Putting the Time into Transportation Costs

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How do transportation costs influence the individual decision to vote? In past research, transportation costs are measured by the physical distance from a voter's residence to their polling place. Existing research demonstrates that voters who live further from their polling place are less likely to vote. However, distance-based measures of transportation costs suffer from validity concerns: the same distance can take a different amount of time to travel, and the real cost voters face on election day is the time it takes them to get to the polling place, not the amount of space they have to travel. Drawing on actual travel times for a sample of Philadelphia voters on the day of the 2024 presidential election, I find that voters substitute mail-in and absentee method for in-person voting when their travel times to the polls are high. The model fit of the time measurement of transportation cost is also superior to the model fit of the distance measure. The results suggest that transportation costs measured by distance suffer from validity issues by excluding impedance measures that travel time measures can capture .

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INTRODUCTION

A basic finding in the study of voter turnout is that people vote more often when it is easier to vote (Downs 1957). There are many costs to voting: whether one needs to take time off work to vote, whether someone needs to show voter identification, or how difficult it is for someone to learn about the candidates on the ballot. Another cost voters face is the difficulty of journeying to the polls, often called the transportation costs of voting. (Gimpel and Schuknecht 2003; Haspel and Knotts 2005; Dyck and Gimpel 2005; Gimpel et al. 2006; McNulty et al. 2009; Brady and McNulty 2011). Evidence suggests that even small increases in the distance between a voter's residence and their precinct is associated with decreases in the probability of turnout (Gimpel and Schuknecht 2003; Haspel and Knotts 2005; Dyck and Gimpel 2005; Gimpel et al. 2006; McNulty et al. 2009; Brady and McNulty 2011). As distances increase, voters also select voting methods that remove the costs of travel, such as absentee voting (Dyck and Gimpel 2005; Brady and McNulty 2011).

Scholars generally measure these costs via the distance between a voter's home and their polling place.[1] While this traditional measure benefits from its intuitiveness and simplicity, it obscures an important context: not all equal distances take the same time to travel. A measure of transportation costs that approximates the effort required to mitigate the distance from the real street network to the voter's precinct location is more representative of unique transportation costs at the individual level. When a trip to the polls takes more time—because of traffic, the number of stop signs or stoplights, or construction—a voter should be less likely to vote in person.

I build on past research of transportation costs in the calculus to vote by developing a time-based rather than distance-based measure. My time-based approach offers a deeper look at the changing traffic conditions, transportation infrastructure, and road-network distance an individual voter must mitigate on Election Day. The time-based measure is meant to capture the real-world measures the

[1] Often, studies of distance and turnout leverage distance measures such as a straight-line, "as the crow flies" measurement (McNulty et al. 2009, Brady and McNulty 2011). Other studies have worked to complicate the measurement, adding approximations of impedance measures and distance measures that follow the segments of the street network between the origin of a voter's address and their precinct (Gimpel and Schuknecht 2003; Haspel and Knotts 2005).

individual faces on their own commute to polling locations, which adds additional costs to the voter that are excluded in distance measures. I demonstrate that, by including these factors, the time-based measure is a more valid measure of transportation costs than distance alone.

Using data from the Pennsylvania Voter File and Precinct locations for Philadelphia County and the Google Distance API, I calculate the driving travel time for a sample of 48,295 registered voters in Philadelphia on the day of the 2024 presidential election. I find that higher distances between voter residential addresses and their assigned precinct location deters voting in-person. Comparatively, the time-based measurement of transportation costs creates a better model fit in estimating the substitution effect of voter methods. Ultimately, higher travel times deter the individual voter from selecting an in-person vote and increase the substitution of mail-in and absentee methods. I conclude that voters do select voting method based on the travel time between their residential address and precinct

This project contributes to three ongoing puzzles in American politics. First, the research contributes to the turnout literature and the costs to vote by providing a more valid measure of individual transportation costs that were previously only approximated by measures of distance. Second, the research contributes to the turnout literature by identifying sources of cost variation at the individual-level, and the neighborhood level. Third, the literature on election laws and mobilization can benefit from this project, as we are able to comprehend the impact of in-person voting requirements on voter turnout, and the possible benefits of voter convenience laws that permit voters to "opt out" of costly commutes to the polls.

THE COSTS OF VOTING

Dating back to Downs (1957) and Ricker and Ordeshook (1968), scholars have generally thought of political participation as a function of the probability a voter will be pivotal in an election, the "reward" the potential voter would receive if her preferred candidate wins on election day, the cost of political participation, and a voter's sense of civic duty. Generally speaking, people are more likely to vote when the perceived reward is higher, when the costs of voting are lower, and when they have a greater sense of civic duty (Blais 2000, Feddersen and Sandroni 2006). Outside of the rational choice framework, the literature identifies any barrier to vote as a cost. Whenever a cost increases, the probability of participation decreases.

Motivated by the understanding that even "tiny variations in cost have tremendous effects on the distribution of political power" (Downs 1957), scholars have conceptualized the "costs" of political participation in a variety of ways (Wolfinger and Rosenstone 1980; Rosenstone and Hansen 1993; Highton 2006; Sondheimer and Green 2010; Burden et al. 2013; Citrin et al. 2014). For example, information costs describe the obligation of understanding the "rules of the game," such as where and when to register, voter ID requirements, and which candidates to vote for (Wolfinger and Rosenstone 1980; Rosenstone and Hansen 1993; Sondheimer and Green 2010; Burden et al. 2013; Citrin et al. 2014). Search costs impose a requirement to find a precinct, which is subject to change for certain voters. (McNulty et al. 2009; Brady and McNulty 2011). The time commitment to voting is also an important cost. Factors such as long lines and backed up voting machines create a high enough inconvenience for voters and impact voter turnout (Highton 2006). Even inconveniences outside of human control such as bad weather can create high enough costs that discourage voter turnout (Gomez et al. 2007).

Another type of cost is the journey to the polls, or the transportation costs of voting. (Gimpel and Schuknecht 2003, Haspel and Knotts 2005; Dyck and Gimpel 2005; Gimpel, Dyck, and Shaw 2006; McNulty, Dowling, and Ariotti 2009; Brady and McNulty 2011). Evidence suggests that even small changes in the distance between a voter's residence and their precinct dissuades voters (Gimpel and Schuknecht 2003, Haspel and Knotts 2005; Dyck and Gimpel 2005; Gimpel, Dyck, and Shaw 2006; McNulty, Dowling, and Ariotti 2009; Brady and McNulty 2011). Dyck and Gimpel (2005) studying the 2002 midterm election in Clark County find that increased distance affects voting method, motivating voters to select an absentee option over an in-person option. The choice to replace in-person voting with absentee voting suggests that voters are aware of their own high transportation costs and effectively select an option that removes those transportation costs. Perhaps absentee voting has become the choice of habitual voters, who are determined to complete their civic duty, and also have the knowledge of experience to consciously choose a voting method that is less costly (Plutzer 2002). Brady and McNulty (2011) also find that voters are sensitive to distances when choosing their voting method. As distances increase, voters are less likely to vote in person, and more likely to substitute mail-in or absentee options. In short, scholars have amassed a variety of evidence that people become less likely to participate in politics when it is harder to do so. While this cost has been conceptualized in many ways, the physical cost of getting to the polls has emerged in the past twenty years as a major potential determinant of voter participation. But is distance the best approximation of the effort required to travel?

