. This allows for the value of schools to change following redistricting and capture the potential spillover effects of rezoning on homes that were not redistricted. Given the results of the estimation of Equation (13) in Table 7 and the complexity of the estimating equation and the similarity in the treatment coefficients in Ding et al. (2022), we aggregate sales in the post-approval and post-opening period into a single treatment period and exclude sales during the post announcement period from the sample.

Table 7 reports the estimated school fixed effects for both pre-rezoning and post-rezoning periods in our generalized *DID* regression as specified in (13). Column (1) only includes house attributes and column (2) adds tract level percent of white and median household income to control for neighborhood characteristics. Column (3) further includes a set of interaction between $Post$ and house and tract attributes. Column (4), our preferred specification, is the most flexible specification as it allows for time-varying coefficients on both house and locational characteristics and also considers the potential complementarity between elementary and high school quality.[13] The base group is the Bryan Station zone, both for the pre-redistricting and post-redistricting. From the table, we see, for instance, that a house in Henry Clay High School has a 10.7 percent higher property value than a similar house in Bryan Station prior to the redistricting, but the difference between the two houses increases to 16.1 percent after. Homes that were redistricted from Bryan Station to the newly constructed Frederick Douglass school have 5.7 percent higher value relative to homes that remained in the Bryan Station zone.

While the signs of the results, that is, the changes in property values for redistricted homes relative to those are in the same original school zone but not redistricted are similar in the pair-wise comparisons found in Table 6 and those in Table 7, their magnitudes are not. From 7 we find that homes redistricted from Bryan Station to Frederick Douglass post-redistricting will result in a 5.7 percent appreciation in property values, compared to a 2.7 percent increase in a traditional *DID* estimate in Table 6. Again from Table 7, homes redistricted from Bryan Station to Paul Dunbar

[13] We thank Sebastien Bradley for pointing out this.

increase in value by 9.2 percent in contrast to the 6.3 percent increase reported in column (2) Table 6. That the pairwise comparison result in lower capitalization estimates in consistent with the discussions found in Kuminoff and Pope (2014) and Banzhaf (2021). Other capitalization effects for different school pairs can be obtained by calculating the differences between the *Post* school dummies between pairwise schools. We bootstrap those estimates and show the results in Table 9 Panel A. Being rezoned from Henry Clay to Frederick Douglass causes a decline in property values of 10.5 percent and a nine percent decrease for homes rezoned from Henry Clay to Tates Creek. The effects for Lafayette and Paul Dunbar are noisier where we see a 6.4 appreciation for Lafayette to Henry Clay and no impact from Paul Dunbar to Lafayette.

A Comparison of Methods and Estimates (Violation of SUTVA) We next proceed to compare the discrepancies between two models, one that incorporates general equilibrium spillovers (Equation (13)) with estimation results in Table 7 and one that does not (Equation (14)) with its estimation results found in Table 8. The upper panel shows the differences between areas to be rezoned to those that are not within each original school catchment area, reflecting the idea of being compared to the "same school." The lower panel shows the estimates of the interactions between school-school pair dummies and *Post* which imply the appreciation of house values for the rezoned areas. Under this specification, where we do not allow school effect to vary over time, homes redistricted from Bryan Station to Frederick Douglass see an insignificant 1.4 percent decrease in value while those redistricted from Bryan Station to Paul Dunbar increase in value by 5.8 percent. In contrast to the consistent relationship between school ranking (based on mean ACT score) and the direction of housing price changes in the general equilibrium model, homes redistricted from Henry Clay to Frederick Douglass slightly decreased and homes redistricted from Henry Clay to Tates Creek even increase in value.

The comparison between the two models are summarized in Table 9. It is worth noting that failure to account for the spillover effects of school redistricting on the original schools will not only bias the estimates, but may also alter the signs of the effects.

6.1.2 Continuous Measures of School Characteristics

The previous results pose a question relevant to any hedonic estimation of school quality and the impact of school boundary changes–"what school characteristics matter?" Our preferred model, following Banzhaf (2021), that used school dummies shows the value of the bundle of all attributes attached to a school. Our estimates of school quality from this approach are likely to differ from those estimated using a single measures or set of measures of school quality. To examine the extent of differences between the the two approaches, we estimate a set of hedonic models (Equation (15)) and report the results in Table 10. Columns (1) and (2) estimate two cross-sectional regressions in which we only include school characteristics. This is a more flexible way of estimating a *DID* model because we allow the marginal willingness to pay for each school characteristic to vary over time with the difference between each coefficient represents the change in the marginal willingness to pay for a specific school quality attribute. Essentially we are estimating both pre and post-redistricting hedonic functions separately as shown in Figure A2. In column (3) we pool pre-redistricted and post-redistricted sales and interact all the school characteristics with $Post$ to account for the time-varying preferences for school characteristics – an application of the Banzhaf (2021) approach. In this case, the coefficients for the school characteristics will be similar to the pre-period estimates and the interaction terms represent the *DID* estimates, which would be close to the differences between the first two columns.

The results are consistent with the literature that finds student body and teacher quality affects the valuation of schools. However, after the redistricting, we see a decline in the impact of student demographics on housing prices and a significant increase in the importance of graduation rate. The marginal willingness to pay for the test scores also increases, but this increase is not statistically significant. These estimates serve our baseline parameters to calculate the welfare effects for different pairwise rezoning.

We only include ACT and its interaction with the $Post$ variable in column (4), which does not account for the changing preference for other attributes of the house and schools over time as criticized by Kuminoff and Pope (2014). In this case, the coefficient on ACT score (0.40) is greater than the estimate of it when controlling for other school characteristics (0.002) before redistricting with a statistically-insignificant impact following redistricting.

6.2 Evaluating Welfare Effects Using Alternative Methodologies

We follow Banzhaf (2021), as discussed in Sections 4 and 5.2, to calculate welfare benefits from a hedonic *DID*. As he shows, the appropriate measure of welfare is from differences in housing prices between the treated and comparison, post-treatment. In our case, we obtain welfare estimates using two approaches: 1) the effect of being rezoned to another school on housing prices based on the estimated coefficients on post-approval school dummies (Table 7); and 2) the effect that a change in mean school ACT through rezoning has on housing prices (Table 10).

In Table 7 we report the results of estimating a hedonic that allows for the effect of being zoned to a high schools, the coefficient on the high school dummy, to vary before and after approval of the zoning. Then following Banzhaf (2021) the estimated change in welfare from a house being rezoned from one high school zone to another is based on the post-approval coefficients on the high school dummies. We also apply our estimates in the post period from the discrete *DID* models and the *DID* models with school attributes to the assessed value of houses in 2013, the year prior to the redistricting, to evaluate the welfare effects of school boundary changes. Row A in Table 11 shows the number of houses in each area and row B lists the average assessed value of those homes. Clearly, the Bryan Station and Henry Clay zones were subject to the largest changes as a result of construction of the Frederick Douglass.

6.2.1 Discrete Measures

Panels C and E of Table 11 report the corresponding estimates of rezoning from Table 9 separately. We multiply the number of houses, average assessed value, and the percent change of those homes due to redistricting, to get the welfare measures and report them in panels D and F. Based on column (3) of Table 7, the coefficients from our preferred estimate, being rezoned from Bryan Station (the base school) to Frederick Douglass increases housing prices by 5.7 percent.

Then as seen in panel D in Table 11, as the average assessed value in 2013 was \$164,262 and there are 7,912 houses in the rezoned area this translates to an increase in welfare of \$74.08 million. In contrast, as housing prices in the Henry Clay zone are 16.1% higher than in the Bryan Station zone, the difference in the coefficients on Henry Clay Post and Frederick Douglass Post (.161-.057), with an average assessed value of \$248,370 and 2,783 houses rezoned from Henry Clay to Frederick Douglass, this results in a loss of \$72.58 million in welfare. In total, the estimated welfare gain from the rezoning and opening of Frederick Douglass was \$1.5 million. The estimated construction cost of Frederick Douglass was \$82 million (Kennedy, 2017). Inspection of row D for the welfare effects from redistricting of other zones reveals smaller welfare effects. In column (2) houses redistricted from Bryan Station to Paul Dunbar received the largest return of redistricting, a 9.2% increase in property value, but the associated welfare is around \$14 million due to smaller number of homes redistricted. Homes redistricted from Henry Clay to Tates Creek had the greatest decrease in property value, 10.50%, and resulted in a decrease in welfare of \$72.58 million. In total, redistricting was estimated to increased welfare by \$27.82 million meaning that the redistricting unrelated to the opening of Frederick Douglass increased welfare by \$27.82 - \$1.5 =\$26.32 million.

When we compare our welfare results from estimates of our generalized discrete *DID* model (row D) to other of the *DID* without time-varying coefficients (row F) we see much smaller estimates of the welfare effects, consistent with the smaller estimates of capitalization (row E) and in the cases of houses redistricted from Henry Clay to Frederick Douglass and those redistricted from Henry Clay to Tates Creek different signs on the capitalization and welfare effects. Most pronounced are the differences in the welfare effects of redistricting from Bryan Station to Frederick Douglass (\$74.08 million with GE vs. -\$18.19 without GE), Henry Clay to Frederick Douglass (-\$72.58 vs. -\$0.14) and Henry Clay to Tates Creek (-\$17.41 vs. \$5.22). One exception to the smaller magnitude of capitalization and welfare effects is for homes redistricted from Lafayette to Henry Clay, which, as discussed in Ding et al. (2022), may reflect an anticipatory effect that may bias the estimate. The welfare under *DID* without general equilibrium only has \$11.36 million appreciation.

6.2.2 Continuous Measures of School Characteristics

In contrast is the estimated impact on welfare based on mean school ACT scores. Again, following Banzhaf (2021), in Table 10 we report the estimate effect of mean school ACT score in column (4). We estimate that in the post-approval period, the coefficient on ACT score is -0.002, that is, a point increase in the mean school ACT score decreases housing prices by 0.2 percent. We then multiply the difference in ACT scores between the schools and, as with the dummy variable approach, calculate the effect for each rezoned area based on the number and average assessed value of houses in each of the rezoned areas with the results reported in column (7). In total and in stark contrast to the results based on our estimation with school dummies, rezoning resulted in an estimated $52.96 million decrease in total welfare compared to $27.82 million increase in the nonparametric *DID* model.[14]

The most significant differences in welfare changes were found in the areas rezoned from Bryan Station to Frederick Douglass ($74.08 million versus $14.69 million). These differences account for 74 percent of the difference in the estimates.[15] In the other direction, the estimated effect of rezoning from Henry Clay to Frederick Douglass based on mean ACT score was a loss of $77.62 million versus a loss of $72.58 million using school dummies. Other school pairs also have discrepancies between the two models. One obvious explanation for the differences associated with the rezoning from Bryan Station to Frederick Douglass is the value of attending a new high school independent of the difference in mean ACT score. Of course, this explanation would seem to be inconsistent with the greater estimated loss with the school dummies rather than with mean ACT score for rezoning from Henry Clay to Frederick Douglass. Perhaps it is important to bear in mind that particularly for Frederick Douglass the first school ACT was only available in 2018 and might have carried less weight to potential homeowners in its zone post-opening as a result.

In panels J and K we include all school characteristics and also allow them to vary over time to account for the general equilibrium effect of rezoning. As can be seen in column (1), the estimated

[14] Figure 7 shows the comparison of estimated welfare effects and their corresponding confidence bands for different models. In Figure A7 we present the welfare estimates for each school pair separately.

[15] $(14.69 - 74.08)/(-52.96 - 27.82) \approx 0.74$.

welfare effect for Bryan Station to Frederick Douglass is much closer ($68.62) to the one we obtain from the discrete model with GE ($74.08). Similar results are also found in Bryan Station to Paul Dunbar rezoning pair where the two models yield similar aggregate gains in property values for the rezoned area. Other school pairs also see improvements in terms of the point estimates of welfare effects once we account for more school level characteristics. This set of results shows that using only test scores for school quality could have potential biases, especially when changes in school zones are large and the inclusion of school attributes both before and after redistricting helps reduce the gap between these models.

7 Conclusion

Utilizing school redistricting reform in Fayette County, Kentucky, we employ a *DID* hedonic model to examine the capitalization effects and welfare changes of school quality. Following Banzhaf (2021), we estimate a discrete, non-parametric *DID* hedonic model that uses school dummies in both pre- and post-redistricting periods to measure school quality. We include a flexible set of interactions between house attributes and school characteristics and the post-treatment variable to incorporate general equilibrium effects. We also estimate an alternative *DID* model that does not have time-varying coefficients and compare the estimates from this model to estimates using our approach. We find that the estimated capitalization is much larger under our approach. As well, the welfare changes found using the conventional *DID* model differ greatly from those found with our general equilibrium specification. Using the housing stock in 2013 (one year prior to the redistricting announcement) in Fayette County we find that rezoning from a less-performing school (Bryan Station) to the new school amounts to approximately $120.87 million. The gain from increased ACT scores is around $15.98 million and the gain from changes in all school and housing time-varying attributes is $65.86 million.

In addition to the *DID* models that use discrete, non-parametric measures of school quality, we also follow the literature that uses test scores and other dimensions of school characteristics such as demographics, graduation rates, and behavior events to measure school quality (Downes and Zabel, 2002; Clapp, Nanda, and Ross, 2008; Ries and Somerville, 2010). In the case of redistricting in Fayette County, we find large discrepancies in the estimates of welfare changes from redistricting based on changes in mean ACT score and those obtained using our non-parametric approach. However, the inclusion of a more comprehensive set of school characteristics and their time-varying effects to the model with ACT scores leads to a closer estimate to the welfare effects found using our non-parametric approach.

Our research contributes to several strands of literature. First, we address concerns related to *DID* models in hedonic estimation by demonstrating that neglecting to factor in the general equilibrium effects of major policy changes can lead to imprecise estimates of capitalization. Second, we present an example that illustrates the inaccurate nature of the welfare assessments associated with the standard *DID* methodology when general equilibrium effects are present. Our study is particularly pertinent to local policy of school redistricting and the establishment of new schools, which has attracted considerable attention in the literature owing to its substantial expenditure. In particular, with respect to the literature utilizing hedonic estimation for evaluating school quality, our non-parametric approach to assessing school quality and measuring it through test scores reveals substantial variations in the welfare evaluations.