The turnout literature has relied on different examples of distance measures to approximate transportation costs, and there is a notable tradeoff between computational efficiency and measurement error for each.[2] Boeing (2019) exclusively studies the "circuity" of cities, the ratio of straight-line to network-based measures of distance across 40 cities. His study left strong conclusions about the pitfalls of opting for non-network-based measures of distance. On average, the straight-line measures across the cities were at least 14% shorter than the true network difference, and for certain routes, the network measure was a length 50% or greater than that of the straight-line measure (Boeing 2019). Boeing (2019) cites that the design, topography, and transportation technologies of cities vary greatly, a difference that non-network measures cannot capture. There is a strong emphasis on the importance of operationalizing network-based distances or even travel times on the network in place of the biased measures that has not received adequate attention in the voter turnout literature (Boeing 2019).

I argue for the same concern of measurement error and strive for accuracy in political science as in applied fields. The growth in computational methodology and measurement obligates that we acknowledge when measurement can be improved. Additionally, we are missing an opportunity to study variation in costs and turnout that could deepen our comprehension of turnout. Even the most precise measurement of distance using the street network for a directed route does not include impedance measures. If time obstacles like high traffic density are a deterrent to voting, or redirect voters to convenience methods, then we are missing an important piece of the set of transportation costs the individual faces when voting. In finding that simplistic measurement strategies have significant effects on turnout, a natural next step is to discover what variation we are able to study at the individual-level with more precise measurement.

[2]See Appendix for a review of the distance measurements leveraged in the turnout literature.

THE IMPORTANCE OF IMPEDANCE AND TIME SENSITIVITY

The existing approaches to measuring distance vary in the algorithms they use, but they all assume that an equal distance is a uniform cost regardless of where, geographically, that distance is located. Each voter lives in a unique place designed with variable transportation infrastructure. Any distance-based measure of transportation costs lacks information about the difficulty of travel a voter faces as they consider whether to travel to the polls.

In transportation engineering and traffic flow optimization, route evaluations also include impedance measures. As defined previously, impedance measures capture an element of the route that slows movement (Esri GIS Dictionary 2025). Examples include transportation infrastructure differences, such as one-way roads or traffic lights, and traffic density. Impedance measures are the reason why a five-mile drive in a quiet suburb is a different experience than a five-mile drive in the downtown of a major city or in a rural area.

Physical distance is one way to quantify the amount of effort a voter must expend to get to and from their polling place, but it suffers from the drawbacks noted above. What a human perceives during a commute is not just the distance, but rather the time spent sitting in the car, stopped in traffic, pauses at lights, and an overall comprehension that some commutes are more tedious than others because they demand more time-not more distance. I argue that the amount of time it takes to travel to the polling place, not just the physical distance, provides a more valid measure of the transportation cost of voting. Additionally, a time-based measure accounts for differences in the effort necessary to traverse the same distance with different impedance measures.

A selection of studies on the transportation costs of voting do include impedance measures to account for geographical differences in commutes. Gimpel and Schucknecht (2003) approximate a measure of impedance via residential density between precinct locations and the centroid of voter districts in their model. In this case, higher residential density is assumed to increase the amount of traffic and therefore impede travel for the voters in their district. This approach is a meaningful attempt to incorporate information about traffic flows and the influence of place on commuting experiences.

However, the authors make a major assumption that residential density can proxy traffic density. While it is reasonable to assume traffic density is higher where there are higher volumes of people, it is extreme to replace traffic flow information with residential density. Consider for example a residentially dense neighborhood in a city where most residents do not own a car and commute by foot or public transportation and do not contribute to car traffic. The use of centroids also forces the authors to collapse individual-level data to the precinct level.

Gimpel et al. (2006) operationalize a variable for the percent of voters in a neighborhood that must commute 60 minutes or more to work, defined as time sensitivity. A higher percent of residents with a commute time over 60 minutes is an indication of a neighborhood of voters accustomed to long commutes, and less sensitive to poll changes that demand a further travel distance. Gimpel (2006) makes strides in considering the difficulty of navigation depending on place and impedance measures that affect an individual's commute on the road network. Yet individual-level variation in unique impedance measures on the road network are lost in this research design, as the measures are based on aggregate measures at the neighborhood-level.

To date, there have been a range of distance measures implemented in studies of transportation costs and the effect on voter turnout. In studies so far, notable attempts have been made to include impedance measures and time sensitivity to achieve a more specific measure of transportation costs (Gimpel and Schuknecht 2003; Gimpel et al. 2006). Although these studies are fundamental to our understanding of transportation costs and the simple fact that the physical journey to the polls does impact decision making, the current measurement strategy of transportation costs is limiting. A better measure would capture individual-level differences in routes, impedance measures and their variation depending on place, and capture the time requirement for the commute.

THEORY: TIME AND THE TRANSPORTATION COSTS OF VOTING

This discussion suggests that distance-based measures do a poor job of validly measuring the transportation costs of voting. Therefore, assessments of the transportation costs of voting should emphasize the time voters must take to get to the polling place, not simply the distance they must travel to arrive at the polls. There are at least three reasons why a time-centric measure of transportation costs is superior: psychological implications, impedance, and time sensitivity.

First, psychologically, people often speak about distance in terms of time. The human experience and commitment of travel is best described by the time commitment it takes to get from point A to point B. When a commute is described by a distance, it is to communicate the time it will take to complete, because each unit of distance demands more time from the commuter. More concisely, trips with a longer distance are discouraging to personal travel, because they are indicative of a higher time commitment. As the time commitment increases, the more likely the commuter can see the opportunity costs of travel versus other activities in their lives. What is important about traveling is how much time a distance takes people to traverse. I argue that a trip summarized by its distance communicates nearly no information without understanding roughly how much time that distance will take to traverse. Measuring this time commitment rather than the distance should be a more valid measurement strategy of transportation costs, because time is the direct cost of traveling a given distance. Psychologically, distance is an indirect measure of the human cost of travel, that we only comprehend under a mental conversion to units of time.

Second, impedance includes forces that make travel more difficult for a specific location. It is precisely because of impedance that some commutes are more difficult to complete than others. Impedance explains why you may have learned to only commute to certain parts of town at specific times of the day, and why there may be areas you choose to avoid all together. What impedance measures add up to are an overall travel time, which explains exactly how much time the individual must dedicate to travel instead of on another task or for leisure. Because impedance is variable from place to place, commutes that are equidistant can vary greatly in costs when a time measurement is operationalized instead.

Third, I recognize time sensitivity. While some trips might have a high distance measure, possibly indicating a higher travel time, certain individuals might be more sensitive to time than others. Some people may for example live in a location where they frequently make trips that require more time. A trip such as the route to their voting precinct from their house might be less discouraging, even if it has high transportation costs if they are less sensitive to the time constraints of traveling. A person who is not used to these higher travel costs might be more time sensitive and decide that trips with high travel time are too costly.

Although I do not approximate a measure of time sensitivity for the voters in my case study, building a time measure establishes an avenue for future research, where we might consider individual conditions that influence attitudes toward travel and high transportation costs. Because distance measures exclude impedance measures and do not consider cases where a high distance could be completed in a short amount of time, we are limited in studying unique time sensitivities to travel. Given a measure of the time it would take a voter to arrive at the polls, increased time to the polls should be associated with an increased cost of voting. Since the probability of in person voter participation should decrease as transportation costs increase, all else equal, the probability of voting should decline. Therefore:

H1: As travel time increases, voters will be less likely to cast a vote in person.

Next, I will consider methods of voter turnout. In many places, voters can opt to cast a mail in or absentee ballot before election day instead of traveling to the polls on election day to vote. Transportation costs should also affect the probability that these alternative vote methods—which voters can do from home without needing to travel to the polls—are selected. These methods are considered "convenience methods" of voting in the Cost of Voting Index (COVI), because of the release from travel they provide for voters in states that provide mail-in and absentee voting (Schraufnagel et al. 2022). If transportation costs are low, it might not be worth the administrative costs to use mail-in and absentee voting options. However, as Brady and McNulty (2011) find in their study of distances to the polls, voters do tend to substitute convenience methods when transportation costs measured by distance are high. I build the same expectation from the time measure of transportation costs.

H2: As travel time increases, voters will be more likely to select mail-in and absentee ballots over in-person voting.

The main argument of my study is that a time-based measurement of the transportation costs between a voter's address and their precinct is more valid than a distance measure. To compare the two measures, I will compare the model fit difference between using the time measurement and distance measurement. It is difficult to compare the measures another way, as the units are different. Specifically, I will compare the BIC of two models fit with the time and distance measures.

H3: Transportation costs measured by time will be a more precise measure than distance, and have a better model fit in predicting voter method.

RESEARCH DESIGN AND DATA

Case Selection

My data come from Philadelphia County, Pennsylvania. When studying voter turnout, a case study of a single election in one county is particularly rewarding in the research design of a new measurement, as employed in this project. There are electoral factors such as the races included on the ballot, the exposure to advertisement, and demographic features of the county that are constant in a study of a single election in a single city. Additionally, there are discrepancies in turnout between different electoral races. For example, presidential elections have higher turnout rates than midterm, primary, and local elections, and different (States United Democracy Center 2024; Hartig et al. 2023). Using a single election in a single county allows me to hold the external factors of geography and the electoral race constant, rather needing to adjust my measures to account for the variance between cities, states, and the type of race.

Of course, the selection of a single election in Philadelphia County has its limitations. It is difficult to argue that election results in Philadelphia County are generalizable to the rest of the state or country. While the case selection is a feasible starting point of a time-based measurement for transportation costs, my analysis and general conclusions are reserved to only Philadelphia County. I also cannot expand my conclusions to elections in general. I use the 2024 General Election, and I do not consider smaller elections. It is difficult to determine if voter method selection is a relic of this election alone, or if high travel times have the same predictive effect of voter method across elections.

Data

I use the full voter file from the Pennsylvania Department of State twice. On October 28th, 2024 (after the final voter registration deadline of October 21), I requested and received the list of all voters in Philadelphia who were registered to vote in the 2024 presidential election. This list included each voter's home address. The Philadelphia City Commissioners office provided me with information on the polling place in each precinct, including the address. After election day, on December 9th, 2024, I received an updated Philadelphia County voter file that contained information about voter turnout in the November 2024 election. Due to resource constraints, I subset the full voter file to a stratified random sample of voter addresses representative of each of the 1703 precinct locations in Philadelphia County. As shown in the Appendix, my sample is representative of the population in the whole voter file.[3] In total, my data includes 48,295 voters from Philadelphia County.[4]

Measuring the Dependent Variable: Voter Turnout

My dependent variable is a categorical outcome of voter method in the November 2024 Presidential Election. Possible voting methods in Pennsylvania include an in-person, absentee, mail-in, and provisional vote. Because I am unable to determine where voters who cast a provisional ballot physically voted on election day, I removed the 536 voters who used that vote method from the dataset. More information on provisional voting in Pennsylvania is included in the Appendix. I also combine mail-in voting and absentee voting. In my study, I view both absentee and mail-in ballots as a method that does not have transportation costs. Because both mail-in and absentee voting allow voters to skip their commute to the polls, I group them together. My dependent voter turnout variable includes three levels in the final analysis: at polls voting, mail in and absentee voting, and not voting. Figure 1 shows the distribution of the sampled voters who used each method that I include in the analysis.

[3] These figures are included in the Appendix.

[4] Because I am unable to determine where voters who cast a provisional ballot physically voted on election day, I removed the 536 voters who used that vote method from the dataset. More information about provisional voters in Pennsylvania can be found in the Appendix. I also found an inaccurate calculation for a collection of voters with the same address, causing extreme values in my distance and time measures. I removed these 59 voters with inaccurate Google Distance calculations.

FIGURE 1. The Distribution of Voting Methods Used in the Study Sample of Philadelphia County Voters in the 2024 presidential election.

Distribution of Voting Methods in 2024 Sample

Characteristic	N	N = 48,295[1]
Voting Method	48,295	
No Vote		16,616 (34.4%)
Vote at Polls		23,012 (47.6%)
Vote by Mail & Absentee		8,667 (17.9%)

[1] n (%)

Measuring the Independent Variable: Distance and Travel Time

The voter file contains the residential addresses for every registered voter in Philadelphia County by the final registration date, October 21st 2024, and I obtained from Philadelphia County election officials the location of the polling place for each precinct. I calculated the estimated drive time between the voter's home address and their polling place using Google Distance API.[5] The precinct address is used as the destination point in my Google Distance API calculations. Voter addresses and their precinct assignments are available in the voter file. I use each voter's address as their starting

[5]The under-the-hood computation of travel times by the Google Distance API can function as either a real-time traffic travel time report, or a predictive travel model based on historical traffic conditions and real-time traffic conditions. I use the predictive model based on two considerations. The first is that my sample of origin and destination points is large enough that the parse time through the API takes several hours to calculate drive times between each point. Therefore, if I began running my code at 6:30am, I would extract times around 6:30am for only the first voters in the script, and the last voters would have reported travel times for 11:30am. The predictive model still incorporates real traffic conditions but allow me to use the same measure and predicted time for each voter rather than analyzing real time traffic data for each voter at different times throughout the day. Second, voters are likely to consider historical traffic patterns themselves. On familiar routes in a familiar neighborhood, it is not likely that a voter will check the real-time traffic conditions of their route but rather will consider where their polling location is and reference from their own experience on how long the commute will be. In this way, it is practical to incorporate historical traffic data and mimic the likely commute calculations.