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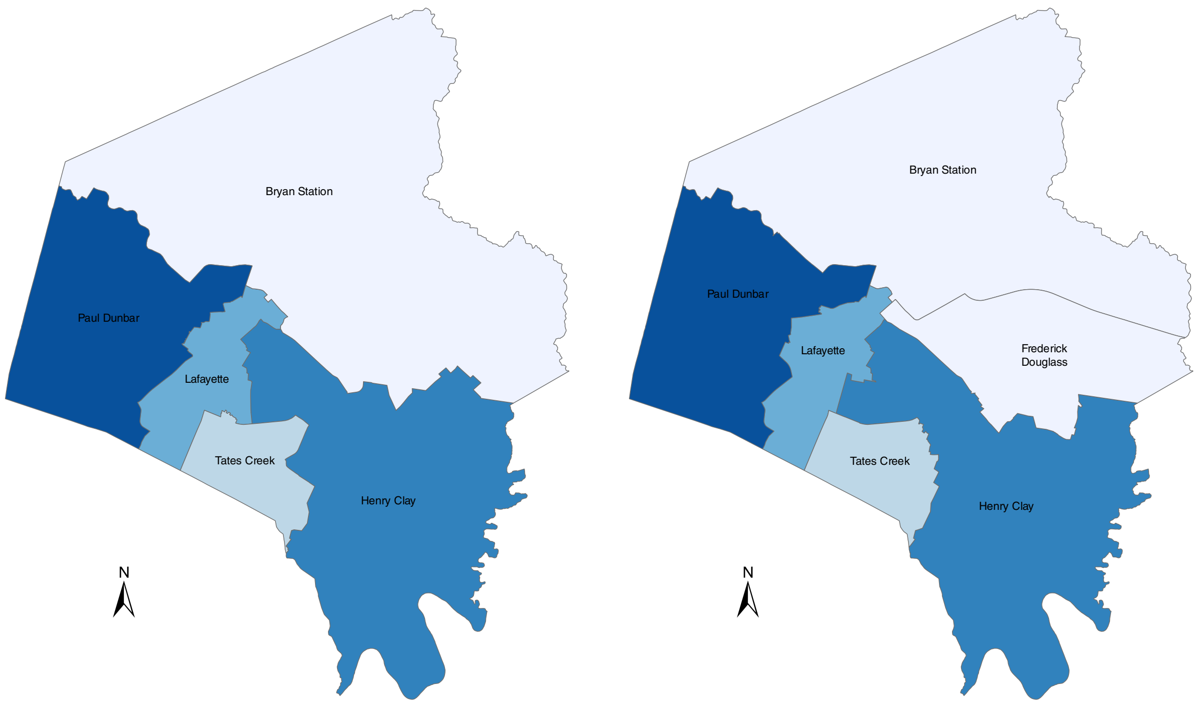
8 Figures



(a) Old School Attendance Zones (b) New School Attendance Zones

Figure 1: Pre-Approval (Old) and Post-Approval (New) Fayette County High School Catchment Areas

Figure 2: Changes in High School Catchment Area Boundaries

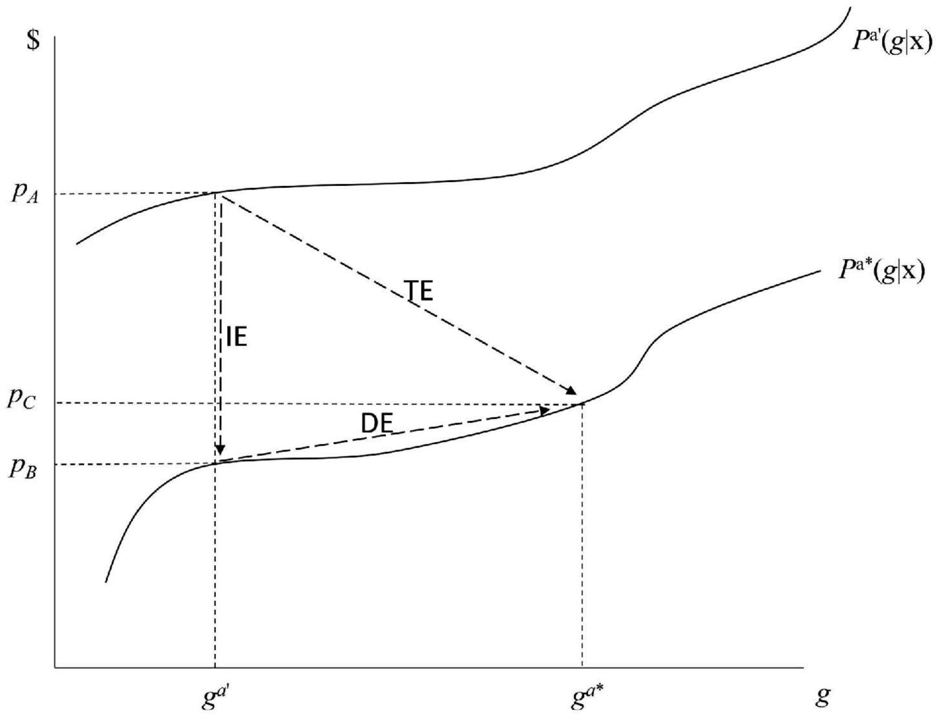
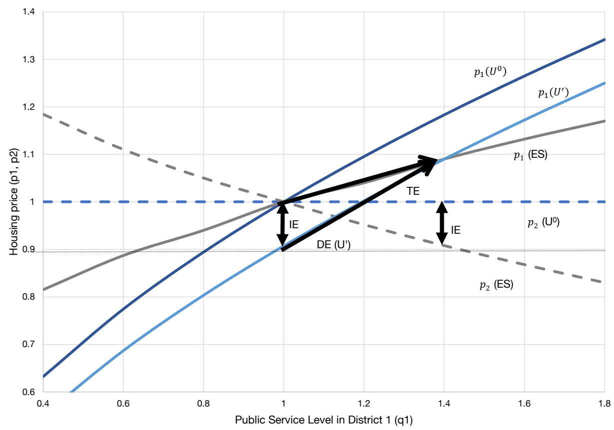
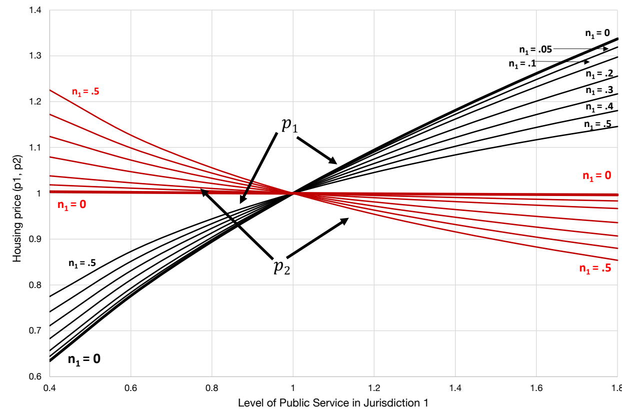


Figure 3: Figure 1 in Banzhaf (2021)



(a) Housing Prices, Atomistic (Constant Utility) and Equal Share Districts



(b) Level of Public Service in Jurisdiction 1 versus Housing Prices in Jurisdictions 1 & 2

Figure 4: Housing Prices in Our Simulated Models

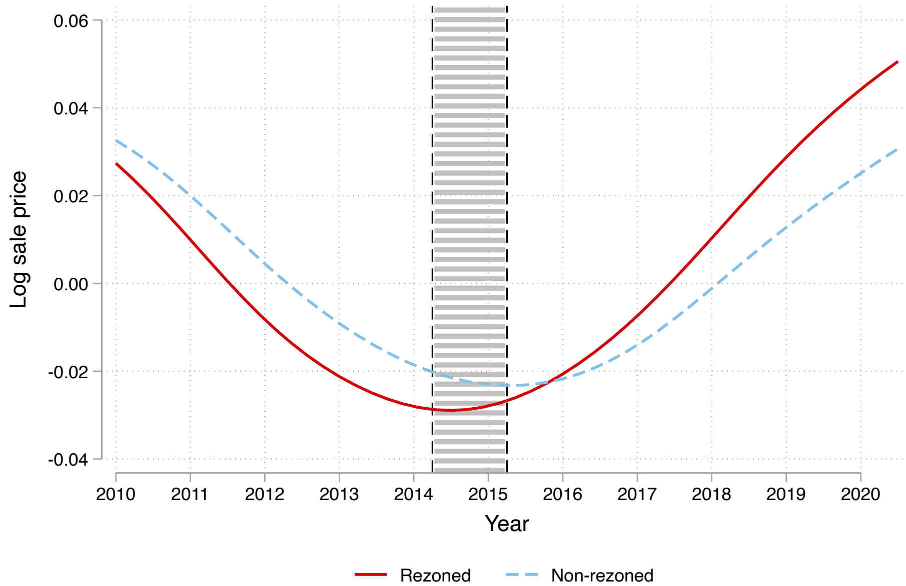


Figure 5: Sales Price Trends for Rezoned and Nonrezoned Homes

Notes: This figure compares the trend of log sales prices in rezoned area and non-rezoned area. Houses sold in areas that are subject to redistricting are in rezoned group and houses that are not subject to redistricting in included in non-rezoned group. We first regress log sale price on house attributes and obtain the residuals. Then we use local polynomial regressions to quarterly smooth the residuals. Shaded area refers to the period after announcement and before approval. We drop sales in this period in our empirical analysis for the ease of interpretation.

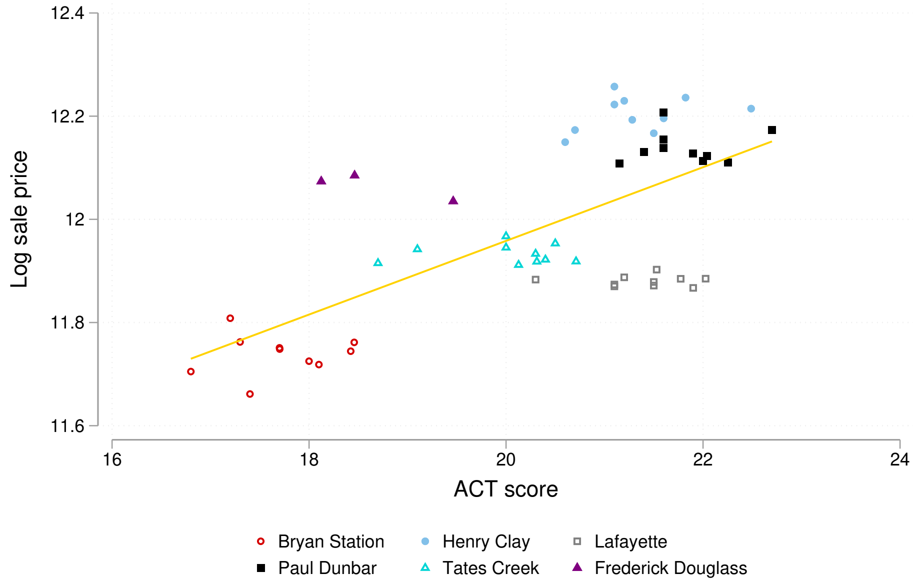


Figure 6: Scatter Plot of Mean Price and Composite ACT Score by High School and Year

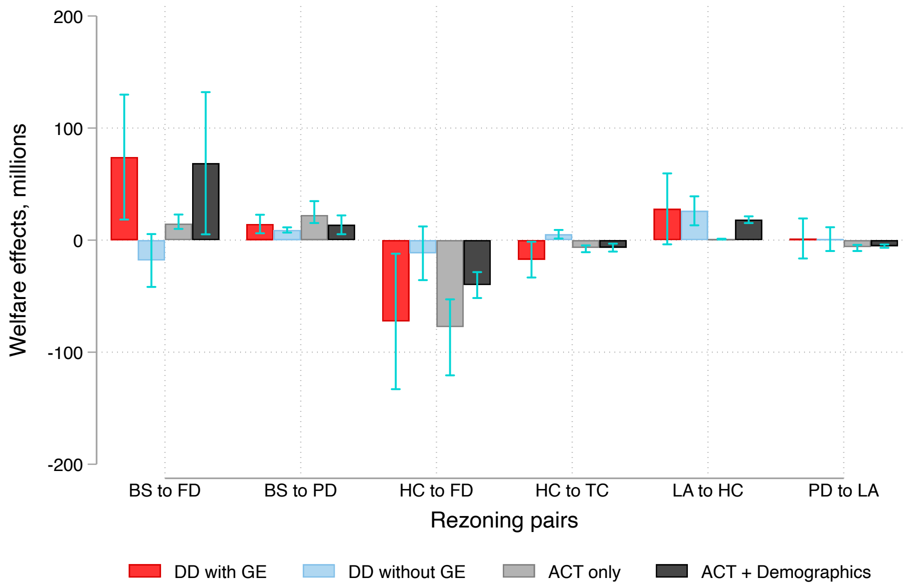


Figure 7: Comparison of Welfare Estimates

Notes: This figure shows the estimated welfare effects from four models and their corresponding confidence intervals.

9 Tables

Table 1: Timeline for Planning and Implementation of Redistricting

Date	Event	Treatment
April 29, 2014	Announce plan to redistrict/add school	
April 14, 2015	Present plan to board/public	Announcement
April 21, 2015	Board meets to get feedback	
June 3, 2015	Approve plan	Approval
August 16, 2017	Open Fredrick Douglass and implement new zones	Opening

Notes: This tables shows the timeline of the rezoning process. The data is obtained from Fayette County Public Schools.

Table 2: A Numerical Example

	$\rho_1 \longrightarrow 0$			$\rho_1 = 0.5$		
e_1	p_1	p_2	Utility	p_1	p_2	Utility
0.4	0.63	1	9	0.815	1.184	8.75
0.6	0.77			0.887	1.11	8.86
0.8	0.89			0.94	1.05	8.95
1	1.00			1	1	9.00
1.2	1.10			1.04	0.952	9.05
1.4	1.18			1.09	0.908	9.08
1.6	1.26			1.132	0.868	9.11
1.8	1.34			1.17	0.83	9.14

Notes: This table shows the numerical values of simulating the general equilibrium model.

Table 3: Summary Statistics for Houses in Rezoned and Nonrezoned Locations before Announcement

	(1) Rezoned	(2) Nonrezoned	(3) Difference
Price	156,511.2	159,853.1	-3,341.924
	(81005.6)	(84573.8)	(16,719.243)
ln Price	11.86	11.87	-0.012
	(0.436)	(0.463)	(0.089)
Sqft	1784.0	1808.6	-24.558
	(623.5)	(667.6)	(129.580)
ln Sqft	7.431	7.437	-0.005
	(0.327)	(0.353)	(0.067)
Age	0.243	0.312	-0.068
	(0.209)	(0.244)	(0.078)
Stories	1.400	1.419	-0.019
	(0.451)	(0.454)	(0.071)
Full bath	1.994	1.908	0.087
	(0.640)	(0.660)	(0.157)
All brick	0.343	0.379	-0.035
	(0.475)	(0.485)	(0.106)
Urban	0.992	0.992	-0.000
	(0.0904)	(0.0878)	(0.004)
Dist to school	3.267	2.129	1.138**
	(1.304)	(1.439)	(0.297)
Dist to park	0.360	0.335	0.025
	(0.282)	(0.283)	(0.053)
Dist to USB	1.237	1.163	0.074
	(0.850)	(1.010)	(0.346)
Observations	2,668	7,983	10,651

Notes: This table reports the summary statistics of major house attributes. USB refers to urban service boundary. Columns (1) and (2) report the mean for houses in rezoned and nonrezoned areas respectively. Column (3) reports the estimated difference between the two columns. Standard deviations are in parentheses in the first two columns and robust standard errors are clustered at the old school level in column (3). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Exogeneity Test: Differences of Sale Price and Demographics along New School Boundaries