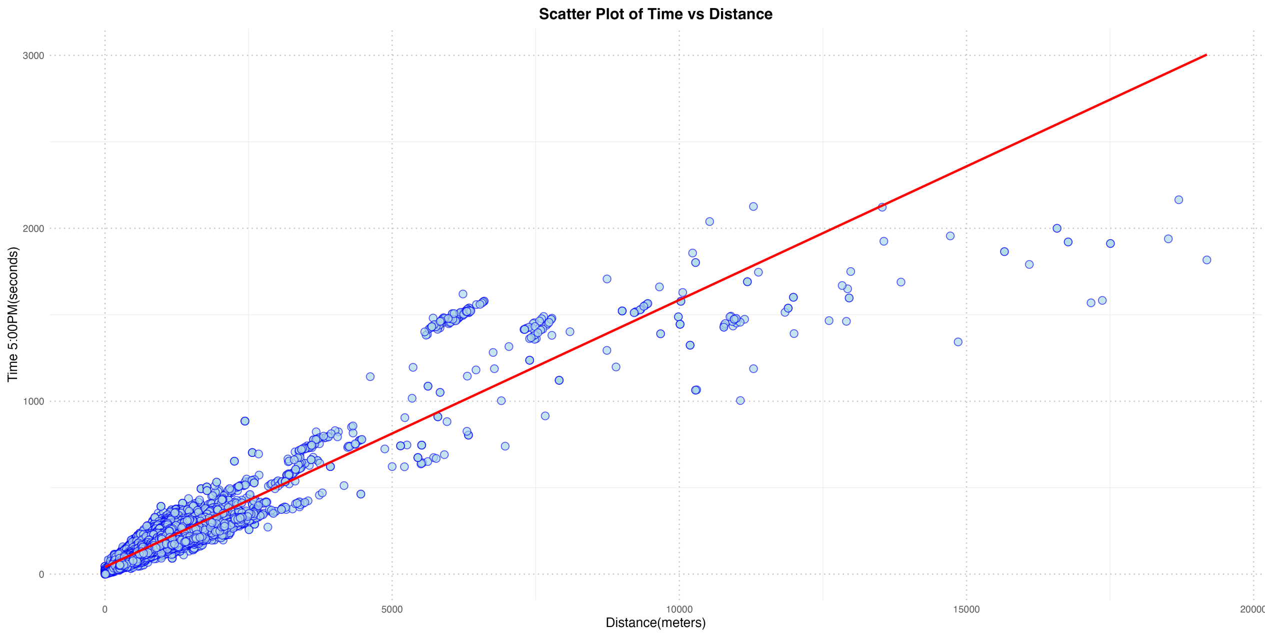
point, then connect them to their precinct destination point to perform the routing distance and time calculations in Google Distance API. Because travel times vary throughout the day, I extracted real drive times between origin and destination points for four selected times of the day. I chose times to capture when traffic is historically high in Philadelphia County, and when the polls are busiest. The common peaks across all regions of the county include the morning peak of 8:00am to 9:00am and the commuter peak of of 5pm-9pm. The polls are open from 7am to 8pm, and so my selected times include 6:30am, 8:30am, 5:00pm, and 7:30pm.[6]

How much, on average, does time of day affect the time it takes voters to get to the polls? Overall, the average voter in my sample lived about 3.0 minutes from their polling location at 5:00pm and about 2.4 minutes from the polls at 7:30pm. On average, Philadelphia County voters are assigned to precinct locations that are a short distance and drive time from their residential address. In the interest of parsimony, I focus my analysis on only the 5:00pm drive times. In the appendix, I provide the results for the 7:30pm drive times, the other time point for which I have data for all Philadelphia County residents in my sample. I compare the drive times to a second measure, Google's measure of the distance, in meters, on the street network between a voter's home and their polling place. The average voter lives 730 meters away from their precinct on the road network.

To what extent do drive times differ from a distance-based measure? Figure 2 plots these two measures of transportation costs. Overall, the correlation between the 5:00pm drive times and distance is high: r = 0.93. As the figure shows, there is a strong positive relationship between the two concepts, there is increasing disagreement between the two measures as distance increases: when distances become large, drive times become more variable.

[6]Before Election Day, I had prepared script in R to complete the four time extracts for my sample of voters to their precinct. Because the connection to the API relies on an internet connection, part of my data collection for the 6:30am and 8:30am travel times was interrupted when my wifi connection went down. I only have data for about 10,000 voters for the 6:30 and 8:30am time. I have data for my complete stratified sample for 5:00pm and 7:30pm.

FIGURE 2. The Correlation Between Sampled Distance Measures and the Travel Time of Commuting that Distance at 5:00pm.Travel Time Varies for Similar Distance Measures based on Location Differences of the Voter and Precinct.



Model Specification

Because the outcome variable has multiple unordered categories, I use multinomial logistic regression to test my hypotheses. The dependent variable, voter method is modeled with three levels for “At Polls” voters, “Mail-In and Absentee” voters, and “No Vote” voters, or those who did not vote in the 2024 Presidential election. “No Vote” serves as my reference category in the model.

I estimate two different models. The first model uses the 5:00pm drive time as the measure of transportation costs. Then, I estimate a second measure using physical distance as the measure of transportation costs. The time-based measurement in seconds and the distance measurement in meters are logged to handle both the right skew of the data and the exponential relationship between each measure and voter outcome. After logging, the time measure in second and distance measure in meters are transformed into a linear relationship for the multinomial logistic models.

My independent variables are sourced from the Pennsylvania Voter File. These include the major party that the voter registered under, age, and sex. Party identification is categorized by Democrat, Independent, Republican, or “Other,” for the voters registered under a smaller party. The Sex identification is self-reported by the voter, and includes Female, Male, Unknown, or a "No Response" for voters who did not report their sex.

FIGURE 3. Summary Statistics of Each Independent Variable Used for Overall Voting Methods, and for Each Voting Method.