	(1) Log price	(2) White	(3) Bachelor	(4) Median income
A. 0.25 mile				
Rezoned	0.069	-0.047	0.055	74.921
	(0.104)	(0.024)	(0.043)	(8,504.608)
Observations	1,898	1,898	1,898	1,898
R^2	0.247	0.553	0.529	0.409
B. 0.5 mile				
Rezoned	0.056	-0.030	0.066	-3,171.243
	(0.123)	(0.024)	(0.046)	(10,272.591)
Observations	4,178	4,178	4,178	4,178
R^2	0.206	0.497	0.474	0.303
C. 0.75 mile				
Rezoned	0.005	-0.015	0.060	-3,615.671
	(0.154)	(0.028)	(0.048)	(11,019.697)
Observations	6,094	6,094	6,094	6,094
R^2	0.209	0.463	0.428	0.273

Notes: This table reports the results of our exogeneity test of random boundaries using sales prior to the approval. Each column shows the mean difference for houses in rezoned areas compared to houses stay in the original school zones in terms of sale prices, census tract level percent of white, percent of bachelor's degree holders, and median household income. Sample consists of houses located within 0.25, 0.5, and 0.75 mile from the boundary. Robust standard errors are clustered at old school level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Exogeneity Test for School Pairs

(New School - Old School)	(1) Log price	(2) White	(3) Bachelor	(4) Median income
Frederick Douglass-Bryan Station	0.065	-0.068	-0.041	-5,846.707
	(0.038)	(0.040)	(0.149)	(12,193.943)
Observations	642	642	642	642
R^2	0.701	0.198	0.025	0.026
Paul Dunbar-Bryan Station	0.015	-0.127***	0.030	16,531.503
	(0.009)	(0.021)	(0.122)	(11,251.038)
Observations	544	544	544	544
R^2	0.691	0.613	0.012	0.231
Henry Clay-Frederick Douglass	0.060*	-0.027	-0.089	19,009.347*
	(0.034)	(0.044)	(0.071)	(10,857.514)
Observations	1,106	1,106	1,106	1,106
R^2	0.767	0.015	0.061	0.088
Tates Creek-Henry Clay	-0.125**	0.060**	0.229***	-7,497.070
	(0.054)	(0.027)	(0.053)	(11,967.814)
Observations	953	953	953	953
R^2	0.755	0.043	0.192	0.015
Henry Clay-Lafayette	0.142*	-0.035	0.058	-10,815.968
	(0.074)	(0.046)	(0.128)	(10,859.380)
Observations	1,030	1,030	1,030	1,030
R^2	0.700	0.025	0.018	0.053
Lafayette-Paul Dunbar	0.067	-0.030	-0.015	-35,859.870***
	(0.051)	(0.051)	(0.063)	(11,070.042)
Observations	794	794	794	794
R^2	0.831	0.014	0.004	0.305

Notes: This table reports the results of our exogeneity test of random boundaries using sales prior to the approval within each school rezoning pair. The coefficient reports the mean difference between rezoned and nonrezoned homes within 0.5 miles from the redistricting boundaries. We control for sale year fixed effect. Robust standard errors are clustered at census tract level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Simple *DID* Redistricting Effects by School-Pair

	(1) Bryan Station to Frederick Douglass (6)⟶(5)	(2) Bryan Station to Paul Dunbar (6)⟶(1)	(3) Henry Clay to Frederick Douglass (2)⟶(5)	(4) Henry Clay to Tates Creek (2)⟶(4)	(5) Lafayette to Henry Clay (3)⟶(2)	(6) Paul Dunbar to Lafayette (1)⟶(3)
$Rezoned \times Post$	0.027*	0.063***	-0.009	-0.013	0.031***	-0.010
	(0.013)	(0.015)	(0.016)	(0.027)	(0.007)	(0.010)
Observations	8,706	5,772	5,899	5,209	5,841	4,063
R^2	0.858	0.816	0.862	0.868	0.726	0.907

Notes: This table reports estimates of redistricting effects based on a simple two-period *DID* model. Each column is a separate regression. We drop post-announcement stage sales and group post-approval and post-opening into one period. High school rankings by average ACT score are listed in parentheses. Each column shows a separate regression using sales only from one old school catchment area. House attributes, census tract, elementary school, year and seasonal fixed effects are included. Robust standard errors are clustered at census tract level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: General Equilibrium *DID*, Pooled Sample with High School Dummies before and after Approval of Redistricting

	(1)	(2)	(3)	(4)
Henry Clay Pre	0.191***	0.151***	0.110***	0.107***
	(0.044)	(0.039)	(0.032)	(0.029)
Lafayette Pre	0.113***	0.077***	0.034	0.006
	(0.028)	(0.027)	(0.029)	(0.030)
Paul Dunbar Pre	0.157***	0.123***	0.109***	0.098***
	(0.033)	(0.024)	(0.021)	(0.022)
Tates Creek Pre	0.073**	0.044*	0.020	0.020
	(0.029)	(0.023)	(0.023)	(0.022)
Henry Clay Post	0.247***	0.199***	0.219***	0.161***
	(0.053)	(0.048)	(0.054)	(0.048)
Lafayette Post	0.186***	0.148***	0.162***	0.097***
	(0.034)	(0.032)	(0.032)	(0.032)
Paul Dunbar Post	0.167***	0.126***	0.130***	0.092***
	(0.046)	(0.035)	(0.035)	(0.032)
Tates Creek Post	0.114***	0.075***	0.083***	0.071***
	(0.034)	(0.027)	(0.027)	(0.024)
Frederick Douglass Post	0.117***	0.084***	0.093***	0.057**
	(0.036)	(0.029)	(0.028)	(0.026)
Observations	26,908	26,908	26,908	22,949
R^2	0.794	0.809	0.811	0.817
House attributes	✓	✓	✓	✓
Tract attributes		✓	✓	✓
Time-varying attributes			✓	✓
Elementary school				✓
Year & Season FE	✓	✓	✓	✓

Notes: This table reports estimates based on Equation (13). We include all sales except those between announcement and approval day. Old schools represent the school zones before approval of the plan and new schools represent the school zones after approval of the redistricting plan. Column (1) includes house attributes and column (2) adds census tract demographics. Column (3) further controls for these time varying attributes. Column (4) adds elementary school performance. Year and seasonal fixed effects are included in all regressions. Robust standard errors are clustered at census tract level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Redistricting Effects by Pooling School Pairs in Difference-in-Differences

	(1) Log sale price
Bryan Station - Frederick Douglass	0.065**
	(0.029)
Bryan Station - Paul Dunbar	0.025***
	(0.021)
Henry Clay - Frederick Douglass	0.137***
	(0.040)
Henry Clay - Tates Creek	0.033
	(0.021)
Lafayette - Henry Clay	0.129*
	(0.066)
Paul Dunbar - Lafayette	0.157***
	(0.034)
Bryan Station - Frederick Douglass×$Post$	-0.014
	(0.011)
Bryan Station - Paul Dunbar×$Post$	0.058***
	(0.009)
Henry Clay - Frederick Douglass×$Post$	-0.017
	(0.021)
Henry Clay - Tates Creek×$Post$	0.027**
	(0.012)
Lafayette - Henry Clay×$Post$	0.060***
	(0.018)
Paul Dunbar - Lafayette×$Post$	0.003
	(0.022)
Observations	22,949
R^2	0.818

Notes: This table reports estimates of redistricting effects based on the pooling regression that includes old school-new school fixed effect. Time-varying effect for school redistricting pairs are represented by the interactions. Elementary school quality is also included. We drop post-announcement stage sales and group post-approval and post-opening into one period. Robust standard errors are clustered at census tract level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Redistricting Effects from School Dummies Regression and Difference-in-Differences Regression

	(1) Bryan Station to Frederick Douglass (6)⟶(5)	(2) Bryan Station to Paul Dunbar (6)⟶(1)	(3) Henry Clay to Frederick Douglass (2)⟶(5)	(4) Henry Clay to Tates Creek (2)⟶(4)	(5) Lafayette to Henry Clay (3)⟶(2)	(6) Paul Dunbar to Lafayette (1)⟶(3)
Panel A.						
School Dummies with GE	0.057^{**}	0.092^{***}	-0.105^{**}	-0.090^{*}	0.064	0.005
	(0.026)	(0.032)	(0.053)	(0.050)	(0.044)	(0.037)
Panel B.						
DID without GE	-0.014	0.058^{***}	-0.017	0.027^{**}	0.060^{***}	0.003
	(0.011)	(0.009)	(0.021)	(0.012)	(0.018)	(0.022)

Notes: This table reports estimated differences between schools using coefficients from school dummies regression column (4) in Equation (13) Table 7 and DD estimates for rezoning effects under no general equilibrium effect in Equation (14) Table 8. Column (1) and (2) are coefficients from Frederick Douglass Post and Paul Dunbar Post. Columns (3) to (6) are differences between estimated coefficients of corresponding schools in which robust standard errors are bootstrapped with 100 repetitions. Robust standard errors are clustered at census tract level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: *DID* Hedonics with Continous Measures of School Quality

	(1) Pre	(2) Post	(3) All Time-Varying	(4) Only ACT
% White student	-1.849***	-1.333***	-1.881**	
	(0.530)	(0.191)	(0.911)	
% Black student	-1.046*	-0.776***	-1.087	
	(0.574)	(0.229)	(0.813)	
% Hispanic student	-1.953***	-1.446***	-2.003*	
	(0.676)	(0.231)	(1.131)	
% Lunch program	-0.297	0.220**	-0.300	
	(0.181)	(0.090)	(0.271)	
Student-Teacher Ratio (STR)	0.011	0.001	0.011	
	(0.007)	(0.003)	(0.012)	
% behavior	-0.061*	-0.161**	-0.063**	
	(0.032)	(0.081)	(0.031)	
Grad rate	-0.108	0.844***	-0.078	
	(0.207)	(0.138)	(0.268)	
Elementary proficiency	0.002***	0.003***	0.002***	
	(0.000)	(0.000)	(0.001)	
ACT	0.004	0.025***	0.002	0.040***
	(0.016)	(0.003)	(0.023)	(0.006)
Post×% White student			0.544	
			(0.861)	
Post×% Black student			0.305	
			(0.898)	
Post×% Hispanic students			0.552	
			(1.078)	
Post×% Lunch program			0.521*	
			(0.298)	
Post×STR			-0.010	
			(0.012)	
Post×% Behavior			-0.098	
			(0.153)	
Post×Grad rate			0.922***	
			(0.347)	
Post×Elementary			0.001*	
			(0.001)	
Post×ACT			0.024	-0.002
			(0.027)	(0.003)
Observations	4,908	18,041	22,949	22,949
R^2	0.835	0.811	0.816	0.788

Notes: This table shows hedonic estimation of ACT scores and its impact on housing prices. Columns (1) and (2) are two cross-sectional regressions using sales from pre and post periods separately. Column (3) combines the first two columns in one regression where we allow all attributes to change over time by interacting them with the *Post* dummy. Column (4) excludes all school characteristics and neighborhood demographics except the ACT score. *Post* = 1 if houses were sold after the approval date. Sales between announcement date and approval data are dropped. House attributes are omitted in the reported table for space saving purpose. Year and seasonal fixed effects are included. Robust standard errors are clustered at census tract level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Capitalization of Rezoning Using Post-Approval School Dummies and School Characteristics

	(1) Bryan Station to Frederick Douglass (6)⟶ (5)	(2) Bryan Station to Paul Dunbar (6)⟶(1)	(3) Henry Clay to Frederick Douglass (2)⟶(5)	(4) Henry Clay to Tates Creek (2)⟶(4)	(5) Lafayette to Henry Clay (3)⟶(2)	(6) Paul Dunbar to Lafayette (1)⟶(3)	(7) Total
A. No. houses	7,912	1,291	2,783	1,633	2,066	2,384	18,069
B. Avg assessed value in 2013	$164,262	$121,033	$248,370	$118,458	$210,912	$122,690	
C. % change in sale price Model 1	5.70%	9.20%	-10.50%	-9.00%	6.40%	0.50%	
D. Discrete (mil)	$74.08	$14.38	-$72.58	-$17.41	$27.89	$1.46	$27.82
	[$18.32, $129.83]	[$6.13, $22.63]	[$-133.02, $-12.13]	[-$33.37, $-1.45]	[-$3.57, $59.52]	[-$16.39, $19.32]	[-$162.08, $217.72]
E. % change in sale price Model 2	-1.40%	5.80%	-1.70%	2.70%	6.00%	0.30%	
F.DD without GE (mil)	-$18.19	$9.06	-$11.75	$5.22	$26.14	$0.88	$11.36
	[-$41.78, $5.39]	[$6.74, $11.38]	[-$35.70, $12.20]	[$1.39, $9.05]	[$13.20, $39.09]	[-9.74, $11.49]	[-$65.89, $88.61]
G. ACT difference Post	0.33	4.21	-3.30	-1.05	0.05	-0.63	
H. % change in ACT Only Model	1.13%	14.32%	-11.23%	-3.58%	0.18%	-2.14%	
I. ACT (mil)	$14.69	$22.38	-$77.62	-$6.93	$0.78	-$6.26	-$52.96
	[$10.00, $22.83]	[$15.24, $34.78]	[$-120.66, -$52.85]	[-$10.76, -$4.72]	[$0.53, $1.22]	[-$9.73, -$4.26]	[-$115.38, -$3.00]
J. % change in ACT + Demo Model	5.28%	8.74%	-5.80%	-3.46%	4.18%	-1.84%	
K. ACT + Demo (mil)	$68.62	$13.66	-$40.11	-$6.70	$18.22	-$5.37	$48.31
	[$5.18, $132.06]	[$5.27, $22.04]	[-$51.68, $-28.54]	[-$10.24, -$3.16]	[-$15.22, $21.21]	[-$6.85, -$3.90]	[-$43.08, $139.70]

Notes: This table shows the welfare measures of school redistricting. Each column is a school-pair rezoning. Row C uses coefficients from Table 9. Row G shows the average ACT scores differences between two schools post redistricting. Rows D, F, I, and K show the predicted property value changes based on rezoning estimates by multiplying rows A, B, and the corresponding percentage changes. Row H uses coefficients for ACT and *Post*× ACT from column (4) Table 10. Row J uses coefficients of ACT and demographics from column (3) Table 10. 95% confidence interval is in bracket.