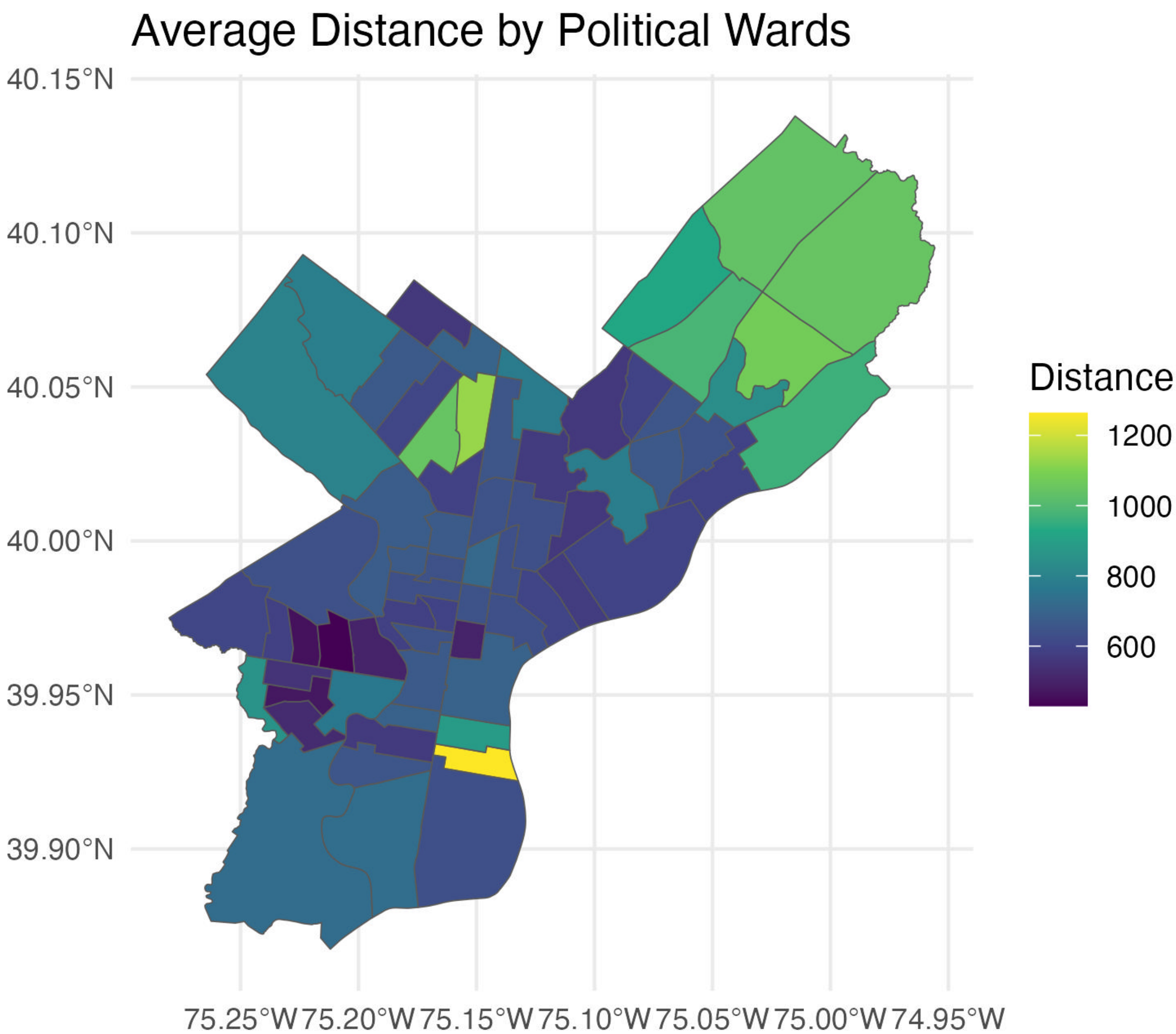
Final Model Sample

	Other (N=7032)	Democrat (N=35110)	Independent (N=349)	Republican (N=5804)	Overall (N=48295)
Sex					
No Response	929 (13.2%)	2071 (5.9%)	5 (1.4%)	382 (6.6%)	3387 (7.0%)
Female	2555 (36.3%)	16942 (48.3%)	154 (44.1%)	2228 (38.4%)	21879 (45.3%)
Male	3096 (44.0%)	12230 (34.8%)	165 (47.3%)	2653 (45.7%)	18144 (37.6%)
Unknown	452 (6.4%)	3867 (11.0%)	25 (7.2%)	541 (9.3%)	4885 (10.1%)
Age (years)					
Mean (SD)	39.8 (15.2)	48.3 (18.3)	47.1 (18.5)	50.3 (18.8)	47.3 (18.2)
Median [Min, Max]	36.0 [19.0, 102]	45.0 [19.0, 108]	44.0 [19.0, 97.0]	49.0 [19.0, 107]	43.0 [19.0, 108]
Distance (meters)					
Mean (SD)	720 (803)	705 (798)	714 (833)	762 (660)	714 (784)
Median [Min, Max]	598 [0, 19200]	587 [0, 18700]	583 [0, 10000]	655 [0, 17200]	596 [0, 19200]
Drive Time (seconds)					
Mean (SD)	154 (131)	151 (134)	152 (138)	152 (101)	151 (130)
Median [Min, Max]	135 [0, 1820]	131 [0, 2170]	130 [0, 1530]	140 [0, 1690]	133 [0, 2170]
Vote Method					
No Vote	3448 (49.0%)	11077 (31.5%)	160 (45.8%)	1931 (33.3%)	16616 (34.4%)
Vote at Polls	2735 (38.9%)	16970 (48.3%)	137 (39.3%)	3170 (54.6%)	23012 (47.6%)
Vote by Mail & Absentee	849 (12.1%)	7063 (20.1%)	52 (14.9%)	703 (12.1%)	8667 (17.9%)

Excludes Provisional voters and 59 voters with incorrect distance calculations from Google Distance API.

Both models include fixed effects for the prospective voter's ward assignment to control for the unobserved differences between voters and the wards they reside in. The Philadelphia County wards are representative of geographic variation that I expect to influence the impedance measures and the overall travel times I will collect. I demonstrate the variation in geography and transportation infrastructure by presenting the average street network distance of the sampled voters in each ward in Figure 4. Note that in the wards that are further from the city center, the average street network distance for voters increases. Other wards have highways or water that make the street network more complex, and lengthen the average street network measures. Ward fixed effects are included in my model by including the ward assignment of each voter as a factor in my regression models to account for examples of geographic and transportation infrastructure differences.

FIGURE 4. A Map of the Average Distance between Sampled Voters and their Precinct in each Ward.



Analysis

Recall that I have three hypotheses: **H1:** As travel time increases, voters will be less likely to cast a vote in person.

H2: As travel time increases, voters will be more likely to select mail-in and absentee ballots over in-person voting.

H3: Transportation costs measured by time will be a more precise measure than distance, and have a better model fit in predicting voter method.

I find that as the logged drive time increases at 5:00pm, the odds of casting an in-person vote instead of not voting decrease by 5.6%. Additionally, as logged time increases, the odds of casting a vote by mail or absentee methods increases by 7.5% compared to not voting. This supports my first and second hypothesis that increases in travel time are deterministic of voter method. The second model uses logged distance instead of logged time to estimate voter method. While the effect directions are the same, the effect sizes are not comparable, given the different units of measurement. As the distance measured in logged meters increases, the odds of selecting an in-person vote over not voting decreases by 3.3%. Voters are 6.0% more likely to select mail-in and absentee methods when their logged distance to the polls increases over not voting . To compare the model fit of the time and distance measures, I compare the two models by their BIC measures. The model with logged time shows a smaller BIC of 95806.065 compared to the logged distance model of 95815.393, indicating that the logged-time model fits the data best. Because there is about a 9-point difference in the BIC scores, I conclude that there is strong evidence that the time measure has a superior model fit over the distance measure (Raftery 1995). The results are presented as odds ratios in Table 1.]'

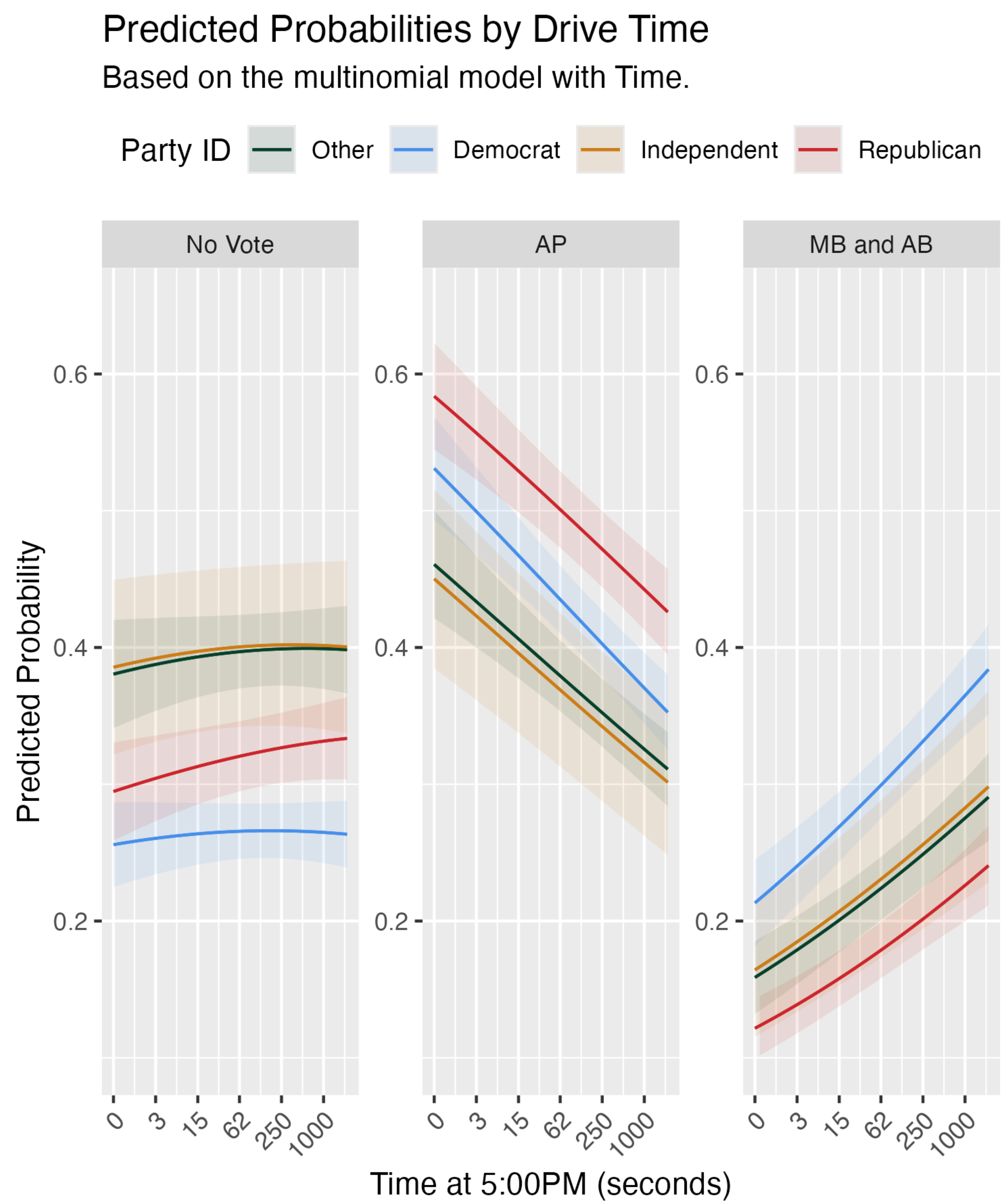
I addition to the multinational regression model, I build a predictive probability plot of voter method conditional on the logged drive times collected at 5:00pm (Figure 5). Although there are intercept differences between political parties and their voting methods, the conclusion that voters are sensitive to time and choose their voting method accordingly holds across parties. I note that Republicans were more likely to vote in person than Democrats, while Democrats were more likely to vote by mail or absentee for all drive times. Yet, the slopes are comparable across all parties, showing that al voters are predicted to substitute in-person voting for convenience methods when transportation costs measured

TABLE 1. Final Model Results of the Time and Distance Measure Multinomial Models.

	Dependent variable:			
	Vote at Polls	Vote by Mail and Absentee	Vote at Polls	Vote by Mail and Absentee
	(1)	(2)	(3)	(4)
Time at 5:00PM (sec)	0.944***	1.075***		
	(0.014)	(0.018)		
Distance (meters)			0.967***	1.060***
			(0.011)	(0.013)
Age (Years)	1.007***	1.030***	1.007***	1.030***
	(0.001)	(0.001)	(0.001)	(0.001)
Democrat	1.714***	1.998***	1.715***	1.999***
	(0.030)	(0.043)	(0.030)	(0.043)
Independent	0.964***	1.021***	0.967***	1.025***
	(0.122)	(0.171)	(0.122)	(0.171)
Republican	1.636***	0.989***	1.637***	0.988***
	(0.040)	(0.062)	(0.040)	(0.062)
Female	2.170***	1.841***	2.169***	1.844***
	(0.042)	(0.057)	(0.042)	(0.057)
Male	1.554***	1.289***	1.554***	1.289***
	(0.042)	(0.057)	(0.042)	(0.057)
Unknown	2.376***	1.381***	2.374***	1.382***
	(0.053)	(0.071)	(0.053)	(0.071)
Constant	0.771***	0.050***	0.716***	0.050
	(0.131)	(0.172)	(0.130)	(0.170)
Ward Fixed Effects	Yes	Yes	Yes	Yes
BIC	95806.065	95806.065	95815.393	95815.393
Number of Observations	48295	48295	48295	48295
Akaike Inf. Crit.	94,505.870	94,505.870	94,515.200	94,515.200
Note:				*p<0.1; **p<0.05; ***p<0.01

by time increase. Republicans are slightly more sensitive to time costs, and are predicted to not vote as logged time increases. However, this sample is taken from the voter file, so it is expected that all voters have a low likelihood of abstaining on Election Day.

FIGURE 5. The Predicted Probability of each Voting Method as Time (in Seconds) increases by Party ID.



DISCUSSION

My empirical findings support my theoretical argument and hypotheses about transportation costs measured by time rather than distance. Specifically, I theorized that measuring transportation costs with a time-based measure would capture impedance measures on the road network that even the most robust measure of distance cannot capture. I also argued that time is a better approximation of the human experience of transportation costs. After collecting the real drive times for voters on Election Day, and the distance of their route to their precinct from their residential address, I speculated that voters with high drive times would choose to vote in-person at their precinct location less frequently than voters with low drive times. I also proposed that voters with high drive times would select mail-in and absentee options over in-person voting to avoid the time commitment required to vote in-person.

My results offer strong support for past findings that transportation costs are an important factor in political participation. Additionally, I find support for my own theory that the measurement of transportation costs ought to be in units of time rather than distance. Because the time measurement includes impedance measures that distance alone cannot approximate, the time-based measure is a more valid and precise way to present the unique costs each voter faces on Election Day.

I fit two multinational models to estimated the odds ratios of a voter choosing to vote in-person and by mail-in and absentee methods compared to not voting at all. Each model shared the same predictors, including Age, Party Identification, and Sex. The only difference between the models was the measure of transportation costs. The first is estimated with a time-based measure taken at 5:00pm versus a stationary distance measure of the street route.

I find that as logged seconds increase, there is a notable substitution effect in which voters opt for mail-in and absentee methods rather than an in-person vote. Because time and distance are so correlated, it is not surprising the distance relays the same information. I could re-write my first and second hypotheses with expectations about the distance measure, and would find the same support for each. As distance increases, I note the same conclusion that I find with time: voters will sub mail-in and absentee methods over in-person voting. However, the model fit for the time measure is superior to the distance measure. The BIC difference between the two models is significant enough to support the claim of a strong difference between the two (Raftery 1995). This supports my third hypothesis that the time measure is superior to the distance measure. I attribute the superior fit of the model using the time distance to the improved measurement of the variability in transportation costs. Because the time measure accounts for all the impedance measurements that even the most precise distance measure will miss, I am able to measure transportation costs at the individual level in a more statistically valid way.