Appendices

A Additional Figures

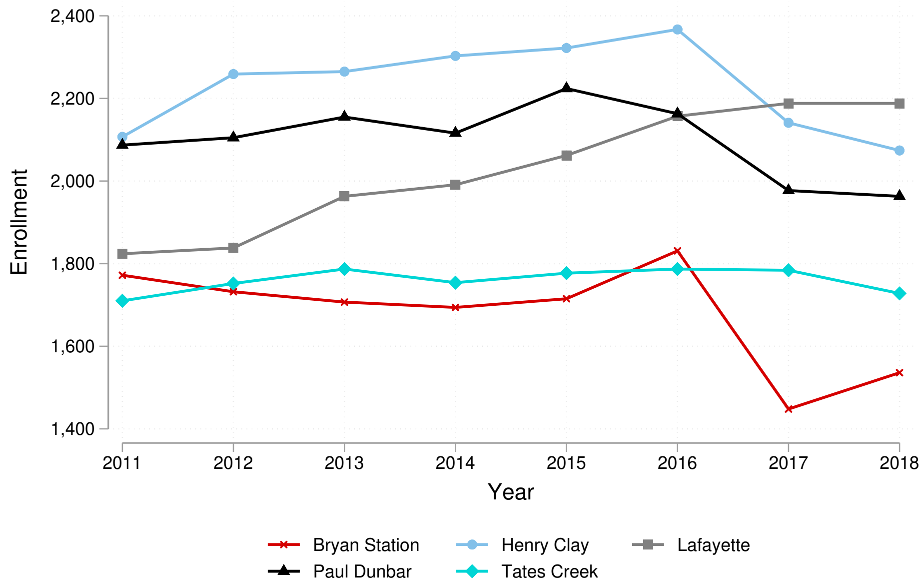


Figure A1: Annual Enrollment in Fayette County High Schools

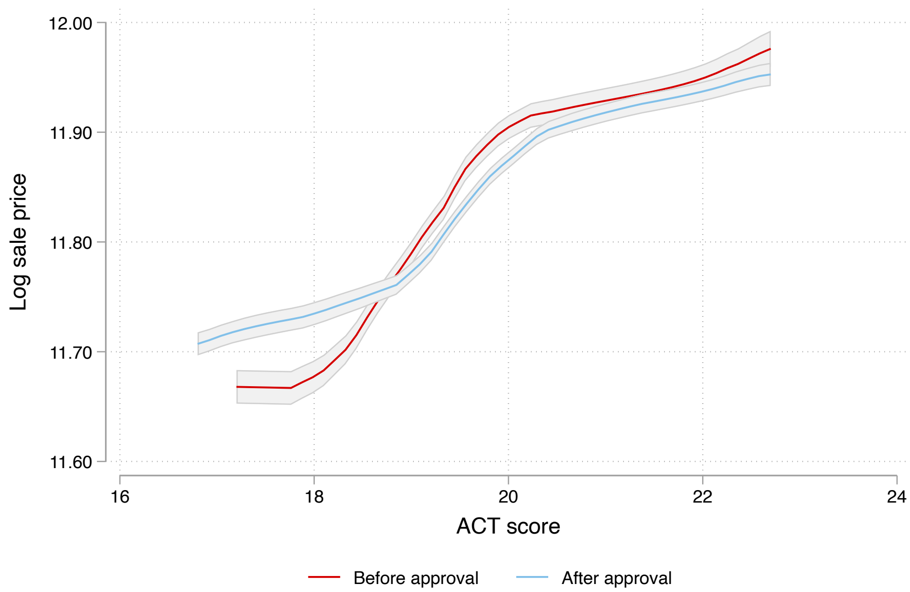


Figure A2: Hedonic Price Functions before and after Approval

Notes: This figure plots the hedonic price functions of school quality for sales before and after approval of the redistricting plan separately using local polynomial regressions. Shaded areas are 95 percent confidence interval bands.

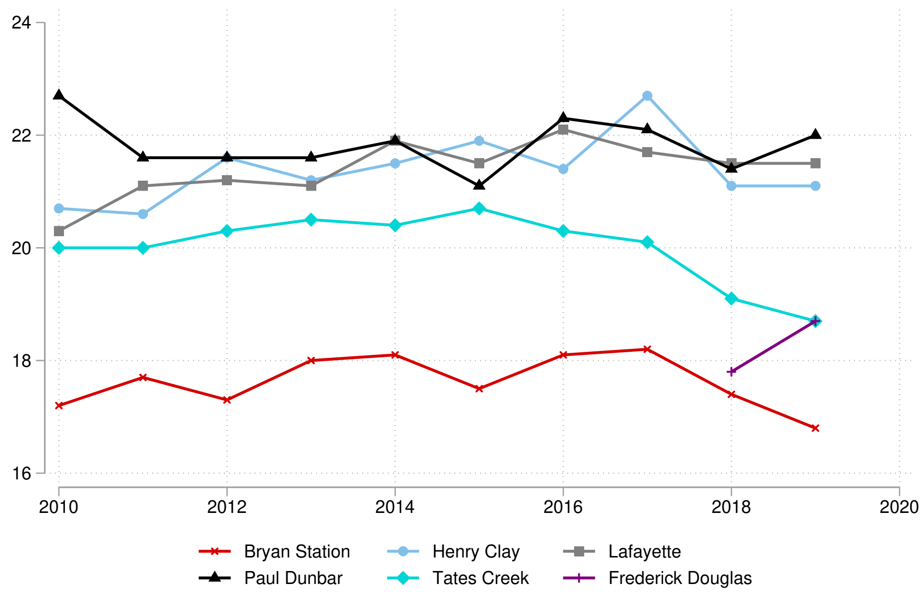


Figure A3: ACT Composite Scores by High School Catchment Area and Year

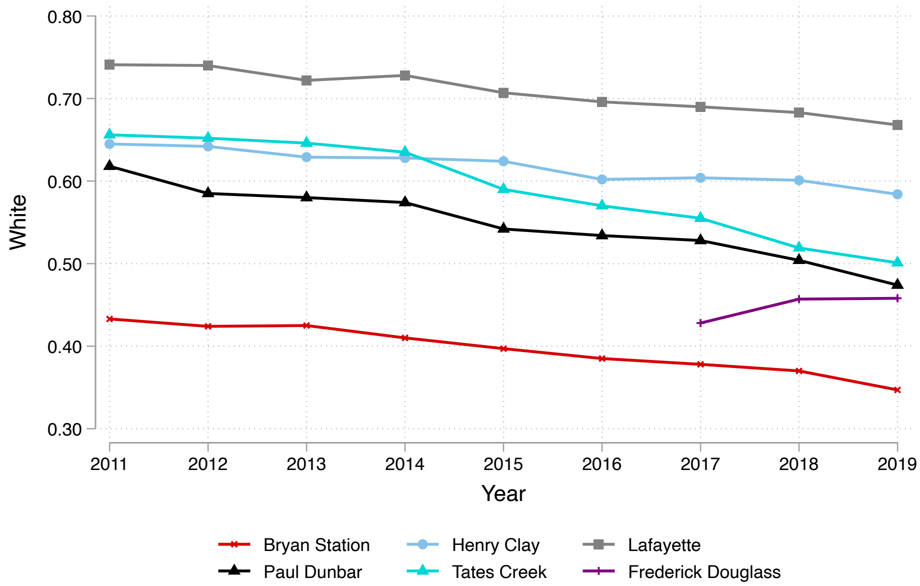


Figure A4: Percent of White Students

Notes: This figure plots the percentage of white students in each high school.

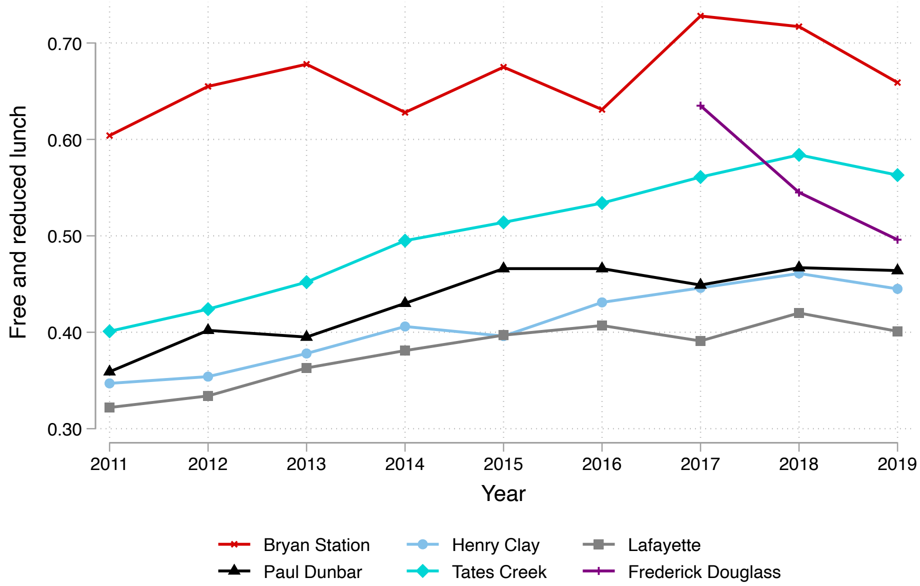


Figure A5: Percent of Free and Reduced Lunch Students

Notes: This figure plots the percentage of students participating in the lunch program.