CONCLUSION

In this project, I theorize a more precise measurement of transportation costs in the calculus to vote by considering the importance of time in commutes. I considered traditional ways of calculating transportation costs from the turnout literature, approximated from distance. This project builds on these past measurement strategies by not only using the most precise measure of distance on the road network, but considers the human cost of commuting on the road network by weighting for impedance measures, such as real traffic conditions to form a time-based measure. I find that two voters with the same distance can have different transportation costs when the impedance measures of the commute are included in the time measurement.

Specifically, as the number of seconds recorded increases, the odds that a voter chooses to vote at the polls instead of choosing not to vote decrease by 5. 5%. Additionally, the odds of a voter choosing mail in and absentee voting methods increases by 7.5% compared to not voting as time increases. Overall, a time-based measure of transportation costs was highly predictive of voter method in the Philadelphia County 2024 General Election. The time-based measure also proved to be a more valid estimation of individual transportation costs than distance.

Overall, this project leads to a better understanding of the costs that direct voter's decisions of voting method or voting in general. Refining the measurement of transportation costs to a more variant measure will lead to better answers to questions on who has access to voting, where those voters are, and what factors impede their access to the vote. This study also has policy implications for voting in the states. Where states restrict convenient voting methods for voters who have high travel costs to the polls, there may be sizable decreases in turnout overall. I note that there is a high substitution effect of mail-in and absentee voting compared to in-person voting in this study. This substitution effect also could be indicative of a "learning effect," where those with higher transportation costs have learned to substitute in-person voting with mail-in options. Preconscious ideas, such as the idea that it is costly to vote, can be reformed with learning (Taber and Lodge 2016). Perhaps voter turnout would increase overall if people learn their options to vote and opt out of transportation costs. This has policy implementations for the states who do not permit in-person voting.

Other modes of transportation, such as public transportation, biking, and walking were likely used by voters on Election Day. Especially in the case of Philadelphia County, where voters live close to their polling locations, it would be inaccurate to assume that every voter drove to their polling locations. Instead, I focus only on drive times in this case to study the inclusion of impedance measures on voter turnout compared to a distance measure. In future research, analyzing the impact of the multiple options available to the voter and their impact on turnout and voter method could offer an important understanding of the benefits of extensive transportation options.

I began this project with dissatisfaction in the current measurement strategies for transportation costs. Commuting can be a time-consuming, stressful part of many Americans' days. Yet, I was not confident that a distance measure fully captured the transportation costs involved in commutes. In operationalizing a time-based measure of transportation costs, I am able to estimate the drive time of voters starting from their residence to their polling place and include all measures of impedance that are lost in a distance measure. I find that while both distance and time measures are highly explanatory of voter method, the time measurement strategy does capture more variation in the individual decision to vote than distance. Although I find that the time measurement has more validity than the distance measure, it is not without limitations. One of the largest limitations of the project is that I do not know when voters cast their ballot for the in-person vote.

I used 5:00pm drive times, but a voter could have voted very early in the morning when traffic was low, or in the afternoon. I also do not have data on population subgroups. For example, those with more education obtainment might navigate the process of voting by mail more efficiently and choose this option regardless of time or distance. However, this project raises further questions about transportation and public access to goods. If high transportation costs are enough to steer the voting method of voters in this study, how much does travel time impact access to other goods such as health care facilities, grocery stores, or libraries? Measuring transportation costs with a time-based measure is applicable to any public good that demands a commute for access. This project is pivotal in measuring access to goods at the most primitive step: commuting there.

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APPENDIX

I use the dplyr package in R to take a stratified sample by precinct allocation from the full Philadelphia County voter file that I obtained on October 28, 2024. This was the first version of the voter file available post October 21, 2024, Pennsylvania's final day to register to vote. My sample size was predetermined based on my calculations of what I could pay for in the Google Distance API from a grant award from the Political Science Department at the Pennsylvania State University. I wanted to sample just under 50,000 voters from the file so that I could collect four drive times throughout the day for each voter.

Sampling a proportion size of 0.045 out of the 1,106,115 voters yielded a sample size of 48,936. I checked that the initial sample was representative of the whole voter file by comparing measures I used in my final model: Age, Sex, Party ID. The proportions of all groups were equal in my sample and the population. This sample is what I performed my Google Distance Analysis on.

After Election Day, I obtained the December 9, 2024 version of the voter file, with the reported election results and voting method for the 2024 General Election. I merged the sample I had taken before the election with the post-election voter file. I then check to see that the voters sampled before election day that had the distance and time calculations could be found in the post-election voter file, so I could observe and analyze their voting behavior. I removed 536 voters from my post-election sample who had voted provisionally. I had no information to confirm what their voting method was, and why they were marked as a provisional voter. An example of a provisional vote is an in-person vote cast at the incorrect precinct location. Another case would be voting at the correct location with uncertain eligibility to vote. Because location and voting method are key in my analysis, I do not include provisional voters. I cannot identify their method or voting location.

I also drop 59 voters due to extreme values in their distance and time calculations. I looked up the addresses of these voters and their precinct to confirm that the calculations were incorrect. This error happened systematically for voters at the same few polling locations and could be an error in the Google Distance API. I checked the validity of Google Distance by going through each Ward and randomly choosing a voter. Then, I looked up their address and polling address myself to get the drive time and distance as a validity check. My final sample for analysis included 48,295 voters. This sample is still representative of the whole voter file. In Figures 5 and 6 I demonstrate that the proportion of voters who belong to the groups I include in my analysis are nearly identical between the full voter file and my stratified sample. Note that I did not remove the provisional voters from the full voter file to demonstrate that the final sample of voters are representative of the full voter file on the demographic measures I include in my final models regardless of including provisional voters in the sample.

FIGURE 6. Summary Statistics of the Full Voter File as of December 9th, 2024, organized by voter method used in the 2024 presidential election.

Full Voter File

	No Vote (N=392246)	Provisional Vote (N=12507)	Vote at Polls (N=516409)	Vote by Mail & Absentee (N=195990)	Overall (N=1117152)
Sex					
Female	156371 (39.9%)	6512 (52.1%)	245557 (47.6%)	97316 (49.7%)	505756 (45.3%)
Male	167248 (42.6%)	4552 (36.4%)	183595 (35.6%)	67180 (34.3%)	422575 (37.8%)
No Response	37312 (9.5%)	536 (4.3%)	27678 (5.4%)	11792 (6.0%)	77318 (6.9%)
Unknown	31315 (8.0%)	907 (7.3%)	59579 (11.5%)	19702 (10.1%)	111503 (10.0%)
Age (years)					
Mean (SD)	43.3 (17.2)	44.1 (17.9)	47.1 (17.5)	53.4 (20.2)	46.9 (18.2)
Median [Min, Max]	38.2 [0.413, 143]	39.6 [18.5, 105]	44.8 [18.5, 125]	54.7 [18.5, 110]	42.9 [0.413, 143]
Missing	1 (0.0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.0%)
Party ID					
Democrat	261757 (66.7%)	9124 (73.0%)	379325 (73.5%)	158229 (80.7%)	808435 (72.4%)
Independent	3627 (0.9%)	114 (0.9%)	3072 (0.6%)	1160 (0.6%)	7973 (0.7%)
Other	81039 (20.7%)	2021 (16.2%)	61530 (11.9%)	19983 (10.2%)	164573 (14.7%)
Republican	45823 (11.7%)	1248 (10.0%)	72482 (14.0%)	16618 (8.5%)	136171 (12.2%)

Requested December 9, 2024

FIGURE 7. Summary Statistics of study sample of voters from Philadelphia County, organized by voter method used in the 2024 presidential election. The proportions of each category in this table can be compared to the Full Voter File table in Figure 6 to confirm that the sample is representative of all registered voters in Philadelphia County in 2024.

Final Model Sample

	No Vote (N=16616)	Vote at Polls (N=23012)	Vote by Mail & Absentee (N=8667)	Overall (N=48295)
Sex				
No Response	1650 (9.9%)	1208 (5.2%)	529 (6.1%)	3387 (7.0%)
Female	6633 (39.9%)	10978 (47.7%)	4268 (49.2%)	21879 (45.3%)
Male	6980 (42.0%)	8150 (35.4%)	3014 (34.8%)	18144 (37.6%)
Unknown	1353 (8.1%)	2676 (11.6%)	856 (9.9%)	4885 (10.1%)
Age (years)				
Mean (SD)	43.8 (17.1)	47.3 (17.5)	53.8 (20.3)	47.3 (18.2)
Median [Min, Max]	39.0 [19.0, 108]	45.0 [19.0, 102]	55.0 [19.0, 105]	43.0 [19.0, 108]
Party ID				
Other	3448 (20.8%)	2735 (11.9%)	849 (9.8%)	7032 (14.6%)
Democrat	11077 (66.7%)	16970 (73.7%)	7063 (81.5%)	35110 (72.7%)
Independent	160 (1.0%)	137 (0.6%)	52 (0.6%)	349 (0.7%)
Republican	1931 (11.6%)	3170 (13.8%)	703 (8.1%)	5804 (12.0%)

Excludes Provisional voters and 59 voters with incorrect distance calculations from Google Distance API.

Conceptualizing and Measuring Distance to the Polls

Scholars have operationalized transportation costs in a variety of different ways.[7] The most primitive of these measures is the straight-line (or Pythagorean) distance (McNulty et al. 2009; Brady and McNulty 2011). Here, two points are geospatially located by their longitude and latitude coordinates. The calculation of distance between the two points is an applied geometry problem, where one can solve the straight-line between the two points by considering a right-angled triangle and solving for the hypotenuse. This measure benefits from its simplicity; yet, on a curved surface as large as the Earth, straight-line measures are sufficient for very small measures of distance but quickly accrue errors in distance calculations (Boeing 2019). Moreover, a straight-line distance measure does not account for the network of road infrastructure or geophysical features of the landscape that affect the ease with which potential voters can travel that difference.

A second approach, the Great Circle method, is another computationally convenient approach (Brady and McNulty 2004, 2011). This measure accounts for the curvature of the earth, yet it is prone to error at short distances, where the arc of the sphere's surface is a larger unit of measure than a simple straight line drawn between the two points (McNulty et al. 2009). This is particularly concerning given that most voters live a relatively close distance to their polling place. A third measurement strategy, the Manhattan city block method, constructs a grid (or "blocks") between the voter's residence and their polling place and measures the segments of the grid one would travel between the two points to equate the total distance measure (Dyck and Gimpel 2005; Gimpel and Schuknecht 2003). While this approach improves on the straight-line distance by adjusting for the distance of streets around city blocks, it produces great rounding errors on cities that do not follow a clean grid layout, for example Boston, Massachusetts.[8]

A fourth approach incorporates the transportation system, such as the road network. With

[7] McNulty et al. 2009 compiled a list of distance measures leveraged in the voting turnout literature.

[8] Others (Gimpel et al. 2006; Kinsey et al. 2010) measure distance at the district level. One such approach considers all voters in a district and calculate the center, or "centroid" of that district, then perform a straight-line distance measure to the precinct of that district. The centroid location can be refined by adding geographic attributes to the district to adjust the centroid location around parks or large bodies of water where the residential density is low. However, as a district-level measure, this approach cannot account for variation in distance among

information on the actual paths voters would travel to get from their residence, researchers can compute a shortest distance algorithm between the two points on segments of the road network. For example, Haspel and Knotts (2005) use roads distance, a measure of the distance between origin and destination points on the city streets in their paper. However, to my knowledge, this is the only application of this type of measure in published research on voter behavior.

The choice of what distance measure to operationalize has been based on another calculus of costs: that of the social scientist researcher. Here, the scientist must weigh if the most accurate measure of distance, which is a calculation of the route between origin and destination points on the true street network, is worth the extra work to compute that measure, versus a straight forward, straight-line calculation. McNulty et al. (2009) weigh the utility of calculating each method. They ultimately argue that the easiest computation method, straight-line, does not produce very different measures of distance compared to other methods except for one: the GIS street network-based measure. They argue that this difference is not worth reconciling given the computational demands of the researcher.

In more applied fields such as geography, using any measure of distance that is not based on the travel network is highly critiqued. Boeing (2019) exclusively studies the "circuity" of cities, the ratio of straight-line to network-based measures of distance across 40 cities. His study left strong conclusions about the pitfalls of opting for non-network-based measures of distance. On average, the straight-line measures across the cities were at least 14% shorter than the true network difference, and for certain routes, the network measure was a length 50% or greater than that of the straight-line measure (Boeing 2019). Boeing (2019) cites that the design, topography, and transportation technologies of cities vary greatly, a difference that non-network measures cannot capture. There is a strong emphasis on the importance of operationalizing network-based distances or even travel times on the network in place of the biased measures that has not received adequate attention in the voter turnout literature (Boeing 2019).

I argue for the same concern of measurement error and strive for accuracy in political science as in applied fields. The growth in computational methodology and measurement obligates that we acknowledge when measurement can be improved. Additionally, we are missing an opportunity to study

voters within a distance.

variation in costs and turnout that could deepen our comprehension of turnout. Even the most precise measurement of distance using the street network for a directed route does not include impedance measures. If time obstacles like high traffic density are a deterrent to voting, or redirect voters to convenience methods, then we are missing an important piece of the set of transportation costs the individual faces when voting. In finding that simplistic measurement strategies have significant effects on turnout, a natural next step is to discover what variation we are able to study at the individual-level with more precise measurement. (Aldrich 1993; Blais 2000; Boeing 2019; Brady and McNulty 2004, 2011; Burden et al. 2013; Citrin et al. 2014; Downs 1957; Druckman et al. 2009; Dyck and Gimpel 2005; Esri GIS Dictionary 2025; Feddersen and Sandroni 2006; Gimpel et al. 2006; Gomez et al. 2007; Haspel and Knotts 2005; Highton 2006; Kinsey et al. 2010; Latané 1995; McNulty et al. 2009; Plutzer 2002; Raftery 1995; Riker and Ordeshook 1968; Rosenstone and Hansen 1993; Sondheimer and Green 2010; Taber and Lodge 2016; Wolfinger and Rosenstone 1980)