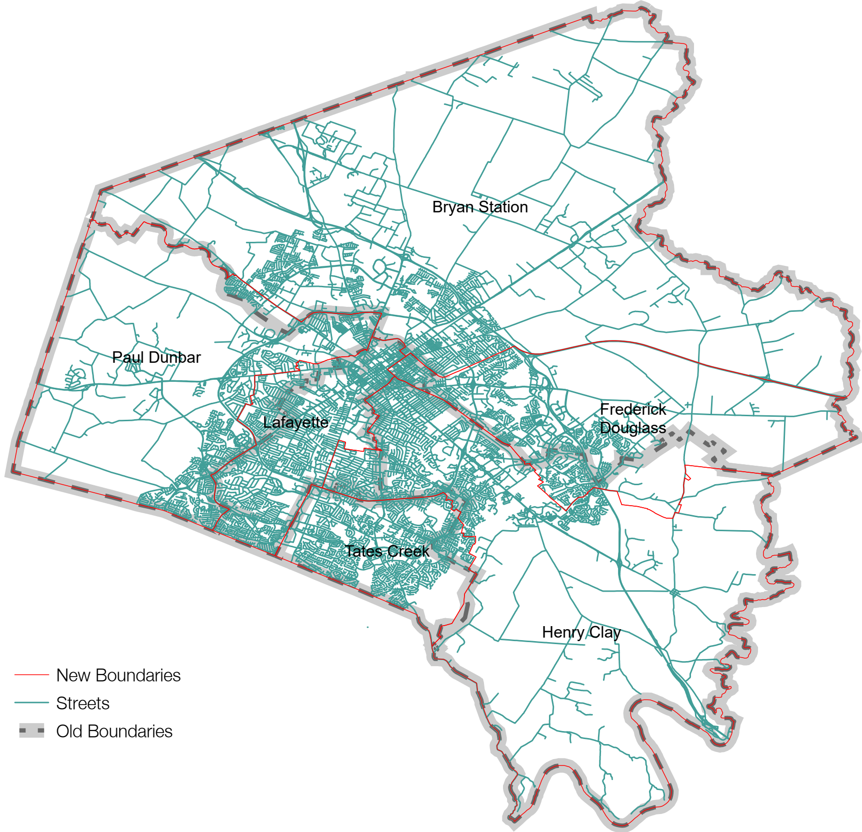
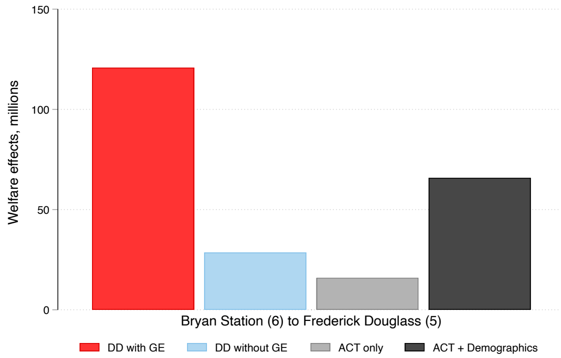
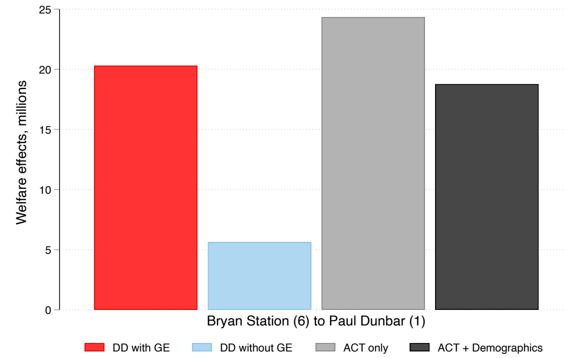


Figure A6: School Boundaries and Streets

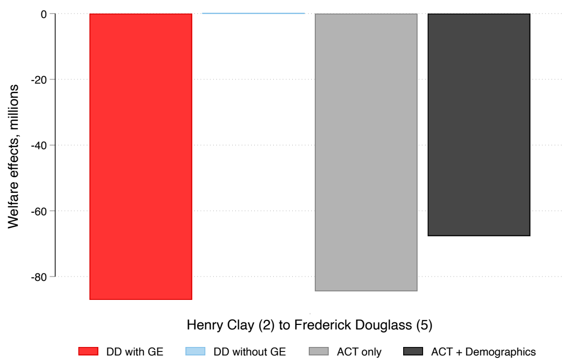
Notes: This figure shows the overlap of old and new school boundaries and main streets in Fayette County, KY.



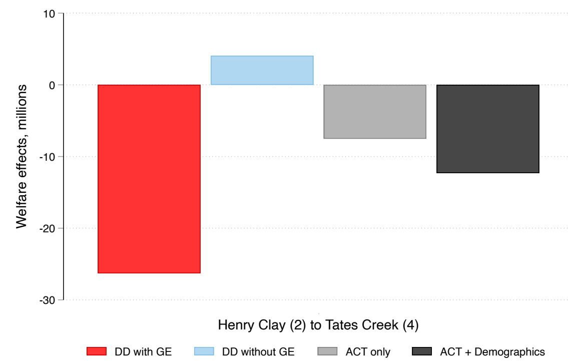
(a) Bryan Station (6) to Frederick Douglass (5)



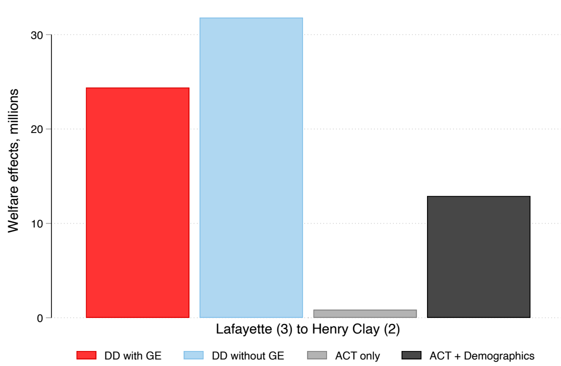
(b) Bryan Station (6) to Paul Dunbar (1)



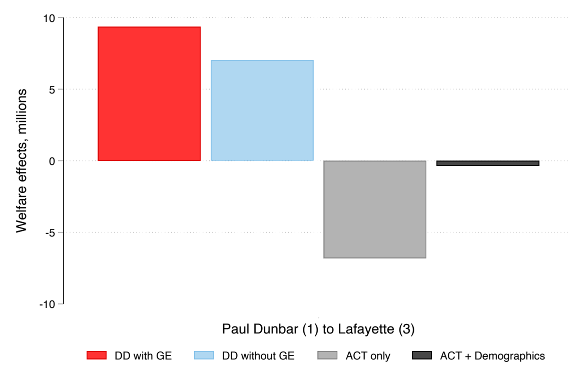
(c) Henry Clay (2) to Frederick Douglass (5)



(d) Henry Clay (2) to Tates Creek (4)



(e) Lafayette (3) to Henry Clay (2)



(f) Paul Dunbar (1) to Lafayette (3)

Figure A7: Welfare Effects for Each School Rezoning Pair

B Additional Tables

Table B1: Percent of Rezoned Homes

	Percent of rezoned homes
Bryan Station	39.87%
Henry Clay	22.77%
Lafayette	18.38%
Paul Dunbar	19.39%
Tates Creek	2.31%

Notes: This table shows percentage of rezoned homes in each original school zone prior to the redistricting.